Chapter 16

Parylene

Category: Engineering Resin

General Description: Parylene is the generic name for members of a unique polymer series. The basic member of the series, called Parylene N, is poly-para-xylylene, a completely linear, highly crystalline material.[2018]

Parylene C is produced from the same monomer modified only by the substitution of a chlorine atom for one of the aromatic hydrogens. Parylene C has a useful combination of electrical and physical properties plus a very low permeability to moisture and other corrosive gases. Along with its ability to provide a true pinhole free conformal insulation, Parylene C is the material of choice for coating critical electronic assemblies.[2018]

Parylene D is produced from the same monomer modified by the substitution of the chlorine atom for two of the aromatic hydrogens. Parylene D is similar in properties to Parylene C with the added ability to withstand higher use temperatures.[2018]

Processing Methods: The Parylene polymers are deposited from the vapor phase by a process which in some respects resembles vacuum metallizing. Unlike vacuum metallizing, the deposition is not line of sight, and all sides of an object to be encapsulated are uniformly impinged by the gaseous monomer. Due to the uniqueness of the vapor phase deposition, the Parylene polymers can be formed as structurally continuous films from as thin as a fraction of a micrometer to as thick as several mils.[2018]

Applications: Parylene is used as a coating on electronics ranging from advanced military and aerospace electronics to general-purpose industrial products, medical devices ranging from silicone tubes to advanced coronary stents, synthetic rubber products ranging from medical grade silicone rubber to EPDM.[2018]

Permeability to Oxygen, Other Gases, and Water Vapor: MVTR for Parylene C is superior to almost all polymeric materials. Parylene C and N are resistant to permeation by most solvents.[2018]

Permeability Data by Material Supplier Trade Name: See Tables 16-01 through 16-03.

Table 16-01. Oxygen, Nitrogen, Carbon Dioxide, Hydrogen, and Water Vapor Through SCS Parylene N Film

Material Family	**PARYLENE**				
Material Supplier/Grade	**SCS PARYLENE N FILM**				
Reference Number	2018				
TEST CONDITIONS					
Penetrant	oxygen	nitrogen	carbon dioxide	hydrogen	water vapor
Test Method	ASTM D1434			ASTM E96	
PERMEABILITY (source document units)					
Gas Permeability ($cm^3 \cdot mil/100\ in^2 \cdot 24h \cdot atm$)	39	7.7	214	540	
Gas Permeability ($g \cdot mil/100\ in^2 \cdot day$)					1.5
PERMEABILITY (normalized units)					
Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	15.3	3.03	84	212	
Permeability Coefficient ($g \cdot mm/m^2 \cdot day$)					0.59

Table 16-02. Oxygen, Nitrogen, Carbon Dioxide, Hydrogen, and Water Vapor Through SCS Parylene C Film

Material Family	**PARYLENE**				
Material Supplier/Grade	**SCS PARYLENE C FILM**				
Reference Number	2018				
TEST CONDITIONS					
Penetrant	oxygen	nitrogen	carbon dioxide	hydrogen	water vapor
Test Method	ASTM D1434			ASTM E96	
PERMEABILITY (source document units)					
Gas Permeability ($cm^3 \cdot mil/100\ in^2 \cdot 24\ h \cdot atm$)	7.2	1.0	7.7	110	
Gas Permeability ($g \cdot mil/100\ in^2 \cdot day$)					0.21
PERMEABILITY (normalized units)					
Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	2.83	0.393	3.03	43	
Permeability Coefficient ($g \cdot mm/m^2 \cdot day$)					0.083

Table 16-03. Oxygen, Nitrogen, Carbon Dioxide, Hydrogen, and Water Vapor Through SCS Parylene D Film

Material Family	**PARYLENE**				
Material Supplier/Grade	**SCS PARYLENE D FILM**				
Reference Number	2018				

TEST CONDITIONS

Penetrant	oxygen	nitrogen	carbon dioxide	hydrogen	water vapor
Test Method	ASTM D1434			ASTM E96	

PERMEABILITY (source document units)

Gas Permeability ($cm^3 \cdot mil/100\ in^2 \cdot 24h \cdot atm$)	32	4.5	13	240	
Gas Permeability ($g \cdot mil/100\ in^2 \cdot day$)					0.25

PERMEABILITY (normalized units)

Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	15.6	1.77	5.1	94	
Permeability Coefficient ($g \cdot mm/m^2 \cdot day$)					0.098

Chapter 17

Nylon Overview

Category: Nylon, Polyamide, Engineering Thermoplastic

General Description: Nylon is a generic name for a family of long-chain polyamide engineering thermoplastics. The nylon family members have recurring amide groups [—CO—NH—] as an integral part of the main polymer chain and are named by the number of carbon atoms in the monomers. Where there are two monomers, the polymer will carry two numbers (e.g., nylon 6/6).[1004] Commercial nylons are as follows: nylon 4, nylon 6, nylon 6/6, nylon 6/10, nylon 6/12, nylon 11, and nylon 12.

Nylon films provide a barrier to oxygen, flavors, and aromas.[2019]

Nylons are available in many varieties with ranges of properties (see Table 17-01). Sometimes a mix of nylons will provide the best solution for a particular application.

Nylon 6 is the least costly of the nylons and used where an oxygen barrier is required. It has the best gas and aroma barrier and the least moisture barrier. Nylon 66 is used where temperature resistance is needed and nylon 6/66 where co-extrusion compatability is required. In Table 17-01, in descending order, the gas barrier decreases and moisture barrier increases. Nylon 12 has the best moisture barrier and the poorest gas barrier. A mixture of nylons may provide the best solution for a given need.[1080]

See *Collected Comparative Barrier Properties of Plastics and Elastomers* for more information.

Nylon films, while providing a barrier to many gases, aromas, and flavors, are hydroscopic. Commonly, both oriented and unoriented nylon films are combined with moisture barrier materials to achieve optimum gas and water vapor protection.[2019] See Chapter 59, *Polyvinylidene Chloride Coated Films-PVDC Coated Films*, for more coated nylon film data.

Processing Methods: Extrusion, injection molding, blow molding, rotational molding and, for nylon 6 materials, casting or anionic polymerization. Nylon is also sold as sheet and film.[1004]

Orientation: Orientation improves the inherent barrier and mechanical properties of unoriented nylon film. After biaxial orientation, nylon film exhibits a significant improvement in oxygen and aroma barrier.[2019]

Applications: Typical applications for nylons are automotive parts, electrical/electronic uses, and packaging. Nylon's strength, durability, and barrier characteristics make it a valuable component in multi-

Table 17-01. Nylon Family Differences[1080]

Nylon Family Member	Density	Melt Point °F	H_2O Absorption Max	Gas & Aroma Barrier	Cost (Relative)
Nylon 6	1.13	428°	9.5%	Best	1.0
Nylon 6/66	1.13	400°	9.0%	↑	1.2
Nylon 66	1.14	491°	8.5%		1.3
Nylon 610	1.07	419°	3.3%		1.4
Nylon 612	1.07	410°	3.3%		1.5
Nylon 11	1.04	367°	1.8%	↓	1.8
Nylon 12	1.01	352°	1.6%	Poorest	1.7

layer film. Nylons are combined with polyolefins, foils, and other materials to enhance barrier properties.[2019]

Coated or laminated structures containing nylon can be heat sealed into pouches or thermoformed to provide cavities into which hot dogs, sliced meats, and cheeses can be positioned for aesthetic display and sales appeal in the supermarket.[2019]

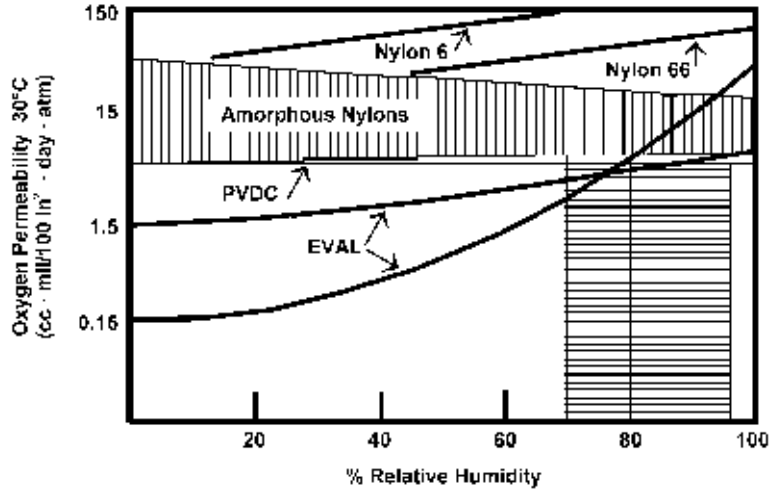
Packaging applications where oriented films perform best utilize either PVDC coatings, laminations to aluminum foil, polyethylene or ionomer film and/or metallized structures. Applications include pouch and vacuum brick coffee packages, soft cookies, bag-in-the-box packages, and snack food packages.[2019]

Oriented nylon is also used extensively in non-food packaging where migrating gases and odors are contained either within the package or prevented from entering from the adjacent packages. Examples include multiwalled bags for shipping materials impregnated with petroleum derivatives such as ready-to-light charcoal briquettes, agricultural and industrial chemicals. Photographic film is also packaged in structures containing nylon to afford better protection for the contents.[2019]

Permeability to Oxygen and Other Gases: Graph 17-01 shows the oxygen (gas) transmission rate for different nylons, PVDC, and EVAL (EVOH). The gas transmission rate measures how many cubic centimeters of gas pass through 100 square inches of a 1 mil-thick nylon film in 24 hours at the normal air pressure at sea level with increasing levels of relative humidity.[1080]

Permeability to Water and Other Liquids: Polar materials such as alcohols, glycols, and water softeners are absorbed by nylons.[1004] All nylons are hygroscopic. The amount of moisture absorbed will depend upon the ambient humidity and grade of nylon. Nylon parts exposed to the atmosphere take a long time to reach equilibrium moisture conditions.[2019]

Graph 17-01. Comparative oxygen barriers at increasing humidity.



Chapter 18

Amorphous Nylon

Category: Nylon, Polyamide

General Description: DuPont Selar PA is an amorphous nylon (polyamide) resin that exhibits superior transparency, good barrier properties to gases, water, solvents and essential oils, and high temperature structural properties.

Blending even low percentages (20%) of Selar PA with nylon 6, nylon 66, and nylon copolymers will result in a product that behaves like an amorphous polymer. These blends retain all of the advantages of the Selar PA resin with some of the mechanical property advantages of semicrystalline nylon.

EMS Chemie Grivory G16 and Grivory G21 are amorphous, partially aromatic nylon copolymers. The outstanding oxygen barrier, particularly in very damp conditions, and greater rigidity than nylon 6 (even after water absorption) makes Grivory G16 and G21 ideal for direct contact with nonalcoholic foodstuff.[2021]

DuPont has developed a special grade of Selar PA, known as 2072, which is specially designed for blending with EVOH.[2022]

Processing Methods: The Selar PA resin can be processed by the same blown film, cast film, or cast sheet equipment used with semicrystalline nylons or polyolefins. Selar PA-nylon 6 blends can be made by dry-blending.

Selar PA 2072 can be tumble-blended with most grades of ethylene vinyl alcohol copolymers.

Grivory G16 and Grivory G21 can be processed by film or sheet extrusion, paper coating, injection molding, and injection or extrusion blow molding.[2021]

Applications: The amorphous nylons can be used as a monolayer or as a component of multilayer flexible as well as rigid packaging. Selar PA is suitable for a variety of packaging applications that require clarity, barrier, and processing flexibility. Because of the excellent barrier at refrigerated conditions, Selar PA and Selar PA blends have benefits in meat and cheese packages, replacing the nylon 6, PVDC, or EVOH barrier layer.

Grivory G16 and Grivory G21, multilayer or monolayer, are used in transparent hollow vessels (bottles), packaging films, deep-drawn plates. Grivory G21 is also particularly effective as an additive for nylon 6 and other nylon base resins to improve film properties.[2021]

Permeability to Oxygen and Other Gases, and Water Vapor: Selar PA is unique in that its gas barrier improves with increasing relative humidity.

At wet conditions, 95–100% RH, Selar PA is an excellent barrier to oxygen, carbon dioxide, and water vapor. It is equivalent to the EVOH and substantially better than nylon 6 as an oxygen barrier at the same wet conditions.

At 30°C, 80% RH, the following container structures will provide equivalent oxygen barrier: 1 mil layer of high barrier PVDC or EVOH in a multilayer container, 8 mil monolayer of amorphous nylon, or 1.3 mil layer of amorphous nylon in a multilayer structure.

At dry conditions, 0–5% RH, Selar PA is a good barrier. At 0% RH, oxygen and carbon dioxide barrier properties are the same as for nylon 6.

The barrier properties of nylon 6/Selar blends fall between the performance of Selar PA alone and nylon 6. However, as the humidity increases, adding even small amounts of Selar PA improves the barrier more than would be predicted by a straight-line correlation.

Films of Grivory G21 have exceptional oxygen and carbon dioxide barrier properties, even under high humidity conditions. When 15–30% Grivory G21 is mixed with other nylons, films can be produced with better transparency and gas barrier properties.[2021]

Selar PA 2072 can be blended with EVOH (up to 40 wt% addition) without compromising the oxygen

barrier properties of EVOH, especially at high humidity.[2022]

See *Collected Comparative Barrier Properties of Plastics and Elastomers* for more information.

Permeability Data by Material Supplier Trade Name: See Tables 18-01 through 18-05 and Graphs 18-01 through 18-04.

Table 18-01. Oxygen and Water Vapor Through EMS Chemie Grivory G16 and Grivory G21 Amorphous Nylon

Material Family	AMORPHOUS NYLON				
Material Supplier	EMS CHEMIE GRIVORY				
Grade	**G21/G16**	**G21**	**G21/G16**	**G21**	**G21/G16**
Reference Number	2021	307	2021	307	2021
ATERIAL CHARACTERISTICS					
Sample Thickness (mm)	0.05				
EST CONDITIONS					
Penetrant	oxygen				water vapor
Temperature (°C)	23				
Relative Humidity (%)	0	50	85	100	85
Test Method	ASTM D3985	DIN 53380	ASTM D3985	DIN 53380	DIN 53122
ERMEABILITY (source document units)					
Gas Permeability ($cm^3/m^2 \cdot day \cdot bar$)	30	30	10	8	
Vapor Permeability ($g/m^2 \cdot day$)					7
ERMEABILITY (normalized units)					
Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	1.5	1.5	0.5	0.4	
Vapor Transmission Rate ($g/m^2 \cdot day$)					0.35

Table 18-02. Carbon Dioxide and Nitrogen Through EMS Chemie Grivory G21 Amorphous Nylon

Material Family	AMORPHOUS NYLON				
Material Supplier	EMS CHEMIE GRIVORY				
Grade	G21/G16	G21	G21/G16	G21/G16	G21
Reference Number	2021	307	2021	2021	307
MATERIAL CHARACTERISTIC					
Sample Thickness (mm)	0.05				
TEST CONDITIONS					
Penetrant	carbon dioxide			nitrogen	
Temperature (°C)	23				
Relative Humidity (%)	0	50	85	0	50
Test Method	EMS	DIN 53380	EMS	DIN 53380	DIN 53380
PERMEABILITY (source document units)					
Gas Permeability ($cm^3/m^2 \cdot day \cdot bar$)	90	75	40	10	10
PERMEABILITY (normalized units)					
Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	4.5	3.8	2.0	0.5	0.5

Table 18-03. Carbon Dioxide Through DuPont Selar PA Amorphous Nylon

Material Family	AMORPHOUS NYLON			
Material Supplier	DUPONT SELAR PA			
Reference Number	2022			
MATERIAL CHARACTERISTIC				
Sample Thickness (mm)	0.025			
TEST CONDITIONS				
Penetrant	carbon dioxide			
Temperature (°C)	0	0	30	30
Relative Humidity (%)	0 – 5	95 – 100	0 – 5	95 – 100
PERMEABILITY (source document units)				
Gas Permeability ($cc \cdot mil/100\ in^2 \cdot day \cdot atm$)	5.5	12.2	18.0	9.8
PERMEABILITY (normalized units)				
Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	2.16	4.8	7.07	3.85

Table 18-04. Water Vapor Through DuPont Selar PA Amorphous Nylon

Material Family	**AMORPHOUS NYLON**
Material Supplier/ Grade	**DUPONT SELAR PA**
Features	barrier properties
Reference Number	264

TEST CONDITIONS

Penetrant	water vapor
Temperature (°C)	40
Relative Humidity (%)	90

PERMEABILITY (source document units)

Vapor Transmission Rate (g ·mil/100 in^2 ·day)	1.4
Vapor Transmission Rate (g ·25 µm/m^2 ·day)	21.7

PERMEABILITY (normalized units)

Vapor Transmission Rate (g ·mm/m^2 ·day)	0.55

Table 18-05. Water Vapor, Carbon Dioxide, and Oxygen Through DuPont Selar PA Amorphous Nylon Film

Material Family	**AMORPHOUS NYLON**				
Material Supplier/Grade	**DUPONT SELAR PA**				
Product Form	**FILM**				
Features	barrier properties				
Reference Number	294				

TEST CONDITIONS

Penetrant	water vapor	carbon dioxide		oxygen	
Temperature (°C)	37.8	22.8		22.8	
Relative Humidity (%)	90	0	80	0	80

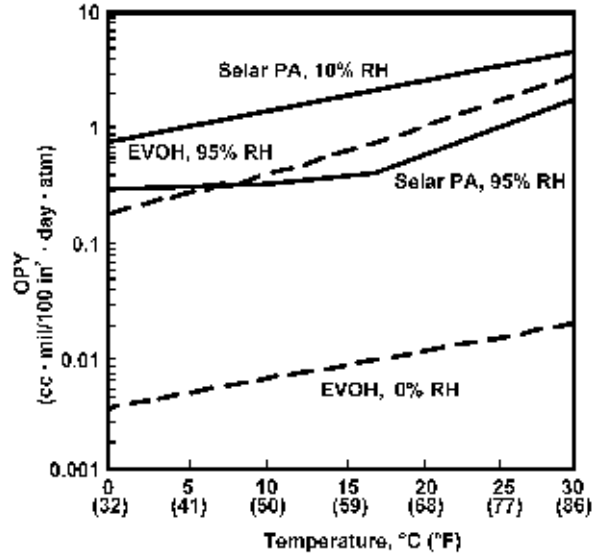
PERMEABILITY (source document units)

Vapor Transmission Rate (g ·mil/100 in^2 ·day)	1.2				
Gas Permeability (cm^3 ·mil/100 in^2 ·day)		4.5	2.8	2.5	1.2

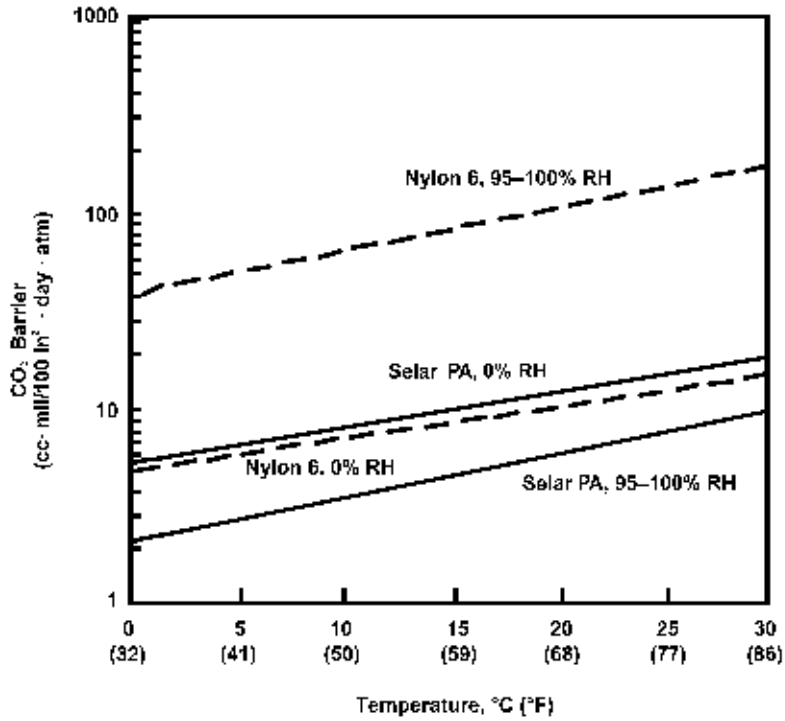
PERMEABILITY (normalized units)

Permeability Coefficient (cm^3 ·mm/m^2 ·day ·atm)		1.8	1.1	0.98	0.47
Vapor Transmission Rate (g ·mm/m^2 ·day)	0.47				

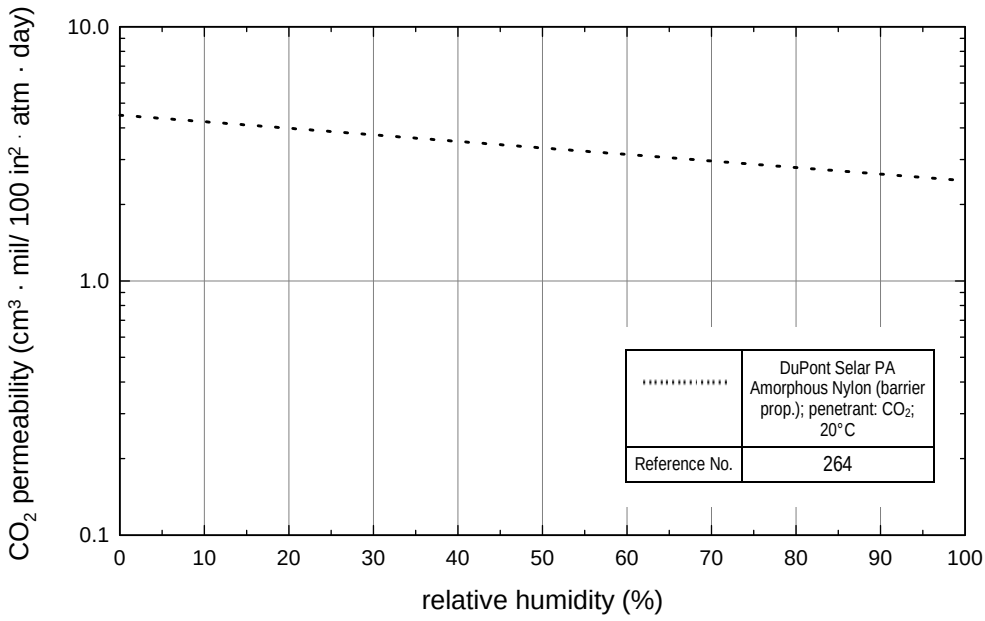
Graph 18-01. Oxygen vs. temperature through Selar PA and EVOH at 10% RH and 95% RH.[2022]



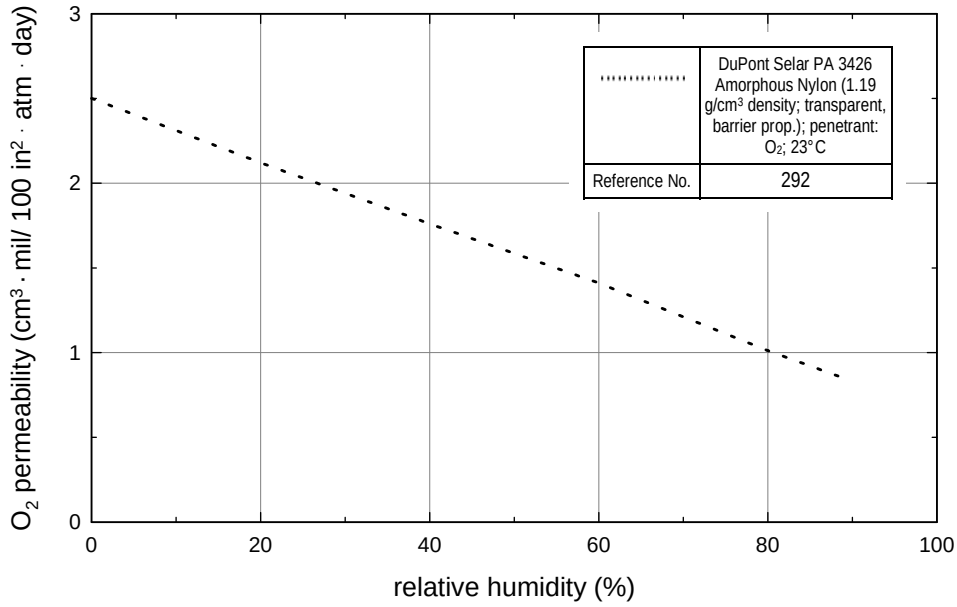
Graph 18-02. Carbon dioxide vs. temperature through Selar PA and Nylon 6 at 10% RH and 95% RH.[2022]



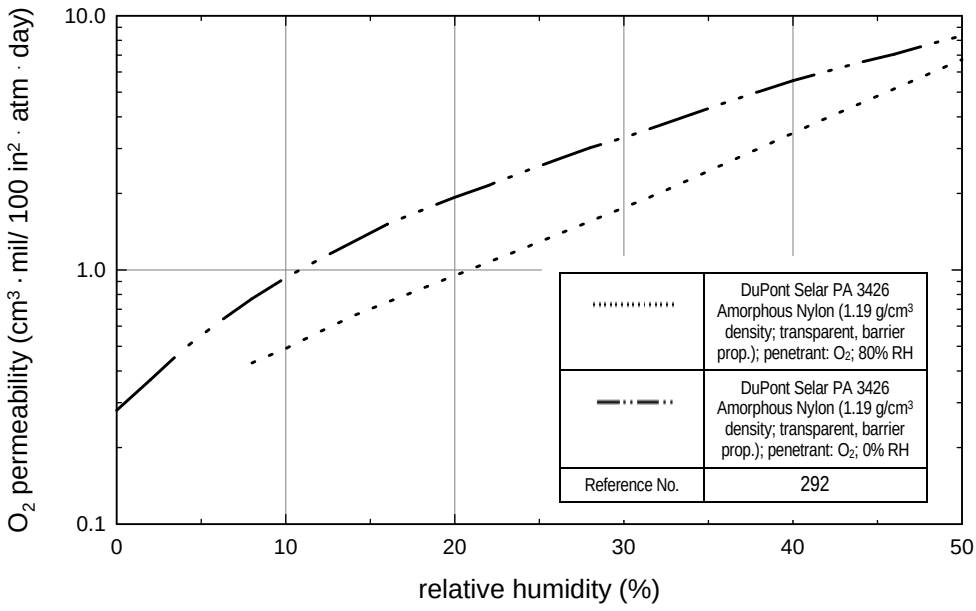
Graph 18-03. Carbon dioxide vs. relative humidity through DuPont Selar PA Amorphous Nylon.



Graph 18-04. Oxygen vs. relative humidity through DuPont Selar PA Amorphous Nylon.



Graph 18-05. Oxygen vs. temperature through DuPont Selar PA Amorphous Nylon.



Chapter 19

Nylon 6 – PA 6

Category: Nylon, Polyamide, Engineering Thermoplastic

General Description: Nylon 6 provides excellent barrier to oils and fats and does not absorb or transmit most flavors. The main deficiencies are processing difficulties and poor water barrier. These factors limit the use of nylon 6 in packaging.[1080]

EMS Grilon F34 is specifically suited for the production of biaxially oriented film.

EMS Grilon F50 is specifically suited for use in monolayer blown films and extrusion blow molded containers.

Processing Methods: Injection molding, extrusion, extrusion coating, blown film, blow molding. Nylon films can easily be thermoformed and bi-axially stretched.

Applications:

- *Multilayer Packaging.* Food and medical.
- *Industrial Containers.* Automotive underhood reservoirs.

Permeability to Oxygen and Other Gases: Nylon 6 demonstrates low oxygen permeability.

Permeability to Water and Other Liquids: Nylon 6 is permeable to water vapor.

Permeability Data by Material Supplier Trade Name: See Tables 19-01 through 19-11, and Graph 19-01.

Table 19-01. Carbon Dioxide Through Honeywell Plastics Capron 8207F Type 6 Nylon

Material Family	**NYLON 6**			
Material Supplier	**HONEYWELL PLASTICS CAPRON 8207F TYPE 6 NYLON**			
Reference Number	1080			
MATERIAL CHARACTERISTICS				
Sample Thickness (mm)	0.025			
TEST CONDITIONS				
Penetrant	carbon dioxide			
Temperature (°C)	0		30	
Relative Humidity (%)	0 – 5	95 – 100	0 – 5	95 – 100
PERMEABILITY (source document units)				
Gas Permeability ($cc \cdot mil/100\ in^2 \cdot day \cdot atm$)	5	39	15	160
PERMEABILITY (normalized units)				
Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	1.97	15.3	5.9	63

Table 19-02. Oxygen, Carbon Dioxide, and Water Vapor Through BASF Ultramid Nylon 6 Film

Material Family	NYLON 6					
Material Supplier Trade Name	BASF ULTRAMID					
Grade	**B4**	**B36**	**B4**	**B36**	**B4**	**B36**
Features	moderate flow	enhanced clarity, moderate flow	moderate flow	enhanced clarity, moderate flow	moderate flow	enhanced clarity, moderate flow
Manufacturing Method	flat film, tubular film					
Reference Number	93					

MATERIAL CHARACTERISTICS

Sample Thickness (mm)	0.02 - 0.1		0.02 - 0.1		0.02 - 0.1	

TEST CONDITIONS

Penetrant	oxygen		carbon dioxide		water vapor	
Temperature (°C)	23					
Relative Humidity (%)	40		0		85%-0% gradient	
Test Method	DIN 53380				DIN 53122	

PERMEABILITY (source document units)

Gas Permeability ($cm^3 \cdot 100\ \mu m/m^2 \cdot day \cdot bar$)	6 - 7	6 - 7	40 - 45	40 - 45		
Vapor Transmission Rate ($g \cdot 100\mu m/m^2 \cdot day$)					1.5 - 1.6	1.5 - 1.6

PERMEABILITY (normalized units)

Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	0.61 - 0.71	0.61 - 0.71	4.0 - 4.6	4.0 - 4.6		
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)					15 - 16	15 - 16

Table 19-03. Carbon Dioxide, Nitrogen, Helium, and Water Vapor Through Oriented Nylon 6

Material Family	NYLON 6	
Features	oriented	biaxially oriented
Reference Number	264	

TEST CONDITIONS

Penetrant	carbon dioxide	nitrogen	helium	water vapor
Temperature (°C)	35	23	35	40
Relative Humidity (%)	0			90

PERMEABILITY (source document units)

Gas Permeability ($cm^3 \cdot mil/100\ in^2 \cdot day$)	6.62	0.7	116	
Gas Permeability ($cm^3 \cdot 25\ \mu m/m^2 \cdot day \cdot atm$)	102.6	10.8	1798	
Vapor Transmission Rate ($g \cdot mil/100\ in^2 \cdot day$)				10.2
Vapor Transmission Rate ($g \cdot 25\ \mu m/m^2 \cdot day$)				158.1

PERMEABILITY (normalized units)

Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	2.61	0.28	45.7	
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)				4.02

Table 19-04. Oxygen Through Oriented and Un-Oriented Nylon 6

Material Family	NYLON 6					
Features	oriented			unoriented		
Reference Number	264					
TEST CONDITIONS						
Penetrant	oxygen					
Temperature (°C)	5	23	35	5	23	35
Relative Humidity (%)	0					
PERMEABILITY (source document units)						
Gas Permeability ($cm^3 \cdot mil/100\ in^2 \cdot day$)	0.49	1.78	3.3	1.439	5.08	10
Gas Permeability ($cm^3 \cdot 25\ \mu m/m^2 \cdot day \cdot atm$)	7.59	25.59	51.15	22.3	78.74	154.9
PERMEABILITY (normalized units)						
Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	0.19	0.7	1.3	0.57	2	3.9

Table 19-05. Oxygen and Water Vapor Through BASF Ultramid B4 Nylon 6 Film

Material Family	NYLON 6			
Material Supplier/Grade	BASF ULTRAMID B4			
Features	unstretched	biaxially stretched	unstretched	biaxially stretched
Reference Number	252			
MATERIAL CHARACTERISTICS				
Sample Thickness (mm)	0.02 - 0.025	0.02	0.02 - 0.025	0.02
TEST CONDITIONS				
Penetrant	water vapor		oxygen	
Temperature (°C)	20			
Relative Humidity (%)	85-0% gradient		40	
Test Method	DIN 53122		DIN 53380	
PERMEABILITY (source document units)				
Vapor Transmission Rate ($g/m^2 \cdot day$)	50 - 80	40 - 60		
Gas Permeability ($cm^3/m^2 \cdot day \cdot bar$)			25 - 35	12 - 15
PERMEABILITY (normalized units)				
Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)			0.57 - 0.8	0.24 - 0.3
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)	1.13 - 1.8	0.8 - 1.2		

Table 19-06. Oxygen, Nitrogen and Carbon Dioxide Through Honeywell Capran 6

Material Family	**NYLON 6**									
Material Supplier/Grade	**HONEYWELL CAPRAN 6**									
Product Form	**FILM**									
Reference Number	285									
MATERIAL CHARACTERISTICS										
Sample Thickness (mm)	0.0254	0.0254	0.019	0.0254	0.0254	0.0254	0.0254	0.0254	0.0254	0.0254
TEST CONDITIONS										
Penetrant	oxygen				nitrogen			carbon dioxide		
Temperature (°C)	0	23	23	50	0	23	50	0	23	50
Relative Humidity (%)	0									
Test Note	STP conditions									
PERMEABILITY (source document units)										
Gas Permeability ($cm^3/100\ in^2 \cdot day \cdot atm$)	0.5	2.6	3.2	14	0.2	0.9	12	0.6	4.7	44
PERMEABILITY (normalized units)										
Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	0.2	1.02	0.94	5.5	0.08	0.35	4.7	0.24	1.8	17.3

Table 19-07. Water Vapor and Oxygen Through Honeywell Capran 6 Film

Material Family	**NYLON 6**			
Material Supplier/Trade Name	**HONEYWELL CAPRAN**			
Product Form	**FILM**			
Reference Number	284		296	

MATERIAL CHARACTERISTICS

Sample Thickness (mm)	0.0254			

TEST CONDITIONS

Penetrant	water vapor	oxygen	oxygen	water vapor
Temperature (°C)	37.8	23	22.8	37.8
Relative Humidity (%)	90	0	0	90
Test Method	pouch method	permeability cell	ASTM D1434	ASTM F1249
Test Note	STP conditions			

PERMEABILITY (source document units)

Vapor Transmission Rate ($g/m^2 \cdot day$)	295 - 310			
Vapor Transmission Rate ($g/day \cdot 100\ in^2$)	19 - 20			
Vapor Transmission Rate ($g \cdot mil/\ 100\ in^2 \cdot bar \cdot day$)				23
Gas Permeability ($cm^3/m^2 \cdot day$)		40.3		
Gas Permeability ($cm^3 \cdot mil/\ 100\ in^2 \cdot bar \cdot day$)			3	
Gas Permeability ($cm^3/100\ in^2 \cdot day \cdot atm$)		2.6		

PERMEABILITY (normalized units)

Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)		1.02	1.2	
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)	7.5 - 7.9			9.2

Table 19-08. Water Vapor Through Honeywell Capran Nylon 6 Film

Material Family	**NYLON 6**			
Material Supplier/Grade	**HONEYWELL CAPRAN**			
Product Form	**FILM**			
Reference Number	285			
MATERIAL CHARACTERISTICS				
Sample Thickness (mm)	0.019	0.0254	0.019	0.019
TEST CONDITIONS				
Penetrant	water vapor			
Temperature (°C)	23		37.8	
Relative Humidity (%)	50		90	
Test Note	pouch method			
PERMEABILITY (source document units)				
Vapor Transmission Rate (g/day ·100 in^2)	0.8	0.6	24-26	19-20
PERMEABILITY (normalized units)				
Vapor Transmission Rate (g ·mm/m^2 ·day)	0.24	0.24	7.1 - 7.7	5.6 - 5.9

Table 19-09. Water Vapor, Carbon Dioxide, and Oxygen Through Nylon 6 Film

Material Family	**NYLON 6**				
Product Form	**FILM**				
Features	barrier properties				
Reference Number	294				
TEST CONDITIONS					
Penetrant	water vapor	carbon dioxide		oxygen	
Temperature (°C)	37.8	22.8		22.8	
Relative Humidity (%)	90	0	80	0	80
PERMEABILITY (source document units)					
Vapor Transmission Rate (g ·mil/100 in^2 ·day)	25				
Gas Permeability (cm^3 ·mil/100 in^2 ·day)		4.7	8.0	3.6	7.0
PERMEABILITY (normalized units)					
Permeability Coefficient (cm^3 ·mm/m^2 ·day ·atm)		1.8	3.2	1.4	2.8
Vapor Transmission Rate (g ·mm/m^2 ·day)	9.8				

Table 19-10. Oxygen, Carbon Dioxide, Nitrogen, and Water Vapor Through EMS Grilon F 34 Type 6 Nylon

Material Family	**NYLON 6**				
Material Supplier/Grade	**EMS GRILON F 34**				
Reference Number	2021				
MATERIAL CHARACTERISTICS					
Sample Thickness (mm)	0.05				
TEST CONDITIONS					
Penetrant	oxygen	oxygen	carbon dioxide	nitrogen	water vapor
Temperature (°C)	23				--
Relative Humidity (%)	0	85	0	0	--
Test Method	DIN 53380			DIN 53122	
PERMEABILITY (source document units)					
Gas Permeability ($cm^3/m^2 \cdot day \cdot bar$)	25	100	65	10	
Gas Permeability ($g/m^2 \cdot day$)					20
PERMEABILITY (normalized units)					
Permeability Coefficient ($cm^3\ mm/m^2 \cdot day \cdot atm$)	1.26	5.05	3.28	0.50	
Permeability Coefficient ($g \cdot mm/m^2 \cdot day$)					1

Table 19-11. Oxygen, Carbon Dioxide, Nitrogen, and Water Vapor Through EMS Grilon F 50 Type 6 Nylon

Material Family	**NYLON 6**
Material Supplier	**EMS GRILON F 50**
Reference Number	2021

MATERIAL CHARACTERISTICS

Sample Thickness (mm)	0.05

TEST CONDITIONS

Penetrant	oxygen		carbon dioxide		nitrogen	water vapor
Temperature (°C)	23		23		23	--
Relative Humidity (%)	0	85	0	85	0	--
Test Method	ASTM D3985		EMS	DIN 53380	DIN 53122	

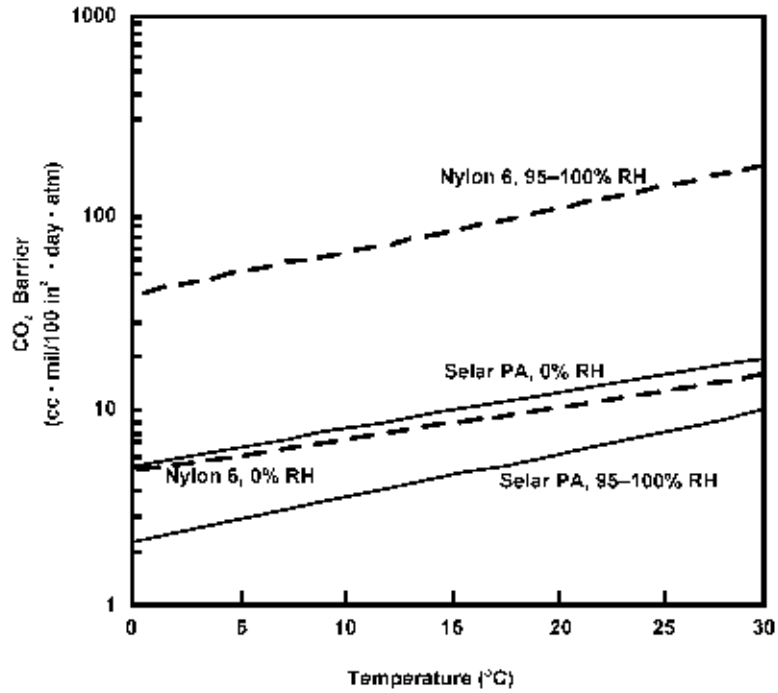
PERMEABILITY (source document units)

Gas Permeability ($cm^3 \cdot / m^2 \cdot day \cdot bar$)	25	70	80	250	10	
Gas Permeability ($g/m^2 \cdot day$)						20

PERMEABILITY (normalized units)

Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	1.26	3.53	4.04	12.6	0.50	
Gas Permeability ($g \cdot mm/m^2 \cdot day$)						1

Graph 19-01. Carbon dioxide vs. temperature through Selar PA and Nylon 6 at 10% RH and 95% RH.[2022]



Chapter 20

Nylon 66 – PA 66

Category: Nylon, Polyamide, Engineering Thermoplastic

General Description: Nylon 6,6, hexamethylene diamine adipic acid, is one of the most widely used nylons.[1004] DuPont Canada Dartek films are made from Nylon 6,6, and, depending upon grade can be: transparent, PVDC coated, high barrier properties, treated for ink, adhesive and coating receptivity, machine direction oriented tape or monoaxially oriented.[2023]

- *Dartek F-101*. A clear, cast nylon film designed for thermoforming applications.
- *Dartek N-201*. A nylon film made from type 66 polymer.
- *Dartek O-401*. A machine-direction oriented nylon type 66 film.
- *Dartek UF-410*. A monoaxially oriented nylon 66 film with good "slip" characteristics.
- *Dartek B-602*. A strong transparent nylon film with PVDC coating applied to one side.
- *DuPont Zytel*. A nylon 66 resin.[2024]

See Ch. 59, *Polyvinylidene Chloride Coated Films-PVDC Coated Films*, for more coated nylon 66 film data.

Processing Methods:

- *Dartek*. Depending upon grade, can be printed, laminated, extrusion coated, thermoformed, and metallized.[2023]
- *Zytel*. Injection molding, extrusion: shapes and films.[2024]

Applications:

- *Dartek*. Assorted shapes for packaging meat and cheese, industrial end uses, pouch and primal bag, stiff packages, snacks, condiments, shredded cheese, and coffee.[2023]
- *Zytel*. Food packaging, potable water and electrical applications.[2024]

Permeability to Oxygen and Other Gases:

- *Dartek B-602*. Specially formulated for use in high humidity.
- *Dartek N-201*. Low permeability to oxygen and odor.
- *Dartek O-401*. Gas permeability improved due to orientation
- *Dartek UF-410*. Excellent gas barrier.[2023]
- *Zytel*. An excellent barrier to some gases, including most Freon gases.[2024]

Permeability to Water and Other Liquids:

- *Dartek B-602*. Specially formulated for use in high humidity.
- *Dartek N-201*. Barrier to oils and grease.[2023]
- *Zytel*. An excellent barrier to fuels and lubricants.[2024]

Permeability Data by Material Supplier Trade Name: See Tables 20-01 through 20-06.

Table 20-01. Oxygen and Water Vapor Through DuPont Canada Dartek F-101 and N-201

Material Family	**NYLON 66**			
Material Supplier	**DUPONT CANADA DARTEK**			
Grade	**F-101**		**N-201**	
Reference Number	2023			
MATERIAL CHARACTERISTICS				
Sample Thickness (mm)	0.025			
TEST CONDITIONS				
Penetrant	oxygen	water vapor	oxygen	water vapor
Temperature (°C)	23			
Relative Humidity (%)	0	90	0	90
Test Method	ASTM D1434	Honeywell MVTR	ASTM D1434	ASTM E398
PERMEABILITY (source document units)				
Gas Permeability (cc/100 in^2 ·24 hr)	3.5		3.5	
(cc/m^2 ·24 hr)	54.3		54.3	
Vapor Permeability (g/100 in^2 ·24 hr)		19		19
(g/m^2 ·24 hr)		295		295
PERMEABILITY (normalized units)				
Permeability Coefficient (cm^3 ·mm/m^2 ·day ·atm)	1.36		1.36	
Vapor Transmission Rate (g ·mm/m^2 ·24 hr)		7.4		7.4

Table 20-02. Oxygen and Water Vapor Through DuPont Canada Dartek O-401 and U-401

Material Family	**NYLON 66**			
Material Supplier	**DUPONT CANADA DARTEK O-401 and U-401**			
Reference Number	2023			
MATERIAL CHARACTERISTICS				
Sample Thickness (mm)	0.015			
TEST CONDITIONS				
Penetrant	oxygen			water vapor
Temperature (°C)	23		4	
Relative Humidity (%)	0	100	100	
Test Method	ASTM D1434			Honeywell MVTR
PERMEABILITY (source document units)				
Gas Permeability (cc/100 in^2 · 24 hr)	2.5	5.0	0.7	
(cc/m^2 · 24 hr)	39	77	11	
Vapor Permeability (g/100 in^2 · 24 hr)				9.5
(g/m^2 · 24 hr)				145
PERMEABILITY (normalized units)				
Permeability Coefficient (cm^3 · mm/m^2 · day · atm)	0.585	1.155	0.165	
Vapor Transmission Rate (g · mm/m^2 · 24 hr)				2.2

Table 20-03. Oxygen, Carbon Dioxide, and Water Vapor Through BASF Ultramid A5 Nylon 66 Film

Material Family	**NYLON 66**					
Material Supplier/Grade	**BASF ULTRAMID A5**					
Features	low flow					
Manufacturing Method	flat film	tubular film	flat film	tubular film	flat film	tubular film
Reference Number	93					

MATERIAL CHARACTERISTICS

Sample Thickness (mm)	0.02 - 0.1

TEST CONDITIONS

Penetrant	oxygen	carbon dioxide	water vapor
Temperature (°C)	23		
Relative Humidity (%)	40	0	85%-0% gradient
Test Method	DIN 53380		DIN 53122

PERMEABILITY (source document units)

Gas Permeability ($cm^3 \cdot 100\ \mu m/m^2 \cdot day \cdot bar$)	6 - 7	3 - 4	45	30		
Vapor Transmission Rate ($g \cdot 100\ \mu m/m^2 \cdot day$)					11 - 12	8

PERMEABILITY (normalized units)

Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	0.61 - 0.71	0.3 - 0.41	4.6	3.0		
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)					1.1 - 1.2	0.8

Table 20-04. Oxygen and Water Vapor Through BASF Ultramid A5 Nylon 66 Film

Material Family	**NYLON 66**	
Material Supplier/Grade	**BASF ULTRAMID A5**	
Manufacturing Method	blown film	blown film
Reference Number	252	

MATERIAL CHARACTERISTICS

Sample Thickness (mm)	0.05

TEST CONDITIONS

Penetrant	water vapor	oxygen
Temperature (°C)	20	
Relative Humidity (%)	85-0% gradient	40
Test Method	DIN 53122	DIN 53380

PERMEABILITY (source document units)

Vapor Transmission Rate ($g/m^2 \cdot day$)	30	
Gas Permeability ($cm^3/m^2 \cdot day \cdot bar$)		15

PERMEABILITY (normalized units)

Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)		0.76
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)	1.5	

Table 20-05. Oxygen, Carbon Dioxide, Nitrogen, Helium, and Water Vapor Through DuPont Zytel 42 Nylon 66 Film

Material Family	**NYLON 66**
Material Supplier/Grade	**DUPONT ZYTEL 42**
Product Form	**FILM**
Features	low flow
Reference Number	68

TEST CONDITIONS

Penetrant	water vapor		oxygen	carbon dioxide	nitrogen	helium
Temperature (°C)	23					
Relative Humidity (%)	50	100	50			

PERMEABILITY (source document units)

Gas Permeability ($cm^3 \cdot mil/100\ in^2 \cdot day$)			2	9	0.7	150
Vapor Transmission Rate ($g \cdot mil/100\ in^2 \cdot day \cdot atm$)	1.0	20				

PERMEABILITY (normalized units)

Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)			0.79	3.5	0.28	59.1
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)	0.39	7.9				

Table 20-06. Liquids Through DuPont Zytel 42 Nylon 66 Bottles

Material Family	**NYLON 66**
Material Supplier/Grade	**DUPONT ZYTEL 42**
Product Form	**BOTTLES**
Features	low flow
Reference Number	68

MATERIAL CHARACTERISTICS

Sample Thickness (mm)	2.54

TEST CONDITIONS

Penetrant	kerosene	methyl salicylate	motor oils	toluene	ASTM Fuel Oil B	water	carbon tetrachloride	naphtha
Concentration (%)								VMP naphtha
Penetrant Note			SAE 10		isooctane and toluene blend			

PERMEABILITY (source document units)

Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)	0.08	0.2	1.2 - 2.4	2.0	2.4
Vapor Transmission Rate ($g \cdot mil/100\ in^2 \cdot day \cdot atm$)	0.2	0.5	3 - 6	5	6

PERMEABILITY (normalized units)

Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)	0.08	0.2	1.2 - 2.4	2	2.4

Chapter 21

Nylon 6/66 – PA 6/66

Category: Nylon, Polyamide, Engineering Thermoplastic

General Description: BASF and Honeywell Plastics offer materials combining the benefits of both PA 6 and PA 66. Through the combination of properties of both polymers, together with the addition of a heat stabilizer system, specific grades can be tailor made to meet the requirements of applications in respect of the level of heat, barrier, toughness, and puncture resistance, as well as greater productivity and superior ability to thermoform.[2025]

Permeability Data by Material Supplier Trade Name: See Tables 21-01 through 21-03.

Table 21-01. Oxygen, Carbon Dioxide and Water Vapor Through BASF Ultramid C Nylon 6/66 Film

Material Family	**NYLON 6/66**		
Material Supplier/Grade	**BASF ULTRAMID C35**		
Features	moderate to high flow		
Manufacturing Method	flat film, tubular film		
Reference Number	93		
MATERIAL CHARACTERISTICS			
Sample Thickness (mm)	0.02 - 0.1		
TEST CONDITIONS			
Penetrant	oxygen	carbon dioxide	water vapor
Temperature (°C)	23		
Relative Humidity (%)	40	0	85%-0% gradient
Test Method	DIN 53380		DIN 53122
PERMEABILITY (source document units)			
Gas Permeability ($cm^3 \cdot 100\ \mu m/m^2 \cdot day \cdot bar$)	8 - 9	40 - 45	
Vapor Transmission Rate ($g \cdot 100\ \mu m/m^2 \cdot day$)			15 - 18
PERMEABILITY (normalized units)			
Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	0.81 - 0.91	4.0 - 4.6	
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)			1.5 - 1.8

Table 21-02. Water Vapor, Oxygen, Carbon Dioxide, and Nitrogen Through Honeywell Capron Nylon 6/66 Film

Material Family	**NYLON 6/66**				
Material Supplier/Trade Name	**HONEYWELL CAPRAN**				
Product Form	**FILM**				
Reference Number	284				
MATERIAL CHARACTERISTICS					
Sample Thickness (mm)	0.0254				
TEST CONDITIONS					
Penetrant	water vapor	oxygen		carbon dioxide	nitrogen
Temperature (°C)	37.8		23		
Relative Humidity (%)	90	0 (dry)	90 (wet)	dry	
Test Method	cup method	ASTM D3985	permeability cell	ASTM D1435; Dow Cell	
PERMEABILITY (source document units)					
Vapor Transmission Rate ($g/m^2 \cdot day$)	341				
Gas Permeability ($cm^3/m^2 \cdot day$)		37.2	232.5	113.2	7.75
PERMEABILITY (normalized units)					
Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)		0.94	5.91	2.88	0.2
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)	8.7				

Table 21-03. Air Conditioning Refrigerant Loss Through Nylon 6/66 Copolymer Tubes

Material Family	**NYLON 6/66**		
Reference Number	275		
MATERIAL CHARACTERISTICS			
Sample Thickness (mm)	1		
Sample Length (mm)	305		
Sample Inside Diameter (mm)	15.9		
TEST CONDITIONS			
Penetrant	Freon 12	HCFCX-134a	HCFC-22/HCFC-124 HFC-152a
Penetrant Note	air conditioning refrigerant @ saturated vapor pressure		air conditioning refrigerant, ternary blend @ saturated vapor pressure
Temperature (°C)	93		
Test Note	calculated from permeation coefficient data		
PERMEABILITY (source document units)			
Permeation Loss (lb/ft-yr)	0.067	0.077	0.178

Chapter 22

Nylon 6/12 – PA 6/12

Category: Nylon, Polyamide, Engineering Thermoplastic

General Description:

- *EMS Chemie Grilon CF 85.* A nylon copolymer specially developed for the manufacture of co-extruded blown and cast films. Grilon CF 85 is extremely effective at reducing curl in asymmetric co-extruded film structures.[2021]
- *Grilon CA 6E.* A nylon copolymer developed for film co-extrusion. This product is not warm water extracted, and contains a relatively high (3 – 5%) fraction of low molecular weight components. The advantage of this copolyamide is its low melt temperature, high flexibility, and high shrinkage after orientation.[2021]
- *Grilon CF 6S.* A nylon film grade resin for use in multilayer blown and cast films and is particularly suitable for boil-in bag applications.[2021]
- *Grilon CR 9.* A nylon film grade resin for use in multilayer blown or cast films. It is suitable for multilayer food packaging films for dry, non-fatty foods.[2021]
- *Grilon CR 9 HV.* A high viscosity nylon copolymer developed for the manufacture of co-extruded films. Grilon CR 9 HV is a superior product for extreme draw thermoforming films.[2021]

Permeability Data by Material Supplier Trade Name: See Tables 22-01 through 22-05.

Table 22-01. Oxygen, Carbon Dioxide, Nitrogen, and Water Vapor Through EMS Chemie Grilon CF 85

Material Family	**NYLON 6/12**					
Material Supplier	**EMS CHEMIE GRILON CF 85**					
Reference Number	2021					
MATERIAL CHARACTERISTICS						
Sample Thickness (mm)	0.05					
TEST CONDITIONS						
Penetrant	oxygen		carbon dioxide		nitrogen	water vapor
Temperature (°C)	23					–
Relative Humidity (%)	0	85	0	85	0	–
Test Method	ASTM D3985		EMS		DIN 53380	DIN 53122
PERMEABILITY (source document units)						
Gas Permeability ($cm^3/m^2 \cdot day \cdot bar$)	60	85	–	–	–	
($g/m^2 \cdot day$)						–
PERMEABILITY (normalized units)						
Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	3	4.25	–	–	–	
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot d$)						

Table 22-02. Oxygen Through EMS Chemie Grilon CA 6E

Material Family	**NYLON 6/12**	
Material Supplier	**EMS CHEMIE GRILON CA 6E**	
Reference Number	2021	
MATERIAL CHARACTERISTICS		
Sample Thickness (mm)	0.025	
TEST CONDITIONS		
Penetrant	Oxygen	
Temperature (°C)	23	
Relative Humidity (%)	0	100
PERMEABILITY (source document units)		
Gas Permeability ($cm^3/m^2 \cdot day \cdot bar$)	240	320
PERMEABILITY (normalized units)		
Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	6	8

Table 22-03. Oxygen, Carbon Dioxide, Nitrogen, and Water Vapor Through EMS Chemie Grilon CF 6S

Material Family	**NYLON 6/12**				
Material Supplier	**EMS CHEMIE GRILON CF 6S**				
Reference Number	2021				
MATERIAL CHARACTERISTICS					
Sample Thickness (mm)	0.05				
TEST CONDITIONS					
Penetrant	Oxygen		Carbon Dioxide	Nitrogen	Water Vapor
Temperature (°C)	23				—
Relative Humidity (%)	50	100	50		—
Test Method	DIN 53380				DIN 53122
PERMEABILITY (source document units)					
Gas Permeability ($cm^3/m^2 \cdot day \cdot bar$)	120	300	400	60	
Vapor Permeability ($g/m^2 \cdot day$)					13
PERMEABILITY (normalized units)					
Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	6	15	20	3	
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)					0.65

Table 22-04. Oxygen, Carbon Dioxide, Nitrogen, and Water Vapor Through EMS Chemie Grilon CR 9

Material Family	**NYLON 6/12**						
Material Supplier	**EMS CHEMIE GRILON CR 9**						
Reference Number	2021						
MATERIAL CHARACTERISTICS							
Sample Thickness (mm)	0.05						
TEST CONDITIONS							
Penetrant	oxygen		carbon dioxide		nitrogen	water vapor	
Temperature (°C)	23						
Relative Humidity (%)	50	85	0	85	0	85	
Test Method	ASTM D3985		EMS		DIN 53380	DIN 53122	
PERMEABILITY (source document units)							
Gas Permeability ($cm^3/m^2 \cdot day \cdot bar$)	55	100	170	13			
Vapor Permeability ($g/m^2 \cdot day$)					15		
PERMEABILITY (normalized units)							
Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	2.75	5	8.5	0.65			
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)					0.75		

Table 22-05. Oxygen, Carbon Dioxide, Nitrogen and Water Vapor Through EMS Chemie Grilon CR 9 HV

Material Family	**NYLON 6/12**				
Material Supplier	**EMS CHEMIE GRILON CR 9 HV**				
Reference Number	2021				

MATERIAL CHARACTERISTICS

Sample Thickness (mm)	0.05

TEST CONDITIONS

Penetrant	oxygen		carbon dioxide	nitrogen	water vapor
Temperature (°C)	23				—
Relative Humidity (%)	0	85	50		—
Test Method	DIN 53380				DIN 53122

PERMEABILITY (source document units)

Gas Permeability ($cm^3/m^2 \cdot day \cdot bar$)	55	75	200	350	15
Vapor Permeability ($g/m^2 \cdot day$)					15

PERMEABILITY (normalized units)

Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	2.75	3.75	10	17.5	0.75
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)					0.75

Chapter 23

Nylon 6/6.9 – PA 6/69

Category: Nylon, Polyamide, Engineering Thermoplastic

General Description: EMS Chemie Grilon BM 13 SBG and BM 17 SBG are film grade resins with high barrier and high shrinkage that exhibit excellent deep drawability and exceptional shrinkability in hot water.[2021]

Processing Methods:

- *Grilon BM 13 SBG.* Coextruded blown and cast films.

Permeability Data by Material Supplier Trade Name: See Tables 23-01 through 23-02.

Table 23-01. Oxygen, Carbon Dioxide, Nitrogen, and Water Vapor Through EMS Chemie Grilon BM 13 SBG

Material Family	NYLON 6/6.9					
Material Supplier	EMS CHEMIE GRILON BM 13 SBG					
Reference Number	2021					
MATERIAL CHARACTERISTICS						
Sample Thickness (mm)	0.05					
TEST CONDITIONS						
Penetrant	oxygen		carbon dioxide		nitrogen	water vapor
Temperature (°C)	23					
Relative Humidity (%)	0	85	0	85	0	85
Test Method	ASTM D3985		EMS		DIN 53380	DIN 53122
PERMEABILITY (source document units)						
Gas Permeability ($cm^3/m^2 \cdot day \cdot bar$)	50	100	130	500	10	
Vapor Permeability ($g/m^2 \cdot day$)						15
PERMEABILITY (normalized units)						
Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	2.5	5	6.5	25	0.5	
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)						0.75

Table 23-02. Oxygen, Carbon Dioxide, and Water Vapor Through EMS Chemie Grilon BM 17 SBG

Material Family	**NYLON 6/6.9**				
Material Supplier	**EMS CHEMIE GRILON BM 17 SBG**				
Reference Number	2021				
MATERIAL CHARACTERISTICS					
Sample Thickness (mm)	0.05				
TEST CONDITIONS					
Penetrant	oxygen		carbon dioxide		water vapor
Temperature (°C)	23				
Relative Humidity (%)	0	85	0	85	
Test Method	ASTM D3985		EMS		DIN 53122
PERMEABILITY (source document units)					
Gas Permeability ($cm^3/m^2 \cdot day \cdot bar$)	65	45	205	470	
Vapor Permeability ($g/m^2 \cdot day$)					18
PERMEABILITY (normalized units)					
Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	3.25	2.25	10.25	23.5	
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)					0.9

Chapter 24

Nylon 6.6/6.10 – PA 66/610

Category: Nylon, Polyamide, Engineering Thermoplastic

General Description: EMS Chemie Grilon BM 20 SBG is a nylon copolymer developed for co-extruded film structures requiring a very "clean" polymer.[2021]

Processing Methods: Grilon BM 20 SBG can be readily converted using cast or blown film equipment, and can be oriented using most systems.[2021]

Application:

- *Films.* Grilon BM 20 SBG is particularly suitable for medical packaging applications.[2021]

Permeability Data by Material Supplier Trade Name: See Table 24-01.

Table 24-01. Oxygen, Carbon Dioxide, Nitrogen, and Water Vapor Through EMS Chemie Grilon BM 20 SBG

Material Family	NYLON 6.6/6.10 – PA66/610					
Material Supplier	EMS CHEMIE GRILON BM 20 SBG					
Reference Number	2021					
MATERIAL CHARACTERISTICS						
Sample Thickness (mm)	0.05					
TEST CONDITIONS						
Penetrant	oxygen		carbon dioxide		nitrogen	water vapor
Temperature (°C)	23					
Relative Humidity (%)	0	85	0	85	0	
Test Method	ASTM D3985		EMS		DIN 53380	DIN 53122
PERMEABILITY (source document units)						
Gas Permeability ($cm^3/m^2 \cdot day \cdot bar$)	55	75	250	450	15	
Vapor Permeability ($g/m^2 \cdot day$)						15
PERMEABILITY (normalized units)						
Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	2.8	3.8	12.6	22.7	0.76	
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)						15

Chapter 25

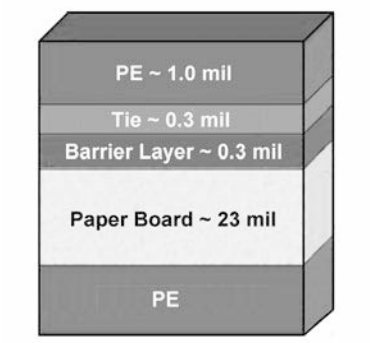
Polyamide Nanocomposite

Category: Nylon, Polyamide

General Description:

- *Honeywell Aegis OX and NC.* A new family of polymerized nanocomposite resins, dramatically improves on the strength, stiffness, barrier, and heat resistance properties of Nylon 6. Aegis barrier resins exhibit reduced moisture absorption and increased melt stability.[1119]
- *Aegis OX.* An oxygen scavenging polyamide/nanocomposite for use in applications that require high gas barrier such as fruit juice and beer. Aegis OX combines high gas barrier with other packaging related attributes such as high transparency in co-injection/stretch blow molding.[1119]
- *Aegis NC.* A polymerized Nylon 6 (PA 6) based nanocomposite for use in high gas barrier packaging applications where oxygen and carbon dioxide barrier is required. Aegis NC is easily processed and well suited to co-injection and co-extrusion processing.[1119]

Graph 25-01. Aegis NC multilayer structure.[1119]



Processing Methods: Co-injection and co-extrusion processing, stretch blow-molding, injection molding, blown film, cast film.[1119]

Applications:

- *Aegis OX.* Co-injection molded PET bottle applications, including beer bottles and orange juice containers.[1119]
- *Aegis NC.* Coating or base resin for cast or blown films, replacement for Nylon 6 coatings in paperboard juice cartons and process meat and cheese packaging.[1119]

Permeability of Oxygen and Other Gases: Aegis NC provides orange juice cartons with approximately three times better oxygen barrier of Nylon 6. Aegis NC yields 60% OTR improvement vs. PA 6 in paperboard carton structure.[1119]

Permeability of Water and Other Liquids: Aegis OX resin oxygen barrier properties and its ability to function as a barrier to d-Limonen—the oil responsible for orange juice's flavor—can greatly extend orange juice shelf life.

Aegis OX and NC barrier properties, especially relating to petroleum-based fluids and gases, could allow for significant use in the automotive OEM.[1119]

Permeability Data by Material Supplier Trade Name: See Graph 25-01 and Tables 25-01 through 25-02.

Table 25-01. Oxygen, and Carbon Dioxide Through Honeywell Aegis OX and NC Films

Material Family	**POLYAMIDE POLYMERIZED NANOCOMPOSITE**		
Material Supplier	**AEGIS OX and NC FILMS**		
Grade	**Aegis OX**		**Aegis NC**
Reference Number	1119		
MATERIAL CHARACTERISTICS			
Sample Thickness (mm)	-		0.0075
TEST CONDITIONS			
Penetrant	oxygen	carbon dioxide	oxygen
Temperature (°C)	25		—
Relative Humidity (%)	80		—
PERMEABILITY (source document units)			
Gas Permeability ($cc \cdot mil/100\ in^2 \cdot day \cdot atm$)	0.001	2.5	
($cc/100\ in^2 \cdot day \cdot atm$)			1.5
PERMEABILITY (normalized units)			
Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	0.0004	0.98	0.177

Table 25-02. Ingress Comparison: Oxygen Through Honeywell Aegis OX Bottle vs. Glass Bottle

Material Family	**POLYAMIDE POLYMERIZED NANOCOMPOSITE**
Material Supplier/Grade	**AEGIS OX BOTTLE**
Reference Number	1119
TEST CONDITIONS	
Penetrant	Oxygen
INGRESS (source document units)	
Gas Permeability (µg/day)	2.5
(µmoles/day)	0.08

Chapter 26

Polycarbonate

Category: Polycarbonate

General Description: Polycarbonates, one of the strongest, toughest, and most rigid thermoplastics,[1004] are not generally considered good barrier materials. It is possible to use polycarbonate as the structural layer in a composite (co-extruded) film for use in barrier application. In such cases, polycarbonate contributes toughness and heat resistance to the final product while other components in the composite film may provide the barrier properties.[2025]

Processing Methods: Injection molding, extrusion, blow molding, and rotational molding.

Applications:

- *Packaging.* Milk bottles, baby bottles, food containers.
- *Medical.* Dialysers, artery cannulas.
- *Electrical.* Distribution box lids, fuses, sockets, lamp holders, and covers.[2025]

Permeability Data by Material Supplier Trade Name: See Tables 26-01 through 26-03.

Table 26-01. Oxygen, Carbon Dioxide, and Nitrogen Through Dow Calibre Polycarbonate

Material Family	POLYCARBONATE								
Material Supplier/Trade Name	DOW CHEMICAL CALIBRE								
Grade	300-4	300-15	800-6	300-4	300-15	800-6	300-4	300-15	800-6
Features	general purpose grade, transparent		flame retardant, transparent	general purpose grade, transparent		flame retardant, transparent	general purpose grade, transparent		flame retardant, transparent
Reference Number	78								

TEST CONDITIONS

Penetrant	nitrogen			oxygen			carbon dioxide		
Test Method	ASTM D2752								

PERMEABILITY (source document units)

Gas Permeability ($cm^3 \cdot mil/100\ in^2 \cdot day$)	31	27	57	260	230	314	1950	1720	2100

PERMEABILITY (normalized units)

Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	12.2	10.6	22.4	102	90.6	124	768	677	827

Table 26-02. Water Vapor, Carbon Dioxide, and Oxygen Through Polycarbonate Film

Material Family	POLYCARBONATE			
Product Form	FILM			
Reference Number	294	264	294	294

TEST CONDITIONS

Penetrant	water vapor		carbon dioxide	oxygen
Temperature (°C)	37.8	40	22.8	
Relative Humidity (%)	90		0	

PERMEABILITY (source document units)

Vapor Transmission Rate ($g \cdot mil/100\ in^2 \cdot day$)	9.7	11		
Vapor Transmission Rate ($g \cdot 25\ \mu/m^2 \cdot day$)		170.5		
Gas Permeability ($cm^3 \cdot mil/100\ in^2 \cdot day$)			780	260

PERMEABILITY (normalized units)

Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)			307	102
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)	3.82	4.33		

Table 26-03. Water Vapor, Oxygen, Nitrogen, and Carbon Dioxide Through Bayer Makrolon Polycarbonate Film

Material Family	**POLYCARBONATE**
Material Supplier/Grade	**BAYER MAKROLON**
Product Form	**FILM**
Reference Number	289

MATERIAL CHARACTERISTICS

Sample Thickness (mm)	0.1

TEST CONDITIONS

Penetrant	oxygen	nitrogen	carbon dioxide	water vapor
Temperature (°C)				23
Relative Humidity (%)				85
Test Method	DIN 53380, pt. 3			DIN 53122

PERMEABILITY (source document units)

Gas Permeability ($cm^3/m^2 \cdot day \cdot bar$)	670	110	4300	
Vapor Transmission Rate ($g/m^2 \cdot day$)				15 (approximate)

PERMEABILITY (normalized units)

Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	67.9	11.2	436	
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)				1.5 (approximate)

Chapter 27

Polybutylene Terephthalate (PBT)

Category: Polyester, Thermoplastic

General Description: Thermoplastic polyesters are comparable in properties to Nylon 6 and 66 but have lower water absorption and higher dimensional stability. Most PBT is sold in the form of filled and reinforced compounds for engineering applications.[1004]

Processing Method: Melt processable.

Applications: Packaging, automotive, electrical, and consumer markets.

Permeability: The barrier properties of BASF Ultradur B 4550 film can be greatly improved by vacuum metallizing with aluminum.

Permeability Data by Material Supplier Trade Name: See Table 27-01.

Table 27-01. Water Vapor, Nitrogen, Oxygen, and Carbon Dioxide Through BASF AG Ultradur Polybutylene Terephthalate

Material Family	**POLYBUTYLENE TEREPHTHALATE**			
Material Supplier/Grade	**BASF AG ULTRADUR B 4550**			
Reference Number	180			
MATERIAL CHARACTERISTICS				
Sample Thickness (mm)	0.25			
TEST CONDITIONS				
Penetrant	water vapor	nitrogen	oxygen	carbon dioxide
Temperature (°C)	23			
Relative Humidity (%)	85%-0% gradient	50		
Test Method	DIN 53122	DIN 53380		
Test Condition Note	standard laboratory atmosphere			
PERMEABILITY (source document units)				
Gas Permeability ($cm^3/m^2 \cdot day \cdot bar$)		12	60	550
Vapor Transmission Rate ($g/m^2 \cdot day$)	10			
PERMEABILITY (normalized units)				
Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)		3.04	15.2	139
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)	2.5			

Polyethylene Napthalate (PEN)

Category: Polyester, Thermoplastic

General Description: Polyethylene napthalate resin can be processed into films, fibers, and containers.[1004] Biaxially oriented PEN films offer improved physical properties when compared with OPET.

DuPont Teijin PEN Films are designed for special situations, where films are subject to especially stringent conditions or for those applications where exceptional barrier performance is required.[1055]

Processing Methods: May be thermoformed and blow molded into containers. Films may be biaxially oriented.[312]

Applications: Electrical, industrial, general purpose, high-value-added applications in labels, laminates, circuitry, and release.[1055]

Permeability: Thermoformed and blow molded containers offer improved gas and moisture barrier over containers made from PET homopolymer.[312] Pen has up to five times the oxygen barrier of PET.[1004]

Permeability Data by Material Supplier Trade Name: See Tables 28-01 through 28-02.

Table 28-01. Oxygen, Carbon Dioxide, and Water Vapor Through Teijin DuPont Films

Material Family	**POLYETHYLENE NAPTHALATE (PEN)**		
Material Supplier	**TEIJIN DUPONT FILMS Q51**		
Product Form	**FILM**		
Reference Number	1055		
MATERIAL CHARACTERISTICS			
Sample Thickness (mm)	0.625		
TEST CONDITIONS			
Penetrant	oxygen	carbon dioxide	water vapor
Test Method	ASTM D1434–63		JIS Z–0208
PERMEABILITY (source document units)			
Gas Permeability (10^{-12} cc ·cm/cm² ·sec ·cm Hg)	0.8	3.7	
Vapor Permeability (g/m² ·day)			6.7
PERMEABILITY (normalized units)			
(cm³ ·mm/m² ·day · atm)	0.525	2.43	
(g ·mm/m² ·day)			4.19

Table 28-02. Oxygen and Water Vapor Through Eastman Chemical PEN Film

Material Family	**POLYETHYLENE NAPTHALATE (PEN)**
Material Supplier	**EASTMAN CHEMICAL 14991**
Product Form	**EASTMAN CHEMICAL**
Reference Number	312

MATERIAL CHARACTERISTICS

Sample Thickness (mm)	0.25

TEST CONDITIONS

Penetrant	oxygen	water vapor
Test Method	ASTM D3985	ASTM F372

PERMEABILITY (source document units)

Gas Permeability ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	1.5	
($cm^3 \cdot mil/100\ in^2 \cdot day \cdot atm$)	3.8	
Vapor Permeability ($g/m^2 \cdot day$)		2.9
($g/100\ in^2 \cdot day$)		0.2

PERMEABILITY (normalized units)

($cm^2 \cdot mm/m^2 \cdot day \cdot atm$)	1.5	
($g \cdot mm/m^2 \cdot day$)		0.73

Chapter 29

Polycyclohexylenedimethylene Terephthalate (PCTG)

Category: Copolyester

General Description: Clear amorphous copolyester resin. [1117]

Processing Methods: Thermoformed, fabricated, and heat sealed

Applications: Bags, blister packaging.[1117]

Permeability Data by Material Supplier Trade Name: See Table 29-01.

Table 29-01. Water Vapor, Carbon Dioxide, Oxygen, and Nitrogen Through Eastman Eastar PCTG 5445

Material Family	**GLYCOL MODIFIED POLYCYCLOHEXYLENEDIMETHYLENE TEREPHTHALATE (PCTG)**			
Material Supplier/Grade	**EASTMAN PCTG 5445**			
Product Form	**FILM**			
Features	transparent			
Reference Number	166			
MATERIAL CHARACTERISTICS				
Sample Thickness (mm)	0.25			
TEST CONDITIONS				
Penetrant	water vapor	carbon dioxide	oxygen	nitrogen
Temperature (°C)		23		
Test Method	ASTM E96E	ASTM D1434		
PERMEABILITY (source document units)				
Vapor Transmission Rate ($g/m^2 \cdot day$)	7			
Gas Permeability ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)		50	10	3
PERMEABILITY (normalized units)				
Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)		50	10	3
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)	1.75			

Chapter 30

Polycyclohexylenedimethylene Ethylene Terephthalate (PETG)

Category: Copolyester

General Description: Clear amorphous copolyester Resin[1118]

Processing Methods: Extrusion, extrusion blow molding, thermoforming, injection molding, and fabrication, heat sealed.

Applications: Bags, blister packaging, thermoformed containers, bottles for shampoo, soap, detergent and oils, and protective sleeves.[1118]

Permeability Data by Material Supplier Trade Name: See Tables 30-01 through 30-02.

Table 30-01. Oxygen and Water Vapor Through Eastman PETG

Material Family	POLYCYCLOHEXYLENEDIMETHYLENE ETHYLENE TEREPHTHALATE (PETG)	
Reference Number	296	
TEST CONDITIONS		
Penetrant	oxygen	water vapor
Temperature (°C)	22.8	37.8
Relative Humidity (%)	0	90
Test Method	ASTM D1434	ASTM F1249
PERMEABILITY (source document units)		
Gas Permeability ($cm^3 \cdot mil/100\ in^2 \cdot bar \cdot day$)	25	
Vapor Transmission Rate ($g \cdot mil/100\ in^2 \cdot bar \cdot day$)		4
PERMEABILITY (normalized units)		
Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	9.97	
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)		1.6

Table 30-02. Water Vapor, Carbon Dioxide, Oxygen, and Nitrogen Through Eastman Kodar Eastar PETG 6763

Material Family	**POLYCYCLOHEXYLENEDIMETHYLENE ETHYLENE TEREPHTHALATE (PETG)**
Material Supplier/Grade	**EASTMAN KODAR EASTAR PETG 6763**
Product Form	**FILM**
Features	amorphous, transparent
Reference Number	1118

MATERIAL CHARACTERISTICS

Sample Thickness (mm)	0.25

TEST CONDITIONS

Penetrant	water vapor	carbon dioxide	oxygen	nitrogen
Temperature (°C)		23		
Test Method	ASTM E96E	ASTM D1434		

PERMEABILITY (source document units)

Gas Permeability ($cm^3 \cdot mil/100\ in^2 \cdot day$)		125	25	10
Gas Permeability ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)		49	10	5
Vapor Transmission Rate ($g/m^2 \cdot day$)	6			
Vapor Transmission Rate ($g/day \cdot 100\ in^2$)	0.4			

PERMEABILITY (normalized units)

Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)		31.5	9.84	3.94
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)	1.5			

Chapter 31

Polyethylene Terephthalate (PET)

Category: Thermoplastic Polyester

General Description: PET is a water white polymer. DuPont Selar PT is available as a resin.DuPont Teijin Films Melinex Films are biaxially oriented polyester films.

- *Melinex 864.* A polyester film, chemically treated on two sides.[1055]
- *Melinex 854.* A clear, one side coextruded heat sealable surface similar to Melinex 850. The opposite surface is adhesion pretreated.[1055]
- *Melinex 822.* A polyester film that has been chemically pretreated on one side.[1055]
- *Melinex 813.* A polyester film, pretreated on one side.[1055]
- *Melinex 800.* A clear, non-pretreated base film with high gloss, low haze and excellent processability.[1055]
- *Melinex 800C.* A clear, one side corona treated polyester film.[1055]

DuPont Teijin Films Mylar Films, plain or metallized, may be coated for barrier, printing or sealing.[1120]

- *Mylar 200 SBL 300.* A multilayer, polyester-based laminate, which contains several different, nonfoil, barrier layers that work synergistically to provide a super barrier to atmospheric gases and moisture permeation.[1120]

Processing Methods:

- *Bottles.* Injection blow molded.[1121]
- *Melinex.* Industrial, packaging, imaging, printing, technical and consumer products.[1055]
- *Mylar.* Thermoform, heat shrink.[1121]

Applications: The single largest application for PET containers is the carbonated soft drink and water bottle. Neither application requires additional barrier protection beyond the basic plastic performance of PET.[1085]

- *Selar PT.*
  - *4000 series:* monolayer and coextruded heat sealable film used for metallization and/or lamination and oven trays.[1125]
  - *5000 series:* solvent barrier containers for non-food applications.[1125]
  - *7000 series:* sheeting, extrusion coating and film.[1125]
  - *8000 series:* thermoformed clear containers, blister packages extrusion blow molded bottles and coextruded sheet for heat seal use.[1125]
- *Melinex 864.* Designed for printing and extruded polyethylene adhesion.[1055]
- *Melinex 854.* Heat sealable surface acceptable for both water and solvent ink systems.[1055]
- *Melinex 822.* Designed for printing and extruded polyethylene adhesion.[1055]
- *Melinex 813.* Accepts both solvent- and water-based inks.[1055]
- *Melinex 800C.* Suitable for flexible packaging, printing and laminations.[1055]
- *Mylar.* Magnetic media packaging, laminating substrate for flexible packaging, boil-in-bag, lids, microwave applications, oven wrap, snack bags.[1121]
  - *Mylar 200 SBL 300:* Vacuum Insulation Panels, VIP, can improve the insulating characteristics of open cell or other materials by a factor of 3 to 7 times, compared to traditional insulating materials.[1120]

Permeability to Oxygen and Other Gases: "PET is considered to have good barrier properties with permeation rates for oxygen, carbon dioxide, and moisture vapor in the ranges of 0.6–0.8, 3–5, and 2.5–5.0 mol/(m · s · Pa) × 10^{17} at 23°C, 50% RH respectively."[1005]

Melinex 813 film features good clarity and handling characteristics in metallizing operations. When aluminum metallized, the film exhibits excellent aesthetic quality as well as the best barrier to oxygen and moisture in a flexible packaging film.[1125]

Permeability to Water and Other Vapors: Selar PT is an effective flavor and aroma barrier resin.[1122]

Permeability Data by Material Supplier Trade Name: See Tables 31-01 through 31-13.

Table 31–01. Oxygen, Carbon Dioxide, Nitrogen, and Hydrogen Through DuPont Mylar PET Film

Material Family	**POLYETHYLENE TEREPHTHALATE (PET)**			
Material Supplier/Grade	**DUPONT MYLAR**			
Product Form	**FILM**			
Reference Number	270			
TEST CONDITIONS				
Penetrant	carbon dioxide	hydrogen	nitrogen	oxygen
Temperature (°C)	25			
Test Method	ASTM D1434-72			
PERMEABILITY (source document units)				
Gas Permeability (cm^3 · mil/100 in^2 · day)	16	100	1	6
Gas Permeability (µm^3 · mm/m^2 · sec · Pa)	1115	6970	70	418
PERMEABILITY (normalized units)				
Permeability Coefficient (cm^3 · mm/m^2 · day · atm)	6.3	39.4	0.39	2.4

Table 31-02. Oxygen vs. Relative Humidity Through PET Film

Material Family	**POLYETHYLENE TEREPHTHALATE (PET)**			
Product Form	**FILM**			
Reference Number	265			
TEST CONDITIONS				
Penetrant	oxygen			
Temperature (°C)	20			
Relative Humidity (%)	65	85	100	0
PERMEABILITY (source document units)				
Gas Permeability ($cm^3 \cdot mil/100\ in^2 \cdot day$)	2.9			6.4
PERMEABILITY (normalized units)				
Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	1.14			2.52

Table 31-03. Oxygen vs. Temperature and Carbon Dioxide, Nitrogen, and Helium Through Oriented PET Film

Material Family	**POLYETHYLENE TEREPHTHALATE (PET)**						
Features	oriented						
Reference Number	264						
TEST CONDITIONS							
Penetrant	oxygen				carbon dioxide	nitrogen	helium
Temperature (°C)	5	23	35	50	35	23	35
Relative Humidity (%)	0						
PERMEABILITY (source document units)							
Gas Permeability ($cm^3 \cdot mil/100\ in^2 \cdot day$)	0.66	2.3	5.1	16.78	19.6	0.46	180
Gas Permeability ($cm^3 \cdot 25\ \mu/m^2 \cdot day \cdot atm$)	10.23	35.64	79.04	260	303.9	7.1	2790
PERMEABILITY (normalized units)							
Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	0.26	0.91	2.01	6.61	7.72	0.18	70.9

Table 31-04. Water Vapor, Oxygen, Nitrogen, and Carbon Dioxide Through Oriented PET Film

Material Family	**POLYETHYLENE TEREPHTHALATE (PET)**
Features	oriented
Reference Number	138

TEST CONDITIONS

Penetrant	water vapor	oxygen	nitrogen	carbon dioxide
Temperature (°C)	37.8	25		
Relative Humidity (%)	90			
Test Note		STP conditions		

PERMEABILITY (source document units)

Vapor Transmission Rate ($g \cdot mil/100\ in^2 \cdot day$)	1.0 - 1.3			
Gas Permeability ($cm^3 \cdot mil/100\ in^2 \cdot day$)		3.0 - 6.0	0.7 - 1.0	15 - 25
Gas Permeability ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)		1.2 - 2.4	0.28 - 0.39	5.9 - 9.8
Vapor Transmission Rate ($g/day \cdot 100\ in^2$)	0.39 - 0.51			

PERMEABILITY (normalized units)

Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)		1.2 - 2.4	0.28 - 0.39	5.9 - 9.8
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)	0.39 - 0.51			

Table 31-05. Organic Solvents Through PET Film

Material Family	**POLYETHYLENE TEREPHTHALATE (PET)**			
Product Form	**FILM**			
Reference Number	266			

MATERIAL CHARACTERISTICS

Sample Thickness (mm)	0.0254

TEST CONDITIONS

Penetrant	chloroform	xylene	methyl ethyl ketone	kerosene
Temperature (°C)	20			
Relative Humidity (%)	65			

PERMEABILITY (source document units)

Vapor Transmission Rate ($g/day \cdot 100\ in^2$)	20.0	0.11	0.10	0.03

PERMEABILITY (normalized units)

Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)	7.87	0.04	0.01

Table 31-06. Various Vapors Through DuPont Mylar PET Film

Material Family	**POLYETHYLENE TEREPHTHALATE (PET)**
Material Supplier/Grade	**DUPONT MYLAR**
Product Form	**FILM**
Reference Number	270

TEST CONDITIONS

Penetrant	acetone	benzene	carbon tetrachloride	ethyl acetate	hexane	water vapor
Temperature (°C)	40	25	40			37.8
Relative Humidity (%)						90
Test Method	ASTM E96-80					
Test Note	modified test, permeabilities determined at the partial pressure of the vapor at the test temperature					

PERMEABILITY (source document units)

Vapor Transmission Rate ($g \cdot mil/100\ in^2 \cdot day$)	2.22	0.36	0.08	0.12	1.8
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)	0.87	0.14	0.03	0.05	0.7

PERMEABILITY (normalized units)

Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)	0.87	0.14	0.03	0.05	0.71

Table 31-07. Oxygen Before and After Shrinking DuPont Teijin Films Mylar HS PET Film

Material Family	**POLYETHYLENE TEREPHTHALATE (PET)**							
Material Supplier/Grade	**DUPONT TEIJIN FILMS MYLAR HS HEAT SHRINK APPLICATIONS**							
Reference Number	1123							
MATERIAL CHARACTERISTICS								
Sample Thickness (mm)	0.012	0.017	0.020	0.038	0.012	0.017	0.020	0.038
TEST CONDITIONS								
Penetrant	oxygen, before shrinking				oxygen, after shrinking			
Temperature (°C)	22							
Test Method	ASTM D3985							
PERMEABILITY (source document units)								
Gas Permeability (cc/100 in^2 · day · atm)	9	8	7	5	4.5-6	4.5	3-4	2-3
PERMEABILITY (normalized units)								
Permeability Coefficient (cm^3 · mm/m^2 · day · atm)	0.042	0.054	0.055	0.075	0.02-0.03	0.03	0.02-0.03	0.03-0.04

Table 31-08. Water Vapor DuPont Teijin Films Mylar HS PET Film

Material Family	**POLYETHYLENE TEREPHTHALATE (PET)**			
Material Supplier/Grade	**DUPONT TEIJIN FILMS MYLAR HS HEAT SHRINK APPLICATIONS**			
Reference Number	1123			
MATERIAL CHARACTERISTICS				
Sample Thickness (mm)	0.012	0.017	0.020	0.038
TEST CONDITIONS				
Penetrant	water vapor			
Temperature (°C)	38			
Relative Humidity (%)	90			
Test Method	ASTM F1249			
PERMEABILITY (source document units)				
Vapor Permeability (g/m^2 ·day)	43	40	26	15
PERMEABILITY (normalized units)				
Vapor Transmission Rate (g ·mm/m^2 ·day)	0.5	0.68	0.52	0.57

Table 31-09. Oxygen and Water Vapor Through DuPont Teijin Films Mylar 200 SBL 300 PET Multilayer Film

Material Family	**POLYETHYLENE TEREPHTHALATE (PET)**		
Material Supplier/Grade	**DUPONT TEIJIN FILMS MYLAR 200 SBL 300**		
Reference Number	1120		

MATERIAL CHARACTERISTICS

Sample Thickness (mm)	0.058

TEST CONDITIONS

Penetrant	oxygen	water vapor	
Temperature (°C)	23		38
Relative Humidity (%)	20	50	90
Test Method	ASTM D3985	ASTM F1249	

PERMEABILITY (source document units)

Gas Permeability ($cm^3/100\ in^2 \cdot day \cdot atm$)	0.00004		
($cm^3/m^2 \cdot day \cdot atm$)	0.00062		
Vapor Permeability ($g/100\ in^2 \cdot day$)		0.0003	0.004
($g/m^2 \cdot day$)		0.005	0.062

PERMEABILITY (normalized units)

Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	3.6×10^{-5}		
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)		3×10^{-4}	3.6×10^{-3}

Table 31-10. Water Vapor Through DuPont Teijin Films Melinex Films

Material Family	POLYETHYLENE TEREPHTHALATE (PET)					
Material Supplier/Grade	**864**		**854**		**822**	
Reference Number	1055					
MATERIAL CHARACTERISTICS						
Sample Thickness (mm)	0.025		0.031		0.025	
TEST CONDITIONS						
Penetrant	oxygen	water vapor	oxygen	water vapor	oxygen	water vapor
Temperature (°C)	25	38	25	38	25	38
Relative Humidity (%)	75	90	75	90	75	90
Test Method	ASTM D1434	ASTM F372	ASTM D1434	ASTM F372	ASTM D1434	ASTM F372
PERMEABILITY (source document units)						
Gas Permeability ($cm^3/100\ in^2 \cdot day \cdot atm$)	6.0		5.0		2.8	
Vapor Permeability ($g/100\ in^2 \cdot day$)		2.8		2.3		6.0
PERMEABILITY (normalized units)						
Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	2.4		2.5		1.1	
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)		1.1		1.13		2.4

Table 31-11. Oxygen and Water Vapor Through DuPont Teijin Films Melinex 813 and Melinex 800 Metalized and Oxygen, Nitrogen, Carbon Dioxide, and Water Vapor Through DuPont Teijin Films Melinex 813 and Melinex 800 Unmetalized Film

Material Family	POLYETHYLENE TEREPHTHALATE (PET)						
Material Supplier/Grade	DUPONT TEIJIN FILMS MELINEX						
	813 & 800 metalized	813 & 800 unmetalized				813 unmetalized	800 unmetalized
Reference Numbers	1055						
MATERIAL CHARACTERISTICS							
Sample Thickness (mm)	0.025						
TEST CONDITIONS							
Penetrant	oxygen	water vapor	oxygen	nitrogen	carbon dioxide	water vapor	
Temperature (°C)	25	38	25			38	
Relative Humidity (%)	75	90	75			90	
Test Method	ASTM D1434	ASTM F372	ASTM D1434			ASTM F372	
PERMEABILITY (source document units)							
Gas Permeability ($cm^3/100\ in^2 \cdot day \cdot atm$)	0.08		6.0	1.6	31.0		
Vapor Permeability ($g/100\ in^2 \cdot day$)		0.05				2.0	2.8
PERMEABILITY (normalized units)							
Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	0.031			2.36	0.63	12.2	
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)		0.02				0.79	1.1

Table 31-12. Water Vapor and Oxygen Through DuPont Selar PT PET Containers

Material Family	**POLYETHYLENE TEREPHTHALATE (PET)**	
Material Supplier/Grade	**DUPONT SELAR PT**	
Product Form	**CONTAINER**	**CUP**
Features	heat stabilized, hot fill, retort, transparent	hot fill, retort
Applications	food packaging	
Manufacturing Method	thermoforming (DuPont Fortrex process)	
Reference Number	290	

MATERIAL CHARACTERISTICS

Sample Thickness (mm)			0.23

TEST CONDITIONS

Penetrant	water vapor	oxygen		
Temperature (°C)	25			
Relative Humidity (%)	50			
Test Note			container before retort	container after retort

PREEXPOSURE CONDITIONING

Preconditioning Note		retort temperature: 121°C, retort time: 40 min.

PERMEABILITY (source document units)

Permeation (cm^3/pkg/day · atm)			0.204	0.228
Vapor Transmission Rate (g · mil/100 in^2 · day)	1.3			
Gas Permeability (cm^3 · mil/100 in^2 · day)		5		

PERMEABILITY (normalized units)

Permeability Coefficient (cm^3 · mm/m^2 · day · atm)		1.97	
Vapor Transmission Rate (g · mm/m^2 · day)	0.51		

Table 31-13. Oxygen and Water Vapor Through DuPont Selar PT 4274

Material Family	**PET**	
Material Supplier/Grade	**DUPONT SELAR PT 4274**	
Reference Number	2030	

MATERIAL CHARACTERISTICS

Sample Thickness (mm)	0.025	

TEST CONDITIONS

Penetrant	oxygen	water vapor

PERMEABILITY (source document units)

Gas Permeability (cc · mil/100 in^2 · day · atm)	12.4	
Vapor Permeability (cc · mil/100 in^2 · day)		3

PERMEABILITY (normalized units)

Permeability Coefficient (cm^3 · mm/m^2 · day · atm)	4.87	
Vapor Transmission Rate (g · mm/m^2 · day)		1.8

Chapter 32

Liquid Crystal Polymer (LCP)

Category: Polyester, Thermoplastic

General Description: Liquid Crystal Polymer resins are highly crystalline, thermotropic (melt-orienting) thermoplastics and include glass and mineral reinforced and specialty grades.[1002]

Processing Methods: LCP can be processed using conventional film equipment. It can form uniform, pin-hole free barrier layers having excellent clarity. Typically used as a 2 to 5 micron layer in multilayer films, which is 10 times thinner than EVOH-based film at the same oxygen barrier level (at 90% relative humidity). LCP can be biaxially oriented and thermoformed.[1002]

Applications:

- *Electrical/electronic.* Connectors, fiber optic cables, chip carriers, printed circuit boards, and surface mount parts.[1002]
- *Health care.* Sterilizable trays, dental tools, and surgical instruments.[1002]
- *Industrial/consumer.* Printers, copiers, fax machine components, and business machine housings.[1002]
- *Chemical process industry.* Pumps, meters, and valve liners.[1002]
- *High barrier retort.* Pouches, closures, trays, and lids.[1002]

Permeability: Ticona Vectran LCP has exceptional barrier properties, highly impermeable to oxygen, water vapor, carbon dioxide, flavors, and aromas. Vectran develops a high degree of orientation during any blown or cast film process, providing high barrier and high modulus in any film structure. Vectran LCPs have the lowest oxygen permeability of any common packaging barrier film, especially at high humidities.[1002]

Vectran holds its barrier properties with increasing relative humidity, even above 80%.[1002]

Vectran LCP absorbs almost no flavor chemicals, for example, d-limonene and other flavor components from orange juice.[1002]

See *Collected Comparative Barrier Properties of Plastics and Elastomers* for more information.

During retort, relative humidity is 100% and the oxygen barrier of Vectran LCP remains constant. Vectran LCP has the same low permeability to oxygen before and after retort. The LCP absorbs almost no water during retorting, which ensures the structural integrity of the laminate when pressure is released at the end of the process.[1002]

Permeability Data by Material Supplier Trade Name: See Tables 32-01 through 32-04 and Graph 32.01.

Table 32-01. Oxygen, Carbon Dioxide, and Water Vapor Through Ticona Vectran V100P

Material Family	**LIQUID CRYSTAL POLYMER (LCP)**			
Material Supplier/Grade	**TICONA VECTRAN V100P**			
Reference Number	1002			

TEST CONDITIONS

Penetrant	oxygen		carbon dioxide	water vapor
Temperature (°C)	23		25	38
Relative Humidity (%)	0	100	100	
Test Method	DIN 53380		ISO/CD 15105	DIN 53122
	part 3		part 2 Annex C	part 2

PERMEABILITY (source document units)

Gas Permeability (cc · mil/100 in² · day · atm)	0.07	0.06	0.13	
Vapor Permeability (g · mil/100 in² · day)				0.02

PERMEABILITY (normalized units)

Permeability Coefficient (m³ · mm/m² · day · atm)	0.028	0.051	
Vapor Transmission Rate (g · mm/m² · day)			0.008

Table 32-02. Oxygen and Water Vapor Through Ticona Vectran V200P

Material Family	**LIQUID CRYSTAL POLYMER (LCP)**		
Material Supplier/Grade	**TICONA VECTRAN V200P**		
Reference Number	1002		

TEST CONDITIONS

Penetrant	oxygen		water vapor
Temperature (°C)	23		38
Relative Humidity (%)	0	100	
Test Method	DIN 53380		DIN 53122
	part 3		part 2

PERMEABILITY (source document units)

Gas Permeability (cc · mil/100 in² · day · atm)	0.04	
Vapor Permeability (g · mil/100 in² · day)		0.015

PERMEABILITY (normalized units)

Permeability Coefficient (cm³ · mm/m² · day · atm)	0.037	
Vapor Transmission Rate (g · mm/m² · day)		0.006

Table 32-03. Oxygen, Carbon Dioxide, and Water Vapor Through Ticona Vectran V300P

Material Family	**LIQUID CRYSTAL POLYMER (LCP)**			
Material Supplier/Grade	**VECTRAN V300P**			
Reference Number	1002			

TEST CONDITIONS

Penetrant	oxygen		carbon dioxide	water vapor
Temperature (°C)	23		25	38
Relative Humidity (%)	0	100	100	
Test Method	DIN 53380		ISO/CD 15105	DIN 53122
	part 3		part 2 Annex C	part 2

PERMEABILITY (source document units)

Gas Permeability (cc · mil/100 in^2 · day · atm)	0.012	0.10	0.24	
Vapor Permeability (g · mil/100 in^2 · day)				0.04

PERMEABILITY (normalized units)

Permeability Coefficient (cm^3 · mm/m^2 · day · atm)	0.047	0.035	0.094	
Vapor Transmission Rate (g · mm/m^2 · day)				0.016

Table 32-04. Oxygen and Water Vapor Through Ticona Vectran V400P

Material Family	**LIQUID CRYSTAL POLYMER (LCP)**		
Material Supplier/Grade	**VECTRAN V400P**		
Reference Number	1002		

TEST CONDITIONS

Penetrant	oxygen		water vapor
Temperature (°C)	23		38
Relative Humidity (%)	0	100	
Test Method	DIN 53380		DIN 53122
	part 3		part 2

PERMEABILITY (source document units)

Gas Permeability (cc · mil/100 in^2 · day · atm)	0.09	0.08	
Vapor Permeability (g · mil/100 in^2 · day)			0.03

PERMEABILITY (normalized units)

Permeability Coefficient (cm^3 · mm/m^2 · day · atm)	0.035	0.031	
Vapor Transmission Rate (g · mm/m^2 · day)			0.012

Graph 32-01. Oxygen after retort.