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Green Fiber Bottle: Towards a Sustainable Package and a Manufacturing Process

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Abstract: The Green Fiber Bottle is a fully biodegradable bottle made from molded paper pulp, which is a renewable resource. Its development depends on the development of the manufacturing technology. Impulse drying, an innovative way of drying, and FORMCELL, a method to speed the mold reconfiguration, have the potential to improve significantly the manufacturing process of Green Fiber Bottle, towards a sustainable packaging.

Keywords: molded pulp, manufacturing process, impulse drying, FORMCELL.

1 Introduction

The ambition of the Green Fiber Bottle (GFB) project (Figure 1) is to manufacture a fully biodegradable bottle. Carlsberg Group has collaborated with EcoXpac (a Danish SME) to package beer in this bottle.

The GFB will replace plastic and glass bottles, thus reducing their impact on the environment, especially the oceans. For example, the life span of a plastic bottle in the ocean is 500 years, and during its degradation, the plastic is reduced to micro pieces, which cause the starvation of several marine animals. The new bottle is made from molded paper pulp, which is a renewable resource. Nevertheless, due to food and drugs limitations, only virgin paper fibers are to be employed in the production. The bottle could thus be left to biodegrade in nature or enter a recycle system, along with other paper-based product.

Figure 1: Illustrative image of the Green Fiber Bottle (GFB).

In order to contain the liquid, the bottle has an inner coating barrier. The latest solution proposed is to coat the inner walls with silicon dioxide, which is not biodegradable but rather environmentally inert.

To reduce the environmental footprint and enhance the sustainability of the bottle, the manufacturing technology has to offer the possibility of significant energy savings. Molded pulp products are made from wood fibers dispersed in water, and then they are formed, drained and dried. A relatively large quantity of resources (i.e. energy and time) is consumed during the drying process. It is in this process stage that an innovative way of drying the products can be exploited by using the concept of impulse drying. Impulse drying removes large amounts of water from wet paper pulp by combining mechanical pressure and intense heat. At these conditions, the wet pulp is dried in seconds. In this work, in order to optimize the pulp drying process, the effects on the dryness of two variables are investigated: process time and temperature.

Currently, the global packaging market is expanding and projected to reach $975 billion by 2018 [1]. However, more than $700 billion will come from packaging manufactured from mineral oil-based non-sustainable plastics. This means that only 25% of the global packaging market would meet today's criteria for sustainable packaging if packaging industries are going to proceed their ‘business-as-usual’. To contribute to solve this global challenge, a flexible, cost effective and timesaving process of manufacturing is also proposed in this work. This technology is named FORMCELL (Flexible tOol making pRocess for wet Molding of CELLulose) and it will cut down the mold changeover time, which nowadays is the most time consuming and expensive operation in the molded pulp industry. The molding process of three-dimensional closed objects, such as the GFB, is going to be described (Figure 2).

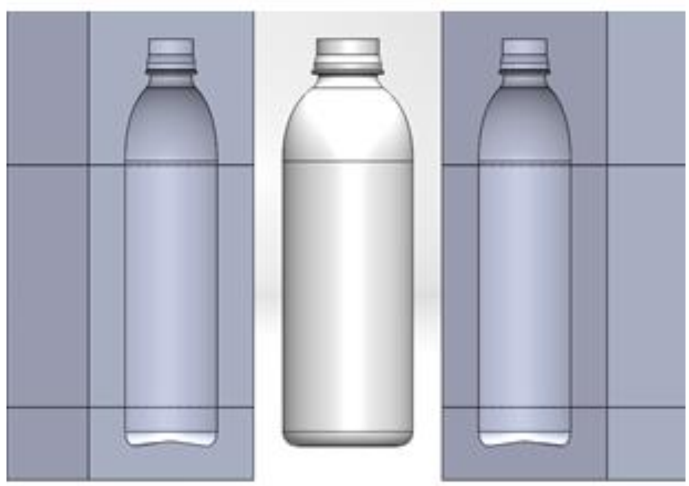

Figure 2: Convex and concave molds for production of closed three dimensional molded pulp objects.

As yet, the two proposed innovations have not been combined. Anyway, they have been individually tested and they proved remarkable benefits in terms of energy savings and ease of flexibility.

Impulse drying and FORMCELL have thus the potential to improve and facilitate the manufacturing of molded pulp products, towards a sustainable packaging.

2 Methods & Materials

In this section, methods and materials used to test experimentally the potential and suitability of impulse drying and FORMCELL are described.

2.1 Impulse drying

Impulse drying is an advance drying technique in which, water is removed from a wet paper web by the combination of mechanical pressure and intense heat. It was introduced in the beginning of the 1980s, and it attracted considerable interest from the paper industry as a means of reducing energy consumption in the drying process. Despite over thirty years of research, this technology has never been applied in the paper industry due to various runnability problems affecting the paper quality.

In this process, the wet web is exposed to pressures ranging from 30 bar to 50 bar and to hot surface temperatures typically between 150 °C to 300 °C. At these conditions, the wet web is dried in few seconds [2]. Enhanced liquid water removal is the key to energy savings in impulse drying.

The application of the impulse drying concept for the manufacture of molded pulp products, such as the GFB, was only recently reported [3]. The processing conditions for molding manufacturing are characterized by the molding temperature, pressure, and process time. As just explained, these are also the three main variables on which the impulse drying technology is based.

Test rig and drying performances

A laboratory-molding machine that exploit the impulse drying concept was designed and developed at EcoXpac. The machine is capable of press dry a preformed pulp disk of Ø200 mm with a grammage of about 500 g/m^2. Process steps are as follows:

1. The chamber, in which the wet pulp disk is placed, is pressurized at 20 bar.
2. A hot surface is put in contact with one side of the disk and the temperature (**T [°C]**) is kept constant for a certain time (contact time, **ct [s]**).
3. Pressure is released from the chamber and vacuum is applied for a certain time to completely dry the disk out (vacuum time, **vt [s]**).

Anyway, the influence of the process parameters (highlighted in bold) on the final dryness of the paper disks were investigated by means of design of experiments. Dryness is seen as a process efficiency, i.e. the ratio of the amount of water removed by the process with respect to the ideal situation, as follows:

$$Dryness = \frac{m_{wet\ disk} - m_{dry\ disk}}{m_{wet\ disk} - m_{bone\ dry\ disk}} \quad (1)$$

2.2 FORMCELL

FORMCELL comprises methods and a set of elements to ease and speed the mold reconfiguration. With a simple set of individual pieces (bricks), it is possible to assemble a large variety of molds of different sizes and shapes.

There are two main steps involved in the manufacturing process of molded pulp products: vacuum forming of the pulp into the desired shape and drying of the product to remove the remains of the water. In the forming process, the pulp is sucked onto a stainless steel mesh, which has the shape of the final product.

FORMCELL provides a replacement of the steel mesh with thermoplastic material, which has the same functions but it is easier to shape and less expensive. The thermoplastic material can be shaped into bottle-shaped via extrusion blow molding. This process uses items called parisons (Figure 3, (1)). The parison is a hollow plastic tube commonly used in the manufacturing of plastic bottles. The parison is clamped between two mold halves and inflated by pressurized hot air until it conforms to the inner shape of the mold cavity (Figure 3, (2)). Next, small holes are drilled by using a standard desktop laser. The laser should make a big number of small holes (Ø200 µm to Ø250 µm) in the same pattern as the steel net (Figure 3, (4)). Finally, the preformed plastic net is cut in two halves and each one of them is mounted on the mold inner cavities (Figure 3, (6)).

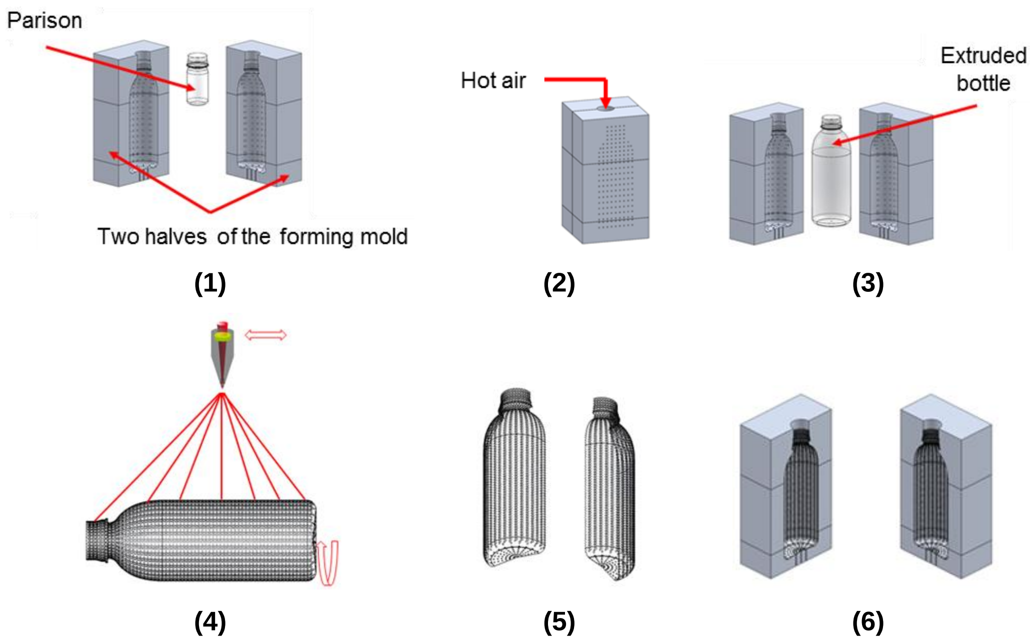

Figure 3: Process steps of the extrusion blow molding technique, used to replace the steel mesh employed in the forming process of the GFB manufacturing.

The drying step is carried out in a set of two female molds placed against each other (Figure 2). To keep the shape and the inner surface quality of the bottle, a balloon made of heat resistant material is air blown inside during the drying step.

3 Results

3.1 Drying performances

An experimental plan was designed and performed, in which the factors under investigation and the corresponding levels are reported in Table 1. The experiments were replicated three times, which gave 81 data sets.

Table 1: Factors and levels under investigation.

Factors	Levels
Contact time, ct [s]	2, 6, 10
Vacuum time, vt [s]	2, 6, 10
Temperature, T[°C]	170, 210, 250

For the sake of simplicity, contact time and vacuum time were added together under the name process time (Figure 4). As it is shown in the graph, at 170 °C, a disk with a grammage of 500 g/m^2 was dried in 4 seconds up to 92%.

Figure 5, instead, depicts what are the contributions to the final dryness of the various process parameters. It is clear that the temperature is the most influential, followed by the vacuum time.

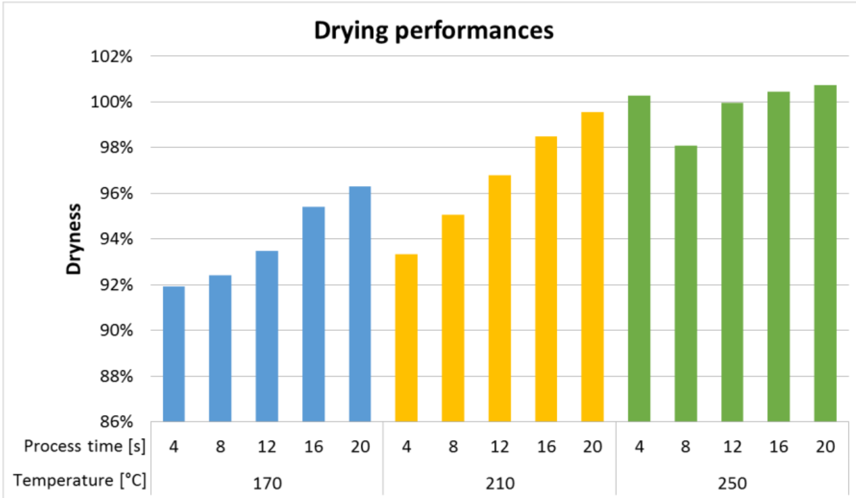

Figure 4: Drying performances.

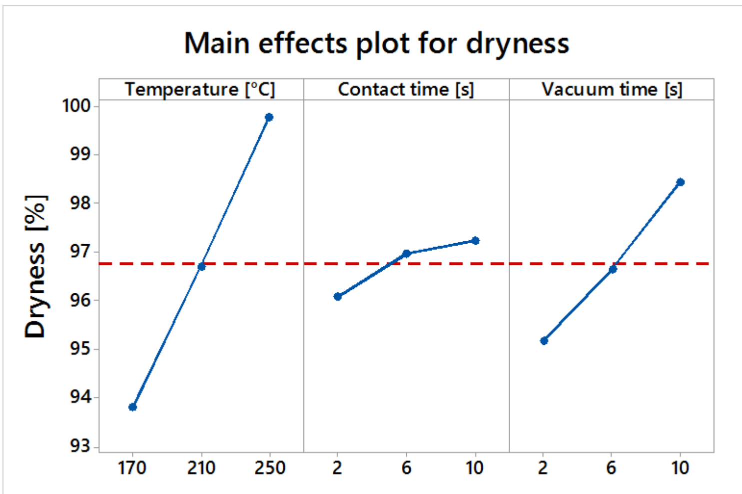

Figure 5: Main effects plot for dryness.

4 Conclusions

Impulse drying and FORMCELL have the potential to improve significantly the manufacturing process of molded pulp products.

The large water removal combined with quick run time speak volumes to the capability of impulse drying technology for molded pulp products.

FORMCELL offers a step forward toward more economical production of molded cellulose packaging.

The integration of the two technologies is certainly going to promote the diffusion of sustainable packaging.

5 Acknowledgement

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