THE INFLUENCE OF PET AND PS PLASTICS ON THE THERMOFORMING PACKAGING OF LIQUID AND VISCOUS DAIRY PRODUCTS

INFLUENȚA MATERIALELOR PLASTICE DE TIP PET ȘI PS ASUPRA PROCESULUI DE AMBALARE PRIN TERMOFORMARE A PRODUSELOR LACTATE LICHIDE ȘI VÂSCOASE

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Abstract: *Plastic has become a widely used material in the food packaging industry in the 21st century because it is easy to process, resistant to mechanical shocks, provides excellent protection for packaged food products, and is readily available. However, the use of plastic as a material for producing packaging intended to protect food products is a factor that generates large amounts of waste every year, which, if not properly managed, can have a significant polluting impact on the surrounding environment. Thus, the competent authorities of institutions responsible for environmental protection are constantly trying to find solutions to reduce the impact of plastic waste from the food industry on the environment, by decreasing the level of plastic pollution. One such solution is the use of more easily degradable plastic materials.*

This paper proposes studying the impact of PET (polyethylene terephthalate) and PS (polystyrene) plastics on the thermoforming process of cup-type containers and the actual packaging of liquid and viscous dairy products.

Keywords: plastic, pollution, termoforming, packaging, dairy products.

Rezumat: *Plasticul a devenit un material foarte utilizat în industria ambalării produselor alimentare la nivelul secolului XXI, deoarece este ușor de prelucrat, este rezistent la șocurile mecanice, protejează foarte bine produsele alimentare ambalate și dispune de un grad de disponibilitate ridicat. Totuși, utilizarea plasticului ca material folosit la obținerea ambalajelor destinate protecției produselor alimentare, reprezintă un factor care generează anual cantități mari de deșeuri, care dacă nu sunt gestionate corect, au un impact poluant mare asupra mediului înconjurător. Astfel, organele competente ale instituțiilor care se ocupă cu protecția mediului înconjurător încearcă să găsească în permanență soluții pentru diminuarea impactului pe care îl au deșeurile plastice din industria alimentară asupra mediului ambient, prin reducerea gradului de poluare cu materiale plastice. O astfel de soluție o reprezintă folosirea unor materiale plastice mai ușor degradabile.*

În cadrul acestei lucrări se propune studierea impactului pe care îl au materialele plastice de tip PET (polietilenă tereftalată) și PS (polistiren) asupra procesului de termoformare a recipientelor de tip pahar, și de ambalare propriu-zisă a unor produse lactate lichide și vâscoase.

Cuvinte cheie: plastic, poluare, termoformare, ambalare, produse lactate.

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INTRODUCTION

The discovery of oil and the refining of this chemical compound allowed the use of by-products from the petroleum industry in the design and manufacturing of new materials, generally referred to as plastics, which are used in various sectors of human activity (from the production of automotive parts and the creation of various everyday items to the production of packaging for the food industry). However, as good and efficient as plastic may be in the packaging of food products, managing the waste generated from the use of this material is equally challenging.

The use of PET and PS plastics in the packaging of dairy products offers multiple advantages for the food industry, but also presents a number of disadvantages for the environment. One of the biggest advantages of plastic is its ease of processing (a factor influenced by the physical properties of the materials), while a major disadvantage of using plastic is that this material does not easily degrade under natural conditions, making it highly polluting (Eriksen *et al*., 2019; Cârlescu, 2022).

Polyethylene terephthalate (PET) is a plastic material produced through the reaction between ethylene glycol and terephthalic acid. It is a highly thermally stable plastic, resistant to temperatures ranging from -60 to +220°C (Cârlescu, 2022).

Polystyrene (PS) is a material obtained by polymerizing styrene in the presence of heat, peroxide, and light. It can be melted at temperatures ranging from +95 to +120°C (Rochman *et al*., 2013).

MATERIAL AND METHOD

The packaging is an essential component of the storage and marketing process of a food product, being defined in the specialized literature as a multifunctional system used for the temporary preservation of food products in a safe and controlled environment, in order to maintain their freshness and quality (Rinkal Patel *et al*., 2018; Macri *et al*., 2021).

Milk and dairy products are classified as staple foods due to their high nutritional and biological value, and are recommended in people’s diets for all age groups (Usturoi *et al*., 2019).

In this paper, we propose studying the influence of certain consumable materials used in the process of forming cup-type containers on the performance and suitability of equipment used in the food sector for the purpose of packaging finished dairy products. For this research, three models of fully automated machines were studied, which we have coded with the names FFS 100-150, FFS 125-150, and FFS 200-400 (the abbreviation “FFS” stands for “Form-Fill-Seal”, a term that describes the working process of these machines, while the numerical ranges represent the volumes of the containers the machines can form, with volumes expressed in grams). Figure 1 shows a general technical diagram that includes all the components of the three machine models studied.

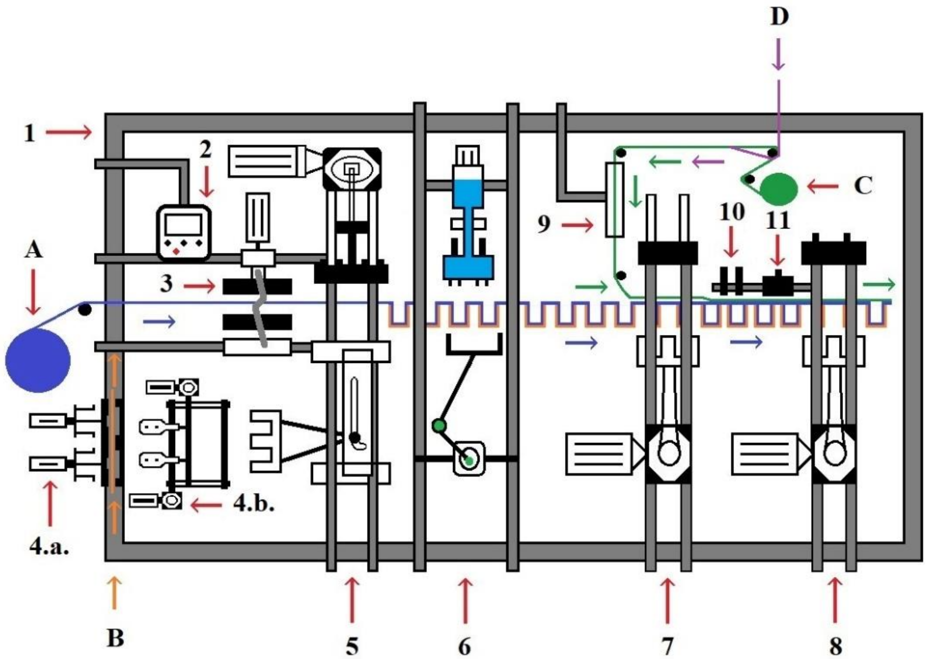

Fig. 1 General technical diagram of the FFS thermoforming machines, showing the specific features of each individual machine model
A - Base film roll; B - The path of movement of the labeling film strip;
C - Sealing film roll for the FFS 100-150 and FFS 125-150 machine models;
D - The path of movement of the sealing film in the case of the FFS 200-400 machine model.; 1 - Machine support frame; 2 - Control and command panel;
3 - Base film heating system; 4.a. - Label cutting system; 4.b. - Label gripping and fastening system; 5 - Container forming system; 6 - Product dosing system;
7 - Container thermo-sealing system; 8 - Container cutting system; 9 - UV light disinfection station for the sealing film strip; 10 - Consumable material gripping and movement system;
11 - Upper container cooling system (a system that is only part of the equipment FFS 100-150 and FFS 125-150).

In this paper, we used three types of consumable materials in the process of forming containers and packaging dairy food products:

1. **Base film** - made from plastic material, it is used for the actual forming of the containers;
2. **C/PAP labeling film** - has two functional sides: one coated with a special adhesive that, when exposed to high temperature, transitions from a solid to a liquid state (this type of adhesive only works when in its liquid form), and the other side on which the labels are printed, which will be cut and applied to the containers;
3. **Sealing film** - used for hermetically sealing the containers, it is of the mixpap type (a film made from multiple layers of different materials) and a sealing film made entirely of aluminum.

The FFS (Form-Fill-Seal) process is carried out automatically, computer-controlled, and its main role is to package food products in a sterile environment that prevents contamination. The stages of container formation, product filling, and cup sealing are performed sequentially, consistently, and automatically (Das *et al*., 2018).

The thermoforming process is carried out by heating a plastic film to a temperature that transforms the material from a solid and brittle state into a malleable one, followed by blowing the heated plastic material into a mold with a cold surface and a single side. The contact between the heated plastic material and the cold surface of the forming mold allows for the rapid cooling of the plastic that comes into contact with the interior of the mold, resulting in containers with regular and uniform shapes (Rosen, 2002; Throne, 2017; Klein, 2022).

All components that make up the FFS machine models are placed on a support frame (1), while modifications to working parameters, as well as the activation/deactivation of certain systems, are carried out from the machine's control and command panel (2).

The working process begins with the movement of the plastic material film (A) using the gripping and conveying system for the consumable materials (10). The movement of the base film is initially carried out towards the pre-heating and heating area of the plastic material (3). During the heating process, the heat-resistant plates are pressed against the plastic material strip, and through the direct contact between the surface of the heat-resistant plate and the surface of the plastic material, thermal energy is transferred between the two components.

Simultaneously with the heating process of the plastic material, the label film strip (B) is moved towards the label cutting area (4.a.). After the labels are separated from the film strip through the cutting process, they are picked up by a label gripping and movement system (4.b.) and are then introduced into the forming mold, where the actual container forming process (5) is carried out. To form the containers, the mold is moved beneath the heated segment of the base film strip. Subsequently, the mold is pushed into the base film strip, creating an airtight seal between the mold and a subsystem of compressed air blowing, which is mounted on the upper part of the forming system (as shown in figure 2). Thus, due to the sealed closed environment, combined with the malleability of the heated plastic segment, and under the action of compressed air blown into the mold, it is possible to produce cup-shaped containers made of plastic with standard shapes and sizes.

The disinfection of the containers was carried out by blowing sterile air into the cups before filling, and after disinfection, the containers were filled with the product (6). After the filling process with liquid dairy product (set yogurt) or viscous dairy product (concentrated coagulated yogurt and 20% fat cream), the containers were hermetically sealed through heat sealing (7), using either aluminum foil or mixpap foil (C), depending on the case. The sealing film was disinfected with UV light and sterile air before being placed and sealed onto the containers (9). Subsequently, the upper part of the containers was cooled using a stainless steel plate (11), which was maintained at a temperature of approximately +10°C. In the final stage, the containers were cut using a cutting system (8) that could separate each container individually or group them into packages of two, four, six, eight, or twelve containers in a single package.

Due to the cooler temperature of the forming mold compared to the plastic material from which the containers are made, it is possible to obtain cups with uniform shapes and sizes that do not exhibit defects after the forming process is completed (fig. 2). The labels from the mold remain attached to the containers after the forming process, due to the adhesive transfer from the unprinted surface of the labeling film and the pressure with which the plastic material is blown into the mold.

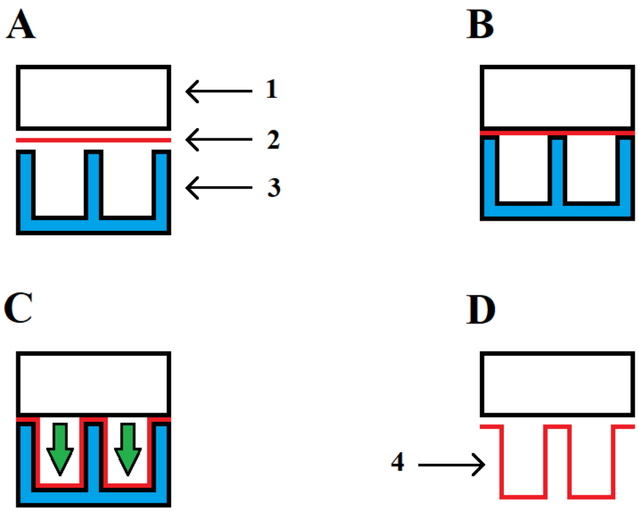

Fig. 2 Schematic illustration of the thermoforming process for cup-shaped containers
A - Basic position; B - Working position (sealing closure);
C - Working position (blowing compressed air into the mold); D - Completion of the thermoforming process (formed cups); 1 - Compressed air blowing subsystem; 2 - Base film banderole; 3 - Forming mold; 4 - Formed cups.

In this paper, we applied the following analysis and research methods:

1. **The observation method** - this involved observing the operation of the three FFS machine models studied, in order to determine how the machines function and what structural and technological differences exist between the equipment
2. **The method of multiple and differentiated trials** - this involved using various types of consumable materials to determine the influence these plastic and cellulose materials have on the working process performed by different machine models used for packaging liquid and viscous dairy products.
3. **The repeated trials method** - involved using multiple numerical values for certain working parameters in order to observe the impact of applying the same thermal range on the heating of PET and PS plastic films, and to assess the influence of different parameters on the thermoforming, filling, and heat sealing processes of the containers.

RESULTS AND DISCUSSIONS

The packaging machine models in the FFS category studied in this work differed from each other in terms of the number of containers formed during a single work cycle, the minimum and maximum production capacity achieved per hour, and the volume of containers they can form, as shown in table 1.

Table 1

General technological operating parameters of the FFS model machines studied

Machine model	Forming area	No.C.F.C.E.	Min.No.C.E. (cycles/minute)	Max.No.C.E. (cycles/minute)
FFS 100-150	240x400 mm	12 containers Packages of 2, 4, 6 or 12 containers	18 nominal 18.4 actual	25 nominal 24.1 actual
FFS 125-150	180x200 mm	8 containers Packages of 2, 4 or 8 containers	16 nominal 16.6 actual	20 nominal (from the factory) 18.9 actual
	180x250 mm			25 nominal (after modification) 23.5 actual
FFS 200-400	250x280 mm	8 individual containers	14 nominal 14.3 actual	20 nominal 16.2 actual

Abbreviations used: No.C.F.C.E. - Number of Containers Formed per Cycle Execution; **Min.No.C.E.** - Minimum Number of Cycles Executed;
Max.No.C.E. - Maximum Number of Cycles Executed.

The thermoforming machines used for packaging liquid and viscous dairy products have three types of operating capacities, expressed in the number of working steps performed per minute (cycles per minute):

1. **Nominal production capacity (N.P.C.) -** represents the maximum working capacity that the machine can achieve under ideal operating conditions;
2. **Set production capacity (S.P.C.) -** is the working capacity that the machine is required to achieve, and which is set from the machine's control panel using a numeric value (it may coincide with the nominal working capacity or may be a lower numeric value than the corresponding nominal capacity);
3. **Actual production capacity (A.P.C.) -** represents the production capacity that the machine achieves at a given moment/within a specific production period.

According to the results obtained in this paper, we recorded differences between the set production capacity and the actual production capacity for all three machine models studied. The results show that none of the machines were able to achieve the set production capacity, with a consistent difference where the actual capacity was always lower than the set capacity. As a result of studying the working process of the three machines, we observed that the differences between the set production capacity and the actual production capacity are mainly due to the time required for certain working stages (especially thermoforming, filling, and heat sealing), as well as the fact that the machines were connected to automated packaging palletizing lines (lines that may complicate the working process).

The working times required for the thermoforming, dosing, and heat sealing stages may vary depending on the machine model used and the consumable material employed in the packaging process. However, due to the wear of certain mechanical and/or electrical components, it is possible for the working process to slow down by increasing the time required for certain technological stages. A practical example is the deformation due to compression in certain areas of the heat sealing plate, a process that leads to equipment wear. In this situation, the exposure time of the cups to the sealing temperature can be increased, but such actions lead to the occurrence of three unfavorable situations:

1. the working process is slowed down by increasing the time required for the heat-sealing stage of the containers;
2. cracks may appear in the sealing foil as a result of exposing the material to high temperatures for too long a period of time;
3. a situation may arise where the sealing foil cannot be removed normally from the container (it is difficult to remove), due to the excessive embedding of the sealing material into the plastic from which the containers are made.

The auxiliary equipment that makes up the entire production line can prolong the duration of a working step (or cycle). In this research, each of the three FFS machine models studied was connected to an automated container palletizing line. The complete production line consisted of the thermoforming packaging machine, the automatic carton forming machine, the equipment for picking up the cups from the conveyor belt and placing them into the cartons, conveyor belts connecting all the machines, and automated robots for palletizing the cartons. Thus, for example, in the case of the FFS 200-400 machine model, it was not possible to achieve a nominal working capacity greater than 16 cycles per minute, as the entire palletizing line would get blocked. This situation occurred due to the lower working capacity of the palletizing line compared to the production capacity of the thermoforming packaging machine.

In this study, we increased the production capacity of the FFS 125-150 machine model from 20 cycles per minute (the maximum working capacity it was originally designed for) to a nominal working speed of 25 cycles per minute. This process was achieved by adjusting the working parameters to allow for a setting of 25 cycles per minute instead of 20 cycles per minute, and by modifying the duration of the thermoforming, filling, and heat sealing stages. By adjusting the duration of the thermoforming, filling, and heat sealing stages, we were also required to increase the heating temperatures of the base film and the sealing film to ensure that the packaging process would proceed under normal conditions. By adjusting the working parameters, we managed to make the machine operate at a maximum of 23.5 actual cycles per minute (with a constant speed of 22.4-22.7 cycles per minute). The identification of the differences that appeared during the container formation and packaging of liquid and viscous dairy products was carried out by analyzing certain technological parameters used in the thermoforming and heat sealing stages of the cups (table 2).

Table 2

Technological parameters used in the process of forming containers and packaging liquid and viscous dairy products

Machine model	Plastic material type + sealing material	THERMOFORMING				HEAT SEALING	
		B.F.H.T. (˚C)	Time (s)	Pressure (bar)	F.M.T. (˚C)	H.S.T. (˚C)	Duration (s)
FFS 100-150	PET + Mi.	117	0.85	6	38	200	0.85
	PS + Mi.	108	0.75	6	21	180	0.75
FFS 125-150	PET + Mi.	115	0.80	5	35	175	1.00
	PS + Mi.	105	0.75	5	23	170	1.10
FFS 200-400	PET + Al.	111	1.20	6	32	175	1.90
	PET + Mi.	111	1.20	6	32	178	2.00

Abbreviations used: Mi. - Mixpap; **Al** - Aluminum; **B.F.H.T.** - Base Film Heating Temperature; **F.M.T.** - Forming Mold Temperature; **H.S.T.** - Heat Sealing Temperature.

The results of the research conducted on the influence of using different consumable materials in the thermoforming process of cup-type containers highlighted that the use of plastic materials such as PET and PS directly affects all the basic technological parameters involved in the thermoforming and thermo-sealing processes of the containers.

According to the results of the research conducted on the FFS 100-150 and FFS 125-150 machine models, we observed that the use of PET plastic materials in the thermoforming process of cup-type containers is a more suitable process in terms of the environmental impact of the packaging (as PET is easier to recycle compared to PS). However, the processing of polyethylene terephthalate (PET) involves a costlier process for the food processor, as the heating temperatures for the base film and the sealing of the containers are higher for PET compared to the use of polystyrene (PS).

The use of polyethylene terephthalate (PET) in the thermoforming process of cup-type containers also requires a longer forming and thermo-sealing time compared to the use of polystyrene (PS), which complicates the production process by reducing the machines' working capacity.

From the perspective of the cooling temperature applied by the forming mold, we had to set a higher thermal value when using polyethylene terephthalate (PET). The compressed air pressure blown into the mold remained constant for both types of plastic materials (PET and PS).

From a technological standpoint, the process of cutting the containers is carried out through two types of cuts: a main cut (which involves the complete separation of the containers from each other) and a secondary or superficial cut (which involves making a fine cut between the cups of the same package, in order to facilitate the separation of containers that are part of the same package). The use of PET plastic material also requires pre-cooling of the upper part of the containers before the cutting process, in order to facilitate the production of cups that do not exhibit defects such as stretching of the plastic material. Thus, it is necessary to install a cooling system for the containers if the machines are not equipped with such equipment, which represents additional costs for the dairy product processor, (in the case of FFS 200-400 machine, pre-cooling of the upper part of the cups was not required, as this type of machine only forms individual containers).

The use of PET plastic material in the thermoforming and sealing processes carried out by the FFS 200-400 machine model was combined with the use of mixpap and aluminum sealing films. The only difference observed in the packaging process was the sealing temperature, which was higher by approximately +3°C to +7°C. Also, in the heat sealing stage of the aluminum film, carried out by the FFS 200-400 machine, the duration of the sealing step was increased to facilitate the bonding of the plastic material with the aluminum film.

CONCLUSIONS

According to the results presented in this paper, the following conclusions can be drawn:

1. The use of PET plastic material in the thermoforming process of cup-type containers requires higher temperatures for the stages of base film heating, container forming, plastic cooling, and sealing film heat sealing, compared to the use of PS plastic material;
2. Cutting the containers made from PET plastic material into packages of containers requires pre-cooling of the upper part of the containers before cutting, in order to facilitate the secondary/superficial cutting of the containers;
3. Multiple types of plastic materials can be used in the thermoforming process for food packaging using the same machine, but it is necessary to adapt the working process and adjust the technological parameters according to the material being used.

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