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ABSTRACT

Metallocene catalysts developed and proven in the UNIPOL® gas-phase PE Process comprise a platform technology for creating new families of improved polyethylenes for volume PE markets. Products which will win in the diverse and fragmented volume film markets of Asia/Pacific must be especially versatile in their ability to be processed on a wide range of fabrication equipment.

Metallocene technology has been used with the UNIPOL Process to demonstrate a range of mPEs with narrow to broad molecular weight distribution, narrow comonomer distribution, and linear to long chain branched structures. Prototype, improved processing mPEs for blown film applications span a wide performance domain of processability and properties. Developmental products are described which target the processability regime of LDPE/LLDPE blends, are useable on both LLDPE and LDPE equipment, and deliver improvements in film toughness. Technical capability has also been demonstrated to produce mPEs gas phase with rheology essentially matching that of LDPE.

INTRODUCTION

The polyethylene industry is a technology intensive industry undergoing a period of major technology renewal. High intensity R&D investment driving this technology renewal extends across a range of technology fronts: catalysis, process engineering, product development, and end-use applications extensions. Some of this technology renewal, principally in the domain of catalysis (metallocene chemistry), has the potential to become revolutionary in scope and impact. Certain very significant technical advances, principally in the area of process/reaction engineering, represent major evolutionary technical progress. Revolutionary metallocene catalyst technology, leveraged with these evolutionary advances, extensions and refinements of polyethylene manufacturing engineering, is now entering mainstream commercial development in the volume PE marketplace. This paper discusses how metallocene catalyst technology and new gas-phase process/reaction technology developments intersect with the polyethylene industry of the Asia/Pacific region.

METALLOCENE BASED POLYETHYLENE (mPE) FOR ASIA/ PACIFIC MARKETS

Polyethylene demand growth in Asia/ Pacific is robust, projected to continue at rates significantly above GDP growth. PE capacity buildup in the region will add more than 3 million TPY of new production by 2000, an increase of more than 30%.[1] New investment will bring new technology.

Metallocene catalysis is a rich and fertile technology, with major implications for the PE industry. It is a very broad technology. The most widely discussed aspect of this technology advance has been the development of new PE products with major improvements in properties and end-use performance. Many conference papers have described the capabilities of this chemistry to control with high precision the structure and properties of new product families of PE materials tailored to very specific applications. Metallocene catalysis represents a tool for PE product development, a capability to engineer polymer structure at the molecular level. There are things this tool can do that other catalyst systems cannot.

In some of the emerging growth markets of the Asia/Pacific region, there exists a potential PE marketing paradox. The technology renewal underway in metallocene catalysis and PE polymer manufacturing capability appears to be in collision with a fragmented, diverse downstream marketplace not yet ready to make full use of, let alone take full advantage of, the high performance specialized capabilities of metallocene catalyzed PE products. To the contrary, molecular engineering capability embodied in metallocene technology can be applied to produce PE resins with property characteristics balanced to adapt to the broad functionality demands of the wide ranging Asia/Pacific marketplace.

UNIVATION mPE FOR VOLUME APPLICATIONS

Union Carbide and Exxon Chemical have formed a 50/50 joint venture to develop, market, and license advanced production process and catalyst technologies for the manufacture of performance and economically advantaged polyethylenes. The joint venture, Univation Technologies, combines EXXPOL® metallocene catalyst systems and capacity-enhancing Super Condensed Mode Technology (SCM-T) with the UNIPOL® gas-phase PE process to accelerate the pace and broaden the global reach of metallocene technology applied to volume PE manufacture.

EXXPOL technology encompasses the first metallocene systems commercialized for gas-phase PE manufacture and also includes complementary UCC metallocene systems developed for UNIPOL. SCM-T is a commercially demonstrated technology that can enable UNIPOL licensees to expand production capacity at investment costs significantly lower than that for new construction. UNIPOL PE process technology combines the lowest capital and operating costs with the broadest conventional catalyst product range of any PE technology.

The new company brings together world-class R&D capabilities and consolidates the momentum of major research efforts to create the best technology program in the industry devoted to metallocene chemistry applied to gas-phase PE production. Univation Technologies is a technology and licensing company committed to driving technology renewal in the polyethylene industry and keeping state-of-the-art a moving target.

We believe that few segments of the PE industry and no region of the world will be untouched by the metallocene technology advances now moving from a specialty niche applications focus into the core of volume PE production and the arena of commodity markets and applications. EXXPOL, SCM-T, and UNIPOL are proven technologies which will provide licensees of Univation the capabilities to capture new business and stay ahead in the expanding markets of the Asia/Pacific region.

POLYETHYLENE DEMAND GROWTH-WORLDWIDE AND IN ASIA/PACIFIC

Polyethylene is an enormously versatile material, serving a very broad array of markets and end uses. This product versatility derives from:

(1) the very attractive intrinsic characteristics of hydrocarbon polymers; toughness, durability, chemical inertness, environmental cleanliness, dielectric strength, etc.

(2) the wide range of molecular structures inherent to polyethylene

(3) the development of efficient reliable manufacturing processes for producing PE polymers at low cost

(4) refined capabilities to manipulate polymer structure and, in turn, the performance-in-use of PE products

In combination, these four elements continue to drive demand growth for this most versatile polymer. The technology elements, (3) and (4), have been fuel for this growth.

Global demand growth for polyethylene continues at ~6%/yr, building from a base which reached 40 million metric tons in 1996. That projects to more than 50 million metric tons of PE demand early in the next decade. Worldwide LLDPE demand growth is forecast (1995-2000) to average ~13%/yr, with consumption reaching ~14 million metric tons in 2000.[1]

Chem Systems projects (1995-2000) total PE consumption in the Asia/Pacific region (ex Japan) to average ~ 9%/yr, growing from a base demand of ~10 million metric tons in 1996. LLDPE demand growth in this region is expected to approach 18% reaching ~4 million metric tons in 2000.[1]

Figure 1 plots projected demand growth for various polyethylenes.

In the period to 2000, LDPE demand will show zero growth. By 2000, LLDPE penetration of the total LD plus LL market is projected by Chem Systems to reach 48% worldwide and 58% in Asia/Pacific (ex Japan).[1]

Figure 2 shows six major end-use markets for polyethylene, accounting for more than 85% of total PE consumption. Film applications represent the largest volume end-use.[2]

Figure 3 shows the major end-use markets for LDPE and LLDPE. Film applications represent nearly 70% of the global demand for these resins.[1]

Figure 1. POLYETHYLENE DEMAND BY RESIN TYPE (GLOBAL AND ASIA/PACIFIC)

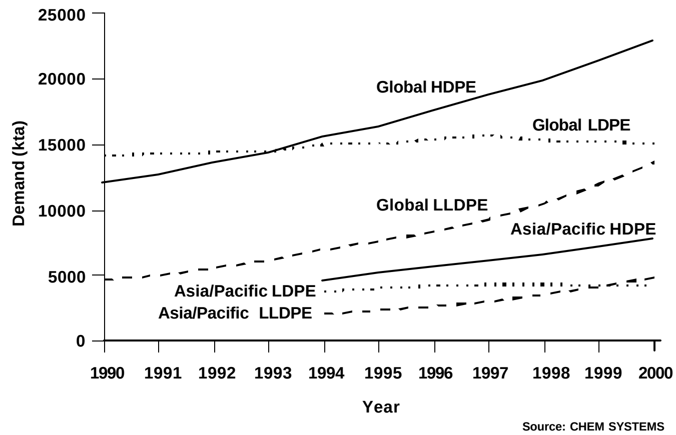


Figure 2. MAJOR END-USE APPLICATIONS FOR POLYETHYLENE

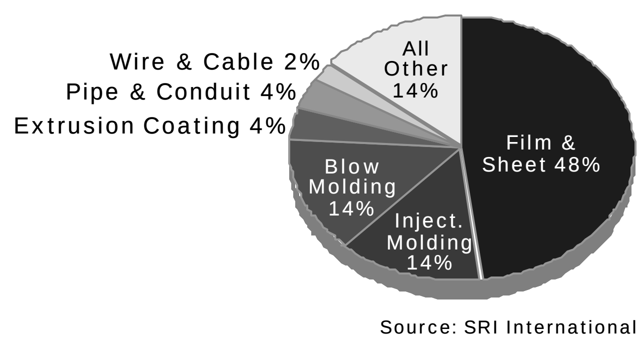
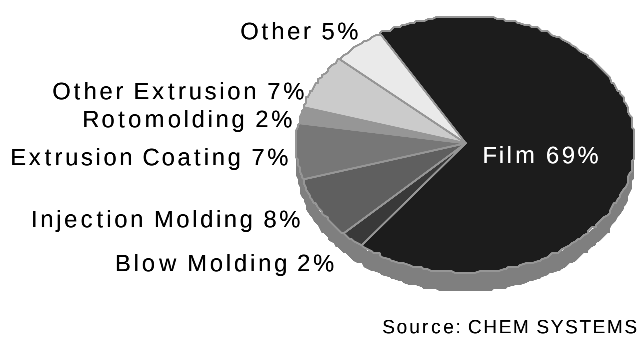


Figure 3. LDPE + LLDPE DEMAND BY END-USE APPLICATION



UNIPOL® PE PRODUCTION CAPACITY-WORLDWIDE AND IN ASIA/PACIFIC

The UNIPOL® Process for PE manufacture is used around the world by Union Carbide, its Joint Ventures, and licensees in 68 reactor lines. By the year 1999, there will be a total of 94 reactors in operation with a combined total licensed capacity of 12.1 million TPY.

In the Asia/Pacific region, there are 24 UNIPOL PE reactor lines with a total licensed capacity of 2.6 million TPY.

THE ASIA/PACIFIC PE MARKETPLACE

Polyethylene production capacity in Asia/Pacific is expanding along with demand. Overall, imports to the region are expected to decrease. Tariffs continue to protect many polymer producers. In these protected economies, the diverse applications scope of local demand requires that polyethylene producers possess broad product capability in their manufacturing processes. The PE marketplace in Asia presents challenges and opportunities to the region's polyethylene manufacturers.

The PE film markets in much of the Asia/Pacific region grew up around LDPE. The blown film fabrication industry continues to encompass many small converters with older processing equipment coexisting with large processors with modern state-of-the-art machinery engineered to process the latest advanced resins. Older film fabrication machinery, locally made and engineered for LDPE processing is common throughout the emerging markets of China, Malaysia, and Indonesia. New investment fabrication facilities capable of 100% LLDPE processing are beginning to be installed throughout this region, but generally not to replace older, underpowered equipment, but rather to add new extrusion capacity. In general, investment funds to retrofit/upgrade the engineering of older equipment are limited. For most older machines, retrofitting may not represent a cost-effective use of capital.

Film fabricators in the region demand the capability to run widely different polymers (e.g., LDPE, LLDPE, HDPE, even PP) on the same processing equipment. This processing flexibility presents quite an engineering challenge to equipment suppliers. Film fabricators use resin blending as a primary vehicle for tailoring material suitability to fit the processing capabilities of their equipment and to meet the performance requirements of the end-use market. Resin blending is also used as a primary vehicle for cost control; the polymer mix is often adjusted according to near term resin pricing.

The polymer fabrication industry in much of Asia/Pacific presents a technology dichotomy. From one engineering perspective, its equipment makeup and operating characteristics are less demanding in terms of the predominance of early generation machinery running at low to moderate production rates, well below the capabilities of the newest state-of-the-art machines designed specifically for the rheology of today's highest performance resins. From a second perspective, however, the industry presents an especially demanding technology challenge because fabricators expect to process all types of polyolefins on a given line. The engineering to deliver fabrication flexibility can be more difficult than refining the equipment to run very specific resins with precise rheology at high throughputs.

In some segments of the global PE marketplace, the fabrication industry has moved to ever more sophisticated processing equipment, in certain cases engineered to fit the rheology of special resins which deliver performance profiles customized and fine tuned to specific end-use needs. The polymer design ethic has been to create polymer resins to bring very specific performance profiles to an end-use market. The equipment suppliers engineered extrusion equipment and/or retrofit engineering upgrades to accommodate the polymer. In this technology development scenario, fabrication engineering can be considered a degree of freedom in polymer design.

In large segments of the downstream commodity PE business, once investments are made and the equipment installed, the fabrication machinery becomes a constraint on polymer design, not a degree of freedom. The polymer resins of choice and utility in the marketplace are the ones which fit the capabilities of the installed assets. This is the dominant situation in Asia/ Pacific today and for the next planning period. The polyethylenes which will win in the volume PE marketplace in Asia/Pacific must be versatile in their ability to be shaped or processed on a wide range of fabrication equipment while simultaneously delivering cost-effective improvements in end-use performance valued in specific markets. Resin producers need good technology tools to enable their businesses to prosper in this challenging marketplace.

For new resins targeting volume PE markets, value will be measured incrementally against what's already working. The measure of the acceptability of a polymer resin product will be determined first in the domain of cost-effective performance:

- does it meet competitive standards in end use performance
- does it do the intended job in a cost advantaged fashion

A second critical domain of new product market acceptance and value, especially in Asia/ Pacific, is resin versatility, principally in the area of processability:

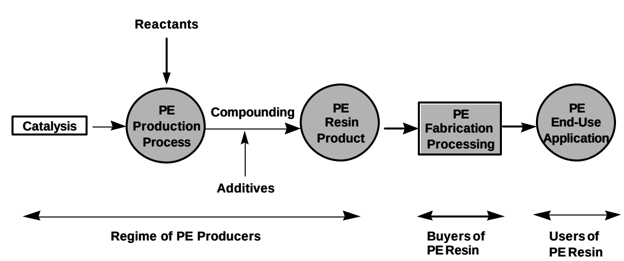
- does it run well on the installed base of fabrication equipment
- does it work as a good blendstock material

UNIVATION: A PLATFORM TECHNOLOGY FOR VOLUME PE PRODUCT DESIGN

Metallocene catalysis sits far upstream in the technology flow of producing and using polyethylene resins. In this technology flow, catalysis determines how "mers" are assembled into polymers of distributed structure and tail-ored performance. The reaction system, i.e., the polymerization process engineering, defines the efficiency of this polymer assembly and the production dynamics of resin manufacture. Process configuration and operating conditions also influence the polymer structure, property profile, and end-use performance behavior. The upstream portion of this technology flow represents the regime of polyethylene producers. Downstream, the technology flow segments into two connected elements of the PE marketplace: (1) the buyers of PE resin, i.e., the fabricators, and (2) the buyers of fabricated goods, i.e., the end-users. Metallocene catalysis can be used to address the needs of both the fabricators demanding improved resin processability and end-users demanding improved performance and functionality in use.

Figure 4 is a concept schematic showing the technology flow from catalysis to PE manufacture to PE products to fabrication processing to end-use applic ations.

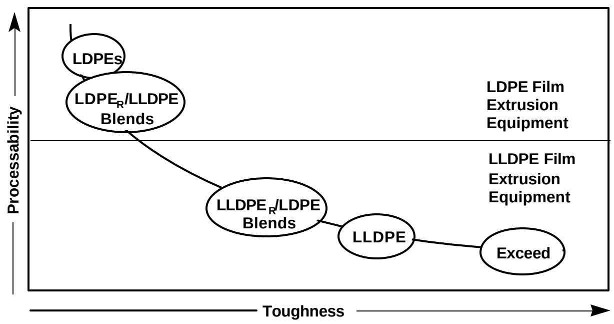
Figure 4. CONCEPT SCHEMATIC SHOWING TECHNOLOGY FLOW



Metallocene chemistry is a powerful molecular engineering tool for polyethylene product development. To capture the full potential of this technology for the design and manufacture of olefin polymer products valued in the volume PE marketplace, it must be integrated with an efficient, cost-effective PE production process. EXXPOL® metallocene technology, customized for the UNIPOL® gas-phase polymerization process, is being used as a technology platform to develop families of improved polyethylenes for volume markets and applications. New mPEs have been demonstrated, with performance profiles which show enhanced processability and enhanced toughness.

Figure 5 is a schematic mapping the processability - toughness profile of various polyethylene blown film resins.

Figure 5. SCHEMATIC MAP OF PROCESSABILITY



In this schematic, processability partitions into two regimes: (1) the domain defined by older fabrication machinery designed for and limited to film extrusion of LDPE or LDPE rich blends with LLDPE and (2) the domain defined by equipment designed for LLDPE.

Univation metallocene technology enables the manipulation of PE structure beyond the familiar narrow molecular weight distribution (MWD), narrow comonomer distribution (CD), linear, and low level long chain branched (LCB) polymers discussed at most all symposia in the field. Data are presented showing the use of EXXPOL® metallocene chemistry with the UNIPOL® Process to produce an expanded range of polyethylenes with broadened MWD, narrow CD, with linear structure (no LCB) to resins with high levels of LCB:

Prototype, improved processing mLLDPEs are described which target the processability of LDPE/LLDPE blends now used in many volume PE blown film applications. They can be processed on LLDPE and LDPE equipment and deliver improvements in film toughness. These materials will be important products for the film markets of the Asia/ Pacific region.

Technical capability has also been demonstrated to produce mPEs, gas-phase, which exhibit intrinsic rheology essentially matching that of LDPE. These materials have shown performance and functionality which will let them access volume PE markets once held to be the exclusive domain of LDPE.

UNIVATION PRODUCT TECHNOLOGY-IMPROVED PROCESSING mPE FILM RESINS

Molecular Structure and Rheology Characterization

Polyethylenes are distributed structure, product-by-process materials. A combination of solution and melt state polymer characterization techniques has been used to map the distributed molecular structure and rheology of mPEs.

Molecular weight distributions (MWD) were determined by size exclusion chromatography (SEC) with a WATERS 150°C GPC instrument equipped with an in-line differential refractometer as the mass detector and a Viscotek viscometer for intrinsic viscosity measurement and LCB sensing. Intrinsic viscosity measurements provide an inference of LCB content. The coupled SEC-viscometry system operated at 140°C with 1,2,4-trichlorobenzene as the solvent and mobile phase. Polydisperse polyethylene standards (with known MW statistics and intrinsic viscosity) were used for calibration to obtain the molecular weight, MWD and LCB information.[3][4]

Temperature Rising Elution Fractionation (TREF) measures short chain branching composition distribution (CD). A single beam infrared concentration detector was used with a UCC developed analytical TREF unit to monitor effluent concentration as a function of temperature (inversely related to SCB content). The solvent used was 1,2,4- trichlorobenzene.

Dynamic rheological measurements (oscillating shear) characterize the viscoelastic behavior of a polymer melt. Dynamic storage and loss moduli are used to determine a material's viscoelastic relaxation time spectrum. These measurements were made using a Weissenberg Rheogoniometer in parallel plate mode, run at 190°C, covering a frequency range of 0.1 to 100 sec^{-1}.

Three polymer structure indices have been used to characterize the distributed structure of mPEs, PDI, CDI and RSI. Long chain branching frequency is presented as LCB/1000C (branches per 1000 carbons in the polymer backbone).

Distribution in molecular weight is characterized by polydispersity index (PDI), the ratio of 2nd to 1st moments of a material's molecular weight distribution.

A composition distribution Index (CDI) is derived from analytical TREF data. CDI quantifies the distribution of chain segment lengths between branch points, defining a crystallizable chain length distribution (CCLD). Like the molecular weight polydispersity index (PDI), CDI is a ratio of 2nd to 1st moments of the CCLD. Calibration of the CDI gives values of 1.5 - 2.5 for the most compositionally homogeneous PEs and values of 13 -1 5 for typical gas-phase Z/N LLDPE film resins.

A Relaxation Spectrum Index is defined as the ratio of 2nd to 1st moments of a material's distribution of relaxation times or relaxation spectrum. This dimensionless index has proven to be a sensitive and reliable indicator of long range melt state order (e.g. molecular entanglements). RSI is a function of polymer molecular weight, molecular weight distribution, and long chain branching. RSI correlates very well with bubble stability and maximum output in high rate blown film extrusion.

Table 1 shows molecular structure data for three families of Univation Technologies metallocene-based PEs, Univation-Type I, Univation-Type II, and Univation-Type III in comparison to standard Ziegler/Natta LLDPE and several High Pressure LDPEs.

The polymer structure indices, PDI, CDI, and RSI and LCB frequency data, are listed for examples of each resin type:

Univation-Type I mLLDPEs are narrow MWD, narrow CD, with no LCB (Exxon Chemical's high performance EXCEED™ resins are Type I structures)

Univation-Type II mLLDPEs are broader MWD, narrow CD with no LCB

Univation-Type III mPEs are narrow to broad MWD, narrow CD with controlled levels of LCB

The Univation Technologies metallocene and Z/N-based resins of Table I were all produced using UNIPOL® I process technology.

Figure 6 shows SEC MWD data comparing Univation-Type I and II mLLDPEs with Z/N LLDPE.

Figure 6. SEC MWD DATA

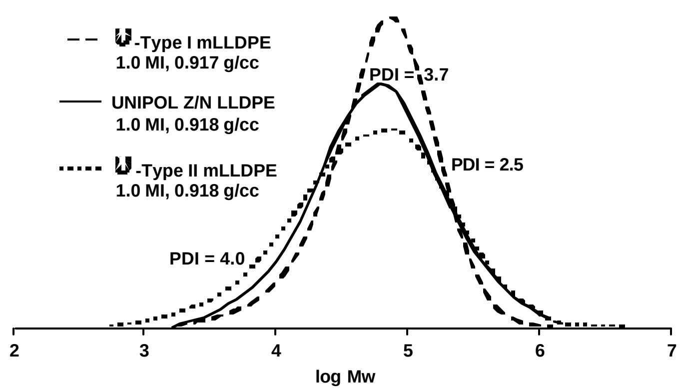
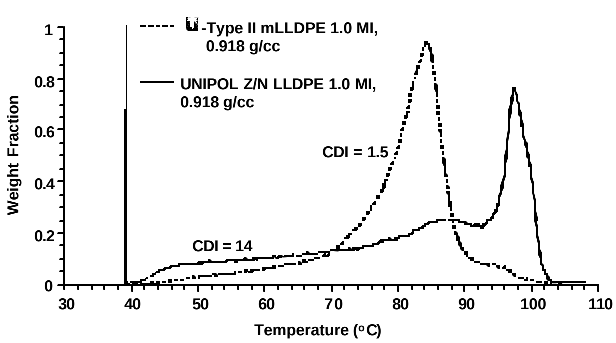


Table 1. MOLECULAR STRUCTURE, RHEOLOGY CHARACTERIZATION DATA

	Ziegler-Natta	Univation Type-I mLLDPE			Univation Type-II mLLDPE				Univation Type-III mLLDPE				HP-LDPE		
	Z-N	I-A	I-B	I-C	II-A	II-B	II-C	II-D	III-A	III-B	III-C	III-D	LD-A	LD-B	LD-C
Melt Index, I_2: g/10 min	1.0	1.0	1.0	3.5	1.1	2.0	0.9	0.9	0.9	1.1	2.4	2.0	2.0	2.0	0.2
Melt Flow Ratio, I_{21}/I_2	27	17	17	17	28	30	38	37	43.0	46.0	52	50	55	75	95
Density, g/cm^3	0.918	0.917	0.917	0.917	0.918	0.921	0.920	0.924	0.919	0.919	0.924	0.918	0.920	0.920	0.920
PDI	3.7	2.5	2.5	2.2	3.0	4.8	6.3	6.7	4.2	5.0	6.3	5.5	4.5	10.8	9.0
CDI	14	4.8	2.8	2.7	2.6	1.9	2.1	2.2	2	2	1.5	1.9	1.5	1.5	1.5
LCB/1000 CH_2	0	0	0	0	0	0	0	0	Low	Low	0.7	0.8	2	4	2.5
RSI	4.5	2.4	2.1	1.5	7	7	14	19	18	20	21	22	13.5	17	44.5

Figure 7 shows TREF traces comparing a Z/N LLDPE with Univation-Type II mLLDPE.

Figure 7. ANALYTICAL TREF TRACES COMPARING Z/N LLDPE WITH UNIVATION-TYPE II mLLDPE



Univation-Type II mPEs have been demonstrated in commercial scale operations. Products have broadened MWD with PDI values from 3.5 to 6.5, yet possess very narrow composition distribution, CDI measuring as low as 1.8. These resins have a linear structure.

Univation-Type III mPEs have been demonstrated at pilot plant scale with PDIs from 4 up to 8, low CDI ~2, and long chain branching up to 4LCB/1000C.

Figure 8 plots the molecular homogeneity of a range of polyethylenes. PDI and CDI are mapped for Univation mPEs Types I, II, and III in comparison to Z/N LLDPEs, Cr-based LLDPEs, and high pressure LDPEs. Univation metallocene technology has been used to produce LPPEs with PDI and CDI values overlapping the span of LDPE.

Figure 9 shows RSI plotted vs melt index (MI) for various LPPEs and LDPEs. Narrow MWD metallocene based LLDPEs with no LCB exhibit very low RSI values in the 2-3 range. Increasing MWD and long chain branching can increase RSI. Polyethylenes produced with Univation metallocene technology have been demonstrated which show RSI - MI ranges matching those of LDPE. Highest RSI resins were achieved by manipulating both MWD and LCB.

Figure 8. MOLECULAR HOMOGENEITY MAP OF LOW DENSITY POLYETHYLENES

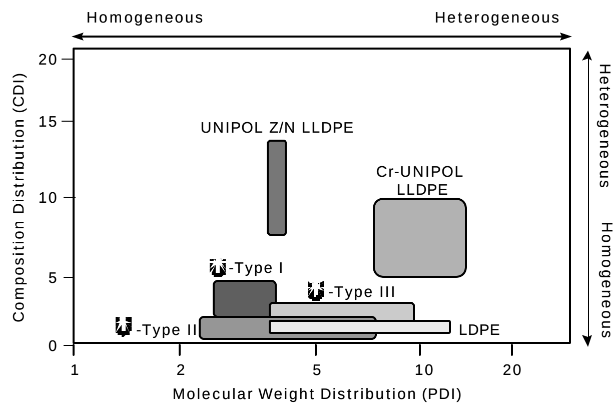
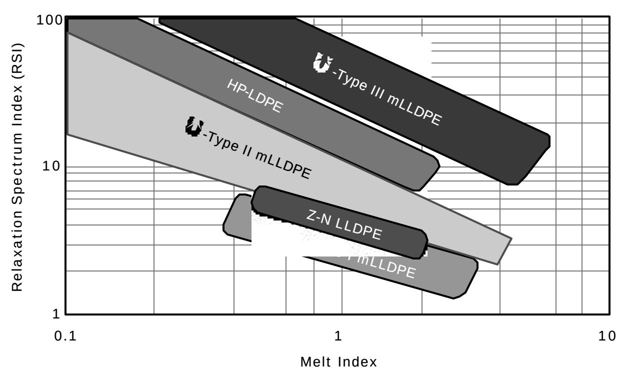


Figure 9. RSI VERSUS MELT INDEX RANGES FOR LOW DENSITY POLYETHYLENES



Blown Film Performance-Univation-Type II mLLDPEs For Processing Flexibility

Univation-Type II mPEs are improved processing LLDPEs. These products traverse the processability of LLDPE/LDPE blends and deliver superior impact toughness properties.

Blown films were prepared using a 92 mm (3.5 inch) Gloucester extruder configured for LLDPE processing with standard barrier screw, 150 mm (6 inch) diameter die, wide die gap (2.3mm/90 mil), and dual lip air ring. Comparative film processing and property data are presented in **Table 2** for three Univation-Type II mPEs in comparison to Z/N LLDPE and LLDPE-rich blends with LDPE. **Table 3** shows blown film data for these two Univation-Type II mPEs extruded using narrow die gap conditions (1.1mm/45 mil) in comparison to HP-LDPE and LDPE-rich blends with Z/N LLDPE.

Univation-Type II mLLDPEs with broadened MWD and narrow CD show improved extrusion and excellent bubble stability in blown film processing. Films exhibit an excellent balance of properties. The processing flexibility of this family of materials will be well suited to the extrusion versatility demands of many Asia/Pacific film fabricators. These resins will bring marketplace value both as neat mLLDPEs and blendstock resins in many blown film applications.

Blown Film Performance-Univation-Type III mPEs With LDPE Processability

Univation metallocene technology has been used to demonstrate the pilot plant production of developmental mPEs with structure and rheology close to that of high pressure LDPE.

Table 4 presents blown film extrusion data for two Univation-Type III mLLDPEs processed on a 62mm (2.5 inch) Egan extruder configured with standard barrier screw, 150 mm (6 inch) diameter die, and narrow die gap (0.8mm/30 mil) in comparison to a 75/25 LDPE/LLDPE blend. These Univation-Type III resins had moderate MWD and low levels of LCB. Processability matched the LD/LL blend. Film properties are improved.

Table 5 presents small scale (38mm/1.5 inch extruder) blown film extrusion data for two additional examples of Univation-Type III mPEs in comparison to LDPE. These resins had broad MWD and moderate LCB.

Univation-Type III mPEs with broad MWD, narrow CD, and moderate long chain branching match the processing ease of LDPE in blown film extrusion. Bubble stability with these materials is exceptional. Films exhibit improved film toughness properties. Univation-Type III mPEs are targeted for LDPE replacement in volume applications.

Table 2. BLOWN FILM COMPARISON: UNIVATION IMPROVED PROCESSING mLLDPE VS. Z/N LLDPE LL/LD BLEND

Resin	UNIPOL® Z/N LDPE	Univation Type II mLLDPE	Univation Type II mLLDPE	Univation Type II mLLDPE	70/30 LL/LD Blend
Melt Index, I_2: g/10 min	1.0	1.1	1.7	1.2	0.9
Melt Flow Ratio, I_{21}/I_2	29	27	32	37	36
Density, g/cc	0.917	0.917	0.919	0.919	0.917
PDI	3.4	3.5	3.7	4.0	4.5
RSI	4.8	5.5	14	16	9.5
CDI	13.5	2.0	1.6	1.5	10
Output Rate, kg/hr (lb/hr)	85.2 (187)	85.5 (188)	86.3 (190)	87.1 (192)	85 (187)
Melt Temperature, °C (°F)	209 (408)	215 (419)	212 (414)	214 (417)	208 (406)
Specific Output Rate, kg/hr/rpm (lb/hr/rpm)	3.0 (6.6)	3.0 (6.6)	3.2 (7.0)	3.2 (7.0)	2.7 (5.9)
Head Pressure, MPa (psi)	30 (4350)	32 (4640)	19 (2760)	21 (3040)	26 (3770)
Motor Load, amps	150	160	115	120	120
Film Gauge, µm (mil)	25 (1)	25 (1)	25 (1)	25 (1)	25 (1)
Dart Impact Strength, g	140	560	320	230	100
MD Tear Resistance, g	310	120	120	90	95
TD Tear Resistance, g	730	470	560	510	730
Haze, %	7.5	5.7	6.9	11.8	3.5
45deg Gloss	67	66	60	45	82

92 mm (3.5 inch) Extruder
Standard barrier screw
die diameter: 150 mm (6 inch)
dual lip air ring
die gap: 2.3 mm (90 mil)
BUR: 3

Table 3. BLOWN FILM COMPARISON: UNIVATION IMPROVED PROCESSING mLLDPE VS. LDPE AND LL/LD BLEND

Resin	HP-LDPE	Univation TYPE II mLLDPE	Univation TYPE II mLLDPE	70/30 LD/LL Blend
Melt Index, I_2: g/10 minutes	1.7	1.7	1.2	1.2
Melt Flow Ratio, I_{21} / I_2	59	32	37	56
Density, g/cm^3	0.920	0.919	0.919	0.920
PDI	5.4	3.7	4.0	4.8
RSI	50	16	14	33
CDI	1.5	1.6	1.5	3.0
Output Rate, kg/hr (lb/hr)	69.3 (153)	69.5 (153)	70.9 (156)	71.8 (158)
Melt Temperature, °C (°F)	212 (414)	211 (412)	212 (414)	216 (421)
Specific Output Rate, kg/hr/rpm (lb/hr/rpm)	2.3 (5.1)	3.0 (6.6)	3.0 (6.6)	2.3 (5.1)
Head Pressure, MPa (psi)	13 (1880)	22 (3190)	23 (3340)	18 (2610)
Motor Load, amps	70	105	110	90
Film Gauge, µm (mil)	25 (1)	25 (1)	25 (1)	25 (1)
Dart Impact, g	94	437	284	90
MD Tear Resistance, g	87	175	136	170
TD Tear Resistance, g	100	576	567	420
Haze, %	4.9	5.8	9.0	5
45deg Gloss	68	64	50	74

92 mm (3.5 inch) Extruder
Standard barrier screw
die diameter: 150 mm (6 inch)
dual lip air ring
die gap: 1.1 mm (45 mil)
BUR: 3

Table 4. BLOWN FILM COMPARISON: UNIVATION IMPROVED PROCESSING mLLDPE VS. LLDPE, LDPE AND LL/LL BLEND

Resin	LLDPE	HP-LDPE	LD/LL Blend 75/25	Univation TYPE III mLLDPE	Univation TYPE III mLLDPE
Melt Index, I_2: g/10 minutes	1.1	0.6	0.6	1.1	0.9
Melt Flow Ratio, I_{21} / I_2	23.9	75.5	48.5	46.0	43.0
Density, g/cm^3	0.919	0.921	0.921	0.919	0.919
PDI	-	-	-	5.0	4.2
RSI	8	64	-	20	-
CDI	-	narrow	-	~2	~2
LCB	none	yes	-	low	low
Output Rate, kg/hr (lb/hr)	51 (112)	52 (114)	52 (114)	52 (114)	52 (114)
Melt Temperature, °C (°F)	221 (430)	212 (414)	216 (421)	214 (417)	216 (421)
Head Pressure, MPa (psi)	23 (3340)	13 (1880)	17 (2460)	16 (2320)	18 (2610)
Motor Load, amps	41	25	31	31	34
Film Gauge, µm (mil)	50 (2)	50 (2)	50 (2)	50 (2)	50 (2)
Dart Impact, g	200	190	170	710	890
MD Tear Resistance, g/50 µm (g/2 mil)	330	270	170	410	400
TD Tear Resistance, g/50 µm (g/2 mil)	470	170	280	850	840
Haze, %	11.8	6.7	8.9	10.2	8.8
45deg Gloss	63	64	61	67	69

- not measured

62 mm (2.5 inch) Extruder
die diameter: 150 mm (6 inch)
die gap: 0.8 mm (30 mil)
BUR: 2.5

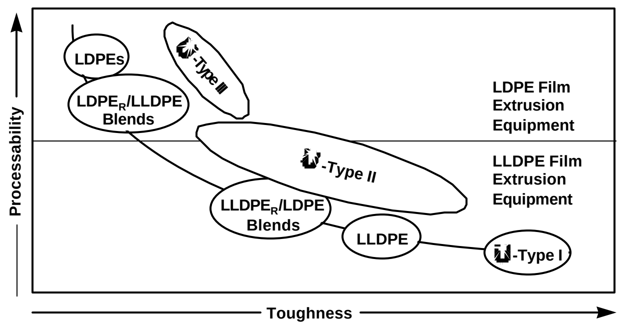
Table 5. BLOWN FILM COMPARISON: UNIVATION IMPROVED PROCESSING mLLDPE TYPE III VS. LDPE

Resin	HP-LDPE	Univation TYPE III mLLDPE	Univation TYPE III mLLDPE
Melt Index, I_2:g/10 minutes	2.0	2.0	2.4
Melt Flow Ratio, I_{21} / I_2	55	50	52
Density, g/cm^3	0.922	0.918	0.924
PDI	4.5	5.5	6.3
RSI	13.3	22	21
CDI	1.5	1.9	1.5
LCB/1000 CH_2	1.5	0.8	0.7
Output Rate, kg/hr (lb/hr)	17.0 (37)	18.0 (40)	18.5 (41)
Melt Temperature, °C (°F)	183 (360)	183 (360)	160 (320)
Specific Output Rate, kg/hr/rpm (lb/hr/rpm)	0.17 (0.37)	0.19 (0.42)	0.19 (0.42)
Head Pressure, MPa (psi)	13.8 (2000)	11.7 (1700)	10.3 (1490)
Motor Load, amps	7.9	7.2	7.7
Film Gauge, µm (mil)	25 (1)	25 (1)	25 (1)
Dart Impact, g	50	110	60
MD Tear Resistance, g	260	51	71
TD Tear Resistance, g	160	345	485
Haze, %	5.4	9.3	10.9
45deg Gloss	65	53	50

die gap: 0.8 mm (30 mil)
BUR: 2

Figure 10 maps the processability - toughness domain of three Univation mPE product families which will access a wide span of low density polyethylene film markets and applications.

Figure 10. SCHEMATIC MAP OF PROCESSABILITY-TOUGHNESS DOMAINS OF UNIVATION mPEs



SUMMARY

Metallocene technology is now entering mainstream commercial development in the volume PE marketplace .

Polyethylene demand growth in Asia/ Pacific is robust. Products which will win in the volume PE markets of the region must be especially versatile in their ability to be processed on a wide range of fabrication equipment and deliver cost-effective improvements in end-use performance across a range of applications.

Polymer molecular engineering capability embodied in Univation metallocene technology has been used to develop prototype, high versatility resins with processability and properties balanced to adapt to the broad functionality demands of PE markets in the Asia/Pacific region.

Univation metallocene technology has been used to produce a range of improved polyethylenes, Univation-Types I, II, and III with narrow to broad MWD, narrow CD, with linear structure (no LCB) to resins with significant levels of LCB.

Univation Technologies combines EXXPOL® metallocene catalyst systems and capacity enhancing Super Condensed Mode Technology with the UNIPOL® gas-phase PE process to accelerate the pace and broaden the global reach of metallocene technology applied to volume PE manufacture. Univation Technol-ogies is the licensing source for this technology.

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