BULLETIN: MIXTURE SELECTOR FOR THERMOSHRINK PACKAGING

1 Introduction

The thermoshrink or retractable film is obtained in the industrial field by the induction of a high grade of molecular biaxial orientation in the polymer during its processing, through blowing and pulling the film when this is extruded. It use in the packaging area is mainly directed towards the application in wrapping of main consumer goods, protective wrap for environmental effects or cohesion packages of various articles or covers are the best examples of use of covers employed for enabling the movement of pallets, as shown in the Figure.

A film which has good thermoshrink properties depends on the appropriate material selection to be manufactured and on the production conditions. Several levels of contraction can be obtained for the same material in the main or machinery direction (MD) and in the transverse direction (TD), modifying the film orientation by changing the blow ratio (BUR), the height of the cooling line (ALE) and the stretching ratio (DDR).

Normally, the material used for thermoshrink package film is low-density polyethylene (PEBD). However, other materials such as PEAD and PELBD are mixed in order to improve specific properties like rigidity, tear penetration resistance, etc. [5][8][9]
There are many playing variables in order to achieve the final desired properties: type of materials, mixture balances and processing conditions. Therefore, it is necessary to find a balance that provides the appropriate balance between the final product properties and processability.
The purpose of this technical bulletin is to introduce the reader to the thermoshrink film mixture selector that POLINTER has developed for its clients, in order to facilitate the task of choosing which material combination is best for the application to be developed, and to help customers in the selection of the processing conditions that would provide the desired properties.

Mixture selectors were developed in form of spreadsheets, wherein the user introduces the basic data (type and amount of resin), nozzle characteristics and processing conditions. As a result, is the prediction is obtained based on experimental studies and statistical analysis carried out by POLINTER research and development laboratories, on the final film properties [6][7][9]. This serves to reduce test and experiment times in plant (with the subsequent time and material saving), and to experiment the possibilities of improvement on the existing products.

There are two types of selectors currently available for POLINTER clients:

- Automatic package mixture selectors (thickness of up to 80 micron).
- Thermoshrink Tubing package mixture selectors.

This technical bulletin covers the main features of the last selector named, to wit: mixture for thermoshrink packaging.

2 Theoretical basis (T_e and R_a deductions)

The final tubular film properties are due to the interaction of several mechanisms which result in a balance between the stretching towards the machine direction due to the cutting stress suffered inside the nozzle, and the biaxial deformation due to the pulling interaction of the film in the machine direction (MD) and the blowing in the transverse direction (TD); on the other hand, the film suffers a stress relaxation during the blowing process. The interaction between the relaxation, biaxial deformation and the crystallization phenomenon will determine the molecular orientation grade that the polymer exhibits when transformed into a film.

A good thermoshrink film is obtained by the appropriate management of the extrusion parameters, which are:

- Blow ratio (BUR).
- Height of the cooling line (ALE).
- Extrusion speed (V_o).
- Casting temperature (T_m).
- Pulling speed (V_f).

The above parameters can be easily analyzed if they are combined in function of the Cooling Time (T_o) and the Thinning Ratio (Ra) [1][2][4][6][8], defined as follows:

$$T_e = \left[\ln\left(\frac{v_f}{v_o}\right)\left(\frac{ALE}{v_f - v_o}\right) \right]$$

This ratio is deduced from basic mass and moment conservation principles, posing a linear velocity profile from the release of the film from the nozzle up to the cooling line. According to this ratio, the cooling time exponentially decreases when the pulling speed increases, being of great importance its measure along with the extrusion speed, which is a parameter that is not measured in most of the blowing equipments. Nevertheless, this last value can be estimated with the following ratio:

$$v_o = \frac{Q}{3600\rho_f \pi (d - 2r_b)}$$

wherein Q is the flow in Hg/h, ρ_f is the density in casting (the normal value of polyethylene is 775 <g/m^3 and can be applied independently from the grade used), d is the nozzle tip openings expressed in m, and r_b is the external radius of the nozzle, also expressed in m. With these factors, v_o is expressed in m/sec.

In cases where the pulling speed measurement, expressed in v_f, is not accurate, a very reasonable estimate can be obtained with the following equation:

$$v_f = \frac{3.33Q}{2e\pi r_b (BUR)}$$

Wherein e is the film thickness expressed in µm. in the same way, the thinning ratio (R_a) can be defined as:

$$R_a = \left(\frac{d}{e(BUR^2)} \right)$$

It is important to point out that in (4) "d" and "e" must be in the same units. Normally, two films manufactured with the same material or mixture, using T_e and R_a, should have similar properties. However, this is not entirely true due to the assumptions that these deductions have are based on some simplifications (ideal cooling, no consideration of the elasticity properties), for practical reasons, it can be considered as a very good approach. These values are automatically calculated by the selector, but they may be implemented in a simple manner on a spreadsheet on behalf of the interested reader.

3 How is a mixture designed?

At the moment of designing a mixture, several steps are usually taken, being in a formal or intuitive and almost unconscious form. If a formal sequence is followed and documented, it is possible to obtain optimizations from the start, which will result in lower costs and/or better performance.

The following list proposes a series of stages that should be considered when designing a mixture:

1) Select the resins to be chosen according to the desired properties, including their cost.
2) Tabulate the advantages and disadvantages of each resin. This will allow the identification of alternatives.
3) Use the selector to choose resin combinations that show potential of fulfilling the mixture requirements. In this stage, do not pay too much attention to the operational conditions, but use the standards.
4) Make rough cost estimate. If the numbers are appealing, keep going; otherwise, select another resin set (step 3).

5) Analyze the selected mixture from the processing and final application point of view. Keep in mind that there are aspects, such as appearance, that cannot be foreseen with the selector:
   - Is it obvious that it will or will not work?
   - Will it be able to be processed with the available equipment?
   - Will it keep its properties along its useful life?
6) If the selected mixture is considered appropriate, use the selector to estimate the film properties. Compare to the desired resin properties. Adjust the component thickness or concentrations of the mixtures in order to optimize the properties.

4 Selector operation

In order to build the mathematical models used in the selector, more than 78 mixtures were prepared, extruded and measured. The following limitations were established:

- Maximum PEAD content: 10%.
- Maximum PELBD content: 30%, there is the possibility of choosing between butene PELBD and octene PELBD, but not both.
- Minimum PEBD content: 60%.
- PEBD type: Venelene® FB 3003 and FB 7000.
- PELBD type: Venelene® 11F1 (butane) and Venelene® 11O1 (octene).
- PEAD type: Venelene® 3200B.
- Film thickness between 50 and 90 µm*. The thickness refers only to one side of the film (not to the collapsed film in the roll).

This sheet can select the materials to be processed and their concentrations, the operating conditions (blow, pull, thickness, etc.). Figure 1 shows the material selector developed as a Microsoft Excel® spreadsheet, where the statistical models are incorporated, developed to do mathematical calculations that provide the results exhibited on the same sheet, for easier handling and visualization.

To use the selector, the user must introduce the data of the grew zone.

- Mixture percent
- Nozzle characteristics; diameter and aperture of lips
- Operation conditions: ALE, flow, thickness and diameter of film, and perimeter (this is the width double of film).

The sheet automatically transforms these values into their T_e and R_a equivalents, verifying that they do not exceed the selector limits (in this case the standard warnings are issued), makes use of the developed models and generates associated possibilities with these conditions: mechanical, optical and thermoshrink, including a cost estimate.

In this way, you have the complete properties on the sheet of the film to be assessed, instead of the complicated thermoshrink diagrams wherein limited behavior information is provided.

Besides, if you add the estimate cost of the raw materials, the price-value optimal ratio calculation of the studied mixture is complemented.

The program warns in case that the sum of the mixture components is not 100%. In the same way, a warning is given if the selected mixture or thicknesses goes beyond the experimental design that served to generate the models, indicating to the user that, in case of continuing, the extrapolated results shall not be as reliable as those contained in the design. In the event that the selected balances are not too far off from the limits of the selector, the results may be used with certain confidence, at least to study the possible trends.

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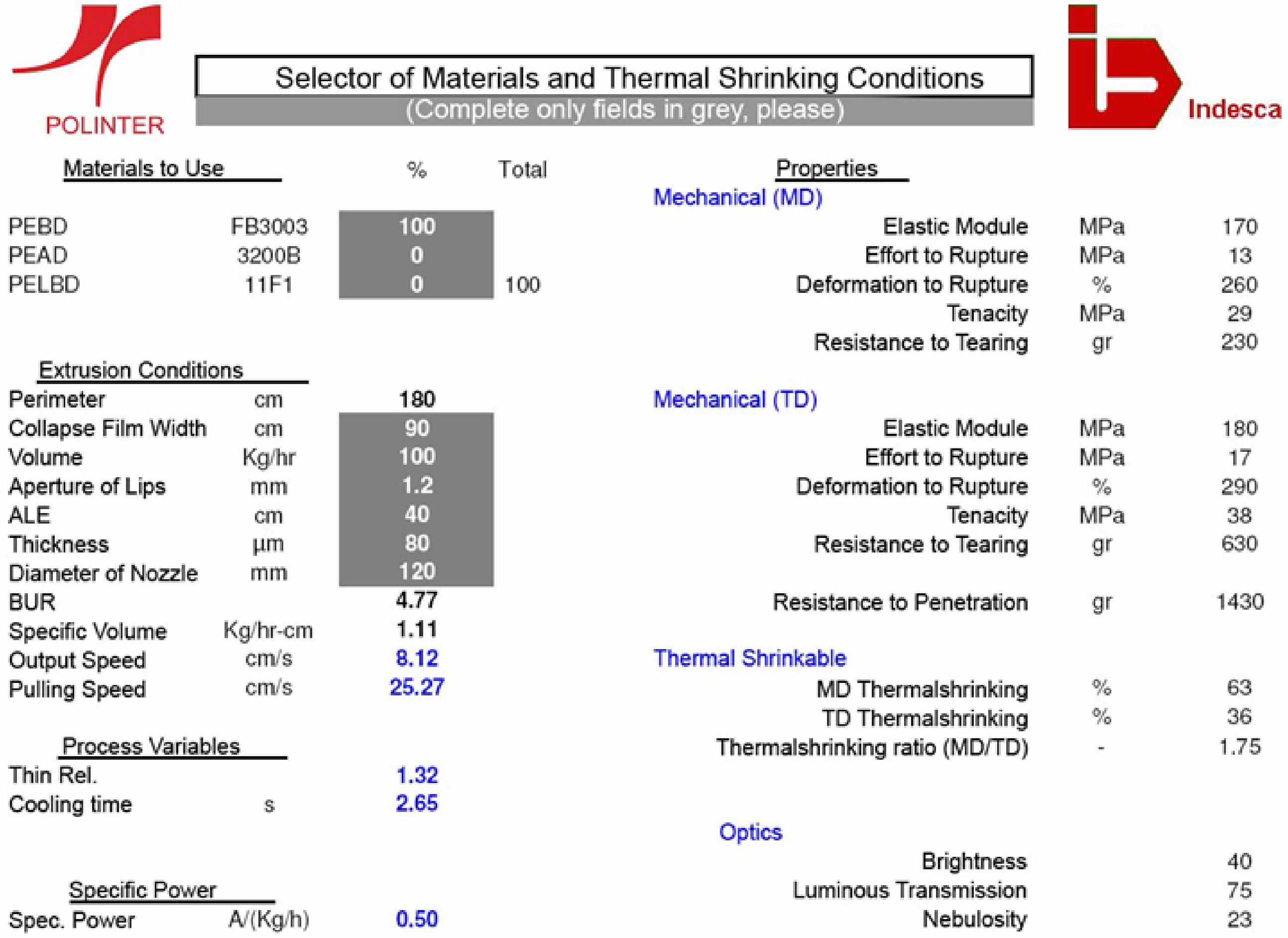
[*] 1 µm is the thousandth part of 1 millimeter or 1 x 10^{-6} m. equivalent to the smallest division that can be seen in most of the conventional tubular film thickness gauges. In some industries the term calibrator is used, which is equal to 10 µm



Selector of Materials and Thermal Shrinking Conditions

(Complete only fields in grey, please)

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Materials to Use		%	Total
PEBD	FB3003	100	
PEAD	3200B	0	
PELBD	11F1	0	100

Extrusion Conditions		
Perimeter	cm	180
Collapse Film Width	cm	90
Volume	Kg/hr	100
Aperture of Lips	mm	1.2
ALE	cm	40
Thickness	µm	80
Diameter of Nozzle	mm	120
BUR		4.77
Specific Volume	Kg/hr-cm	1.11
Output Speed	cm/s	8.12
Pulling Speed	cm/s	25.27

Process Variables		
Thin Rel.		1.32
Cooling time	s	2.65

Specific Power		
Spec. Power	A/(Kg/h)	0.50

Properties		
Mechanical (MD)		
Elastic Module	MPa	170
Effort to Rupture	MPa	13
Deformation to Rupture	%	260
Tenacity	MPa	29
Resistance to Tearing	gr	230
Mechanical (TD)		
Elastic Module	MPa	180
Effort to Rupture	MPa	17
Deformation to Rupture	%	290
Tenacity	MPa	38
Resistance to Tearing	gr	630
Resistance to Penetration	gr	1430
Thermal Shrinkable		
MD Thermalshrinking	%	63
TD Thermalshrinking	%	36
Thermalshrinking ratio (MD/TD)	-	1.75
Optics		
Brightness		40
Luminous Transmission		75
Nebulosity		23

Figure 1. Thermoshrink film material selector

5 Example

The most common thermoshrink package film is the one manufactured with Venelene® FB 3003. Figure 1 shows the extrusion conditions for said film and the main properties of the product, according to the selector's prediction. Suppose that the final user is satisfied with the film, but, as an improvement, he would like to achieve more rigidness, more stretchable, keeping the same thermoshrink, tear resistance and extruder power usage properties at a lower cost. He is willing to sacrifice some optical properties, but he does not want much opaqueness. He also considers that the penetration resistance of the film is very good. This challenge seems to be quite difficult, if not impossible, to accomplish with polyethylene films. The first to option consider is to add a second material.

Among these, the Venelene® 11F1 is assessed by adding a 10%. Even when important improvements are produced in the tear and penetration resistance, the thermoshrink TD properties decrease considerably (see Chart 1). This is why the use of

Venelene® 3200B, also in 10%, is assessed instead of Venelene® 11F1. In this case the thermoshrink properties are recovered (although not completely), the mechanical properties are maintained or improved, but the tear resistance falls, as expected.

Chart 1. Summary of the properties predicted by the selector.

Properties		FB3003	FB3003/11F1	FB3003/3200B	Ap. lab.	ALE	esp.	esp.
Mechanical (MD)		100%	90%/10%	90%/10%	1.8 cm.	48 cm.	70 µm	60 µm
Elastic Module	MPa	170	190	210	210	220	220	210
Effort to Rupture	MPa	13	17	14	19	20	20	21
Deformation of Rupture	%	260	260	280	280	310	300	280
Tenacity	MPa	29	33	36	44	51	49	47
Resistance to Tearing	gr	230	370	240	270	240	210	170
Mechanical (TD)								
Elastic Module	MPa	180	220	250	250	260	260	260
Effort to Rupture	MPa	17	19	19	21	22	21	21
Deformation of Rupture	%	290	320	470	450	500	440	390
Tenacity	MPa	38	46	50	56	62	62	62
Resistance to Tearing	gr	630	840	440	660	580	510	430
Penetration								
Resistance to Penetration	gr	1430	1690	1510	1590	1540	1350	1160
Thermalshrinking								
MD Thermalshrinking	%	63	44	42	52	56	55	56
TD Thermalshrinking	%	36	3	39	25	39	30	21
Thermalshrinking ratio (MD/TD)	-	1.75	14.67	1.08	2.08	1.44	1.83	2.67
Optical								
Brightness		40	33	33	32	32	31	30
Luminous Transmission		75	75	74	74	74	74	74
Nebulosity		23	24	26	25	24	25	25

Due to the fact that the PEAD mixture is the one that best adapts to the required conditions, we continued using it, modifying the operation conditions trying to meet the client's demands. When the tip openings are increased, you can see that the tear resistance has substantially improved, having only to correct the thermoshrink objectives. Increasing the ALE to 48 cm improves the performance with regards to thermoshrinkage, thus placing it under acceptable terms, although the TD tear resistance falls, but still maintaining itself within the limits in which an industrial test may be conducted. In order to attack the low cost requirement, thickness reductions at 70 and 60 µm are tried. The 60 µm film may not be able to withstand performance, but at 70 µm, the tear resistance reduction is relatively small and an industrial test could be conducted. The power consumption variables of 2% were maintained in all tests (not shown in Chart 1). Chart 1 shows a summary of the effects of different changes. The option of using a ternary mixture (80% of FB 3003, 10% of 11F1 and 10% of 3200B) causes the thermoshrink properties to be excessively low (30% and 11% in MD and TD, respectively).

6 Summarizing

Through the example, the potential of the selector can be seen: in a few minutes a person is able to analyze the effects of the mixture changes (both in resin as well as in composition thereof), film thicknesses, ALE, flow and even the head, regarding the final product's key properties, not only those which are sought to improve, but also the "side effects" that almost always arise when these changes are introduced. Just as in any simulator, the results generated by the selector should be considered as a very good first approach, but it should be verified through industrial testings.

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The purpose of this tool is to minimize the required amount of material, human effort and time the machine time, required for optimizing the mixture for thermoshrinkng packaging films.

7 References

For more information, the following references may be consulted:

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This bulletin has been made by the Marketing Department of Polinter with the support of the specialists of Investigación y Desarrollo, C.A. (INDESCA) and by the Technical Services Department of CORAMER. This is intended for all clients and users of the Venelene® resins and we trust that the information contained herein is helpful and useful.

Please contact us at the following email address, info@polinter.com.ve or through our agent: Corporacion Americana de Resinas (CORAMER), with branch offices in Venezuela, Colombia, Peru, Ecuador and Chile (http://www.coramer.com), should you have any suggestions or comments regarding this issue.

In order to obtain more detailed information of the security aspects regarding the use and disposal of our products we invite you to consult the security pages (MSDS) of the Venelene® Polyethylenes.