

PP for Film Capacitors: Origin, Manufacturing and Processing

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Polypropylene Capacitor Film Market

Over the last 5 years, polypropylene consumption for capacitor films has almost doubled from 60 000 to more than 100 000 ton/a. Much of the growth has taken place in China, where the number of BOPP (Biaxial Oriented Polypropylene) lines for capacitor film increased from 8 to 20 in that period. Global manufacturing of thin BOPP capacitor film in 2005 is estimated at 65 000 tons. With an average thickness of 7 μm this equates to 9 000 000 km^2 of film which can cover the total area of the USA.

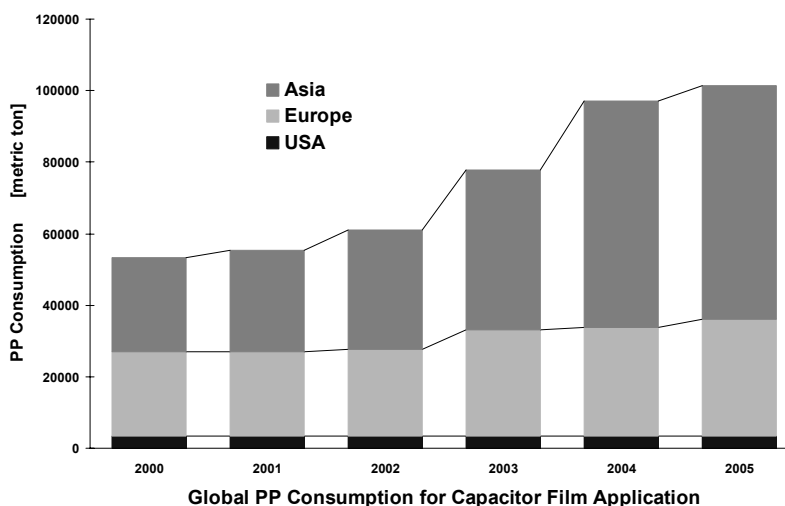


Figure 1: Global PP Consumption for Capacitor Film Application (2000 – 2005).

However, due to price erosion, mainly because of the overcapacity in China, this growth of raw material demand was translated to a limited extra turnover for the final value of shipments for the AC film capacitors.

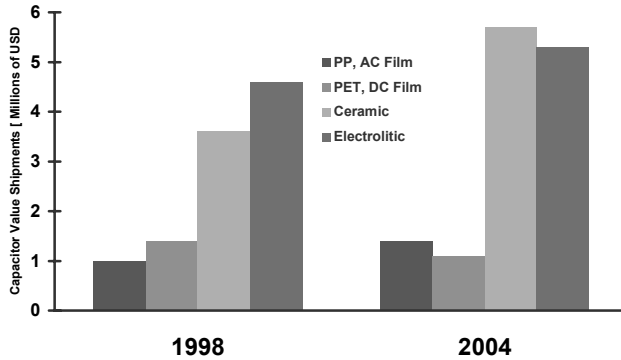


Figure 2: Global Capacitor Value Shipments by Dielectric (1998 – 2004)

What makes polypropylene the obvious choice for AC capacitors?

Polypropylene molecule chains lack any kind of polar groups which orient under electrical field stresses. As a result, polypropylene intrinsically possesses a low loss factor and high volume resistivity. These properties, combined with a relatively high dielectric constant and the self healing character in the capacitor, make polypropylene and polyethylene terephthalate (PET) the preferred choice of raw material for film capacitors. For AC capacitor applications, polypropylene is the most suitable dielectric since the dielectric constant and the low loss factor are largely independent of temperature and frequency.

		<i>Dissipation Factor</i>	<i>Dielectric Constant</i>	<i>Volume Resistivity</i>	<i>Dielectric Strength</i>
		23 °C, 50 Hz	23 °C, 50 Hz	23 °C, DC	8 μm, 23 °C
		[#]	[#]	[log Ω cm]	[V/μm]
<i>Polyethyleneterephthalate</i>	<i>PET</i>	0.002	3.3	18	570
<i>Polypropylene</i>	<i>PP</i>	0.0002	2.3	18	640
<i>Polystyrene</i>	<i>PS</i>	0.0002	2.5	16	
<i>Polycarbonate</i>	<i>PC</i>	0.003	2.3	16	528
<i>Polyethylene</i>	<i>PE</i>	0.001	2.3	15	

Table 1: Dielectric Properties of PP and PET.

Largest application for AC film capacitors is the High Voltage Power Factor Correction Capacitor for HV power transmission and distribution. The capacitor dielectric is a BOPP impregnated with capacitor oil. A similar application, but for lower voltages, is the Industrial PFC Capacitor, wherein no impregnation oil is used.

Other volume important but technically less demanding segments are the Motor Run Capacitors, Lighting Ballast Capacitors and Microwave Oven. Vast majority of these capacitors are nowadays produced in China, Korea and India.

Fastest growing and technically continuous challenging are the Power Film Capacitors with niche applications as Variable Speed Drive Capacitors (traction, turbines...), Pulsed Power Capacitors (Laser, Defibrillator, X-Ray...) and Power Smoothing Capacitors (Inverters, Amplifiers, Motor Drives...).

Polymer properties, film processing, metallising and capacitor manufacturing are stretched to the limit to obtain a combination of one or more of the following properties: electrical stresses of $700 \text{ V}/\mu\text{m}$, energy densities of $1.2 \text{ J}/\text{cm}^3$ and temperature resistance of $120 \text{ }^\circ\text{C}$. However short term industry requirements are demanding $2.5 \text{ J}/\text{cm}^3$ and $135 \text{ }^\circ\text{C}$ at highest possible electrical stresses for films in some cases thinner than $2 \mu\text{m}$.

The dielectric strength or breakdown voltage of polypropylene film is increased considerably by further biaxial orientation, which is obtained by stretching a heated sheet of film in two opposing directions, longitudinal and transverse machine directions, inducing a more perfect crystalline formation and orientation.

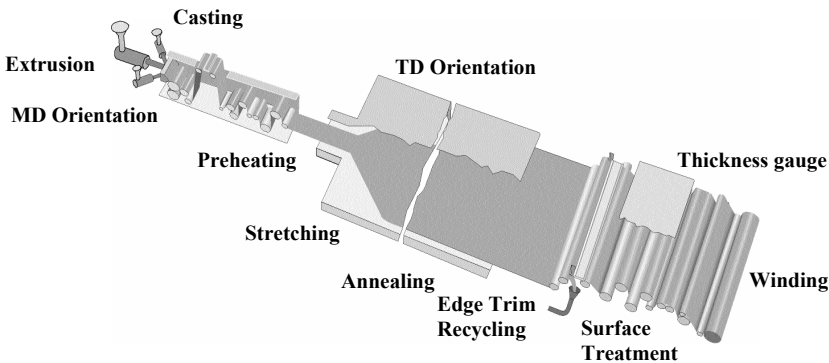


Figure 3: BOPP Stenter Process

The high dielectric strength, volume resistivity and low loss factor are however only valid for pure and super clean polypropylenes. Unfortunately, most polypropylenes on the market – used for all kinds of applications in automotive, building, packaging, textiles and appliances – possess rather a lot of impurities originating from the polymerisation process, from additivation or from contamination during handling and transportation of the polymer.

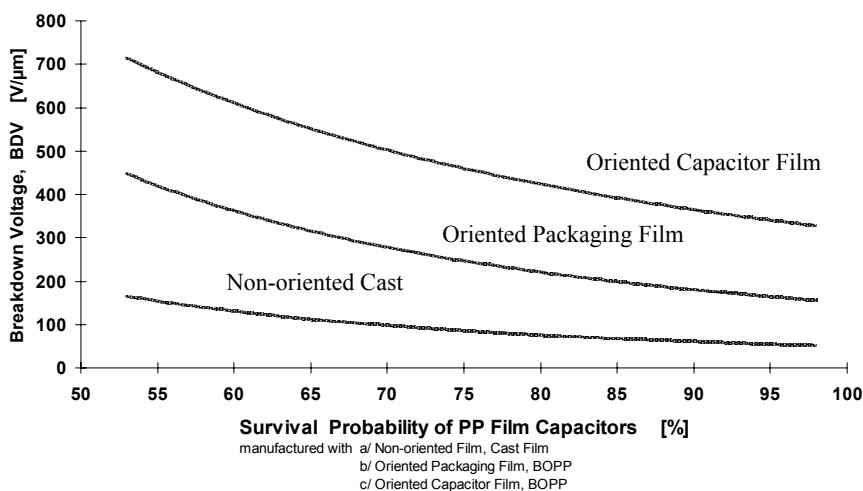


Figure 4: Survival Probability of Capacitors with different Types of PP Films

Manufacturing high purity polypropylene capacitor film resin

Today there are only a few industrial polymerisation processes in the world capable of manufacturing and marketing polypropylenes with stringent and state-of-the-art purity for capacitor film applications.

Polypropylene was discovered in 1954 by Dr G. Natta, using a catalyst type invented by Dr K. Ziegler. Commercial production of polypropylene began in 1957 with Hercules Incorporated, Montecatini and Farbwerke Hoechst AG.

Polypropylene became one of the most important plastics converted into a wide range of products including textiles, pipes, automotive parts, appliances and packaging materials. By the late 1970s, global polypropylene demand was less than 5 000 kton; 25 years later, demand has increased almost tenfold, close to 40 000 kton. With an expected annual growth of about 6%, it remains one of the fastest growing polymers over the years. Of the 40 000 kton, no more than 100 kton is used for BOPP capacitor film production.

The technology of polypropylene polymerization and the concurrent introduction of new catalyst systems have developed tremendously over the years and are still ongoing. The fourth generation of catalyst systems is already a standard in the today's manufacturing processes as bulk and gas-phase polymerization while the first generation of catalysts, based on the Ziegler-Natta concept, are rapidly fading out and used by only a few plants, based on the so-called slurry process.

The conventional slurry process is nevertheless able to manufacture the purest polypropylenes with negligible ash content and catalytic residue of only a few ppms. The first generation catalysts, nowadays modified to a higher activity, are suitable for the slurry process. Due to the relatively low yield of these catalysts, the slurry process needs larger amounts of catalyst, resulting in an initial high amount of atactic propylene and catalytic

residues. Adaptations in catalyst dosage, catalyst deactivation and dissolving, followed by an improved organic washing and drying ensures however the low conductivity of the polymer. In the process incorporated purification section this removes the residues by treating the polymer with an alcohol while a solvent removes part of the atactic polypropylene.

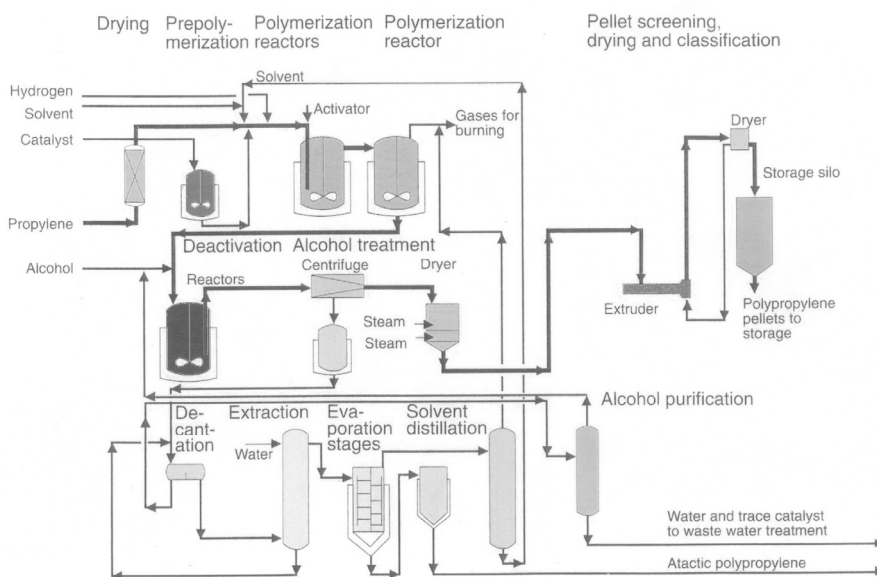


Figure 5: Polypropylene Slurry Process

The characteristics of the polypropylene itself can generally be summarized in the stereo specificity, molecular weight (Mw) and molecular weight distribution (MWD). During the polymerization the propylene units (monomers) are joined together in a particular orientation (stereo specificity), to form a regular three-dimensional polymer chain of a certain length (Mw & MWD).

Stereo specificity

Depending on the orientation of the pendant methyl groups, the PP can be isotactic, syndiotactic or atactic. In isotactic PP the pendant methyl groups are all on the same side of the polymer chain; due to this regular repeating arrangement isotactic PP has a high degree of crystallinity. Syndiotactic PP has the pendant methyl groups alternating on opposite side of the chain. In atactic PP this orientation is randomly. The amount of isotactic PP versus syndiotactic and atactic PP controls the crystallinity of the polymer.

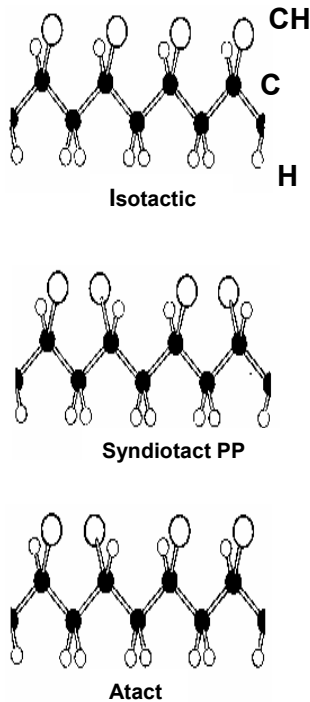


Figure 6: Stereo specificity of PP

Molecular weight and molecular weight distribution

A PP resin is composed of numerous chains of varying lengths, varying molecular weights. The average molecular weight and the distribution of the different molecular weights control the viscosity and elasticity of the polymer depending of course on shear rate and temperature. Best known property in this respect is the melt flow rate (MFR). The higher the Mw and, to a lesser extent, the narrower the MWD, the higher the viscosity and the lower the MFR will be.

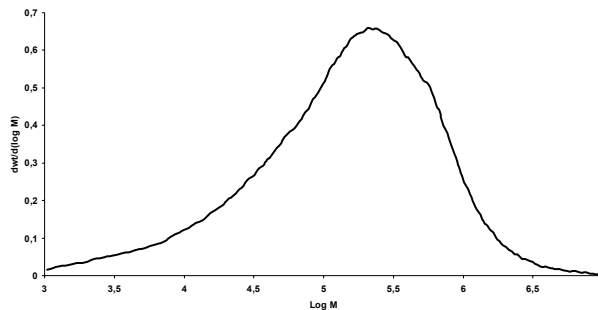


Figure 7: Molecular Weight Distribution of Borclean™ HB300B

Conclusion

The Slurry Process of Borealis offers today the highest purity homopolymer with catalyst residues and chlorines at ppm level; a further reduction of the residues won't bring any improvement towards electrical breakdown.

However a modified catalyst system in a continuous optimized polymerization process will provide a more balanced stereo specificity for an enhanced crystallinity of the BOPP capacitor film, resulting in a higher heat resistance, targeting the 135 °C; with better long-term dielectric properties above 700 V/μm.

Improved mechanical film properties as modulus and shrinkage will enable new and advanced metallisation and capacitor designs.

Tailoring the Mw and MWD eases polymer conversion to films with a challenged thickness of less than 2 μm.