Chapter 33

Polyimide

Category: Engineering thermoplastic

General Description: Resins produced by the condensation reaction of trimellitic anhydride [$OCC_6H_2C_2O_3$] and various aromatic diamines. DuPont Kapton is a transparent, amber-colored film.

- *Kapton Type HN.* All-polyimide film.[1003]
- *Kapton Type VN, Type HN.* Plus superior dimensional stability.[1003]
- *Kapton Type FN, Type HN.* Film coated with Teflon FEP fluoropolymer resin.[1003]
- *Upilex.* Heat resistant polyimide film using BPDA as a monomer, S-highest heat resistance of the series, R, S, and VT.[1003]

Processing Methods: Type HN film can be laminated, metallized, punched, formed, or adhesive coated.[1003]

Applications: Film for tape automated bonding (TAB), flexible printed circuits (FPC), insulation stirrer automotive wiring harness, bar code labels, aerospace, gas connections, fire gloves, and loudspeaker vibration boards.[1003]

Permeability Data by Material Supplier Trade Name: See Tables 33-01 through 33-03.

Table 33-01. Oxygen, Carbon Dioxide, Hydrogen, Nitrogen, and Helium Through DuPont Kapton HN and FN Polyimide Films

Material Family	**POLYIMIDE**				
Material Supplier/Grade	**DUPONT KAPTON HN AND FN**				
Reference Number	1003				
MATERIAL CHARACTERISTICS					
Sample Thickness (mm)	0.025				
TEST CONDITIONS					
Penetrant	carbon dioxide	oxygen	hydrogen	nitrogen	helium
Temperature (°C)	23				
Relative Humidity (%)	50				
Test Method	ASTM D1434				
PERMEABILITY (source document units)					
Gas Permeability ($ml/m^2 \cdot 24\ hr \cdot MPa$)	6840	3800	38,000	910	63,080
($cc/100\ in^2 \cdot 24\ hr \cdot atm$)	45	25	250	6	415
PERMEABILITY (normalized units)					
Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	17	10	100	2	163

Table 33-02. Water Vapor Through DuPont Kapton HN, VN, and FN Polyimide Films

Material Family	POLYIMIDE			
Material Supplier/Grade	DUPONT KAPTON			
	HN and VN	120 FN 616	150 FN 019	400 FN 022
Reference Number	1003			

MATERIAL CHARACTERISTICS

Sample Thickness (mm)	0.025

TEST CONDITIONS

Penetrant	water vapor
Temperature (°C)	23
Relative Humidity (%)	50
Test Method	ASTM E96

PERMEABILITY (source document units)

Vapor Permeability ($g/m^2 \cdot 24$ hr)	54	17.5	9.6	2.4
($g/100\ in^2 \cdot 24$ hr)	3.5	1.13	0.62	0.16

PERMEABILITY (normalized units)

Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)	1.35	0.5	0.2	0.06

Table 33-03. Water Vapor, Oxygen, Nitrogen, Carbon Dioxide, and Helium Through UBE Industries Upilex Films

Material Family	**POLYIMIDE**	
Material Supplier/Grade	**UBE UPILEX R**	**UBE UPILEX S and VT**
Product Form	**FILM**	
Reference Number	97	

MATERIAL CHARACTERISTICS

Sample Thickness (mm)	0.025

TEST CONDITIONS

Penetrant	water vapor	oxygen	nitrogen	carbon dioxide	helium	water vapor	oxygen	carbon dioxide
Temperature (°C)	38	30				38	30	
Relative Humidity (%)	90					90		
Test Method	ASTM E96	ASTM D1434				ASTM E96	ASTM D1434	

PERMEABILITY (source document units)

Gas Permeability ($cm^3 \cdot mil/m^2 \cdot day \cdot atm$)		100	30	115	2200		0.8	1.2
Vapor Transmission Rate ($g \cdot mil/m^2 \cdot day \cdot atm$)	22					1.7		

PERMEABILITY (normalized units)

Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)		2.54	0.76	2.92	55.9		0.02	0.03
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)	0.56					0.04		

Chapter 34

Polyethylene Overview

Category: Polyolefin

General Description: Polyethylenes consist of a family of thermoplastic resins obtained by polymerizing the gas ethylene [C_2H_4]. Copolymers of ethylene with vinyl acetate, ethyl acrylate, and acrylic acid are commercially important.

Polyethylenes are classified by density as follows:

(a) 0.880 to 0.915 g/cu cm (called ultra or very low density and linear low density)
(b) 0.910 to 0.925 g/cu cm (low density)
(c) 0.926 to 0.940 g/cu cm (medium density)
(d) 0.941 to 0.965 g/cu cm (high density)

High molecular weight HDPE are a special class of linear resins with molecular weights in the 200,000 to 500,000 range. Ultra-high density polyethylene has an average molecular weight of over 3 million.[1004]

Major polyethylene applications are packaging, housewares, toys, and communications equipment.

Factors Affecting Permeability: The major factors affecting permeability are density, film gauge and crystalline orientation. Water vapor transmission rate and oxygen gas transmission rate are related for polyethylene. (See Graph 34-01.)[1001]

Permeation occurs almost exclusively in the polymer's non-crystalline region. This accounts for the relationship between permeation rates and crystalline content, indicated by density. The higher the crystalline content, the lower the permeability.[1001]

Permeability coefficients are not independent of film thickness. The higher the gauge, or thickness, the lower the permeation.[1001]

Narrow MWD resins have relatively constant barrier properties per unit thickness. In contrast, permeation rates for broad MWD resins can be significantly higher than for narrow MWD resins at lower gauges (<50 microns).[1001]

Permeability is also lower in films having a crystalline orientation that creates a more "tortuous path."[1001]

Permeability Data by Material Supplier Trade Name: See Table 34-01 and Graphs 34-01 through 34-12.

Graph 34-01. Permeability to oxygen and water vapor through polyethylene.[1001]

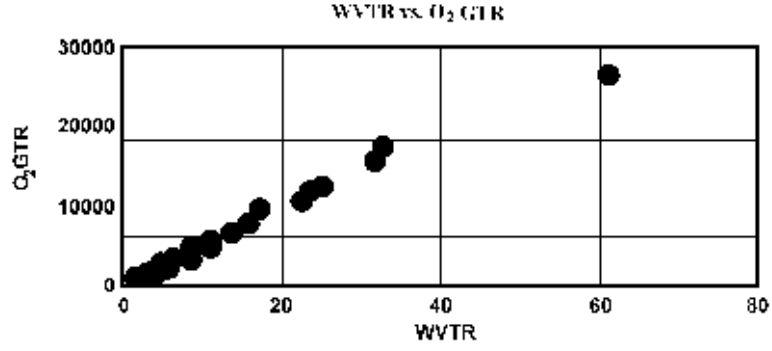
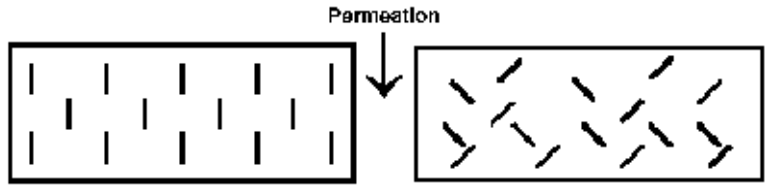


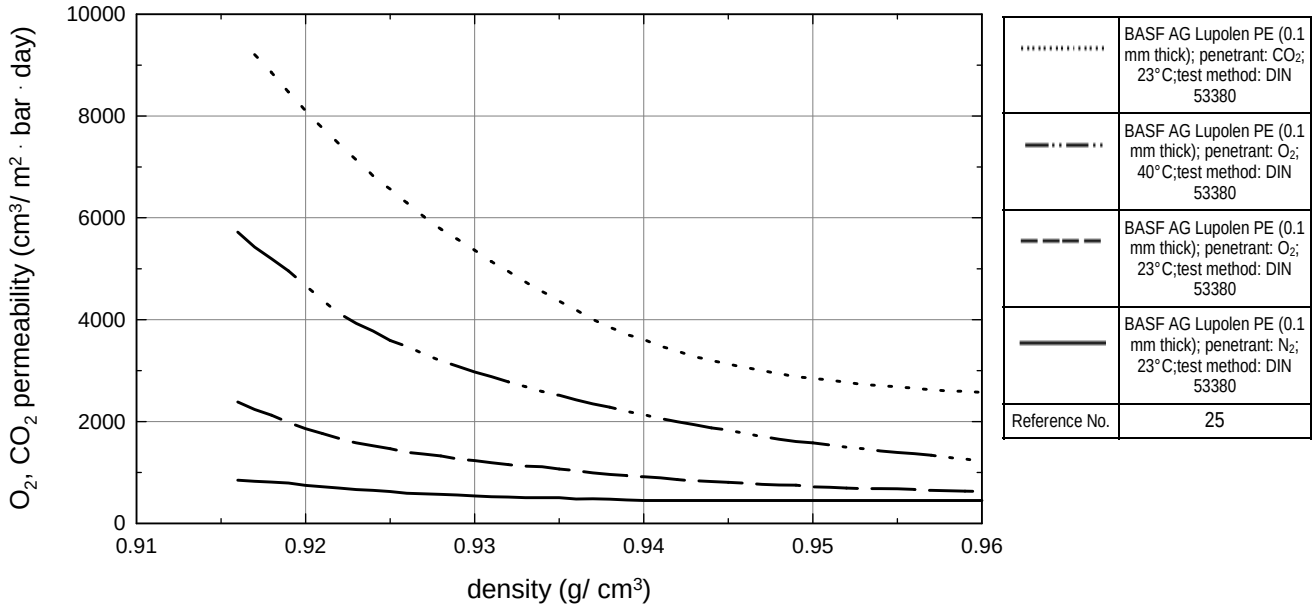
Table 34-01. Oxygen, Carbon Dioxide, and Water Vapor for LDPE, LLDPE, and HDPE

Material Family	POLYETHYLENE							
Material Supplier/Grade	**LDPE**	**HDPE**	**LLDPE**	**LDPE**	**LLDPE**	**LDPE**	**HDPE**	**LLDPE**
Reference Number	1005							
MATERIAL CHARACTERISTICS								
Sample Thickness (mm)	0.025							
TEST CONDITIONS								
Penetrant	oxygen			carbon dioxide		water vapor		
Temperature (°C)	23							
Relative Humidity (%)	50					100		
PERMEABILITY (source document units)								
Gas Permeability (mol/m ·s ·Pa x 10^{-17})	52 - 96	18 - 56	50 - 140	200 - 540	500	2.5 - 3.75	0.76 - 1.0	3.0
PERMEABILITY (normalized units)								
Permeability Coefficient (cm^3 ·mm/m^2 ·day ·atm)	102 - 188	35 - 110	98 - 274	392 - 1058	980			
Vapor Transmission Rate (g ·mm/m^2 ·day)						0.5 - 0.74	0.15 - 0.2	2.5

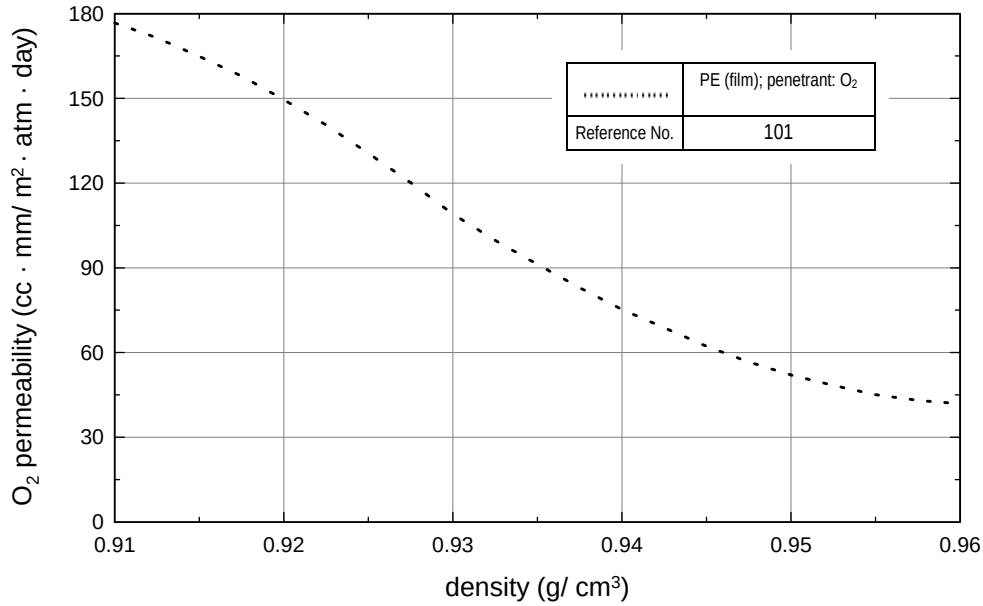
Graph 34-02. Tortuous path concept.



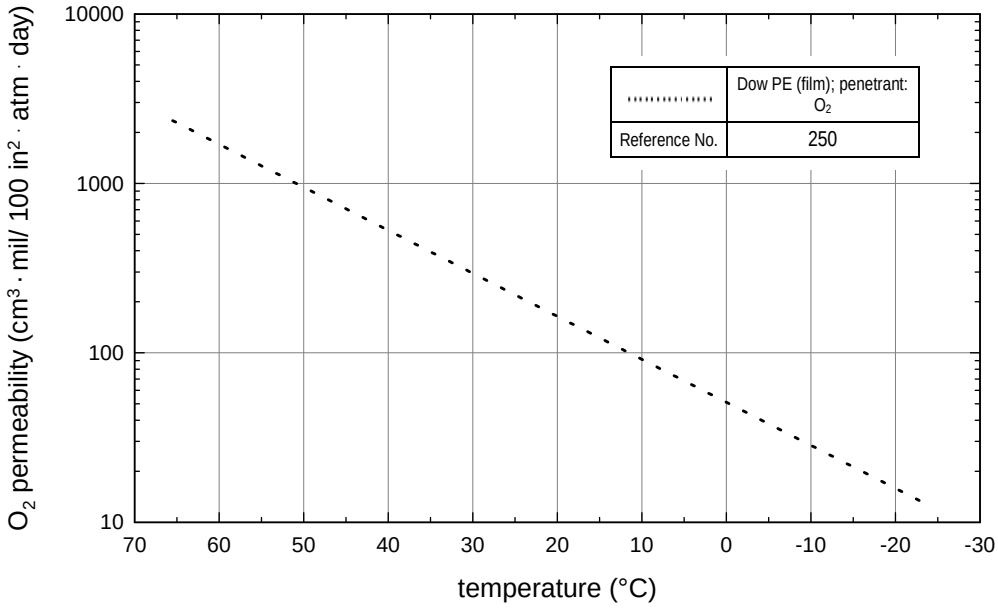
Graph 34-03. Oxygen, carbon dioxide, and nitrogen vs. density through polyethylene.



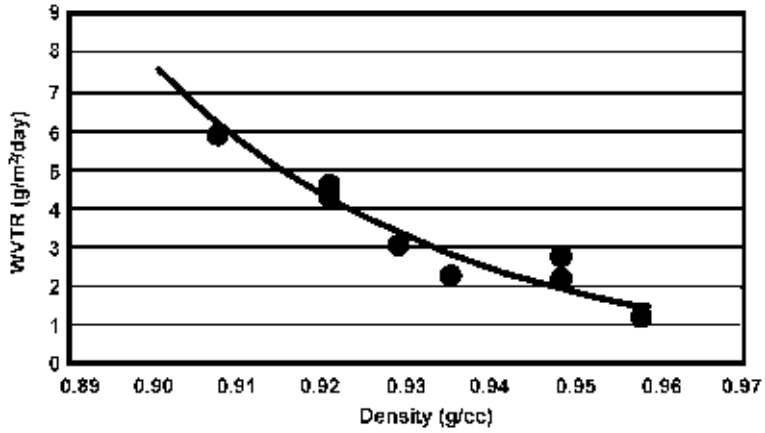
Graph 34-04. Oxygen vs. density through polyethylene.



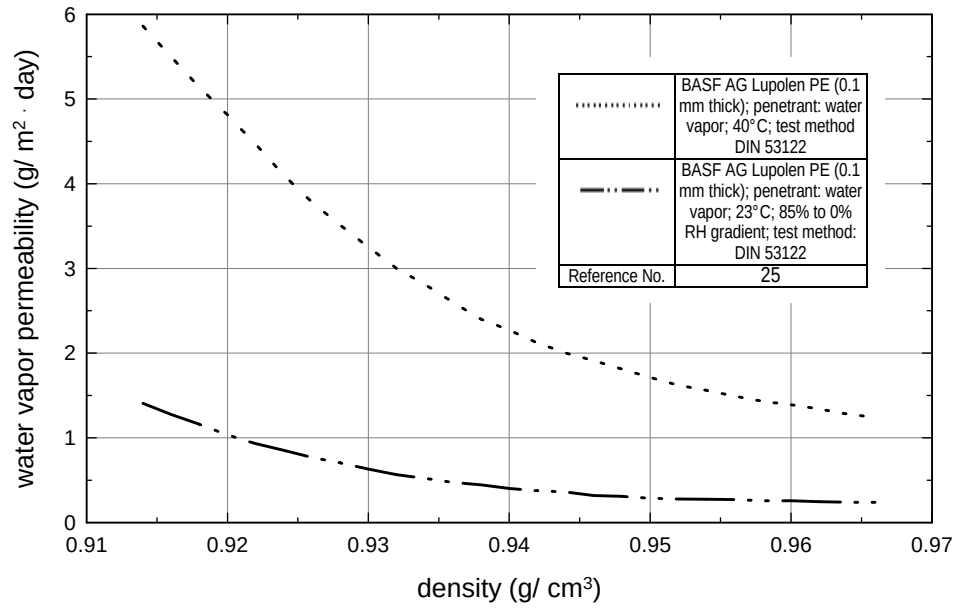
Graph 34-05. Oxygen vs. temperature through polyethylene.



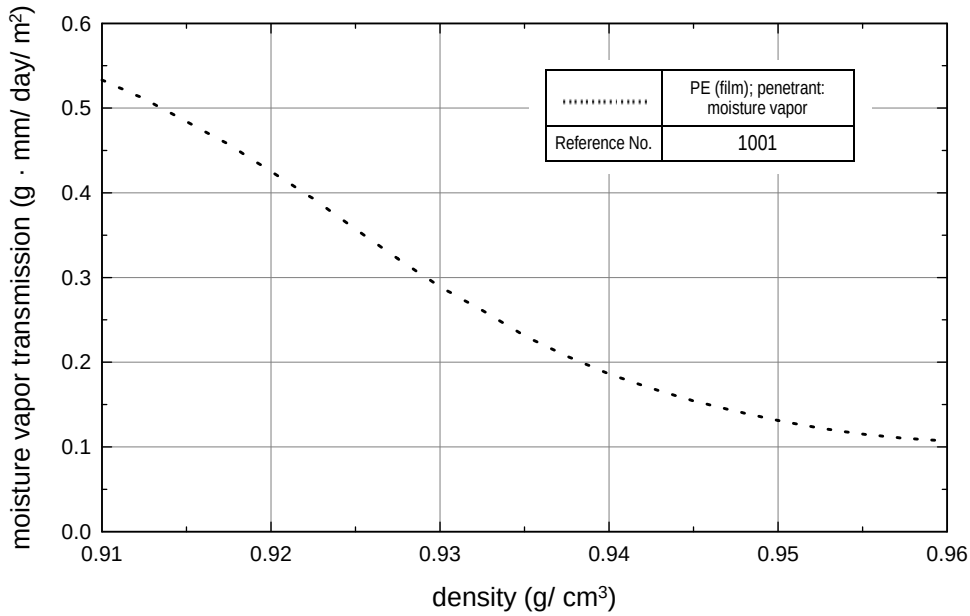
Graph 34-06. Water vapor vs. density through polyethylene.[1005]



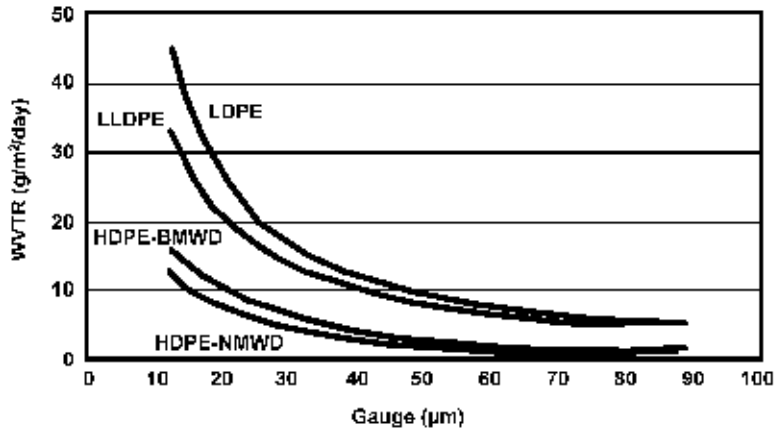
Graph 34-07. Water vapor vs. density through polyethylene.



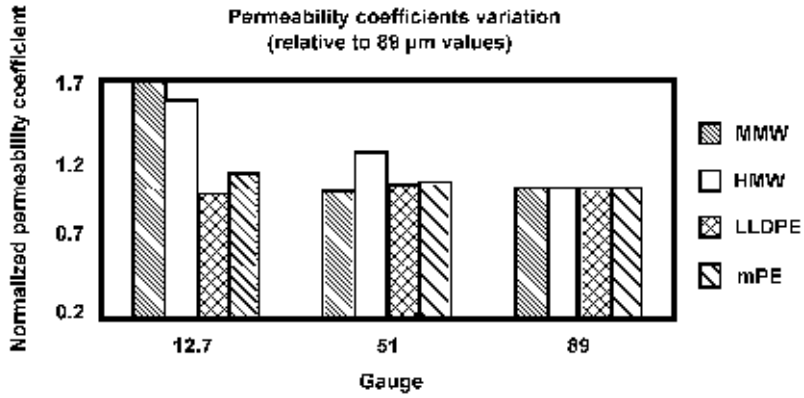
Graph 34-08. Water vapor vs. density through polyethylene.



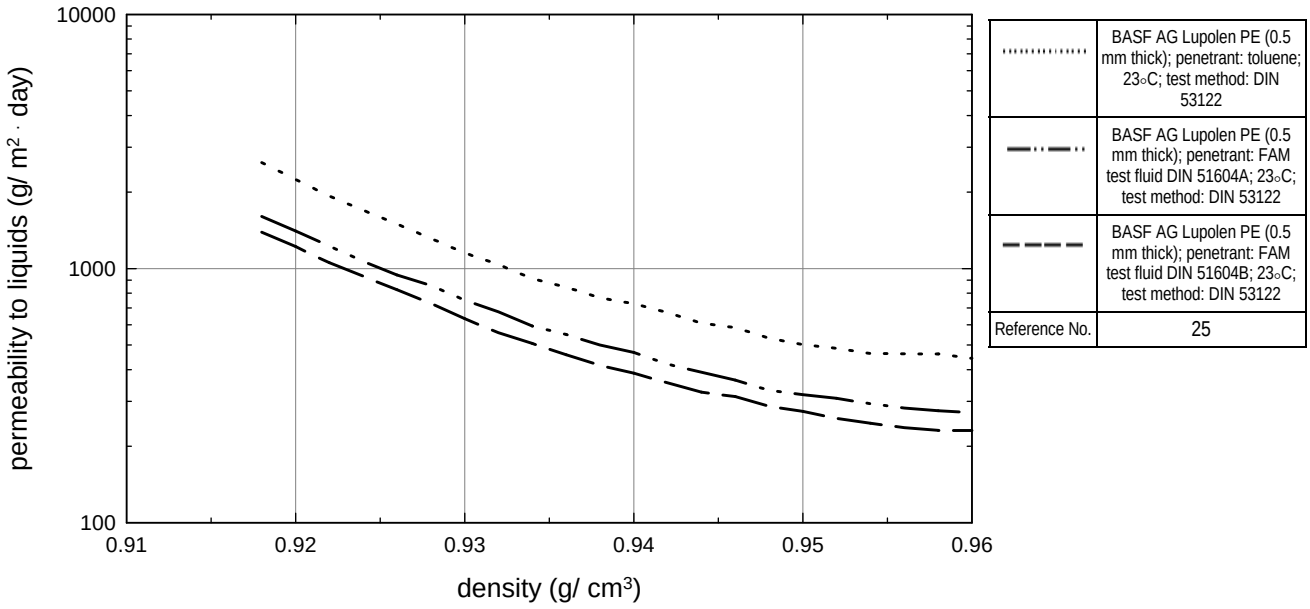
Graph 34-09. Water vapor vs. thickness through polyethylene.[1001]



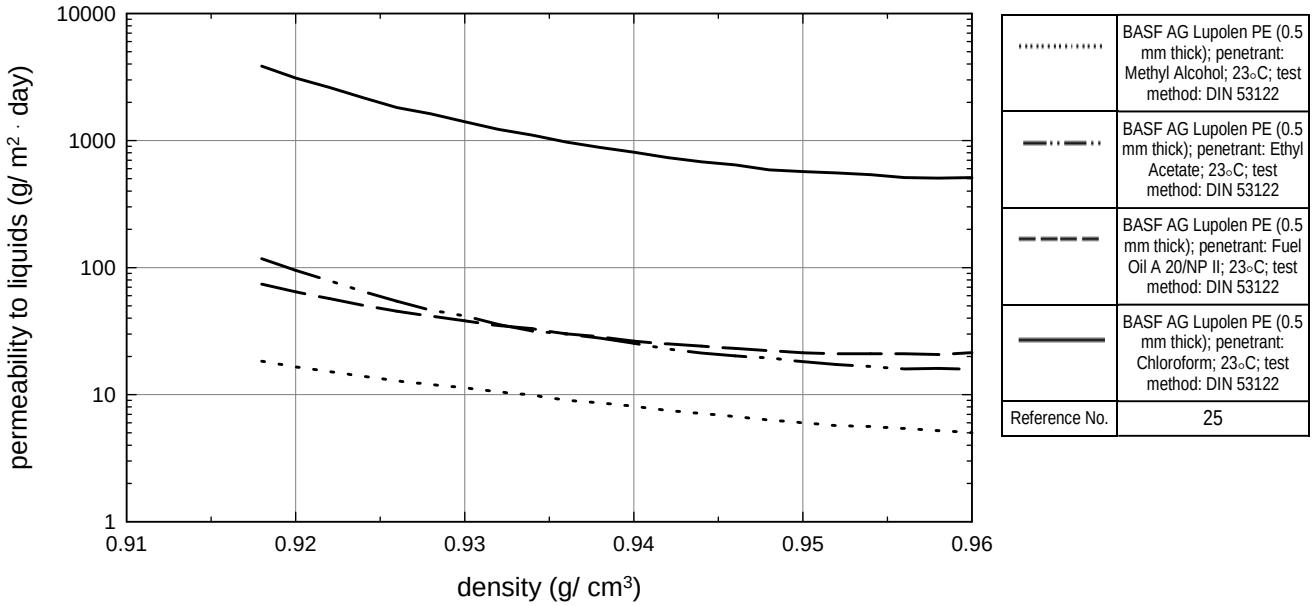
Graph 34-10. Permeability coefficients of water vapor vs. thickness through polyethylene.[1001]



Graph 34-11. Toluene and FAM test fluid vs. density through polyethylene.



Graph 34-12. Methyl alcohol, ethyl acetate, fuel oil, and chloroform vs. density through polyethylene.



Ultra Low Density Polyethylene (ULDPE)

Category: Polyolefin

General Description: Ultra- and very- low density polyethylenes are essentially synonymous designations for linear polyethylenes with densities down to 0.880 g/cu in. ULDPEs are finding applications as impact modifiers for other polyolefins. Dow Chemical's Attane ULDPE is an Ethylene/Octene Copolymer.[1007]

Processing Methods: Blown and cast film.

Applications: Heavy duty sacks, turf bags, consumer bags, packaging for cheese, meat, coffee, and detergents, silage wrap, mulch films, extruded membranes, heating and water pipes, and injection-molded products.

Permeability to Oxygen and Other Gases: Lower crystallinity of ULDPEs results in increased permeability to O_2 and other gases, permeability similar to that of EVAs.[1007]

Permeability to Water and Other Vapors: ULDPE water vapor permeability is much lower than EVAs.[1007]

Permeability Data by Material Supplier Trade Name: See Table 35-01.

Table 35-01. Oxygen, Carbon Dioxide, and Water Vapor Through Dow Chemical Attane Blown Film

Material Family	ULTRA LOW DENSITY POLYETHYLENE (ULDPE)							
Material Supplier	DOW CHEMICAL ATTANE BLOWN FILM							
Grade	4201	4201	4202	4201	4202	4201	4201	4202
Reference Number	1008							
MATERIAL CHARACTERISTIC								
Sample Thickness (mm)	0.02	0.05	0.02	0.05	0.02	0.02	0.05	0.02
TEST CONDITIONS								
Penetrant	oxygen			carbon dioxide		water vapor		
Temperature (°C)	23							
Relative Humidity (%)	50							
Test Method	ASTM F1249							
PERMEABILITY (source document units)								
Gas Permeability ($cc \cdot mil/100\ in^2 \cdot day \cdot atm$)	716	711	695	3138	3340			
Vapor Permeability ($g \cdot mil/100\ in^2 \cdot day \cdot atm$)						1.58	1.39	2.15
PERMEABILITY (normalized units)								
Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	281	279	273	1233	1312			
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day \cdot atm$)						0.62	0.55	0.84

Low Density Polyethylene (LDPE)

Category: Polyolefin

General Description: With the density range of 0.910 to 0.925 g/cu cm, low density polyethylenes are available as base resins, and some grades with additive packages.

Processing Methods: Extrusion coating, extrusion, rotational molding, injection molding, blow molding, blown films, and cast films.

Applications: Extrusion coatings: liquid packaging, milk cartons, flexible and snack food packaging, and multi-wall bags.

Industrial packaging: shrink films, housewares, and personal care squeeze bottles.

See Ch. 34, *Polyethylene - Overview* for more information.

Permeability Data by Material Supplier Trade Name: See Tables 36-01 through 36-10 and Graphs 36-01 through 36-02.

Table 36-01. Water Vapor, Carbon Dioxide, Oxygen, and Ethylene Oxide Through Low Density Polyethylene

Material Family	**LOW DENSITY POLYETHYLENE (LDPE)**			
Product Form	**FILM**			
Features	2.5 blow up ratio			
Manufacturing Method	blown film			
Reference Number	216			
MATERIAL CHARACTERISTICS				
Density	0.920 g/cm^3			
Melt Flow Index	4 g/10 min			
Sample Thickness (mm)	0.05			
TEST CONDITIONS				
Penetrant	water vapor	carbon dioxide	oxygen	ethylene oxide
Test Method	JIS Z0208	ASTM D1434		
PERMEABILITY (source document units)				
Vapor Transmission Rate (g · 100 µm/m^2 · day)	25			
Gas Permeability (cm^3 · 100 µm/m^2 · day · atm)		7900	1500	21,000
PERMEABILITY (normalized units)				
Permeability Coefficient (cm^3 · mm/m^2 · day · atm)		790	150	2100
Vapor Transmission Rate (g · mm/m^2 · day)	2.5			

Table 36-02. Oxygen, Nitrogen, Carbon Dioxide, and Water Vapor Through Dow Chemical Low Density Polyethylene

Material Family	**LOW DENSITY POLYETHYLENE (LDPE)**			
Material Supplier/Grade	**DOW CHEMICAL**			
Product Form	**FILM**			
Reference Number	250			

TEST CONDITIONS

Penetrant	oxygen	nitrogen	carbon dioxide	water vapor
Temperature (°C)	24			

PERMEABILITY (source document units)

Vapor Transmission Rate ($g \cdot mil/100\ in^2 \cdot day$)				1 - 1.5
Gas Permeability ($cm^3 \cdot mil/100\ in^2 \cdot day$)	250 - 350	100 - 200	1000 - 2000	

PERMEABILITY (normalized units)

Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	98 - 138	39 - 79	394 - 787	
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)				0.39 - 0.59

Table 36-03. Oxygen vs. Temperature and Water Vapor Transmission Through Low Density Polyethylene

Material Family	**LOW DENSITY POLYETHYLENE (LDPE)**		
Reference Number	264		

TEST CONDITIONS

Penetrant	oxygen		water vapor
Temperature (°C)	23	35	40
Relative Humidity (%)	0		90

PERMEABILITY (source document units)

Gas Permeability ($cm^3 \cdot mil/100\ in^2 \cdot day$)	554	745	
Gas Permeability ($cm^3 \cdot 25\ \mu/m^2 \cdot day \cdot atm$)	8586	11,547	
Vapor Transmission Rate ($g \cdot mil/100\ in^2 \cdot day$)			1.14
Vapor Transmission Rate ($g \cdot 25\ \mu/m^2 \cdot day$)			17.7

PERMEABILITY (normalized units)

Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	218.1	293.3	
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)			0.45

Table 36-04. Oxygen, Carbon Dioxide, Nitrogen, and Helium Through Low Density Polyethylene Film

Material Family	**LOW DENSITY POLYETHYLENE (LDPE)**			
Product Form	**FILM**			
Reference Number	63			
TEST CONDITIONS				
Penetrant	oxygen	nitrogen	carbon dioxide	helium
Temperature (°C)	25			
Relative Humidity (%)	0			
PERMEABILITY (source document units)				
Gas Permeability ($cm^3 \cdot mil/100\ in^2 \cdot day$)	696	180	2436	1624
Gas Permeability ($cm^3 \cdot 20\ \mu/m^2 \cdot day \cdot atm$)	12,000	3100	42,000	28,000
PERMEABILITY (normalized units)				
Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	274	71	959	639

Table 36-05. Reagents Through Dow Chemical Low Density Polyethylene Film

Material Family	**LOW DENSITY POLYETHYLENE (LDPE)**							
Material Supplier/Grade	**DOW CHEMICAL**							
Product Form	**FILM**							
Reference Number	250							
TEST CONDITIONS								
Penetrant	methyl alcohol	ethyl alcohol	n-heptane	ethyl acetate	formaldehyde	tetrachloro-ethylene	acetone	benzene
Temperature (°C)	24							35
PERMEABILITY (source document units)								
Vapor Transmission Rate ($g \cdot mil/100\ in^2 \cdot day$)	6 - 8	2 - 4	300 - 500	30 - 300	2 - 5	500 - 750	10 - 40	600
PERMEABILITY (normalized units)								
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)	2.4 - 3.1	0.8 - 1.6	118- 197	11.8 - 118	0.8 - 2.0	197 - 295	3.9 - 15.8	236

Table 36-06. Water Vapor Through Dow Chemical Low Density Polyethylene Extrusion Coating Resins

Material Family	LOW DENSITY POLYETHYLENE (LDPE)			
Material Supplier/Grade	DOW CHEMICAL			
	LDPE 722	LDPE 4005	LDPE 4012	LDPE 5004I
Manufacturing Method	extrusion coating			
Reference Number	254			

MATERIAL CHARACTERISTICS

Density	0.916 g/cm^3			0.923 g/cm^3
Melt Flow Index	8 g/10 min. (190/2.16)	5.5 g/10 min. (190/2.16)	12 g/10 min. (190/2.16)	4 g/10 min. (190/2.16)
Sample Thickness (mm) (minimum thickness)	0.01	0.015	0.01	

TEST CONDITIONS

Penetrant	water vapor
Test Method	ASTM F1249

PERMEABILITY (source document units)

Vapor Transmission Rate (g/m^2 · day)	26.4	31	31	23.3
Vapor Transmission Rate (g/day · 100 in^2)	1.7	2.0	1.8	1.5

PERMEABILITY (normalized units)

Vapor Transmission Rate (g · mm/m^2 · day)	0.26	0.46	0.31	0.23

Table 36-07. Water Vapor and Oxygen vs. Relative Humidity Through Low Density Polyethylene

Material Family	**LOW DENSITY POLYETHYLENE (LDPE)**
Product Form	**FILM**
Reference Number	268

MATERIAL CHARACTERISTICS

Sample Thickness (mm)	0.05

TEST CONDITIONS

Penetrant	water vapor	oxygen			
Temperature (°C)	40	35	20		
Relative Humidity (%)	90	0	65	85	100
Test Method	JIS Z0208	JIS Z1707	ASTM D3985		

PERMEABILITY (source document units)

Vapor Transmission Rate ($g \cdot mil/100\ in^2 \cdot day$)	1		
Gas Permeability ($cm^3 \cdot mil/100\ in^2 \cdot day$)		387	174

PERMEABILITY (normalized units)

Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)		152	68.5
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)	0.39		

Table 36-08. Water Vapor, Oxygen, Nitrogen, and Carbon Dioxide Through Low Density Polyethylene

Material Family	LOW DENSITY POLYETHYLENE (LDPE)
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)

Gas Permeability ($cm^3 \cdot mil/100\ in^2 \cdot day$)		500	180	2700
Gas Permeability ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)		195	71	1060
Vapor Transmission Rate ($g \cdot mil/100\ in^2 \cdot day$)	1.0 -1.5			
Vapor Transmission Rate ($g/day \cdot 100\ in^2$)	0.39 - 0.59			

PERMEABILITY (normalized units)

Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)		197	71	106.3
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)	0.39 - 0.59			

Table 36-09. Xylene and Oxygen Through Low Density Polyethylene

Material Family	LOW DENSITY POLYETHYLENE (LDPE)	
Reference Number	293	

TEST CONDITIONS

Penetrant	xylene	oxygen
Temperature (°C)	60	23
Exposure Time (days)	14	
Relative Humidity (%)		75

PERMEABILITY (source document units)

Vapor Transmission Rate ($g \cdot mil/100\ in^2 \cdot day$)	3800	
Gas Permeability ($cm^3 \cdot mil/100\ in^2 \cdot day$)		450

PERMEABILITY (normalized units)

Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)		177.2
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)	1496	

Table 36-10. Organic Solvents Through Low Density Polyethylene Film

Material Family	LOW DENSITY POLYETHYLENE (LDPE)
Product Form	FILM
Reference Number	266

MATERIAL CHARACTERISTICS

Sample Thickness (mm)	0.051

TEST CONDITIONS

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

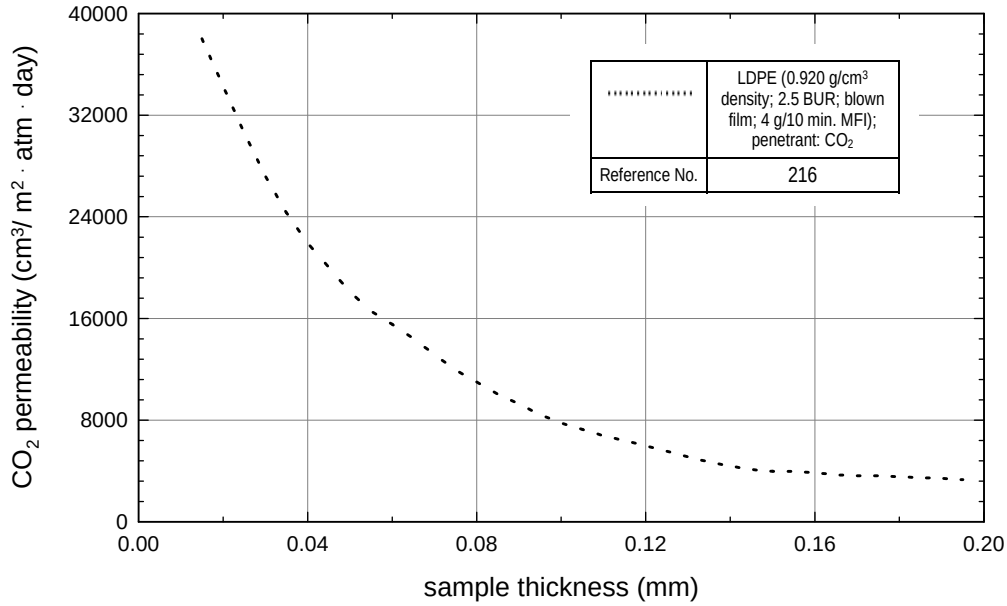
PERMEABILITY (source document units)

Vapor Transmission Rate ($g/day \cdot 100\ in^2$)	178.1	20.97	4.77	4.9

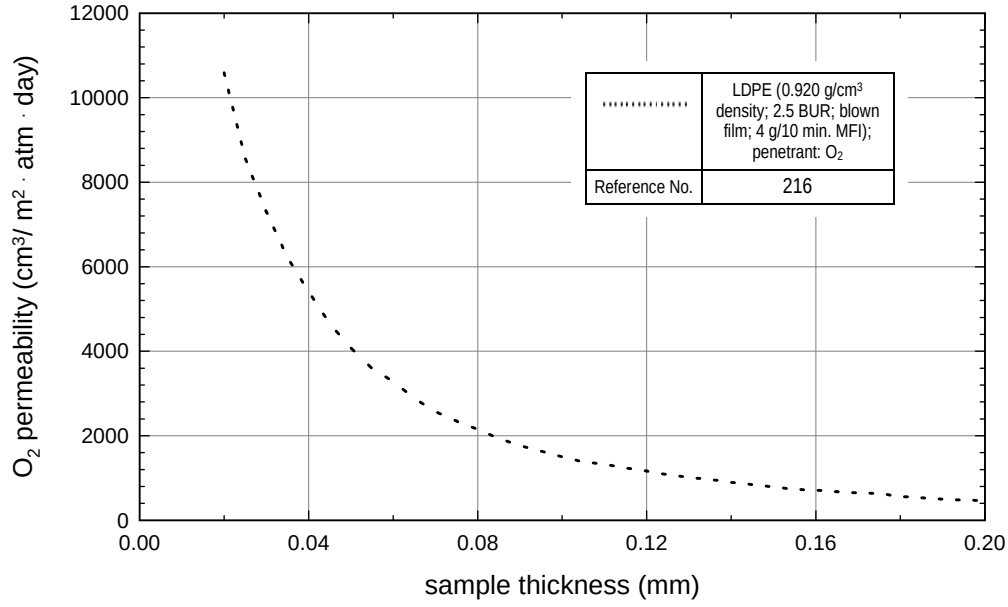
PERMEABILITY (normalized units)

Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)	141	16.6	3.8	3.9

Graph 36-01. Carbon dioxide vs. thickness through low density polyethylene.



Graph 36-02. Oxygen vs. thickness through low density polyethylene.



Linear Low Density Polyethylene (LLDPE)

Category: Polyolefin

General Description: Base resin with co-monomers: Hexene or Butene. The absence of long-chain branching, a characteristic of LLDPE, allows it to yield greater elongation than LDPE and results in stronger products being produced with less material. The ability to downgauge has had a considerable impact in the film markets.[1011]

DuPont Canada Sclairfilm polyolefin films are laminating films often used as a sealant layer in multilayer structures. Sclairfilm can also be used unsupported as a monolayer bag film.

- *Sclairfilm* BL-1 is a one-side PVDC-coated LLDPE sealant film for use in laminated structures. BL-1 is suitable for meat, cheese, snacks, MAP/CAP and other applications requiring good barrier properties and excellent sealing characteristics for improved product protection and longer shelf life.[1011]
- The LX grade of *Sclairfilm* is ideal for use on vacuum packaging equipment for lamination to other materials, such as nylon or polyester films. In converter combinations, LX is particularly suited for the vacuum packaging of processed meats, cheese, coffee, and frozen foods.[1011]
- *Sclairfilm* MPP is an oriented linear low density polyethylene (LLDPE) sealant film. MPP sealant film allows up to 50% down-gauging of the sealant layer in a wide variety of meat, cheese, coffee, snacks, medical, and industrial packaging applications.[1011]
- *Sclairfilm* GL is a general purpose linear low density polyethylene sealant film designed for less critical sealing applications than type SL and may be used in converter laminations with barrier films such as *Mylar* polyester film and *Dartek* nylon film.[1011]
- *Sclairfilm* SL is a linear low density polyolefin film for use on vacuum packaging equipment. Ideal for lamination to other substrates such as *Dartek* nylon film or *Mylar* polyester film for vacuum packaging applications. SL, in converter combinations, is particularly suited for the vacuum packaging of processed meats.[1011]

Processing Methods: Extrusion Coating, Blown and cast film extrusion.

- *Nova Chemicals Sclair.* Often blended with conventional polyethylene.[1010]

Applications: Extrusion coatings: food packaging, milk cartons, paperboard containers, liner films, stretch films, shrink films, disposables, heavy-duty shipping sacks, and grocery sacks.

See Ch. 34, *Polyethylene - Overview* for more information.

Permeability Data by Material Supplier Trade Name: See Tables 31-01 through 31-07.

Table 37-01. Oxygen and Water Vapor Through DuPont Sclairfilms

Material Family	LINEAR LOW DENSITY POLYETHYLENE (LLDPE)							
Material Grade	DUPONT SCLAIRFILMS							
	BL–1	LX–1 / LX–3 / GL / SL						
Reference Number	1011							
MATERIAL CHARACTERISTICS								
Sample Thickness (mm)		0.0375	0.050	0.075	0.0375	0.050	0.075	
TEST CONDITIONS								
Test Method	ASTM D3985	ASTM F372	ASTM D3985			ASTM F372		
Penetrant	oxygen	water vapor	oxygen			water vapor		
PERMEABILITY (source document units)								
Gas Permeability ($cm^3/100\ in^2 \cdot 24\ hr$)	0.1–1.0		400	250	200			
Vapor Permeability ($g/100\ in^2 \cdot 24\ hr$)		0.4				0.8	0.6	0.4
PERMEABILITY (normalized units)								
Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	0.04–0.393		157	98	78			
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)		0.2				0.4	0.3	0.2

Table 37-02. Water Vapor Through DuPont Sclairfilms and Nova Chemical Sclair Extrusion Coating

Material Family	LINEAR LOW DENSITY POLYETHYLENE (LLDPE)			
Material Grade	DUPONT SCLAIRFILMS MPP	DUPONT SCLAIRFILMS LWS		NOVA CHEMICALS SCLAIR
Reference Number	1011			1010
MATERIAL CHARACTERISTICS				
Sample Thickness (mm)	0.025	0.0375	0.050	30 lb Kraft paper with LLDPE coating weight of 30 lb/ream
Test Conditions				
Penetrant	water vapor			
Temperature (°C)				38
Relative Humidity (%)				90
Test Method	ASTM F372			ASTM E96
PERMEABILITY (source document units)				
Vapor Permeability ($g/100\ in^2 \cdot 24\ hr$)	0.6	0.45	0.33	0.9
($g/m^2 \cdot day$)				23.3 – 31
PERMEABILITY (normalized units)				
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)	0.3	0.22	0.16	0.59–0.78

Table 37-03. Oxygen and Water Vapor Through Dow Chemical Dowlex LLDPE

Material Family	**LINEAR LOW DENSITY POLYETHYLENE (LLDPE)**
Material Supplier/Grade	**DOW CHEMICAL DOWLEX 2045**
Manufacturing Method	blown film
Reference Number	11

MATERIAL CHARACTERISTICS

Sample Thickness (mm)	0.0254

TEST CONDITIONS

Penetrant	oxygen	water vapor
Relative Humidity (%)	<1% (dry test)	100
Test Method	ASTM D3985-81	Mocon
Test Apparatus		Mocon Permatron W-1

PERMEABILITY (source document units)

Gas Permeability ($cm^3 \cdot mil/100\ in^2 \cdot day$)	525	
Vapor Transmission Rate ($g \cdot mil/100\ in^2 \cdot day \cdot atm$)		0.7

PERMEABILITY (normalized units)

Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	207	
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)		0.28

Table 37-04. Oxygen Through DuPont Canada Sclair SL1 and Sclair SL3 LLDPE

Material Family	**LINEAR LOW DENSITY POLYETHYLENE (LLDPE)**					
Material Supplier/Grade	**DUPONT CANADA SCLAIRFILM SL1**			**DUPONT CANADA SCLAIRFILM SL3**		
Product Form	**FILM**					
Applications	laminations					
Reference Number	278					

MATERIAL CHARACTERISTICS

Density	0.918 g/cm^3					
Sample Thickness (mm)	0.038	0.051	0.076	0.038	0.051	0.076

TEST CONDITIONS

Penetrant	oxygen					
Test Method	ASTM D3985					

PERMEABILITY (source document units)

Gas Permeability ($cm^3/m^2 \cdot day$)	6200	3900	3100	6200	3900	3100
Gas Permeability ($cm^3/100\ in^2 \cdot day \cdot atm$)	400	250	200	400	250	200

PERMEABILITY (normalized units)

Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	236	199	236	236	199	236

Table 37-05. Water Vapor Through DuPont Canada Sclair SL1 and Sclair SL3 LLDPE

Material Family	**LINEAR LOW DENSITY POLYETHYLENE (LLDPE)**	
Material Supplier/Grade	**DUPONT CANADA SCLAIRFILM SL1**	**DUPONT CANADA SCLAIRFILM SL3**
Product Form	**FILM**	
Applications	laminations	
Reference Number	278	

MATERIAL CHARACTERISTICS

Sample Thickness (mm)	0.038	0.051	0.076	0.038	0.051	0.076

TEST CONDITIONS

Penetrant	water vapor
Test Method	ASTM F372

PERMEABILITY (source document units)

Vapor Transmission Rate ($g/m^2 \cdot day$)	12.4	9.3	4.7	12.4	9.3	4.7
Vapor Transmission Rate ($g/day \cdot 100\ in^2$)	0.8	0.6	0.4	0.8	0.6	0.4

PERMEABILITY (normalized units)

Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)	0.47	0.36	0.47	0.36

Table 37-06. Carbon Dioxide Through DuPont Canada Sclair SL1 and Sclair SL3 LLDPE

Material Family	**LINEAR LOW DENSITY POLYETHYLENE (LLDPE)**	
Material Supplier/Grade	**DUPONT CANADA SCLAIRFILM SL1**	**DUPONT CANADA SCLAIRFILM SL3**
Product Form	**FILM**	
Applications	laminations	
Reference Number	278	

MATERIAL CHARACTERISTICS

Sample Thickness (mm)	0.0254

TEST CONDITIONS

Penetrant	carbon dioxide	nitrogen	carbon dioxide	nitrogen
Test Method	ASTM D3985			
Test Note	approximate values			

PERMEABILITY (source document units)

Gas Permeability ($cm^3/m^2 \cdot day$)	1400	150	1400	150

PERMEABILITY (normalized units)

Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	35.6	3.81	35.6	3.81

Table 37-07. Water Vapor Through DuPont Canada Sclair LLDPE

Material Family	**LINEAR LOW DENSITY POLYETHYLENE (LLDPE)**			
Material Supplier/Grade	**NOVA CHEMICALS SCLAIR 11 SERIES**			
Reference Number	277			

MATERIAL CHARACTERISTICS

Density	0.921 g/cm^3			
Melt Flow Index	0.75 grams/10 min.	1.2 grams/10 min.	1.6 grams/10 min.	0.75 grams/10 min.
Sample Thickness (mm)	0.0254			

TEST CONDITIONS

Penetrant	water vapor	oxygen
Temperature (°C)	38	23
Relative Humidity (%)	90	
Test Method		ASTM D1434
Test Note	values are cooling rate dependent	
Test Apparatus	Honeywell model 825 apparatus	

PERMEABILITY (source document units)

Vapor Transmission Rate (g/m^2 · day)	15	18	20	
Gas Permeability (cm^3/m^2 · day)				5200

PERMEABILITY (normalized units)

Permeability Coefficient (cm^3 · mm/m^2 · day · atm)				132
Vapor Transmission Rate (g · mm/m^2 · day)	0.38	0.46	0.51	

Medium Density Polyethylene and Linear Medium Density Polyethylene (MDPE & LMDPE)

Category: Polyolefin

General Description:

- *Nova Chemicals Novapol*. MDPE with no co-monomer for pipe and with Hexene co-monomer for rotomolding, LMDPE with Hexene for roto-molding.[1010]
- *Nova Chemicals Sclair.* MDPE with Butene co-monomer and LMDPE with Butene or Octene for films and co-extrusion.[1010]

DuPont Sclairfilm LWS is a linear medium density polyolefin film produced from Sclair copolymer resin and designed primarily for laminating end uses. This film differs from low density laminating films in its moisture vapor. LWS is used for laminating to other substrates such as Dartek nylon film or Mylar polyester film for heat-in-bag or boil-in-bag applications.[1011]

Processing Methods: Extrusion, co-extrusion, blow molding, and roto-molding.

Applications: Films, agriculture tanks, housewares, lids, containers, and closures.

See Ch. 34, *Polyethylene - Overview* for more information.

Permeability Data by Material Supplier Trade Name: See Tables 38-01 through 38-03.

Table 38-01. Oxygen and Water Vapor Through DuPont Sclairfilm LWS LMDPE

Material Family	LINEAR MEDIUM DENSITY POLYETHYLENE (LMDPE)			
Material Grade	SCLAIRFILMS LWS			
Reference Number	1011			
MATERIAL CHARACTERISTICS				
Sample thickness (mm)	0.0375	0.050	0.0375	0.050
TEST CONDITIONS				
Penetrant	oxygen		water vapor	
Test Method	ASTM D3985		ASTM F372	
PERMEABILITY (source document units)				
Gas Permeability (cc/100 in^2 · 24 hr)	225	170		
Vapor Permeability (g/100 in^2 · 24 hr)			0.45	0.33
PERMEABILITY (normalized units)				
Permeability Coefficient (cm^3 · mm/m^2 · day · atm)	88	67		
Vapor Transmission Rate (g · mm/m^2 · day)			0.22	0.16

Table 38-02. Oxygen and Water Vapor Through Nova Chemicals Sclair Butene MDPE Blown Film

Material Family	**MEDIUM DENSITY POLYETHYLENE (MDPE)**	
Material Grade	**NOVA CHEMICALS SCLAIR BUTENE MDPE BLOWN FILM**	
Reference Number	277	1010
MATERIAL CHARACTERISTICS		
Sample Thickness (mm)	0.025	
TEST CONDITIONS		
Penetrant	oxygen	water vapor
Test Method	ASTM D1434	ASTM F1249
PERMEABILITY (source document units)		
Gas Permeability ($cm^3/100\ in^2 \cdot 24\ hr$)	3100	
Vapor Permeability ($g/100\ in^2 \cdot 24\ hr$)		0.9
($g/m^2 \cdot day$)		14
PERMEABILITY (normalized units)		
Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	78.7	
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)		0.35

Table 38-03. Water Vapor, Oxygen, Nitrogen, and Carbon Dioxide Through MDPE

Material Family	**MEDIUM DENSITY POLYETHYLENE (MDPE)**			
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)				
Gas Permeability ($cm^3 \cdot mil/100\ in^2 \cdot day$)		250 - 535	85 - 315	100 - 2500
Gas Permeability ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)		100 - 210	35 -125	40 - 985
Vapor Transmission Rate ($g \cdot mil/100\ in^2 \cdot day$)	0.7			
Vapor Transmission Rate ($g/day \cdot 100\ in^2$)	0.28			
PERMEABILITY (normalized units)				
Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)		98 - 211	33 - 124	39 - 984
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)	0.28			

High Density Polyethylene (HDPE)

Category: Polyolefin

General Description: HDPE polymers are highly crystalline, tough materials. High molecular weight high density polyethylene, HMW-HDPE are a special class of linear resins with molecular weights in the 200,000 to 500,000 range.[1004] Due to the fact that the molecular weight distribution of these materials is vital to the processability and end-use properties, some HDPEs are produced with a "bimodal" molecular weight distribution.[1004]

Processing Methods: HDPE can be formed by most processing methods.

Applications: Food packaging: dairy products and bottled water, cosmetics, medical products and household chemicals, automotive gas tanks, 55 gallon drums, sheets, pipes, recreational items, and geosynthetic materials.

See Ch. 34, *Polyethylene - Overview* for more information.

Permeability to Water and Other Vapors: Permeation rates are generally higher in films having a larger tear balance ratio, TD/MD (transverse to machine direction orientation). Films having a lower TD/MD ratio displayed a more random crystalline orientation than those with a larger TD/MD. Changes in orientation are also responsible for the variation seen in permeability coefficients. Narrow MWD resins, such as LLDPE, have almost constant TD/MD ratios and permeability coefficients throughout the gauge range. TD/MD ratios for the broad MWD resins were higher at thinner gauges, contributing to their increased permeability coefficients.[1001]

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

Permeability Data by Material Supplier Trade Name: See Tables 39-01 through 39-19 and Graph 39.01.

Table 39-01. Oxygen, Carbon Dioxide, Nitrogen, and Water Vapor Through BP Solvay Fortiflex HDPE

Material Family	HIGH DENSITY POLYETHYLENE (HDPE)			
Material Grade	BP SOLVAY FORTIFLEX			
Reference Number	1012			
TEST CONDITIONS				
Penetrant	oxygen	carbon dioxide	nitrogen	water vapor
Temperature (°C)	30			25
PERMEABILITY (source document units)				
Gas Permeability ($in^2/sec^2 \cdot atm$)	1.4×10^{-12}	4.6×10^{-12}	0.35×10^{-12}	17×10^{-12}
[$cm^2/(sec \cdot cm \cdot Hg)$]	1.06×10^{-10}	3.5×10^{-10}	0.27×10^{-10}	13×10^{-10}
PERMEABILITY (normalized units)				
Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	n/a			
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)	n/a			

Table 39-02. Oxygen, Carbon Dioxide, Nitrogen, and Water Vapor Through Dow Chemical HDPE

Material Family	**HIGH DENSITY POLYETHYLENE (HDPE)**			
Material Supplier/Grade	**DOW CHEMICAL**			
Product Form	**FILM**			
Reference Number	250			

TEST CONDITIONS

Penetrant	oxygen	nitrogen	carbon dioxide	water vapor
Temperature (°C)	24			

PERMEABILITY (source document units)

Vapor Transmission Rate ($g \cdot mil/100\ in^2 \cdot day$)				0.4
Gas Permeability ($cm^3 \cdot mil/100\ in^2 \cdot day$)	100 - 200	40 - 60	600 - 700	

PERMEABILITY (normalized units)

Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	39.37 - 78.74	15.75 - 23.62	236.22 - 275.59	
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)				0.16

Table 39-03. Oxygen and Water Vapor Through HDPE

Material Family	**HIGH DENSITY POLYETHYLENE (HDPE)**		
Reference Number	264		

TEST CONDITIONS

Penetrant	oxygen		water vapor
Temperature (°C)	23	35	40
Relative Humidity (%)	0		90

PERMEABILITY (source document units)

Gas Permeability ($cm^3 \cdot mil/100\ in^2 \cdot day$)	150	287	
Vapor Transmission Rate ($g \cdot mil/100\ in^2 \cdot day$)			0.38
Gas Permeability ($cm^3 \cdot 25\ \mu/m^2 \cdot day \cdot atm$)	2325	4448	
Vapor Transmission Rate ($g \cdot 25\ \mu/m^2 \cdot day$)			5.9

PERMEABILITY (normalized units)

Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	59.1	113	
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)			0.15

Table 39-04. Oxygen and Water Vapor Through DuPont Canada Sclair HDPE

Material Family	HIGH DENSITY POLYETHYLENE (HDPE)					
Material Supplier/Trade Name	DUPONT CANADA SCLAIR					
Grade	**15A**	**16A**	**19A**	**15A**	**16A**	**19A**
Product Form	BLOWN FILM					
Applications	merchandising bags		co-extrusion, laminations	merchandising bags		co-extrusion, laminations
Reference Number	277					

MATERIAL CHARACTERISTICS

Sample Thickness (mm)	0.0254

TEST CONDITIONS

Penetrant	water vapor	oxygen
Temperature (°C)	38	23
Relative Humidity (%)	90	
Test Method		ASTM D1434
Test Note	values are cooling rate dependent	
Test Apparatus	Honeywell model 825 apparatus	

PERMEABILITY (source document units)

Vapor Transmission Rate ($g/m^2 \cdot day$)	7.3	6.5	5.0			
Gas Permeability ($cm^3/m^2 \cdot day$)				2600	2200	1600

PERMEABILITY (normalized units)

Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)				66.0	55.9	40.6
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)	0.19	0.17	0.13			

Table 39-05. Oxygen and Water Vapor Through HDPE

Material Family	**HIGH DENSITY POLYETHYLENE (HDPE)**
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 ($cm^3 \cdot mil/100\ in^2 \cdot bar \cdot day$)	>190	
Vapor Transmission Rate ($g \cdot mil/100\ in^2 \cdot bar \cdot day$)		0.25

PERMEABILITY (normalized units)

Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	>75.79	
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)		0.1

Table 39-06. Water Vapor, Oxygen, Nitrogen, and Carbon Dioxide Through HDPE

Material Family	**HIGH DENSITY POLYETHYLENE (HDPE)**
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)

Gas Permeability ($cm^3 \cdot mil/100\ in^2 \cdot day$)		185	42	580
Vapor Transmission Rate ($g \cdot mil/100\ in^2 \cdot day$)	0.3			
Vapor Transmission Rate ($g/day \cdot 100\ in^2$)	0.12			

PERMEABILITY (normalized units)

Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)		73	17	228
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)	0.12			

Table 39-07. Hydrogen vs. Temperature and Pressure Through HDPE

Material Family	HIGH DENSITY POLYETHYLENE (HDPE)								
Reference Number	306								

MATERIAL CHARACTERISTICS

Sample Thickness (mm)	0.03								

TEST CONDITIONS

Penetrant	hydrogen								
Temperature (°C)	-15	25	68	-16	25	67	-18	25	67
Pressure Gradient (kPa)	1724			3447			6895		
Test Method/Test Note	mass spectrometry and calibrated standard gas leaks; developed by McDonnell Douglas Space Systems Company Chemistry Laboratory								

PERMEABILITY (source document units)

Gas Permeability ($cm^3 \cdot mm/cm^2 \cdot kPa \cdot sec$)	3.64×10^{-10}	1.78×10^{-9}	8.69×10^{-9}	3.49×10^{-10}	1.76×10^{-9}	8.54×10^{-9}	3.19×10^{-10}	1.84×10^{-9}	8.45×10^{-9}

PERMEABILITY (normalized units)

Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	31.9	156	761	30.6	154	748	27.9	161	740

Table 39-08. Nitrogen vs. Temperature and Pressure Through HDPE

Material Family	HIGH DENSITY POLYETHYLENE (HDPE)								
Reference Number	306								

MATERIAL CHARACTERISTICS

Sample Thickness (mm)	0.03								

TEST CONDITIONS

Penetrant	nitrogen								
Temperature (°C)	-10	25	72	-19	25	69	-17	25	68
Pressure Gradient (kPa)	1724			3447			6895		
Test Method/Test Note	mass spectrometry and calibrated standard gas leaks; developed by McDonnell Douglas Space Systems Company Chemistry Laboratory								

PERMEABILITY (source document units)

Gas Permeability ($cm^3 \cdot mm/cm^2 \cdot kPa \cdot sec$)	1.81×10^{-11}	1.77×10^{-10}	1.98×10^{-9}	1.08×10^{-11}	1.6×10^{-10}	1.46×10^{-9}	1.13×10^{-11}	1.68×10^{-10}	1.71×10^{-9}

PERMEABILITY (normalized units)

Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	1.6	15.5	173	0.95	14.0	127.8	0.99	14.7	150

Table 39-09. Oxygen and Ammonia vs. Temperature and Pressure Through HDPE

Material Family	HIGH DENSITY POLYETHYLENE (HDPE)
Reference Number	306

MATERIAL CHARACTERISTICS

Sample Thickness (mm)	0.03

TEST CONDITIONS

Penetrant	ammonia			oxygen					
Temperature (°C)	-3	25	61	-16	25	51	-15	25	52
Pressure Gradient (kPa)	965			1724			3447		
Test Method/Test Note	mass spectrometry and calibrated standard gas leaks; developed by McDonnell Douglas Space Systems Company Chemistry Laboratory								

PERMEABILITY (source document units)

Gas Permeability ($cm^3 \cdot mm/cm^2 \cdot kPa \cdot sec$)	3.71×10^{-10}	1.4×10^{-9}	7.12×10^{-9}	5.75×10^{-11}	5.75×10^{-10}	2.49×10^{-9}	5.91×10^{-11}	5.64×10^{-10}	2.03×10^{-9}

PERMEABILITY (normalized units)

Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	32.5	122.6	623	5.0	50.3	218	5.2	49.4	178

Table 39-10. Xylene and Oxygen Through HDPE

Material Family	HIGH DENSITY POLYETHYLENE (HDPE)
Reference Number	293

TEST CONDITIONS

Penetrant	xylene	oxygen
Temperature (°C)	60	23
Exposure Time (days)	14	
Relative Humidity (%)		75

PERMEABILITY (source document units)

Vapor Transmission Rate ($g \cdot mil/100\ in^2 \cdot day$)	720	
Gas Permeability ($cm^3 \cdot mil/100\ in^2 \cdot day$)		126

PERMEABILITY (normalized units)

Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)		49.6
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)	283	

Table 39-11. Water Vapor and Various Gases Through HDPE

Material Family	HIGH DENSITY POLYETHYLENE (HDPE)
Product Form	FILM
Reference Number	101

TEST CONDITIONS

Penetrant	water vapor	carbon dioxide	hydrogen	oxygen	helium	ethane	natural gas	Freon 12	nitrogen
Temperature (°C)	37.8	23							
Relative Humidity (%)	90								
Test Method	ASTM D96	ASTM D1434							

PERMEABILITY (source document units)

Gas Permeability ($cm^3 \cdot mil/100\ in^2 \cdot day$)		345	321	111	247	236	113	95	53
Gas Permeability ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)		136	126	44	97	93	44	37	21
Vapor Transmission Rate ($g \cdot mil/100\ in^2 \cdot day$)	0.3								
Vapor Transmission Rate ($g \cdot mm/day/m^2$)	0.12								

PERMEABILITY (normalized units)

Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)		136	126	44	97	93	44	37	21
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)	0.12								

Table 39-12. Various Gases Through HDPE

Material Family	HIGH DENSITY POLYETHYLENE (HDPE)
Material Supplier/Grade	HOECHST AG HOSTALEN
Reference Number	94

TEST CONDITIONS

Penetrant	argon			methane	ethane	propane	ethylene	propylene	sulfur dioxide
Temperature (°C)	20	30	50	20					
Test Condition Note	volume at standard temperature and pressure								
Test Note	useable average for all Hostalen grades								

PERMEABILITY (source document units)

Gas Permeability ($cm^3 \cdot mm/m^2 \cdot bar \cdot day$)	66	89	230	56	89	35	110	76	430

PERMEABILITY (normalized units)

Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	66.9	90.2	233	56.7	90.2	35.5	112	77.0	436

Table 39-13. Penetrant Weight Loss of Various Penetrants Through HDPE Bottles

Material Family	HIGH DENSITY POLYETHYLENE (HDPE)						
Product Form	BOTTLES						
Reference Number	293						

TEST CONDITIONS

Penetrant	cyclohexanone	chlorobenzene	hexane	butyl alcohol	trichloroethene	methyl salicylate	tetrahydrofuran
Temperature (°C)	50						23
Exposure Time (days)	28						180

PERMEABILITY (source document units)

Penetrant Weight Loss (%)	0.6	20.0	32.9	0.2	15.0	1.02	29.19

Table 39-14. Penetrant Weight Loss of Various Penetrants Through HDPE Bottles

Material Family	HIGH DENSITY POLYETHYLENE (HDPE)							
Product Form	BOTTLES							
Reference Number	293							

TEST CONDITIONS

Penetrant	ethyl acetate	isopropyl acetate	acetone	butyl acetate	toluene	xylene	methyl isobutyl ketone	methyl ethyl ketone
Temperature (°C)	50		23	50				
Exposure Time (days)	28		180	28				

PERMEABILITY (source document units)

Penetrant Weight Loss (%)	4.0	2.4	0.91	3.7	45.1	38.1	1.8	2.8

Table 39-15. Penetrant Weight Loss of Various Penetrants Through HDPE Bottles

Material Family	HIGH DENSITY POLYETHYLENE (HDPE)					
Product Form	BOTTLES					
Reference Number	293					

TEST CONDITIONS

Penetrant	kerosene	d-limonene	motor oils	pine oil	diesel fuel conditioner	gas additive
Penetrant Note			2 cycle	cleaner		Brakleen
Temperature (°C)	50					
Exposure Time (days)	28					

PERMEABILITY (source document units)

Penetrant Weight Loss (%)	2.3	6.7	0.4	1.7 (oily surface)	5.5	10.6

Table 39-16. Penetrant Weight Loss of Various Penetrants Through HDPE Bottles

Material Family	HIGH DENSITY POLYETHYLENE (HDPE)					
Product Form	BOTTLES					
Reference Number	293					

TEST CONDITIONS

Penetrant	mineral spirits	turpentine	STP gas treatment	paint thinner	charcoal starter	naphtha
Temperature (°C)	50					
Exposure Time (days)	28					

PERMEABILITY (source document units)

Penetrant Weight Loss (%)	0.8	2.4	16.4	10.3	14.8	8.8

Table 39-17. Penetrant Weight Loss of Various Penetrants Through HDPE Bottles

Material Family	**HIGH DENSITY POLYETHYLENE (HDPE)**
Material Supplier/Grade	**DUPONT**
Product Form	**BOTTLE (1 LITER)**
Reference Number	293

TEST CONDITIONS

Penetrant	xylene			propyl alchohol		xylene		methyl alcohol	
Penetrant Note		with 25% propyl alcohol	with 50% propyl alcohol	with 25% xylene		with 25% methyl alcohol	with 50% methyl alcohol	with 25% xylene	
Temperature (°C)	50					23			
Exposure Time (days)	28					180			

PERMEABILITY (source document units)

Penetrant Weight Loss (%)	28	23.45	16.27	4.71	0.15	20.30	14.99	4.90	0.29

Table 39-18. Gasoline Through HDPE

Material Family	**HIGH DENSITY POLYETHYLENE (HDPE)**
Reference Number	266

MATERIAL CHARACTERISTICS

Sample Thickness (mm)	1.27

TEST CONDITIONS

Penetrant	gasoline

PERMEABILITY (source document units)

Vapor Transmission Rate ($g/day \cdot 100\ in^2$)	1.29

PERMEABILITY (normalized units)

Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)	25.39

Table 39-19. d-Limonene (Flavor Component) Through HDPE

Material Family	**HIGH DENSITY POLYETHYLENE (HDPE)**
Product Form	**FILM**
Reference Number	255

TEST CONDITIONS

Penetrant	d-limonene
Temperature (°C)	25
Relative Humidity (%)	dry

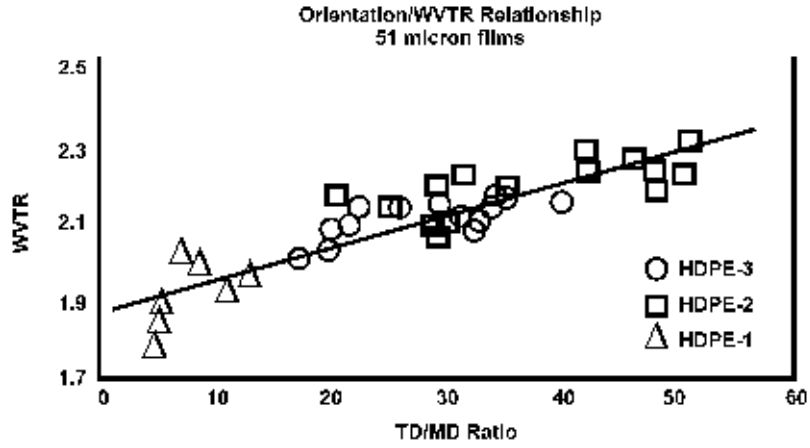
PERMEABILITY (source document units)

Vapor Transmission (10^{-20} kg · m/m^2 · sec · Pa)	1,700,000

PERMEABILITY (normalized units)

Vapor Transmission Rate (g · mm/m^2 · day)	149

Graph 39-01. Water vapor vs. TD/MD ratio for three HDPE resins.[1001]



Polyolefin Plastomers (POP)

Category: Polyolefin

General Description: Dow Chemical's Affinity resins, homogenous ethylene alpha-olefin copolymers, contain up to 20% octene comonomer.[1013]

ExxonMobil's Exact Plastomers are polyolefins produced using a comonomer, butene, hexene, and octene, which significantly affects the properties of the plastic.[1014]

Processing Methods: Extrusion, co-extrusion.

Applications: Focusing on applications requiring both thermoplastic and elastic properties.

- *Packaging.* Fresh vegetables, fruits, flowers and other horticulture products.

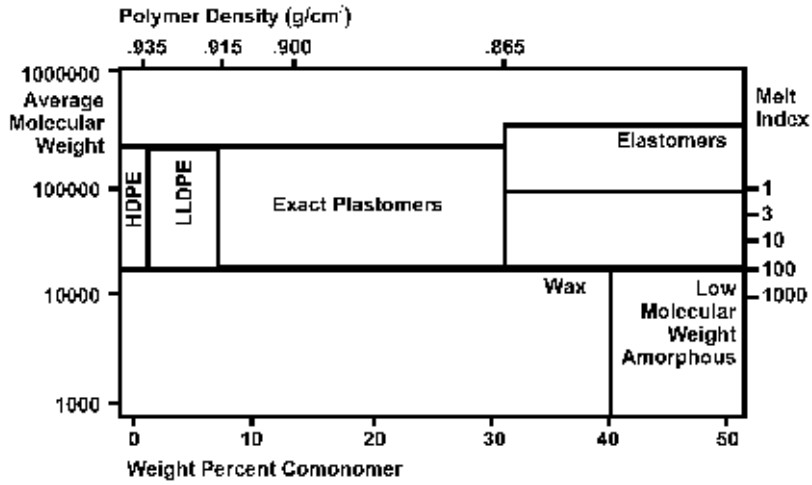
Blends with LLDPE, post-consumer recycle HDPE. Fresh and processed meats, poultry wraps, or pouch containers[1014]

Permeability to Oxygen and Water Vapor: Affinity provides higher oxygen transmission rates than other films to create more "breathable" films.[1013]

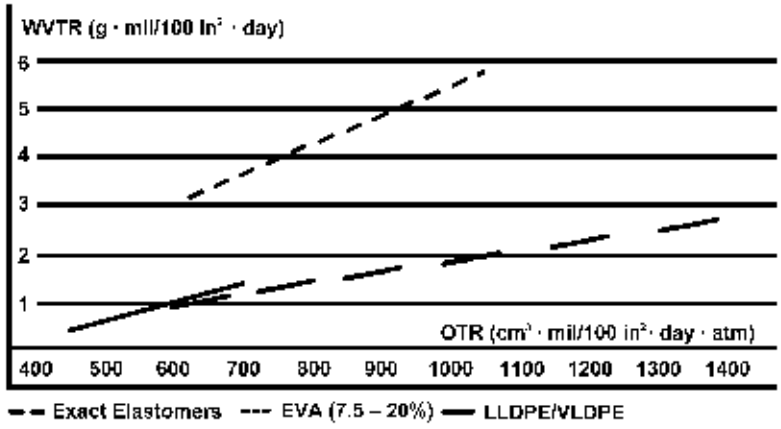
Permeation rates of oxygen and water vapor are variable and controlled, i.e., can be "selected" with Exact.[1014]

Permeability Data by Material Supplier Trade Name: See Graphs 40-01 through 40-02.

Graph 40-01. Ethylene-based polymers product regions.[1014]



Graph 40-02. Barrier balance (OTR/WVTR) of exact plastomers.[1014]



Chapter 41

Cyclic Olefin Copolymer (COC)

Category: Polyolefin

General Description: Ticona Topas are amorphous, glass-clear copolymers of ethylene and norbornene. The Topas product line features several grades differentiated by heat deflection temperatures ranging from 80°C to 180°C.[1015]

Processing Methods: Co-extrusion, lamination into films, then thermoformed into blister packs.[1015]

Applications: Topas is used as a core layer in push-through packaging (PTP), either in five layer co-extruded or three layer laminated film structures.[1015]

Flexible and rigid packaging for food and consumer items. Syringes, vials, and other pre-fillable containers.[1015]

Permeability to Water Vapor: Topas 8007 COC is nearly 10 times less permeable to water vapor than PVC, 0.071 vs. 0.635 g · mil/100 in^2/24 hr · atm, respectively at 23°C and 85% RH.[1017]

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

Permeability Data by Material Supplier Trade Name: See Table 41-01.

Table 41-01. Oxygen, Carbon Dioxide, and Water Vapor Through Ticona Topas COC

Material Family	**CYCLIC OLEFIN COPOLYMER (COC)**		
Material Grade	**TICONA TOPAS (COC)**		
Reference Number	1016		
Test Conditions			
Penetrant	oxygen	carbon dioxide	water vapor
Temperature (°C)			23
Relative Humidity (%)			85
PERMEABILITY (source document units)			
Gas Permeability (cc · mm/m^2 · day)	71	60	
Vapor Permeability (g · mil/100 in^2 · day · atm)			0.071
PERMEABILITY (normalized units)			
Permeability Coefficient (cm^3 · mm/m^2 · day · atm)	71	60	
Vapor Transmission Rate (g · mm/m^2 · day)			0.028

Chapter 42

Ethylene-Vinyl Acetate Copolymer (EVA)

Category: Polyolefin

General Description: Copolymer resin ranging in vinyl acetate content from 7.5 wt% to 33 wt%. Some grades available with antiblock and slip additives. DuPont Elvax grades vary by vinyl acetate content. The vinyl acetate units in the copolymer modify the basic polyethylene structure and its properties.[1018]

Processing Methods: Blown, extrusion, cast and co-extruded film, or blends with other resins.

Applications: Packaging, cap liners, pallet stretch wrapping, bundling, liquid packaging, and as a sealant in barrier bags for primal and subprimal cuts of meat.

HDPE/Elvax or PET/Elvax in medical packaging provide high gas transmission.[1018]

Permeability Data by Material Supplier Trade Name: See Tables 42-01 through 42-03 and Graphs 42-01 through 42-02.

Table 42-01. Oxygen Through DuPont Elvax EVA

Material Family	**ETHYLENE-VINYL ACETATE COPOLYMER (EVA)**
Material Grade	**DUPONT ELVAX**
Reference Number	1019

MATERIAL CHARACTERISTICS

Sample Thickness (mm)	0.0254
Material Note	SB: antiblock additive, SHB: slip additive and high antiblock additive

TEST CONDITIONS

Penetrant	oxygen
Test Method	ASTM D3985

PERMEABILITY (source document units)

Grade	**3120**	**3121 A**	**3128**	**3130**	**3130 SB**	**3130 SBZ**
Vinyl Acetate Content (%)	7.5		8.9	12		
Gas Permeability (cc/100 in^2 · day · atm)	450	580	500	400	570	

PERMEABILITY (normalized units)

Permeability Coefficient (cm^3 · mm/m^2 · day · atm)	177	228	196	157	224	

PERMEABILITY (source document units)

Grade	**3135 X**	**3135 SB**	**3150**	**3165**	**3165 SB**	**3169**
Vinyl Acetate Content	12		15	18		
Gas Permeability (cc/100 in^2 · day · atm)	510	460	500	580	670	500

PERMEABILITY (normalized units)

Permeability Coefficient (cm^3 · mm/m^2 · day · atm)	200	180	196	228	263	196

PERMEABILITY (source document units)

Grade	**3170**	**3170 SHB**
Vinyl Acetate Content (%)	18	
Gas Permeability (cc/100 in^2 · day · atm)	470	535

PERMEABILITY (normalized units)

Permeability Coefficient (cm^3 · mm/m^2 · day · atm)	185	210

Table 42-02. Water Vapor Through DuPont Elvax EVA

Material Family	**ETHYLENE-VINYL ACETATE COPOLYMER (EVA)**
Material Grade	**DUPONT ELVAX**
Reference Number	1019

MATERIAL CHARACTERISTICS

Sample Thickness (mm)	0.0254
Material Note	SB: antiblock additive, SHB: slip additive and high antiblock additive

TEST CONDITIONS

Penetrant	water vapor
Test Method	ASTM E96

PERMEABILITY (source document units)

Grade	**3120**	**3121 A**	**3128**	**3130**	**3130 SB**	**3130 SBZ**
Vinyl Acetate Content (%)	7.5		8.9	12		
Vapor Permeability ($g/100\ in^2 \cdot day$)	1.5	1.5	1.6	2.3	2.2	2.2

PERMEABILITY (normalized units)

Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)	0.74	0.74	0.93	1.1		

PERMEABILITY (source document units)

Grade	**3135 X**	**3135 SB**	**3150**	**3165**	**3165 SB**	**3169**
Vinyl Acetate Content (%)	12		15	18		
Vapor Permeability ($g/100\ in^2 \cdot day$)	2.3	2.4	3.3	4.2	3.6	3.4

PERMEABILITY (normalized units)

Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)	1.1	1.2	1.6	2.1	1.8	1.7

PERMEABILITY (source document units)

Grade	**3170**	**3170 SHB**
Vinyl Acetate Content (%)	18	
Vapor Permeability ($g/100\ in^2 \cdot day$)	3.8	3.7

PERMEABILITY (normalized units)

Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)	1.9	1.8

Table 42-03. Water Vapor, Carbon Dioxide, and Oxygen Through EVA Film

Material Family	**ETHYLENE-VINYL ACETATE COPOLYMER (EVA)**
Product Form	**FILM**
Features	2.5 blow up ratio
Manufacturing Method	blown film
Reference Number	216

MATERIAL CHARACTERISTICS

Density	0.930 g/cm^3
Sample Thickness (mm)	0.05
Vinyl Acetate Content (%)	12.0

TEST CONDITIONS

Penetrant	water vapor	carbon dioxide	oxygen
Test Method	JIS Z0208	ASTM D1434	

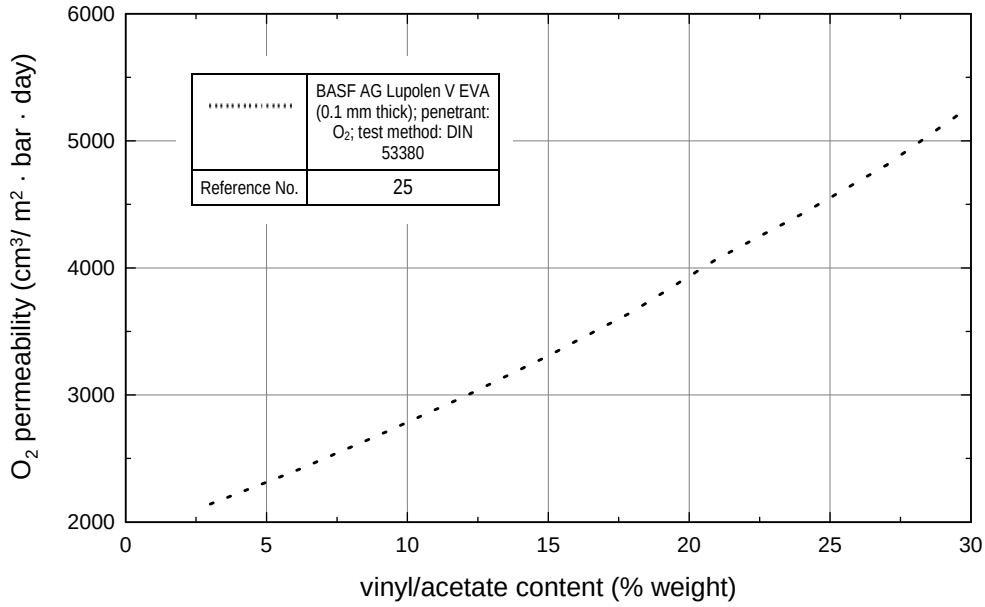
PERMEABILITY (source document units)

Vapor Transmission Rate (g · 100 µm/m^2 · day)	45		
Gas Permeability (cm^3 · 100 µm/m^2 · day · atm)		11,000	1800

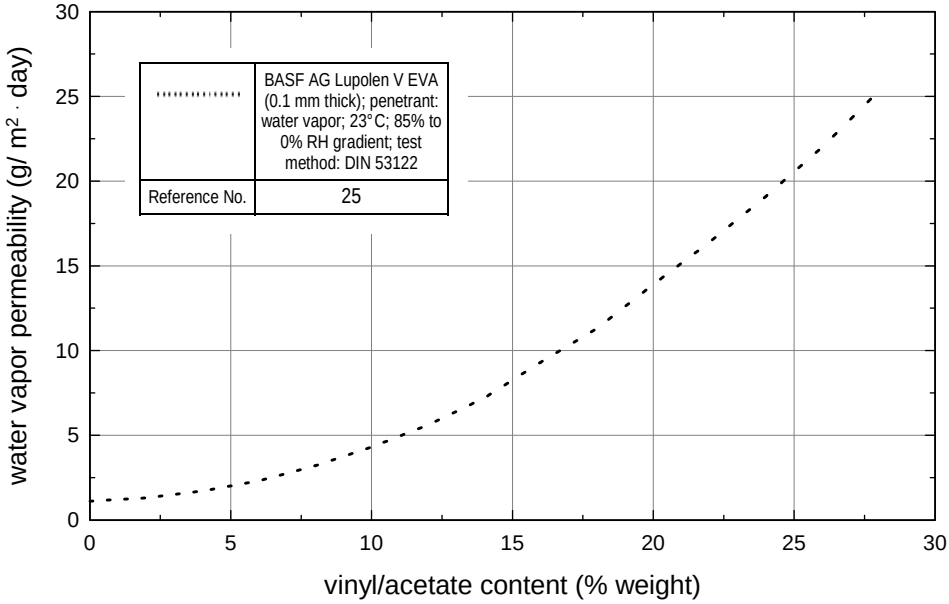
PERMEABILITY (normalized units)

Permeability Coefficient (cm^3 · mm/m^2 · day · atm)		1100	180
Vapor Transmission Rate (g · mm/m^2 · day)	4.5		

Graph 42-01. Oxygen vs. vinyl acetate content through EVA.



Graph 42-02. Water vapor vs. vinyl acetate content through EVA.



Ethylene - Vinyl Alcohol Copolymer (EVOH)

Category: Polyolefin

General Description: Copolymers of ethylene and vinyl alcohol are highly crystalline resins produced with various levels of ethylene content. See Table 43-01 for EVAL Resins.[1020]

Table 43-01. Varous Levels of Ethylene Content[1020]

EVAL	% C_2
L Series	27
F Series	32
H Series	38
K Series	38
E Series	44
G Series	48

Processing Methods: EVAL resins can be co-extruded with all types of polyolefins, nylons, polystyrene, polyvinyl chloride, and polyesters. Downstream processing such as thermoforming, vacuum forming, and printing is easily accomplished with structures containing EVAL resins or EVAL films.[1020]

Heat Treatment and Orientation: EVAL resins are highly crystalline materials. It is this crystallinity that allows EVAL resins to offer superior barrier properties. Crystallinity may be affected by both heat-treating and orientation (stretching). The following general improvements are seen when EVAL films are subjected to either heat treatment, orientation, or a combination of both. Table 43-02 shows the effect of orientation and/or heat treatment.[1020]

- Heat treatment alone can improve gas barrier properties, particularly those at high humidity conditions.
- A combination of heat treatment and orientation will further improve gas barrier properties at high humidity conditions.[1020]
- Improvement by orientation alone without heat treatment is marginal.[1020]

Applications: Rigid packaging: entrees, edible oils, juice, cosmetics, pharmaceuticals, heating pipe, condiments, and toothpaste.

Flexible Packaging: Processed meats, bag-in-box, red meat, cereal, pesticides, and agri-chemicals.

Permeability to Oxygen and Other Gases: EVAL resins offer outstanding gas (oxygen, carbon dioxide, nitrogen, and helium) barrier properties and maintain their barrier property over a wide range of humidities. The oxygen barrier properties of an EVOH will vary according to the ethylene content in the polymer.[1020]

The oxygen barrier properties of the polymer are adversely affected by the amount of moisture absorbed. As the moisture absorption rate of the polymer increases, the oxygen transmission rate increases. By co-extruding EVAL resin between layers of high moisture barrier resins like polyethylene or polypropylene, the loss of oxygen barrier properties is greatly diminished.[1020]

Oxygen transmission rate increases with temperature of the environment.[1020]

Bi-axial Orientation: Barrier properties are affected by heat treating and orientation (stretching). Heat treatment alone can improve gas barrier properties, particularly those at high humidity conditions. A combination of heat treatment and orientation will further improve gas barrier properties at high humidity conditions. Improvement by orientation alone without heat treatment is marginal. Significant improvement in gas barrier properties at high relative humidity are achieved with biaxial orientation (EVAL EF-X L).[1020]

Permeability to Water and Other Vapors: Packages containing EVAL resins can effectively retain fragrances and preserve the aroma of the contents within the package. At the same time, undesirable odors are prevented from entering or leaving the package. Flavor permeation is difficult to measure, many times only a simple component of a flavor is measured, for example, d-limonene from orange juice.[1021]

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

Permeability Data by Material Supplier Trade Name: See Tables 43-02 through 43-23 and Graphs 43-01 through 43-09.

Table 43-02. Orientation and Heat Treatment vs. Oxygen Transmission Rate[1020]

Processing			O_2TR				O_2TR			
Chill Roll Temp. °C	Heat Orientation	Treatment	cc 25u/M_2/24hrs/atm				cc 25u/M_2/24hrs/atm			
			F Series		E Series		F Series		E Series	
			0% RH	100% RH	0% RH	100% RH	0% RH	100% RH	0% RH	100% RH
50	none	none	0.126	40.9	1.18	11.8	0.008	2.6	0.076	0.76
110	none	none	0.118	33.8	1.02	9.4	0.0076	2.2	0.066	0.61
50	none	140	0.102	11.0	0.94	6.3	0.0066	0.71	0.61	0.41
50	uniaxially									
	3 times	none	0.118	32.3	1.02	10.2	0.0076	2.1	0.071	0.71
50	uniaxially									
	3 times	140	0.094	3.9	0.94	3.1	0.0006	0.25	0.061	0.20
50	biaxially									
	3x3	none	0.118	31.5	1.02	10.2	0.0076	2.0	0.071	0.71
50	biaxially									
	3x3	140	0.094	2.3	0.94	2.4	0.0061	0.15	0.061	0.15

Table 43-03. Fluorocarbons Through EVAL Ethylene-Vinyl Alcohol Copolymer (EVOH)

Material Family	**Ethylene-Vinyl Alcohol Copolymer (EVOH)**
Material Grade	**EVAL-EVAL**
Reference Number	1127

TEST CONDITIONS

Penetrant	Fluorocarbons						
	HCFC 22				CFC 12	HCFC 134A	
Temperature (°C)	35	50	60	65	70		

PERMEABILITY (source document units)

Gas Permeability (cc ·mil/m^2 ·24 hr)							
EVAL F	--*				0.24	--*	
EVAL E	ND**		1.3	4.1	8.0	0.56	ND**

PERMEABILITY (normalized units)

Permeability Coefficient (cm^3 ·mm/m^2·day ·atm)							
Eval F	--*				0.006	--*	
Eval E	ND**		0.03	0.1	0.2	0.14	ND**

* not measured ** none detected

Table 43-04. Oxygen vs. Temperature Through EVAL E and EVAL G Series EVOH

Material Family	ETHYLENE-VINYL ALCOHOL COPOLYMER (EVOH)							
Material Supplier/Grade	EVAL COMPANY EVAL E				EVAL COMPANY EVAL G			
Features	barrier properties							
Reference Number	264							
MATERIAL COMPOSITION								
Ethylene Content (mol%)	44				48			
TEST CONDITIONS								
Penetrant	oxygen							
Temperature (°C)	5	23	35	50	5	23	35	50
Relative Humidity (%)	0							
PERMEABILITY (source document units)								
Gas Permeability ($cm^3 \cdot mil/100\ in^2 \cdot day$)	0.017	0.06	0.124	0.344	0.067	0.116	0.174	0.394
Gas Permeability ($cm^3 \cdot 25\ \mu/m^2 \cdot day \cdot atm$)	0.259	0.935	1.922	5.33	1.034	1.8	2.7	6.11
PERMEABILITY (normalized units)								
Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	0.01	0.02	0.05	0.14	0.03	0.05	0.07	0.16

Table 43-05. Oxygen vs. Temperature Through EVAL H and EVAL K Series EVOH

Material Family	ETHYLENE-VINYL ALCOHOL COPOLYMER (EVOH)							
Material Supplier/Grade	EVAL COMPANY EVAL H				EVAL COMPANY EVAL K			
Features	barrier properties							
Reference Number	264							
MATERIAL COMPOSITION								
Ethylene Content (mol%)	38							
TEST CONDITIONS								
Penetrant	oxygen							
Temperature (°C)	5	23	35	50	5	23	35	50
Relative Humidity (%)	0							
PERMEABILITY (source document units)								
Gas Permeability ($cm^3 \cdot mil/100\ in^2 \cdot day$)	0.006	0.025	0.061	0.167	0.006	0.025	0.061	0.167
Gas Permeability ($cm^3 \cdot 25\ \mu/m^2 \cdot day \cdot atm$)	0.09	0.395	0.94	2.6	0.09	0.395	0.94	2.6
PERMEABILITY (normalized units)								
Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	0.0024	0.01	0.02	0.07	0.0024	0.01	0.02	0.07

Table 43- 06. Oxygen vs. Temperature Through EVAL L and EVAL F Series EVOH

Material Family	ETHYLENE-VINYL ALCOHOL COPOLYMER (EVOH)							
Material Supplier/Grade	EVAL COMPANY EVAL L				EVAL COMPANY EVAL F			
Features	barrier properties							
Reference Number	264							
MATERIAL COMPOSITION								
Ethylene Content (mol%)	27				32			
TEST CONDITIONS								
Penetrant	oxygen							
Temperature (°C)	5	23	35	50	5	23	35	50
Relative Humidity (%)	0							
PERMEABILITY (source document units)								
Gas Permeability ($cm^3 \cdot mil/100\ in^2 \cdot day$)	0.001	0.006	0.015	0.041	0.003	0.013	0.031	0.086
Gas Permeability ($cm^3 \cdot 25\ \mu/m^2 \cdot day \cdot atm$)	0.022	0.095	0.231	0.637	0.045	0.2	0.48	1.34
PERMEABILITY (normalized units)								
Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	0.00039	0.0024	0.01	0.02	0.0012	0.01	0.01	0.03

Table 43-07. Carbon Dioxide, Nitrogen, and Helium Through EVAL E Series EVOH

Material Family	ETHYLENE-VINYL ALCOHOL COPOLYMER (EVOH)							
Material Supplier/Grade	EVAL COMPANY EVAL E							
Features	barrier properties							
Reference Number	264							
MATERIAL COMPOSITION								
Ethylene Content (mol%)	44							
TEST CONDITIONS								
Penetrant	carbon dioxide			nitrogen		helium		
Temperature (°C)	5	23	35	23	35	5	23	35
Relative Humidity (%)	0							
PERMEABILITY (source document units)								
Gas Permeability ($cm^3 \cdot mil/100\ in^2 \cdot day$)	0.056	0.214	0.498	0.008	0.015	6.6	23.8	35.6
Gas Permeability ($cm^3 \cdot 25\ \mu/m^2 \cdot day \cdot atm$)	0.87	3.32	7.72	0.124	0.232	102.3	368.9	551.8
PERMEABILITY (normalized units)								
Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	0.02	0.08	0.2	0.0031	0.01	2.6	9.37	14.02

Table 43-08. Carbon Dioxide, Nitrogen, and Helium Through EVAL F Series EVOH

Material Family	ETHYLENE-VINYL ALCOHOL COPOLYMER (EVOH)							
Material Supplier/Grade	EVAL COMPANY EVAL F							
Features	barrier properties							
Reference Number	265							
MATERIAL COMPOSITION								
Ethylene Content (mol%)	32							
TEST CONDITIONS								
Penetrant	carbon dioxide			nitrogen		helium		
Temperature (°C)	5	23	35	23	35	5	23	35
Relative Humidity (%)	0							
PERMEABILITY (source document units)								
Gas Permeability ($cm^3 \cdot mil/100\ in^2 \cdot day$)	0.01	0.032	0.066	0.001	0.002	2.7	9.3	13.7
Gas Permeability ($cm^3 \cdot 25\ \mu/m^2 \cdot day \cdot atm$)	0.155	0.496	1.023	0.015	0.031	41.8	144.1	212.3
PERMEABILITY (normalized units)								
Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	0.0039	0.01	0.03	0.0004	0.0008	1.06	3.66	5.39

Table 43-09. Carbon Dioxide, Nitrogen, and Helium Through EVAL H Series EVOH

Material Family	ETHYLENE-VINYL ALCOHOL COPOLYMER (EVOH)							
Material Supplier/Grade	EVAL COMPANY EVAL H							
Features	barrier properties							
Reference Number	265							
MATERIAL COMPOSITION								
Ethylene Content (mol%)	38							
TEST CONDITIONS								
Penetrant	carbon dioxide			nitrogen		helium		
Temperature (°C)	5	23	35	23	35	5	23	35
Relative Humidity (%)	0							
PERMEABILITY (source document units)								
Gas Permeability ($cm^3 \cdot mil/100\ in^2 \cdot day$)	0.017	0.067	0.214	0.004	0.008	4.6	16.6	23.8
Gas Permeability ($cm^3 \cdot 25\ \mu/m^2 \cdot day \cdot atm$)	0.263	1.04	3.32	0.062	0.124	71.3	257.3	381.3
PERMEABILITY (normalized units)								
Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	0.01	0.03	0.08	0.0016	0.0031	1.81	6.54	9.37

Table 43-10. Oxygen vs. Relative Humidity Through EVAL EF-F Series EVOH Film

Material Family	**ETHYLENE-VINYL ALCOHOL COPOLYMER (EVOH)**							
Material Supplier/Trade Name	**EVAL COMPANY EVAL**							
Grade	**EF-F**	**EF-E**	**EF-F**	**EF-E**	**EF-F**	**EF-E**	**EF-F**	**EF-E**
Product Form	**FILM**							
Reference Number	268							
MATERIAL CHARACTERISTICS								
Sample Thickness (mm)	0.015	0.02	0.015	0.02	0.015	0.02	0.015	0.02
MATERIAL COMPOSITION								
Ethylene Content (mol%)	32	44	32	44	32	44	32	44
TEST CONDITIONS								
Penetrant	oxygen							
Temperature (°C)	35		20					
Relative Humidity (%)	0		65		85		100	
Test Method	JIS Z1707		ASTM D3985					
PERMEABILITY (source document units)								
Gas Permeability ($cm^3 \cdot mil/100\ in^2 \cdot day$)	0.03	0.21	0.03	0.1	0.13	0.21	1.61	0.65
PERMEABILITY (normalized units)								
Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	0.01	0.08	0.01	0.04	0.05	0.08	0.63	0.26

Table 43-11. Oxygen vs. Relative Humidity Through EVAL EF-XL Biaxially Oriented EVOH Film

Material Family	**ETHYLENE-VINYL ALCOHOL COPOLYMER (EVOH)**			
Material Supplier/Grade	**EVAL COMPANY EVAL EF-XL**			
Product Form	**FILM**			
Features	biaxially oriented			
Reference Number	268			
MATERIAL CHARACTERISTICS				
Sample Thickness (mm)	0.015			
TEST CONDITIONS				
Penetrant	oxygen			
Temperature (°C)	35	20		
Relative Humidity (%)	0	65	85	100
Test Method	JIS Z1707	ASTM D3985		
PERMEABILITY (source document units)				
Gas Permeability ($cm^3 \cdot mil/100\ in^2 \cdot day$)	.03	0.02	0.07	0.39
PERMEABILITY (normalized units)				
Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	.01	0.01	0.03	0.15

Table 43-12. Oxygen vs. Relative Humidity Through EVAL EF-XL, EVAL EF-F, and EF-E Series EVOH Film

Material Family	ETHYLENE-VINYL ALCOHOL COPOLYMER (EVOH)											
Material Supplier/ Trade Name	EVAL COMPANY EVAL											
Grade	**EF-XL**	**EF-F**	**EF-E**	**EF-XL**	**EF-F**	**EF-E**	**EF-XL**	**EF-F**	**EF-E**	**EF-XL**	**EF-F**	**EF-E**
Product Form	**FILM**											
Features	barrier properties biaxially oriented	barrier properties		barrier properties biaxially oriented	barrier properties		barrier properties biaxially oriented	barrier properties		barrier properties biaxially oriented	barrier properties	
Reference Number	265											
MATERIAL COMPOSITION												
Ethylene (mol%)		32	44		32	44		32	44		32	44
TEST CONDITIONS												
Penetrant	oxygen											
Temperature (°C)	20											
Relative Humidity (%)	65			85			100			0		
PERMEABILITY (source document units)												
Gas Permeability ($cm^3 \cdot mil/100\ in^2 \cdot day$)	0.01	0.02	0.08	0.04	0.08	0.17	0.23	1.0	0.52	0.02		0.16
PERMEABILITY (normalized units)												
Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	0.004	0.01	0.03	0.02	0.03	0.07	0.09	0.39	0.2	0.01		0.06

Table 43-13. Oxygen Permeability at 0% RH vs. Orientation and Heat Treatment Through EVAL-E Series EVOH

Material Family	ETHYLENE-VINYL ALCOHOL COPOLYMER (EVOH)						
Material Supplier/Grade	EVAL COMPANY EVAL E						
Chill Roll Temperature (°C)	50	110	50	50			
Heat Treatment (°C)	none		140	none	140	none	140
Orientation	none			uniaxially (3 times)		biaxially (3x3)	
Reference Number	264						

MATERIAL COMPOSITION

Ethylene Content (mol%)	44

TEST CONDITIONS

Penetrant	oxygen
Temperature (°C)	20
Relative Humidity (%)	0

PERMEABILITY (source document units)

Gas Permeability ($cm^3 \cdot mil/100\ in^2 \cdot day$)	0.076	0.066	0.061	0.071	0.061	0.071	0.061
Gas Permeability ($cm^3 \cdot 25\ \mu/m^2 \cdot day \cdot atm$)	1.18	1.02	0.94	1.02	0.94	1.02	0.94

PERMEABILITY (normalized units)

Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	0.03	0.026	0.024	0.028	0.024	0.028	0.024

Table 43-14. Oxygen Permeability at 0% RH vs. Orientation and Heat Treatment Through EVAL-F Series EVOH

Material Family	ETHYLENE-VINYL ALCOHOL COPOLYMER (EVOH)						
Material Supplier/Grade	EVAL COMPANY EVAL F						
Chill Roll Temperature (°C)	50	110	50	50			
Heat Treatment (°C)	none		140	none	140	none	140
Orientation	none			uniaxially (3 times)		biaxially (3x3)	
Reference Number	264						

MATERIAL COMPOSITION

Ethylene Content (mol%)	32

TEST CONDITIONS

Penetrant	oxygen
Temperature (°C)	20
Relative Humidity (%)	0

PERMEABILITY (source document units)

Gas Permeability ($cm^3 \cdot mil/100\ in^2 \cdot day$)	0.008	0.0076	0.0066	0.0076	0.0006	0.0076	0.0061
Gas Permeability ($cm^3 \cdot 25\ \mu/m^2 \cdot day \cdot atm$)	0.126	0.118	0.102	0.118	0.094	0.118	0.094

PERMEABILITY (normalized units)

Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	0.0031	0.003	0.0026	0.003	0.0002	0.003	0.0024

Table 43-15. Oxygen Permeability at 100% RH vs. Orientation and Heat Treatment Through EVAL -E Series EVOH

Material Family	ETHYLENE-VINYL ALCOHOL COPOLYMER (EVOH)						
Material Supplier/Grade	EVAL COMPANY EVAL E						
Chill Roll Temperature (°C)	50	110	50	50			
Heat Treatment (°C)	none		140	none	140	none	140
Orientation	none			uniaxially (3 times)		biaxially (3x3)	
Reference Number	264						

MATERIAL COMPOSITION

Ethylene Content (mol%)	44

TEST CONDITIONS

Penetrant	oxygen
Temperature (°C)	20
Relative Humidity (%)	100

PERMEABILITY (source document units)

Gas Permeability ($cm^3 \cdot mil/100\ in^2 \cdot day$)	0.76	0.61	0.41	0.71	0.2	0.71	0.15
Gas Permeability ($cm^3 \cdot 25\ \mu/m^2 \cdot day \cdot atm$)	11.8	9.4	6.3	10.2	3.1	10.2	2.4

PERMEABILITY (normalized units)

Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	0.299	0.24	0.16	0.28	0.079	0.28	0.06

Table 43-16. Oxygen Permeability at 100% RH vs. Orientation and Heat Treatment Through EVAL -F Series EVOH

Material Family	ETHYLENE-VINYL ALCOHOL COPOLYMER (CVOH)						
Material Supplier/Grade	EVAL COMPANY EVAL F						
Chill Roll Temperature (°C)	50	110	50	50			
Heat Treatment (°C)	none		140	none	140	none	140
Orientation	none			uniaxially (3 times)		biaxially (3x3)	
Reference Number	264						

MATERIAL COMPOSITION

Ethylene Content (mol%)	32

TEST CONDITIONS

Penetrant	oxygen
Temperature (°C)	20
Relative Humidity (%)	100

PERMEABILITY (source document units)

Gas Permeability ($cm^3 \cdot mil/100\ in^2 \cdot day$)	2.6	2.2	0.71	2.1	0.25	2	0.15
Gas Permeability ($cm^3 \cdot 25\ \mu/m^2 \cdot day \cdot atm$)	40.9	33.8	11	32.3	3.9	31.5	2.3

PERMEABILITY (normalized units)

Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	1.02	0.87	0.28	0.83	0.1	0.79	0.06

Table 43-17. Organic Solvents Through EVAL EF-E, EVAL EF-F, and EVAL EF-XL Series EVOH Film

Material Family	ETHYLENE-VINYL ALCOHOL COPOLYMER (EVOH)								
Material Supplier/ Trade Name	EVAL COMPANY EVAL								
Grade	**EF-F**	**EF-E**	**EF-XL**	**EF-F**	**EF-E**	**EF-XL**	**EF-F**	**EF-E**	**EF-XL**
Product Form	**FILM**								
Features	barrier properties		barrier properties, biaxially oriented	barrier properties		barrier properties, biaxially oriented	barrier properties		barrier properties, biaxially oriented
Reference Number	265								

MATERIAL COMPOSITION

Ethylene Content (mol%)	32	44		32	44		32	44	

TEST CONDITIONS

Penetrant	chloroform			xylene			kerosene		
Temperature (°C)	20								

PERMEABILITY (source document units)

Vapor Transmission Rate ($g \cdot mil/100\ in^2 \cdot day$)	0.1	0.16	0.006	0.054	0.074	0.016	>0.001	0.0025	0.001

PERMEABILITY (normalized units)

Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)	0.04	0.06	0.0024	0.02	0.03	0.01	>0.0004	0.00098	0.0004

Table 43-18. Organic Solvents Through Biaxially Oriented EVAL EF-XL Series EVOH Film

Material Family	**ETHYLENE-VINYL ALCOHOL COPOLYMER (EVOH)**			
Material Supplier/Grade	**EVAL COMPANY EVAL EF-XL**			
Product Form	**FILM**			
Features	biaxially oriented			
Reference Number	266			
MATERIAL CHARACTERISTICS				
Sample Thickness (mm)	0.015			
TEST CONDITIONS				
Penetrant	chloroform	xylene	methyl ethyl ketone	kerosene
Temperature (°C)	20			
Relative Humidity (%)	65			
PERMEABILITY (source document units)				
Vapor Transmission Rate ($g/day \cdot 100\ in^2$)	0.01	0.03	0.02	<0.003
PERMEABILITY (normalized units)				
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)	0.002	0.007	0.005	<0.0007

Table 43-19. Organic Solvents Through EVAL E Series EVOH Film

Material Family	**ETHYLENE-VINYL ALCOHOL COPOLYMER (EVOH)**							
Material Supplier/Grade	**EVAL COMPANY EVAL E**							
Product Form	**FILM**							
Reference Number	266							
MATERIAL CHARACTERISTICS								
Sample Thickness (mm)	0.02	0.032	0.02	0.032	0.02	0.032	0.02	0.032
MATERIAL COMPOSITION								
Ethylene Content (mol%)	44							
TEST CONDITIONS								
Penetrant	chloroform		xylene		methyl ethyl ketone		kerosene	
Temperature (°C)	20							
Relative Humidity (%)	65							
PERMEABILITY (source document units)								
Vapor Transmission Rate ($g/day \cdot 100\ in^2$)	0.2	0.06	0.09	0.04	0.31	0.03	<0.003	<0.003
PERMEABILITY (normalized units)								
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)	0.06	0.03	0.03	0.02	0.12	0.01	<0.001	<0.002

Table 43-20. Organic Solvents Through EVAL F Series EVOH Film

Material Family	**ETHYLENE-VINYL ALCOHOL COPOLYMER (EVOH)**							
Material Supplier/Grade	**EVAL COMPANY EVAL F**							
Product Form	**FILM**							
Reference Number	266							
MATERIAL CHARACTERISTICS								
Sample Thickness (mm)	0.02	0.032	0.02	0.032	0.02	0.032	0.02	0.032
MATERIAL COMPOSITION								
Ethylene Content (mol%)	32							
TEST CONDITIONS								
Penetrant	chloroform		xylene		methyl ethyl ketone		kerosene	
Temperature (°C)	20							
Relative Humidity (%)	65							
PERMEABILITY (source document units)								
Vapor Transmission Rate (g/day ·100 in^2)	0.13	0.3	0.07	<0.003	0.25	0.02	<0.003	<0.003
PERMEABILITY (normalized units)								
Vapor Transmission Rate (g ·mm/m^2 ·day)	0.04	0.2	0.02	<0.002	0.08	0.01	<0.001	<0.002

Table 43-21. Water Vapor Through EVAL EF-XL, EVAL EF-F, and EVAL EF-E Series EVOH Film

Material Family	**ETHYLENE-VINYL ALCOHOL COPOLYMER (EVOH)**		
Material Supplier/Grade	**EVAL COMPANY EVAL EF-XL**	**EVAL COMPANY EVAL EF-F**	**EVAL COMPANY EVAL EF-E**
Product Form	**FILM**		
Features	biaxially oriented		
Reference Number	268		
MATERIAL CHARACTERISTICS			
Sample Thickness (mm)	0.015		0.02
MATERIAL COMPOSITION			
Ethylene Content (mol%)		32	44
TEST CONDITIONS			
Penetrant	water vapor		
Temperature (°C)	40		
Relative Humidity (%)	90		
Test Method	JIS Z0208		
PERMEABILITY (source document units)			
Vapor Transmission Rate ($g \cdot mil/100\ in^2 \cdot day$)	3	6	2
PERMEABILITY (normalized units)			
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)	1.2	2.4	0.8

Table 43-22. Water Vapor Through EVAL L, EVAL F, EVAL H, EVAL K, EVAL E, and EVAL G Series EVOH

Material Family	ETHYLENE-VINYL ALCOHOL COPOLYMER (EVOH)					
Material Supplier	EVAL COMPANY					
Grade	EVAL L	EVAL F	EVAL H	EVAL K	EVAL E	EVAL G
Features	barrier properties					
Reference Number	264					

MATERIAL COMPOSITION

Ethylene Content (mol%)	27	32	38	44	48

TEST CONDITIONS

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

PERMEABILITY (source document units)

Vapor Transmission Rate ($g \cdot mil/100\ in^2 \cdot day$)	8	3.8	2.1	1.4
Vapor Transmission Rate ($g \cdot 25\ \mu/m^2 \cdot day$)	124	58.9	32.6	21.7

PERMEABILITY (normalized units)

Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)	3.2	1.5	0.8	0.6

Table 43-23. d-Limonene Through EVAL EVOH

Material Family	ETHYLENE-VINYL ALCOHOL COPOLYMER (EVOH)			
Material Grade	EVAL SERIES F	EVAL SERIES E	EVAL 5%	EVAL 7%
Reference Number	1021			

TEST CONDITIONS

Penetrant	d-Limonene
Temperature (°C)	20
Relative Humidity (%)	65

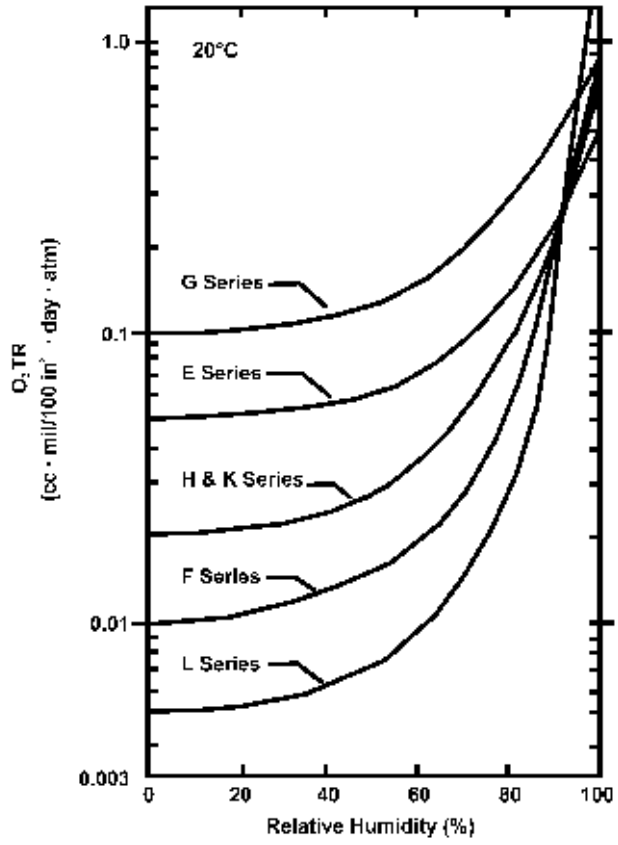
PERMEABILITY (source document units)

Vapor Permeability ($g \cdot mil/100\ in^2 \cdot day$)	0.002	0.003	98	113.5

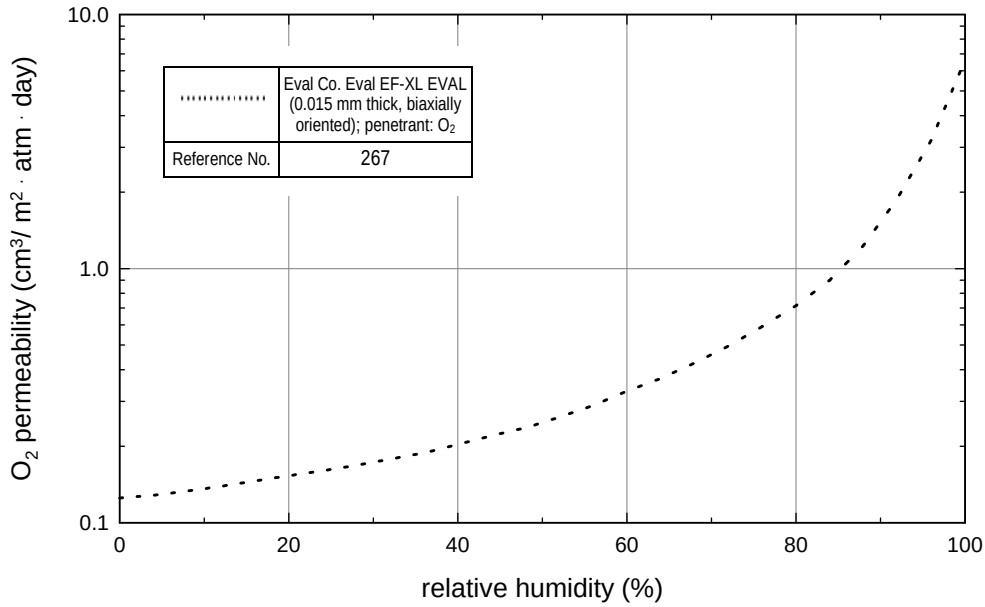
PERMEABILITY (normalized units)

Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)	0.00098	0.0015	48	55.6

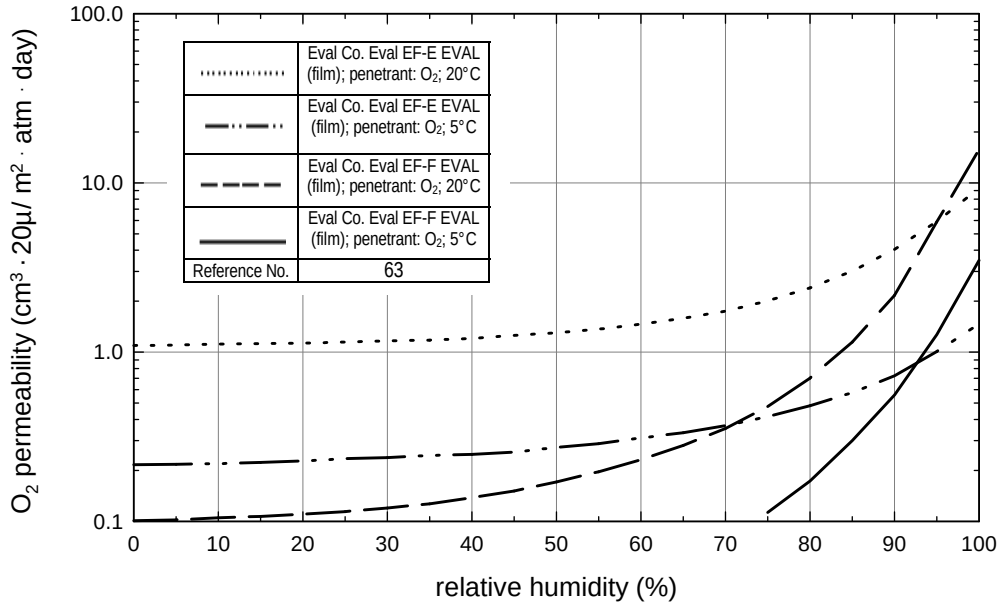
Graph 43-01. Oxygen vs. relative humidity at 20°C through EVAL EVOH.[1020]



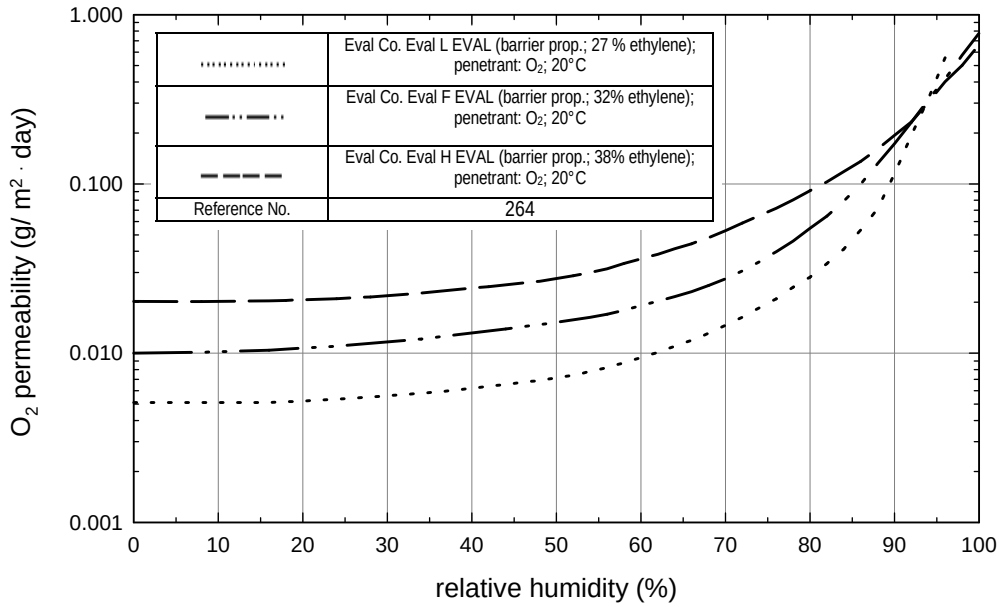
Graph 43-02. Oxygen vs. relative humidity through EVAL EF-XL series EVOH.



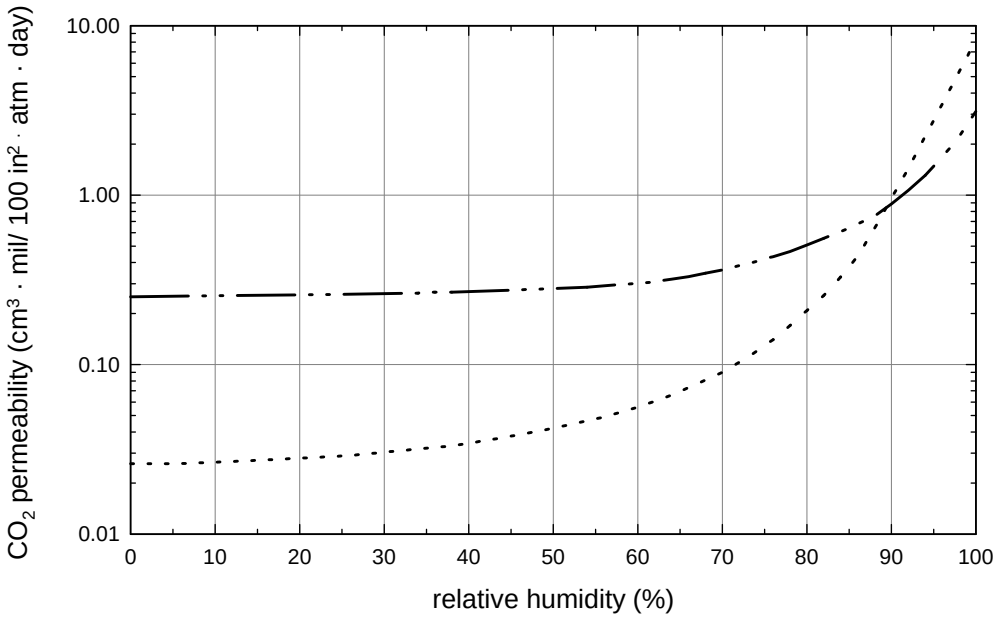
Graph 43-03. Oxygen vs. relative humidy through EVAL EF-E and EVAL EF-F series EVOH Film.



Graph 43-04. Oxygen vs. relative humidity through EVAL L, EVAL F, and EVAL H series EVOH.

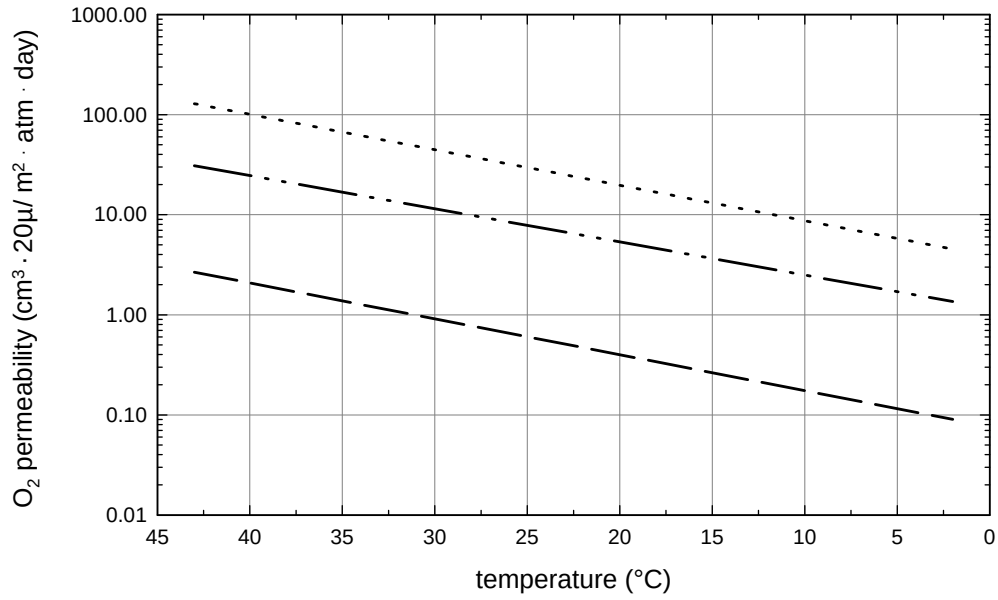


Graph 43-05. Carbon dioxide vs. relative humidity through EVAL F and EVAL E series EVOH.



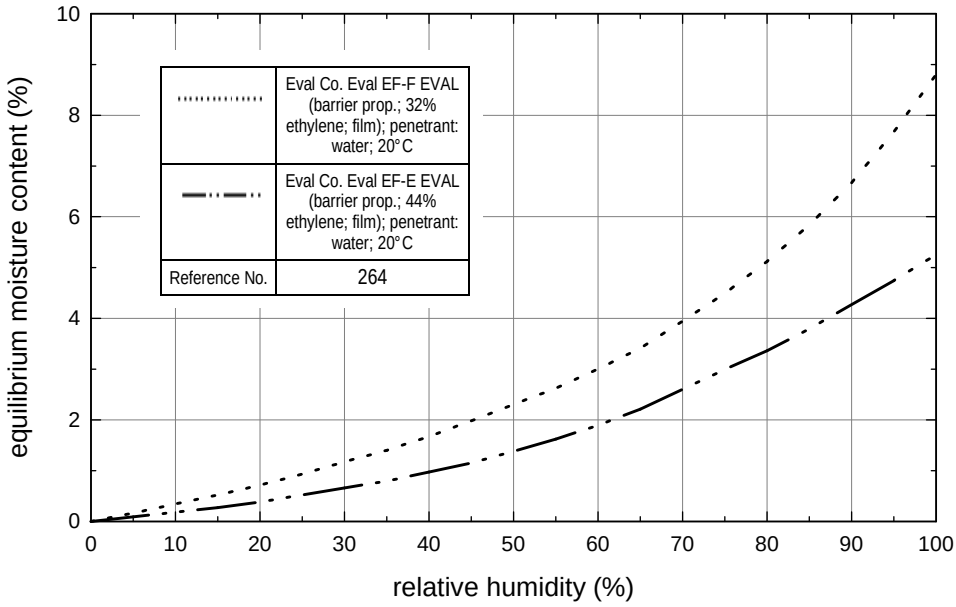
	Eval Co. Eval F EVAL (barrier prop.; 32% ethylene); penetrant: CO_2; 20°C
	Eval Co. Eval E EVAL (barrier prop.; 44% ethylene); penetrant: CO_2; 20°C
Reference No.	264

Graph 43-06. Oxygen vs. temperature and moisture content through EVAL EF-F series EVOH film.

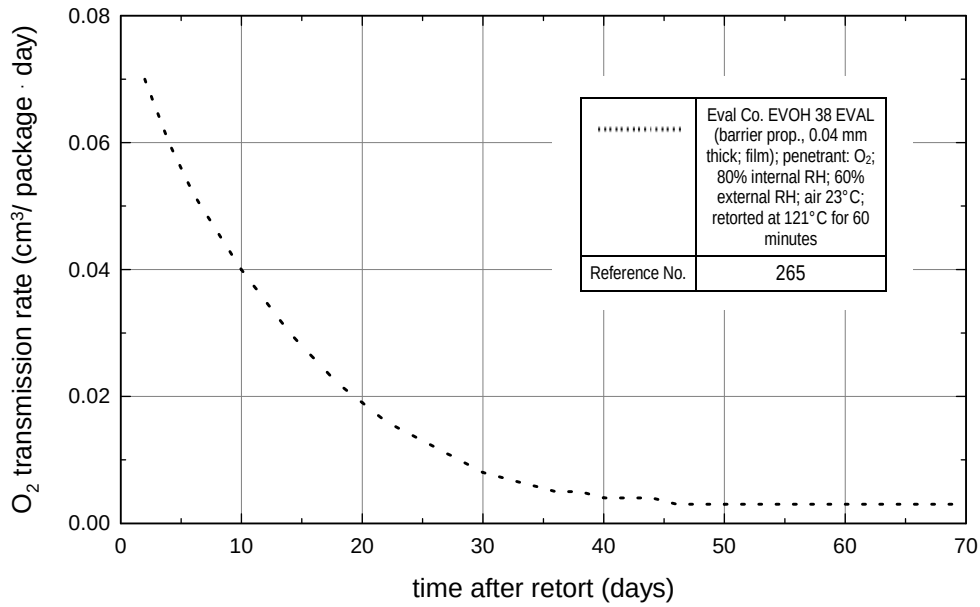


	Eval Co. Eval EF-F EVAL (0.02 mm thick; film); penetrant: O_2; moisture content: 9.6%
	Eval Co. Eval EF-F EVAL (0.02 mm thick; film); penetrant: O_2; moisture content: 7.3%
	Eval Co. Eval EF-F EVAL (0.02 mm thick; film); penetrant: O_2; moisture content: 4.5%
Reference No.	63

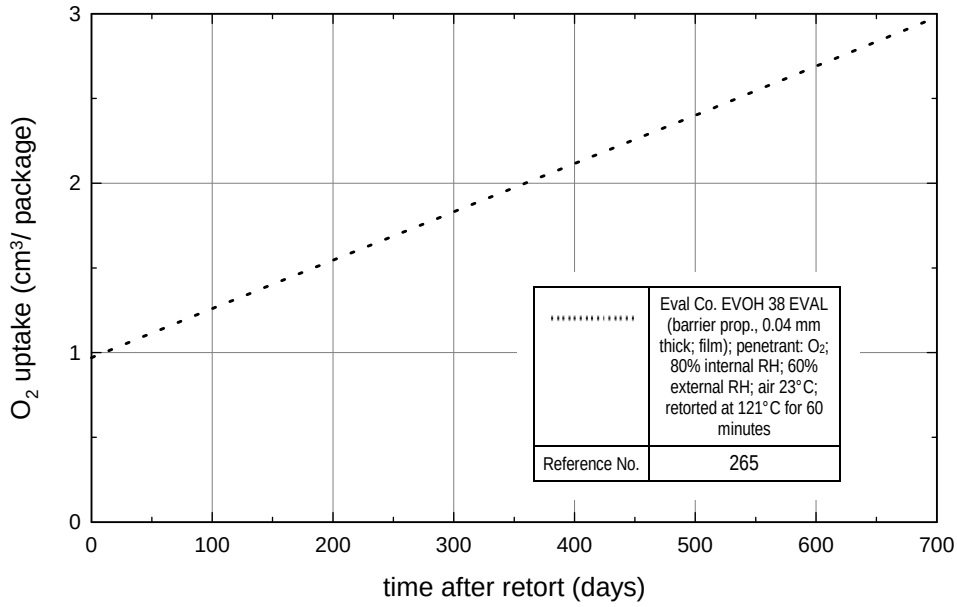
Graph 43-07. Equilibrium moisture absorption vs. relative humidity of EVAL EF-E and EVAL EF-F series EVOH film.



Graph 43-08. Oxygen transmission rate vs. time after retort through 38 EVAL series EVOH film.



Graph 43-09. Oxygen uptake vs. time after retort through 38 EVAL series EVOH film.



Ethylene-Acrylic Acid Copolymer (EAA)

Category: Polyolefin

General Description: EAA copolymers are designed for lasting adhesion to aluminum foil and other polar substrates. EAA copolymers also offer significant benefits as a sealant for packaging of fatty and greasy products.[1023]

Processing Methods: Blown and cast monolayer films, co-extruded and composite films.[1023]

Applications: In flexible packaging tie layer (polar to non-polar materials), they are widely used in extrusion coating to produce drink cartons, toothpaste tubes, and wire and cable shielding. In these applications EAA copolymers not only bond the foil to the substrate, but they protect the contents against tears, punctures, moisture, grease, and air.[1023]

Permeability to Oxygen and Other Gases: The amount of comonomer incorporated in the molecule influences the gas permeability, the higher the mass fraction of comonomer, the greater the permeability to gases.[1023]

Permeability Data by Material Supplier Trade Name: See Table 44-01.

Table 44-01. Oxygen and Water Vapor Through BASF Lucalen EAA

Material Family	POLYETHYLENE-ACRYLIC ACID COPOLYMER (EAA)					
Material Supplier/ Trade Name	BASF LUCALEN					
Grade	A2710H	A2910M	A3710MX	A2710H	A2910M	A3710MX
Reference Number	25					
MATERIAL CHARACTERISTICS						
Melt Flow Index	1.7 g/10 min. (190/2.16)	7 g/10 min. (190/2.16)		1.7 g/10 min. (190/2.16)	7 g/10 min. (190/2.16)	
Sample Thickness (mm)	0.1					
MATERIAL COMPOSITION						
Acrylic Acid Content (wt%)	17	11	8	17	11	8
TEST CONDITIONS						
Penetrant	oxygen			water vapor		
Temperature (°C)	23					
Relative Humidity (%)				85-0 gradient		
Test Method	DIN 53380			DIN 53122		
PERMEABILITY (source document units)						
Gas Permeability ($cm^3/m^2 \cdot day \cdot bar$)	5430	2400	1760			
Vapor Transmission Rate ($g/m^2 \cdot day$)				6.8	2.3	0.8
PERMEABILITY (normalized units)						
Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	550	243	178			
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)				0.68	0.23	0.08

Chapter 45

Polypropylene (PP)

Category: Polyolefin

General Description: Polypropylene is produced commercially in different forms, depending upon the desired properties.

- *Homopolymer Polypropylene.* A translucent, crystalline polymer containing only propylene monomer in the polymer chain.[1024] Homopolymer PP is the main component in the production of BOPP film, bi-axially oriented polypropylene film.[1063]
- *Random Copolymer Polypropylene.* A clear, semi-crystalline polymer produced through the use of a comonomer, typically ethylene.[1024]
- *Impact Copolymer Polypropylene.* A translucent, crystalline polymer formed by the addition of ethylene-propylene rubber (EPR), ethylene propylene-diene monomer (EPDM), polyethylene, or plastomers to homopolymers or copolymers.[1024]
  - Basell Adflex – Adflex resins are highly ethylene-modified heterophasic copolymers, with a flexural modulus ranging from 80 to 500 MPa.[1063]
  - Basell Adsyl – PP sealing resin.[1064]
  - Basell Adstif – High crystallinity homopolymer PP resin offering high oxygen and water vapor barrier performance.[1063]

Processing Methods:

- *BOPP, bi-axially oriented polypropylene film.* Cast Film and Blown Film.[1063]
- *Cast Film.* Ranges from 10 µm to 2.5 mm thick. Depending on film thickness, different techniques are used. In the range of 10 to 250 µm (with exceptions up to 500 µm) cast lines, chill roll, and air knife are used while films from 250 µm up to 2.5 mm are produced using a three stack roll system. These types of films are mainly used as primary sheets for thermoforming applications.[1073]
- *Co-Extrusion.* Allows for the tailoring of film properties through the use of different materials in separate extruders where each material maintains its own set of properties versus the blending of polymers in the mono-extrusion technique.[1073]
- *Homopolymer*. Injection molding, sheet and thermoforming, bi-axially oriented film (BOPP), capacitor film, fiber spinning, and slit tape.[1024]
- *Random Copolymer.* Injection molding, blow molding, and sheet and thermoforming.[1024]
- *Impact Copolymers.* Injection molding, extruded sheet, and thermoforming.[1024]

Applications:

- *Homopolymer.* Thermoforming, slit film and oriented fibers, high clarity, housewares, syringes, and closures.[1024]
- *Random Copolymer.* Food, household chemicals, beauty aid products, clear containers, and hot fill applications.[1024]
- *Impact Copolymers*. Automotive, housewares, film, sheet, profiles, high pressure resistance, medical trays, and thin-wall parts.[1024]

Permeability to Oxygen and Other Gases: Polyolefins are poor barriers to oxygen and carbon dioxide.[1064]

With the addition of Adflex to BOPP film, the permeability to oxygen and water significantly increases thus allowing specific barrier properties to be tailor-made by changing the concentration of the Adflex resin.[1063]

Permeability to Water Vapor: Polyolefins are excellent barriers to moisture. Propylene is highly impermeable to water vapor.[1062]

Because PP has a water vapor barrier approximately 25% higher than LDPE, hydroscopic materials such as salt, certain polymers as well as powders such as cement can confidently be packed in PP based bags.[1062]

Bi-axially oriented polypropylene performs significantly better than cast film because the orientation of the molecules reduces the intermolecular space available for the diffusion mechanism.[1024]

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

Permeability Data by Material Supplier Trade Name: See Tables 45-01 through 45-10.

Table 45-01. Oxygen, Carbon Dioxide, and Water Vapor Through Cast and Oriented Polypropylene Film

Material Family	POLYPROPYLENE (PP)					
Material Grade	CAST FILM	ORIENTED FILM	CAST FILM	ORIENTED FILM	CAST FILM	ORIENTED FILM
Reference Number	1005					
TEST CONDITIONS						
Penetrant	oxygen		carbon dioxide		water vapor	
PERMEABILITY (source document units)						
Gas Permeability (mol/m ·s ·Pa)	30–52 x 10^{-17}	30–32 x 10^{-17}	100–160 x 10^{-17}	108 x 10^{-17}	100 - 175 x 10^{-17}	500 - 125 x 10^{-17}
PERMEABILITY (normalized units)						
Permeability Coefficient (cm^3 ·mm/m^2 ·day ·atm)	59 - 102	59 - 63	196 - 313	212		
Vapor Transmission Rate (g ·mm/m^2 ·day)					196 - 343	98 - 245

Table 45-02. Oxygen, Carbon Dioxide, Nitrogen, Hydrogen, and Water Vapor Through Solvay Fortilene PP

Material Family	**POLYPROPYLENE (PP)**				
Material Supplier/Grade	**SOLVAY FORTILENE**				
Reference	1025				
TEST CONDITIONS					
Temperature (°C)	30				
Penetrant	oxygen	carbon dioxide	nitrogen	hydrogen	water vapor
PERMEABILITY (source document units)					
Gas Permeability ($in^2/sec \cdot atm$)	3.0×10^{-12}	12×10^{-12}	0.57×10^{-12}	53×10^{-12}	6.6×10^{-12}
$cm^2/(sec\text{-}cm\text{-}Hg)$	2.3×10^{-10}	9.2×10^{-10}	0.44×10^{-10}	41.0×10^{-10}	5.1×10^{-10}
PERMEABILITY (normalized units)					
Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	Unavailable without sample thickness				
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)	Unavailable without sample thickness				

Table 45-03. Oxygen and Carbon Dioxide Through Basell Adflex PP

Material Family	**POLYPROPYLENE (PP)**											
Material Supplier/Grade	**BASELL ADFEX**											
	Q401F				KS089P				KS353P			
Reference Number	1062											
MATERIAL CHARACTERISTICS												
Sample Thickness (mm)	0.025	0.050	0.025	0.050	0.025	0.050	0.025	0.050	0.025	0.050	0.025	0.050
TEST CONDITIONS												
Penetrant	oxygen		carbon dioxide		oxygen		carbon dioxide		oxygen		carbon dioxide	
PERMEABILITY (source document units)												
Gas Permeability ($cc/100 \cdot in^2 \cdot day$)	100	45	2200	960	470	240	2250	1060	960	475	5700	2750
PERMEABILITY (normalized units)												
Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	39	35	865	754	185	188	884	833	377	373	2240	2162

Table 45-04. Water Vapor Through Basell Adflex PP

Material Family	POLYPROPYLENE (PP)					
Material Supplier/Grade	BASELL ADFEX					
	Q401F		KS089P		KS353P	
Reference Number	1062					
MATERIAL CHARACTERISTICS						
Sample Thickness (mm)	0.025	0.050	0.025	0.050	0.025	0.050
TEST CONDITIONS						
Penetrant	water vapor					
PERMEABILITY (source document units)						
Vapor Permeability ($g/100\ in^2 \cdot day$)	2.00	0.86	1.60	0.79	1.60	1.53
PERMEABILITY (normalized units)						
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)	0.79	0.67	0.63	0.62	0.63	1.2

Table 45-05. Oxygen and Water Vapor Through Basell Adsyl PP

Material Family	POLYPROPYLENE (PP)			
Material Supplier/Grade	BASELL ADSYL			
	3C37F	5C37F	3C37F	5C37F
Reference Number	1062			
MATERIAL CHARACTERISTICS				
Sample Thickness (mm)	0.025			
TEST CONDITIONS				
Penetrant	oxygen		water vapor	
PERMEABILITY (source document units)				
Gas Permeability ($cc/100\ in^2 \cdot day$)	285	290	1.15	1.16
PERMEABILITY (normalized units)				
Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	112	114		
($g \cdot mm/m^2 \cdot day$)			0.45	0.46

Table 45-06. Oxygen and Water Vapor Through PP

Material Family	POLYPROPYLENE (PP)	
Product Form	FILM	
Reference Number	101	296

TEST CONDITIONS

Penetrant	water vapor	oxygen		water vapor
Temperature (°C)	37.8	23	22.8	37.8
Relative Humidity (%)	90		0	90
Test Method	ASTM D96	ASTM D1434		ASTM F1249

PERMEABILITY (source document units)

Gas Permeability ($cm^3 \cdot mil/100\ in^2 \cdot day$)		272	>250	
Vapor Transmission Rate ($g \cdot mil/100\ in^2 \cdot day$)	1.5			1
Vapor Transmission Rate ($g \cdot mm/day/m^2$)	0.59			

PERMEABILITY (normalized units)

Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)		107	>99.7	
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)	0.59			0.4

Table 45-07. Oxygen and Xylene Through PP

Material Family	**POLYPROPYLENE (PP)**
Reference Number	293

TEST CONDITIONS

Penetrant	xylene	oxygen
Temperature (°C)	60	23
Exposure Time (days)	14	
Relative Humidity (%)		75

PERMEABILITY (source document units)

Vapor Transmission Rate ($g \cdot mil/100\ in^2 \cdot day$)	2500	
Gas Permeability ($cm^3 \cdot mil/100\ in^2 \cdot day$)		200

PERMEABILITY (normalized units)

Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)		78.7
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)	984	

Table 45-08. d-Limonene (Flavor Component) Through PP

Material Family	**POLYPROPYLENE (PP)**
Product Form	**FILM**
Reference Number	255

TEST CONDITIONS

Penetrant	d-limonene
Temperature (°C)	25
Relative Humidity (%)	dry

PERMEABILITY (source document units)

Vapor Transmission ($10^{-20}\ kg \cdot m/m^2 \cdot sec \cdot Pa$)	101,800

PERMEABILITY (normalized units)

Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)	8.9

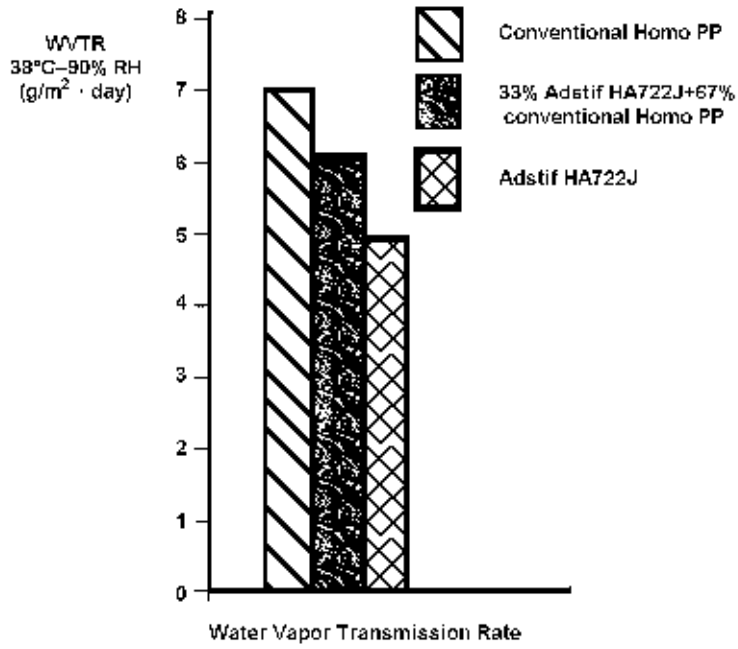
Table 45-09. Oxygen at Different Temperatures Through Oriented PP and Water Vapor Through Biaxially Oriented and Unoriented PP

Material Family	**POLYPROPYLENE (PP)**			
Features	oriented		biaxially oriented	
Reference Number	264			
TEST CONDITIONS				
Penetrant	oxygen		water vapor	
Temperature (°C)	23	35	40	
Relative Humidity (%)	0		90	
PERMEABILITY (source document units)				
Gas Permeability ($cm^3 \cdot mil/100\ in^2 \cdot day$)	163	203		
Gas Permeability ($cm^3 \cdot 25\ \mu/m^2 \cdot day \cdot atm$)	2526	3146		
Vapor Transmission Rate ($g \cdot mil/100\ in^2 \cdot day$)			0.38	0.69
Vapor Transmission Rate ($g \cdot 25\ \mu/m^2 \cdot day$)			5.9	10.7
PERMEABILITY (normalized units)				
Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)	64.2	80.0		
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)			0.15	0.27

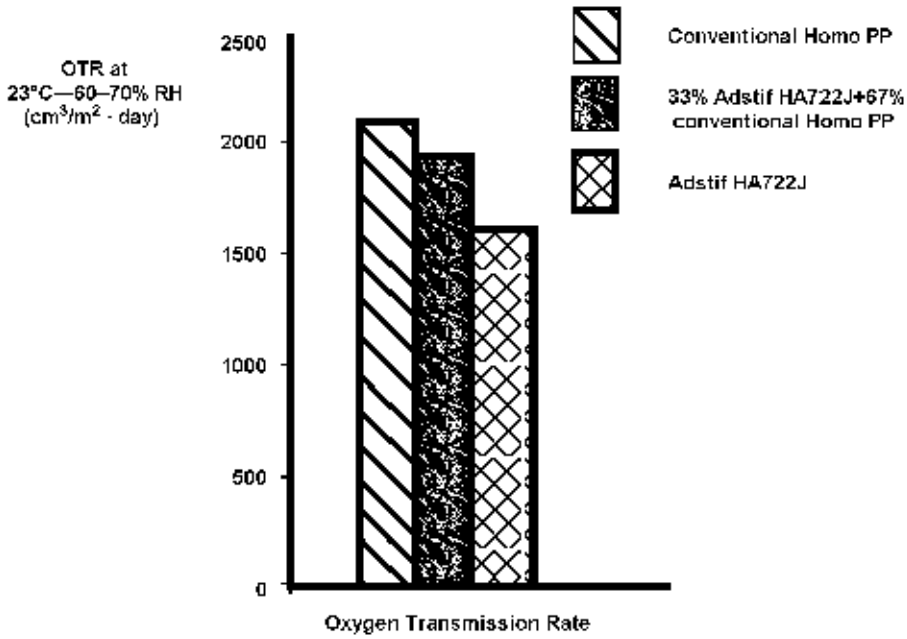
Table 45-10. Organic Solvents Through Oriented PP Film

Material Family	**POLYPROPYLENE (PP)**			
Product Form	**FILM**			
Features	oriented			
Reference Number	266			
MATERIAL CHARACTERISTICS				
Sample Thickness (mm)	0.02			
TEST CONDITIONS				
Penetrant	chloroform	xylene	methyl ethyl ketone	kerosene
Temperature (°C)	20			
Relative Humidity (%)	65			
PERMEABILITY (source document units)				
Vapor Transmission Rate ($g/day \cdot 100\ in^2$)	241.3	22.58	0.77	3.42
PERMEABILITY (normalized units)				
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)	74.8	7	0.24	1.06

Graph 45-01. Water vapor transmission rate through Basell Adstif homopolymer polypropylene vs. conventional homopolymer polypropylene.[1063]



Graph 45-02. Oxygen transmission rate through Basell Adstif homopolymer polypropylene vs. conventional homopolymer polypropylene.[1063]



Polybutene, Polybutylene (PB)

Category: Thermoplastic Polyolefin

General Description: Polybutene–1, PB-1, is a polyolefin, or unsaturated polymer that is expressed as C_nH_{2n}. Basell Polyolefins series polybutene-1 resins are high molecular weight polyolefins manufactured from butene-1 monomer. Available as homopolymer or random copolymer.[1026]

Processing Method: Extrusion.

Applications: PB-1 is used synergistically as a blend component to improve and differentiate the properties of polyolefins in packaging films or nonwoven fabrics.[1026]

Pressurized vessels, pressurized beverage tubing, seals such as beverage closure liners, architectural seals, and gaskets, compression packaging films, peel seal, film modification, hot melt and polyolefin modification applications.

Permeability: Vapors and gases will permeate through polybutene, as with all other plastics, at a rate specific to the liquid or gas and its temperature, concentration, and pressure. Polybutene-1 is similar or slightly better than LDPE.[1026]

Permeability Data by Material Supplier Trade Name: See Tables 46-01 and 46-02.

Table 46-01. Water Vapor, Oxygen, and Carbon Dioxide Through Polybutylene-1 (PB-1) and LDPE

Material Family	POLYBUTYLENE (PB)					
Material Grade	PB–1	LDPE	PB–1	LDPE	PB–1	LDPE
Reference Number	1026					
TEST CONDITIONS						
Temperature (°C)	77		---			
Penetrant	water vapor		oxygen		carbon dioxide	
PERMEABILITY (source document units)						
Vapor Permeability ($g \cdot mil/day \cdot 100 \cdot in^2$)	0.28	0.30				
Gas Permeability ($cc \cdot mil/24\ hr \cdot m^2 \cdot atm$)			6730	9400	3860	6500
PERMEABILITY (normalized units)						
Vapor Transmission Rate ($g \cdot mm/m^2 \cdot day$)	0.14	0.15				
Permeability Coefficient ($cm^3 \cdot mm/m^2 \cdot day \cdot atm$)			171	239	98	165

Table 46-02. Oxygen, Nitrogen, Carbon Dioxide, and Water Vapor Through Shell Chemical Duraflex Polybutylene (PB) Film

Material Family	**POLYBUTYLENE (PB)**	
Material Supplier/Grade	**SHELL CHEMICAL DURAFLEX 1600**	**SHELL CHEMICAL DURAFLEX 1710**
Product Form	**FILM**	
Features	FDA grade, heat sealable	
Applications	peelable seals	
Manufacturing Method	blown film	
Reference Number	304	

MATERIAL CHARACTERISTICS

Density	0.910 g/cm^3	0.909 g/cm^3
Sample Thickness (mm)	0.051	

MATERIAL COMPOSITION

Zinc Oxide (phr)	5	
Note	slip and antiblock formulations	antiblock formulations, slip and antiblock formulations

TEST CONDITIONS

Penetrant	oxygen	nitrogen	carbon dioxide	water vapor	oxygen	nitrogen	carbon dioxide	water vapor
Temperature (°C)	22.8			37.8	22.8			37.8
Relative Humidity (%)	50			90	50			90
Test Method	ASTM D1434, method M			ASTM D96, method E	ASTM D1434, method M			ASTM D96, method E

PERMEABILITY (source document units)

Gas Permeability (cm^3 · mil/100 in^2 · day)	385	110	1425		400	110	1190	
Gas Permeability (cm^3 · µm/cm^2 · day · atm)	15.1	4.3	55.8		16.0	4.3	46.9	
Vapor Transmission Rate (g · mil/100 in^2 · day)				1.2				1.88
Vapor Transmission Rate (g · µm/cm^2 · day)				0.047				0.074

PERMEABILITY (normalized units)

Permeability Coefficient (cm^3 · mm/m^2 · day · atm)	151.6	43.3	561		157.5	43.3	468	
Vapor Transmission Rate (g · mm/m^2 · day)				0.47				0.74