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ABSTRACT

The influence of using the fluoropolymer based polymer processing additive (PPA) Dynamar™ FX-5920A to improve the extrusion of high viscosity linear low density polyethylene (LLDPE) resins in a blown film extrusion process has been investigated. Three resins with melt index (MI) values of 2.0, 0.9, and 0.5 were evaluated in a 0.8 mm (32 mil) and a 1.6 mm (63 mil) die gap configuration, and the 0.5 MI and 0.9 MI resins were also evaluated with PPA present. Several extrusion process parameters were used to assess the effect the PPA had on the extrusion process. These include die adapter pressure, material output, and extruder energy requirements. The physical, mechanical, and optical properties, and also the balance between the machine direction and transverse direction properties were used to assess the effects of resin MI and die configuration.

INTRODUCTION

For the blown film processor, the acceptable extrusion conditions or "processing window" for high viscosity LLDPE resins can be relatively small. Often a material or process parameter must be compromised to gain advantage with another. This balance can represent a minor inconvenience or a significant obstacle for both the extrusion processor and the resin producer who is supplying material to the industry.

One example considers the use of higher molecular weight resins to improve the physical properties of a film product. It is generally recognized that as the molecular weight of the LLDPE resin increases the physical properties of the resin will improve. With this increase in molecular weight an increase in the viscosity of the resin is also observed. [1] This increase in viscosity makes the resin more difficult to process into film and extrusion limits may he observed.

One specific extrusion process parameter which has received attention in the industry is the die gap setting. In the blown film extrusion process, reducing the die gap will reduce the draw down of the melt in the machine direction, which will result in a better balance to the draw down in the transverse direction. This improved balance will reduce the differences observed in machine direction and transverse direction properties for the film product.

In practice, while lower MI resins offer distinct advantages in physical and mechanical properties, they are a greater challenge to process because of higher melt viscosity. One method recognized in the industry to control the processing problems associated with lower MI resins is to increase the extruder die gap. Unfortunately this increase in die gap will reduce the balance between the machine direction and transverse direction properties.

Additional equipment modifications have been identified which improve the capability of extrusion equipment [2,3] These modifications include new and more complex screw designs to accommodate increased melt viscosity and to reduce the high die pressure associated with processing lower MI resins. Unfortunately this retrofitting also requires a significant capital investment.

An effective option which has been identified and gained wide spread commercial acceptance is the use of fluoropolymer based Polymer Processing Additives (PPA) to improve the processing of these higher viscosity polyethylene resins. [4,5] PPA is effective in reducing the apparent viscosity of high molecular weight LLDPE and has been widely used to improve the processing characteristics of these resins.[6] The PPA is thought to function by forming a fluoropolymer coating on the die surface, which provides a low energy surface layer at the polymer melt - metal interface. [7,8,9,10] In fully developed pressure driven flow a zero velocity condition is defined at this interface. It is generally proposed that the presence of the PPA coating eliminates this zero velocity condition and a slip velocity is established, reducing the resistance of the polymer melt to flow from the extrusion die. A primary benefit identified when using a PPA is the elimination of surface melt fracture. Secondary benefits are also observed, which include reduction in die pressure and extrusion motor torque. These benefits expand the acceptable processing window for the resins and improve their extrusion characteristics. Examples of this expanded process window include the ability to reduce extrusion process temperatures, increase extrusion output, change extruder die geometry, or switch to higher viscosity resins or resin blends after the PPA has established a coating in the extruder die.[11]

The focus of this study was to investigate the use of a PPA to allow the film producer to utilize the material advantages provided by a low MI LLDPE resin and also the processing advantage of using a narrower die gap when producing a specific film construction. The data also provides an indication of how significant the processing problems are when changing to lower MI resins or changing die geometry.

These issues can be a significant concern, particularly in developing industrial markets. One example is found in the Peoples Republic of China. Currently 2 MI LLDPE resins are widely used in this market. It is reasonable to expect this market will shift toward 1 MI and lower resins in the near future, following a similar trend observed in other regions of the world. A challenge presents itself when we recognize this shift will take place in an industrial climate which is currently dominated by older extrusion equipment that was designed for processing LDPE.

When we recognize and utilize the benefits of a PPA to improve the extrusion of a high molecular weight LLDPE resin we can take advantage of the properties these resins provide. One objective a film producer may consider is using a higher molecular weight resin to reduce the thickness of a film while maintaining the properties. This reduction in film thickness will also increase the transmittance and the decrease haze of the films produced. A reduction in the raw materials requirements and cost to produce this film will also be recognized when decreasing the film thickness.

EQUIPMENT and MATERIALS

These experiments were performed using a blown film extrusion line which was located in the Peoples Republic of China (PRC). It represents the machinery which is typically used for agricultural and mulch film production in the PRC. The extrusion equipment specifications and die configuration details are given in Table 1. This equipment had interchangeable die pins that allowed the use of 0.8 mm and 1.6 mm die gaps.

Three different LLDPE resins were used in this experiment, 2.0 MI, 0.9 MI, and 0.5 MI. The 2.0 MI (0.918 density, C4 comonomer, Unipol manufacturing process) and the 0.9 MI (0.915 density, C4 comonomer, British Petroleum manufacturing process) LLDPE resins are commercially available in the PRC and are generally used in the production of agricultural and mulch film. The 0.5 MI (0.920 density, C6 comonomer, British Petroleum manufacturing process) LLDPE resin is not commercially available in the PRC, and was imported from North America for this experiment All resins were properly stabilized with primary and secondary antioxidants, and contained antiblock. The fluoropolymer based PPA used in this experiment was Dynamar™ FX-5920A. It was used in the form of a 2 % concentrate in a 2.0 MI LLDPE carrier resin, which was mixed with the base resin by tumble blending prior to extrusion. This concentrate is commercially available in the PRC.

EXPERIMENTAL PROCEDURE

The experiment was divided into two separate evaluations. The first evaluation was to determine the effect of resin melt index on extrusion die pressure at a constant output and also extrusion output at a constant die pressure. All three resins (2.0 MI, 0.9 MI, and 0.5 MI) were evaluated in two die gap configurations (0.8 mm and 1.6 mm). The second evaluation was to determine the effect of the PPA on processing the 0.9 MI and the 0.5 MI resins in the 0.8 mm die gap configuration. The effect of the PPA on die pressure at constant output and also output at constant die pressure was measured.

The process variables monitored during this experiment were: screw speed (rpm), die pressure (MPa) measured at the adapter connecting the die to the extruder, melt temperature (°C) also measured at the adapter, and the extruder amperage (A) and voltage draw (V). The output was measured by weighing film samples taken over a specified period of time.

The comparison points for the specific resin and extrusion conditions were measured after a minimum of one hour extrusion time and after an equilibrium had been established. All extrusion variables were monitored as a function of time to determine when an equilibrium had been established.

Film samples were collected from each equilibrium data point and the properties of these films were measured. The specific film properties measured include; tensile strength, ultimate elongation, and secant modulus (ASTM D 882), dart impact (ASTM D 1709), Elmendorf tear (ASTM D 1922), haze and transmittance (ASTM D 1003).

All the PPA containing evaluation data points were generated using a 1000 ppm (parts per million) PPA level blended into the resin. The minimum PPA level needed to establish a complete die coating and observe the benefits in the extrusion system were not determined in this experiment because the level may vary when changing the LLDPE resin MI. The 1000 ppm level exceeds the minimum level required to establish a complete PPA die coating in the extrusion process, and thereby eliminates any possibility of having variations in PPA coating when switching to different MI resins. Although this level exceeds the required minimum PPA level, it will have no negative effect on the physical or optical properties of the film samples which were generated. [12]

RESULTS AND DISCUSSION

The first evaluation compares the resultant physical properties of the three different LLDPE materials extruded through the two die gap configurations. Data for both 15μm (0.6 mils) and 8μm (0.3 mils) thick films were generated and have been provided in Tables 2 and 3. The data was collected while running at a constant output of 26 kg/hr (57lbs/hr). PPA was present when processing the 0.5 and 0.9 MI resins. The other film samples included in this summary do not contain a PPA.

When considering the data at constant output, for both the 8μm and 15μm films there is a trend of increasing tensile strength, tear strength, secant modulus and dart impact when decreasing melt index (increasing resin molecular weight). Consider the example of dart impact for the 15μm film samples. The 0.5 MI resin results in a 375 g value, compared to a 151 g value for the 2.0 MI resin. Additional examples are found in the summary Tables 2 and 3.

For both the 8μm and 15μm film samples, when decreasing the melt index of the resin a decrease in ultimate elongation when testing in the machine direction is observed. This decrease in ultimate elongation is not observed when testing in the transverse direction. Greater machine direction orientation of the lower melt index (higher molecular weight) polymer during the cooling and draw down process may be responsible for this observation.

The film haze values are directly affected by the resin melt index, film thickness, and die gap used during processing. We observe an increase in film haze when decreasing resin melt index. When we compare films with the same thickness produced using the same melt index resin, but produced using different die gaps, we observe lower haze values for the films produced with a narrow die gap.

As an example: Consider the 15μm film samples produced with a 1.6 mm die gap. We observe a 41.9% haze value in the 0.5 MI resin while only observing a 17.8% haze in the 2.0 MI resin. Next, we should consider the same film thickness (15μm) produced using a 0.8 mm die gap. We observe a 25.1% haze value in the 0.5 MI resin while only observing a 13.9% haze in the 2.0 MI resin.

These observations may be the result of different mechanisms and should be treated independently. The increase in haze observed when decreasing resin melt index may be the result of higher internal strain established in the film as a result of the increase in resin molecular weight. This strain may induce crystallization. The decrease when using a narrower die gap may be the result of shorter cooling times associated with a thinner extrudate which provides less time for crystal formation in the film. Using a narrow die gap will require less draw down of the extrudate and this may also reduce internal strain in the film.

Another trend that is present in the data is for a better balance of machine direction (MD) and transverse direction (TD) physical properties when extruding through the 0.8 mm die gap as compared to the 1.6 mm die gap configuration. This trend is evident in all three LLDPE resins. A ratio can be defined to compare this balance. This ratio is represented by: Balance = MD/TD. When comparing the balance numbers calculated from this equation, a value closer to 1 represents better balance of properties.

We also observe a tendency for increased dart impact when extruding through the 0.8 mm as compared to the 1.6 mm die gap configuration. For example, when using the 0.9 MI resin to produce a 15 μm film, we observe a 198 g dart impact when extruding through the 0.8 mm die gap configuration and a 175 g dart impact when extruding through the 1.6 mm die gap.

The processing of the three different LLDPE resins in the two die gap configurations was also considered. Extrusion data was taken at constant output (26 kg/hr) and also at constant die pressure (22 MPa). The extrusion data for the 15 gm film case has been summarized in Tables 4 and 5. There was no observable difference in extrusion variables when extruding the 8 μm versus the 15 μm film.

Several trends present themselves when looking at the process data summaries in Tables 4 and 5. While most of these observations are expected when making a change in resin MI or die gap setting, it is interesting to note the significance these changes have on the extrusion process parameters.

When decreasing the resin melt index at a constant output, the extrusion die pressure increases significantly. When processing at 26 kg/hr through the 1.6 mm die gap configuration, for the 2.0 MI resin a 9.9 MPa die pressure was observed. In contrast processing the 0.5 MI resin at the same output a 21.9 MPa die pressure was observed. A 12 % increase.

When decreasing the resin melt index at a constant die pressure, the output decreases significantly. As an example, processing at a 22 MPa die pressure through the 0.8 mm die gap configuration, the 2.0 MI resin had an output of 53.0 kg/hr, in contrast the 0.5 MI resin had an output of 15.4 kg/hr. A 71% decrease.

Changing the die gap configuration significantly affects the die pressure for all three resin cases. When processing the 0.9 MI resin at a constant output, through the 1.6 mm die gap a 15.7 MPa die pressure was observed. In contrast when using the 0.8 mm die gap a 21.7 MPa die pressure was observed. A 38% increase. The effect of changing the die gap is also apparent when processing at constant die pressure. When processing the 0.9 MI resin at a constant die pressure of 22 MPa an output of 48.8 kg/hr was observed through the 1.6 mm die gap. In contrast an output of 26.7 kg/hr was observed in the 0.8 mm die gap. A 45 % decrease.

Some of the process limitations for this specific extrusion equipment were observed during this experiment. When extruding the 0.5 MI resin through the 0.8 mm die gap, we reach the process limit of a 25 MPa die pressure before obtaining the comparison output of 26 kg/hr. For the 0.5 MI resin a 19 kg/hr output was observed at this maximum die pressure. The cooling limit was realized when extruding the 2.0 MI resin through the 1.6 mm die gap configuration. The output was increased to obtain the comparison pressure of 22 MPa. Before this pressure was achieved, the bubble stability limit was observed (cooling limitation reached). At 54 kg/hr output a die pressure of 15 MPa pressure was observed. Attempting to increase the output to the comparison pressure of 22 MPa resulted in an unstable bubble and no useable film could be made. These results are also represented by Bar Graphs 1 and 2.

The second evaluation determined the effect of the PPA on processing the 0.9 MI and the 0.5 MI resins in the 0.8 mm die gap configuration. This effect of the PPA is readily seen when looking at the die pressures and outputs, and the data is summarized in Table 6.

When adding the PPA, we observe a decrease in die pressure when processing at the same output (26 kg/hr). When processing the 0.9 MI resin, the die pressure observed when processing through the 0.8 mm die gap was 21.7 MPa. With PPA present the die pressure observed was 16.7 MPa processing at the same conditions. A 23 % decrease.

This reduction in die pressure provided by the PPA can be utilized as an increase output for pressure limited extrusion processes. For example processing the 0.9 MI resin through the 0.8 mm die gap at a constant die pressure. Without PPA present we see an output of 26.7 Kg/hr at 22 MPa die pressure, however with PPA present we observe an output of 48.8 kg/hr at 22 MPa die pressure. The PPA is reducing the resistance to flow and reducing the extrusion die pressure when operating at a constant output. This allows us to increase the extrusion output (by increasing the extruder rpm) and return to the original die pressure of 22 MPa. An 83% increase in output at the same die pressure is observed. These results are also represented by Bar Graphs 3, 4, and 5.

If we compare the conditions with and without PPA present at the same output we observe a reduction in extrusion energy consumption. One example of this is the 0.9 MI resin operating at a constant output. A 6% reduction in extruder energy consumption is observed when the PPA is present. The PPA is reducing the resistance to flow thereby reducing the back pressure which the extruder is pumping against, and allows it to operate more efficiently.

Energy calculations are represented by:
Energy (kW/hr) = Amperage (A) x Voltage (V)

The effect of the PPA can also be assessed by calculating the amount of energy (Kw) required to pump output (Kg) from the extruder. This calculation of output/energy (O/E) is included in Table 6. For the 0.5 MI control condition we are limited to a 19.3 Kg/hr output because the maximum die pressure (26 MPa) was achieved. The O/E for this condition is 2.12 Kg/Kw. With PPA present we increased the output to the target of 26 Kg/hr, while maintaining a die pressure of 21 MPa. The O/E for this condition is 2.92 Kg/Kw. This improvement provides an indication that the PPA is improving the melt pumping as a function of energy consumption. This trend is observed for all control and PPA condition comparisons.

INDUSTRIAL APPLICATIONS EXAMPLES

The data presented here demonstrates that if no changes to the system are made, we observe a decrease in die pressure with the use of the PPA. To demonstrate how PPA can be used to gain an advantage by expanding the processing window or changing the resin, three different scenarios have been proposed. The first will investigate increasing physical properties. The second will investigate getting a better balance of physical properties. The third will investigate reducing film thickness to reduce solid waste.

Scenario A

Situation

A film producer is currently using a 0.9 MI LLDPE resin to produce 15 µm film using a 0.8 mm die gap configuration. This film producers customer is asking for a film with increased physical properties, especially dart impact. The film producer also needs to produce the film without losing production output.

Solution

As was demonstrated in the data from this paper, the physical properties of the film can be increased by switching to a lower Melt Index resin. Table 7A gives the physical property differences between the 0.9 MI resin and the 0.5 MI resin. The problem is that, at constant die pressure, the output in the 0.5 MI resin is significantly less (42% less).

One solution, as demonstrated in this paper, is to add a fluoropolymer based PPA. When using the PPA, the output in the 0.5 MI resin is even higher than the output in the 0.9 MI resin (without PPA) processing at the same die pressure (7% increase). This indicates that this film producer, with the aid of the PPA, can produce film that is stronger than the current product without suffering any loss in output in the system. See Graph 7B.

Scenario B

Situation

A film producer is currently using a 0.9 MI LLDPE resin to produce a 8 μm film using a 1.6 mm die gap configuration. This film is used to produce T-shirt shopping bags, and the customer has complained that the bag tears when dropping heavy grocery goods in them. The film producer needs to improve the balance of properties, especially tear strength, without losing production output.

Solution

As was demonstrated in the data from this paper, a better balance of film physical properties can be achieved by switching to a narrow die gap configuration. Table 8A gives the physical property balance differences in the 0.9 MI resin when extruding through the 0.8 mm and the 1.6 mm die gap configurations. The problem is that, at constant die pressure, the output in the 0.8 mm die gap configuration is significantly less (45 % less).

One solution, as demonstrated in this paper, is to add a fluoropolymer based PPA. When using the PPA, the output in the 0.8 mm die gap configuration is equal to the output of the 1.6 mm die gap configuration (with no PPA) in the 0.9 MI resin case. The film producer can utilize a PPA to produce film with a better balance of properties (including film that has less haze and better dart impact) than their current product without the loss of production output. See Graph 8B.

Scenario C

Situation

The government of a developing country is asking for film producers to produce thinner films in order to reduce the amount of LLDPE resin imports into the country and to reduce the solid waste produced by the society. These thinner films must maintain the physical properties of the original thicker film. The film producer can reduce film thickness by increasing take-off speeds, however a lower melt index resin will be required to maintain film physical properties, and they cannot process this lower melt index resin.

Solution

The physical properties of the film will decrease significantly when reducing thickness, however, as demonstrated in this paper, decreasing the melt index will increase physical properties. In some cases the increase in physical properties can compensate the reduction in thickness. This is demonstrated in Table 9A. In Table 9A, we see that the 0.5 MI resin, processed through a 0.8 mm die gap to an 8 μm film thickness has better or at least comparable properties to a 0.9 MI resin, processed through a 0.8 mm die gap to a 15μm film thickness.

Since the 0.5 MI resin will also be more difficult to process, the use of a fluoropolymer based PPA is beneficial. The output of the 0.5 MI material is higher than the output of the 0.9 MI material running at constant die pressure (7 % increase). This is illustrated in Graph 9B.

CONCLUSIONS

The use of a fluoropolymer based PPA will improve the extrusion of lower melt index resins by reducing the extrusion die pressures. Processing lower MI resins in narrow die gap configurations will provide improved physical properties, but this combination may exceed the capabilities of the extrusion process. Lower MI resins result in higher die pressures at constant outputs or lower outputs when running at constant die pressures.

The PPA reduces the extrusion die pressure and lower extruder energy consumption is observed. This allows the processor to run the equipment more efficiently.

The PPA expands the processing window for the processor. The resin can be changed or the process conditions can be altered to give that processor some advantages in physical properties, output, or processing conditions.

Using PPA allows the processing of low MI resins through narrow die gaps. Using narrow die gaps for processing improves the balance of the machine and transverse direction properties.

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Table 1: Equipment Specifications

BLOWN FILM LINE:		
Model:	SJ6530L/FMB 1600L	
Manufacturer:	Dailian Rubber & Plastics Machinery Factory	
EXTRUDER:		
Model:	SJ-6530L	
Screw Diameter:	65 mm	
Length/Diameter	30/1	
Screw Configuration:	tapered feed and compression section, Maddock mixing element, metering section, and pineapple mixing element	
Temperature Profile :	constant temperature throughout evaluation	
	Zone 1	180 °C
	Zone 2	200 °C
	Zone 3	230 °C
	Adapter	225 °C
	Die 1	205 °C
	Die 2	195 °C
DIE:		
Flow Design:	4 port spiral feed	
Diameter	300 mm	
Die Gap:	1.6 mm & 0.8 mm	
Air Ring:	LLDPE air-ring design	
FILM:		
Layflat:	1 m	
Thickness:	8 µm 15 µm	

Table 2: Physical Property Data Constant Target Output (26 kg/hr)

(15 µm film thickness

MELT INDEX		g/10 min	0.5	0.9	2.0	0.5	0.9	2.0
DIE GAP		mm	1.6	1.6	1.6	0.8	0.8	0.8
TENSILE STRENGTH	MD	MPa	36.3	31.3	26.7	31.1	27.3	23.9
(ASTM D882)	TD	MPa	26.8	18.7	19.5	22.5	21.3	19.3
BALANCE			*1.35*	*1.67*	*1.37*	*1.38*	*1.28*	*1.24*
ULTIMATE ELONGATION	MD	%	468	581	743	521	634	722
(ASTM D882)	TD	%	729	720	785	617	708	714
BALANCE			*0.64*	*0.81*	*0.95*	*0.84*	*0.90*	*1.01*
SECANT MODULUS	MD	MPa	187.3	130.6	130.2	184.9	152.1	137.1
(ASTM D882)	TD	MPa	234.6	171.6	167.3	220.0	176.0	176.0
BALANCE			*0.80*	*0.76*	*0.78*	*0.84*	*0.86*	*0.78*
ELMENDORF TEAR	MD	cN	91.2	57.6	62.4	121.6	66.0	64.0
(ASTM D1922)	TD	cN	403.2	264.0	203.2	382.0	262.4	217.3
BALANCE			*0.23*	*0.22*	*0.31*	*0.32*	*0.25*	*0.29*
DART IMPACT (ASTM D1709)		g	375	175	151	406	198	157
HAZE (ASTM D1003)		%	41.9	33.7	17.8	25.1	21.7	13.9
TRANSMITTANCE (ASTM D1003)		%	94.7	95.6	94.6	94.2	94.9	94.5

Table 3: Physical Property Data Constant Target Output (26 kg/hr)

(8 µm film thickness)

MELT INDEX		g/10 min	0.5	0.9	2.0	0.5	0.9	2.0
DIE GAP		mm	1.6	1.6	1.6	0.8	0.8	0.8
TENSILE STRENGTH	MD	MPa	35.6	30.2	25.3	34.9	28.3	23.6
(ASTM D882)	TD	MPa	24.2	19.6	18.1	23.3	20.2	17.2
BALANCE			*1.47*	*1.54*	*1.40*	*1.50*	*1.40*	*1.37*
ULTIMATE ELONGATION	MD	%	298	337	534	368	428	430
(ASTM D882)	TD	%	647	631	685	664	641	600
BALANCE			*0.46*	*0.53*	*0.78*	*0.55*	*0.67*	*0.72*
SECANT MODULUS	MD	MPa	180	117.6	106.6	177.4	124.7	110.7
(ASTM D882)	TD	MPa	238	131.4	130.3	207.1	154.6	122.1
BALANCE			*0.76*	*0.89*	*0.82*	*0.86*	*0.81*	*0.91*
ELMENDORF TEAR	MD	cN	38.4	16.0	24.0	32.0	32.0	26.7
(ASTM D1922)	TD	cN	280.0	198.0	164.8	214.4	230.4	133.6
BALANCE			*0.14*	*0.08*	*0.15*	*0.15*	*0.14*	*0.20*
DART IMPACT (ASTM D1709)		g	289	112	111	204	136	91
HAZE (ASTM D1003)		%	32.7	23.0	14.6	22.5	19.4	10.6
TRANSMITTANCE (ASTM D1003)		%	94.5	95.4	94.4	94.1	95.3	94.0

Table 4: Extrusion Data at Constant Target Output (26 KG/HR)

MI	DIE GAP (mm)	DIE PRESSURE (MPa)	MELT TEMPERATURE (°C)	OUTPUT (Kg/hr)	VOLTAGE (Volts)	AMPS (Amps)	SPEED (rpm)	POWER** (Kw/hr)
0.5*	0.8	24.8	207	19.3	240	38	30	9.12
0.9	0.8	21.7	194	26.7	245	37	43	9.07
2.0	0.8	13.8	194	26.1	248	40	49	9.92
0.5	1.6	21.9	201	26.1	236	41	40	9.68
0.9	1.6	15.7	202	25.9	233	37	41	8.62
2.0	1.6	9.9	203	26.4	237	38	45	9.01

Table 5: Extrusion Data at Constant Target Die Pressure (22 MPa)

MI	DIE GAP (mm)	DIE PRESSURE (MPa)	MELT TEMPERATURE (°C)	OUTPUT (Kg/hr)	VOLTAGE (Volts)	AMPS (Amps)	SPEED (rpm)	POWER** (Kw/hr)
0.5	0.8	21.2	201	15.4	239	37	21	8.84
0.9	0.8	21.7	194	26.7	245	37	43	9.07
2.0	0.8	21.4	202	53.0	249	46	110	11.45
0.5	1.6	21.9	201	26.1	236	41	40	9.68
0.9	1.6	22.1	195	48.8	228	48	90	10.94
2.0**	1.6	15.5	188	54.3	237	47	100	11.14

Table 6: Extrusion Data (Effects of PPA)

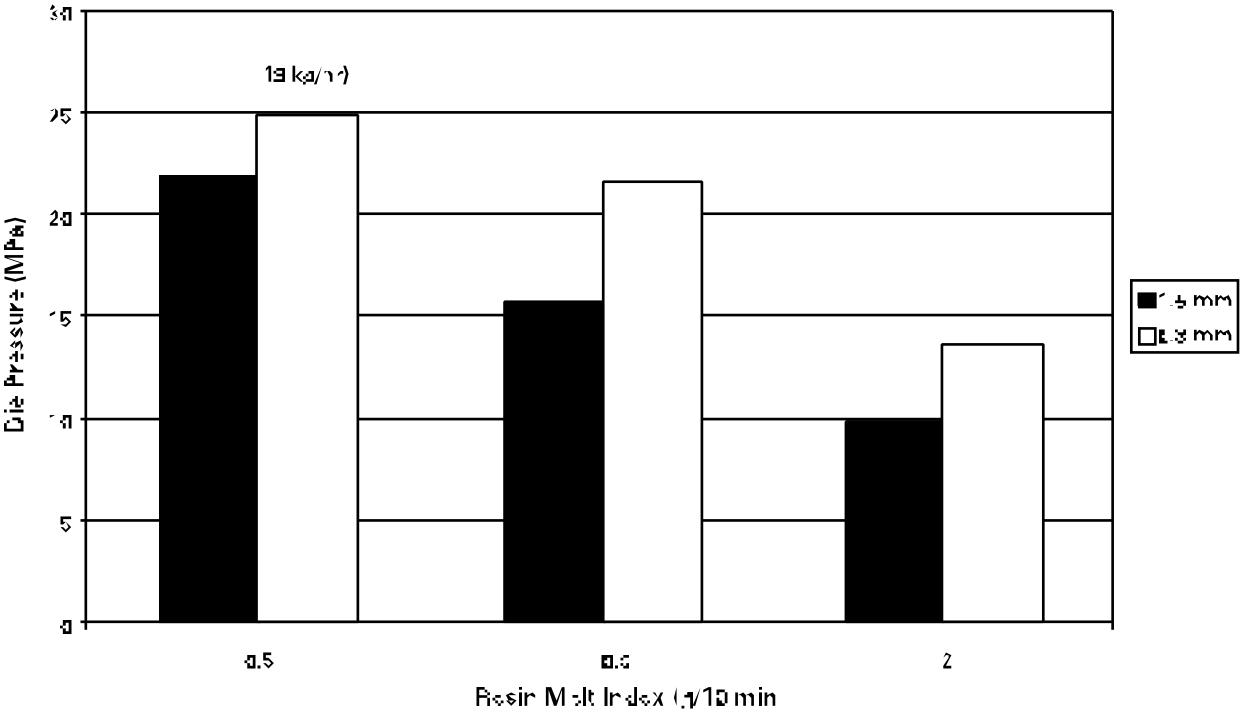
MI	PPA (ppm)	DIE PRESSURE (MPa)	MELT TEMP (°C)	OUTPUT (Kg/hr)	VOLTAGE (Volts)	AMPS (Amps)	SPEED (rpm)	POWER*** (Kw/hr)	O/E (Kg/Kw)
CONSTANT OUTPUT (26 kg/hr)									
0.5*	0	24.8	207	19.3	240	38	30	9.12	2.12
0.5	1000	20.7	202	25.5	236	37	37	8.73	2.92
0.9	0	21.7	194	26.7	245	37	43	9.07	2.94
0.9	1000	16.7	203	26.0	236	36	47	8.50	3.06
CONSTANT DIE PRESSURE (22 MPa)									
0.5	0	21.2	201	15.4	239	37	21	8.84	1.74
0.5	1000	22.0	199	28.5	238	40	42	9.52	2.99
0.9	0	21.7	194	26.7	245	37	43	9.07	2.94
0.9	1000	22.0	201	48.8	237	47	97	11.14	4.38

* This data is not taken at 26 kg/hr. The maximum die pressure of 25 MPa was observed at this condition.

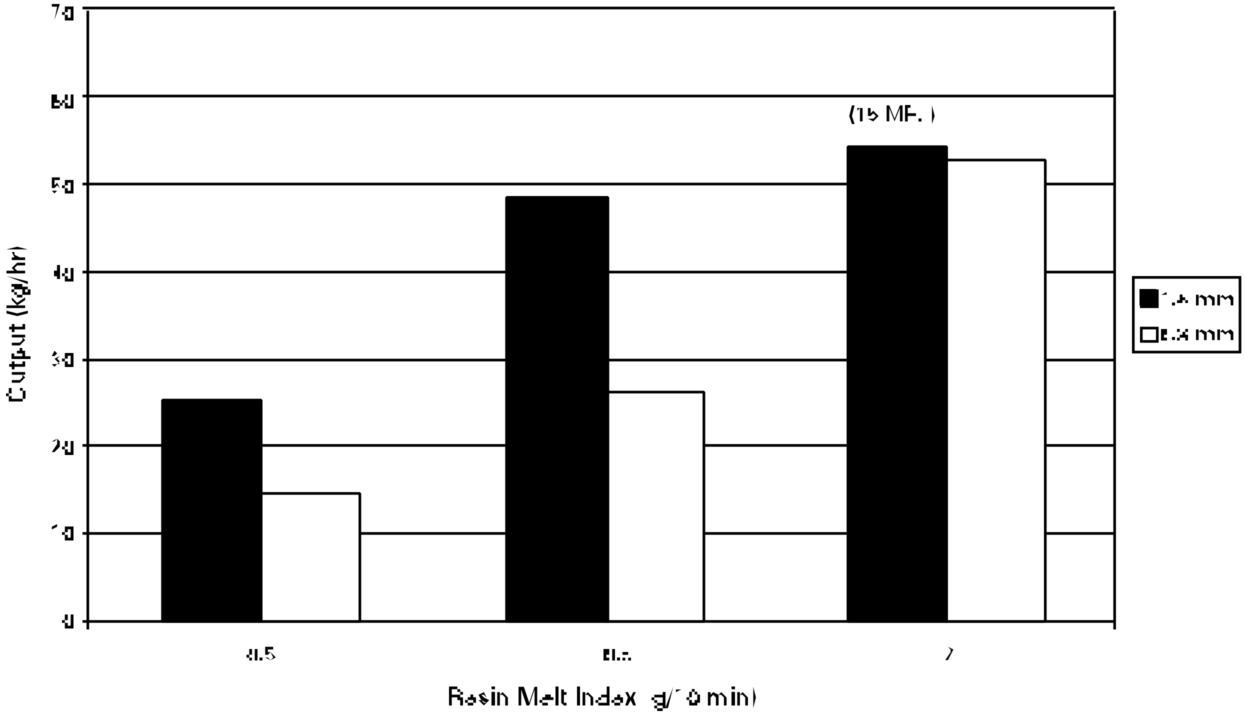
** This data is not taken at 22 MPa. The cooling capability and bubble stability limit was observed at this condition.

*** Power consumption calculated as Voltage x Amperage.

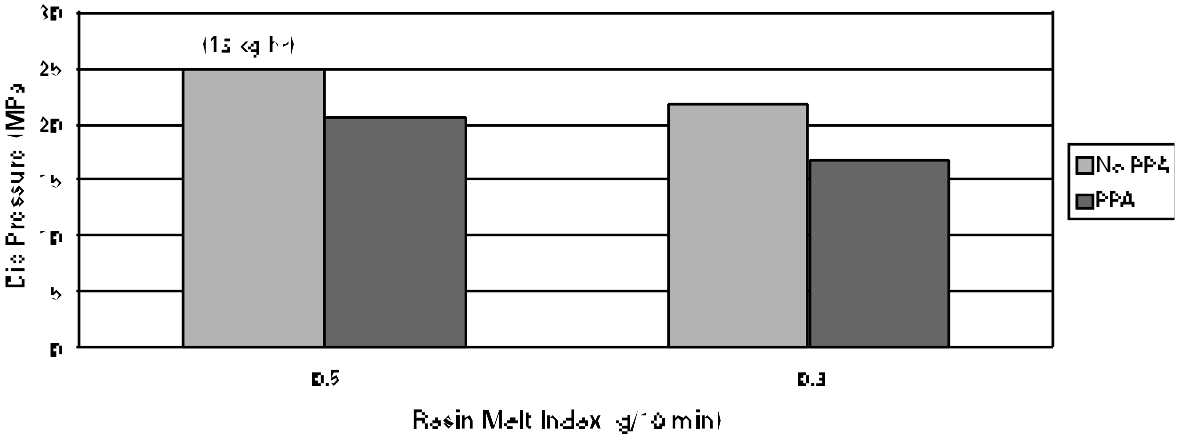
Bar Graph 1 : Effects of Resin Melt Index on Extruder Die Pressure
Constant Target Output (25 kg/hr) through 1.6 mm and 0.8 mm Die Gaps



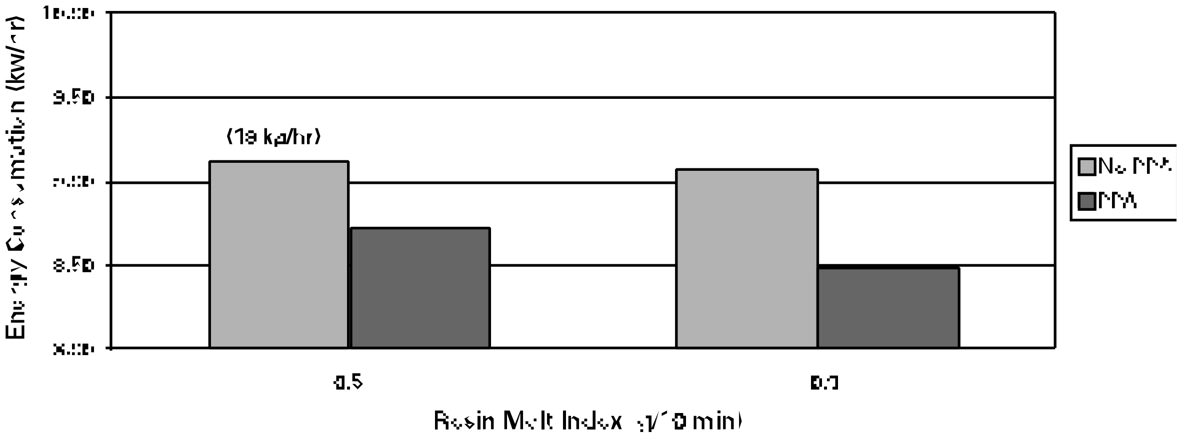
Bar Graph 2 : Effects of Resin Melt Index on Output
Constant Target Die Pressure (22 MPa) through 0.8 mm and 1.6 mm Die Gaps



Bar Graph 3 : Effects of PPA on Extruder Die Pressure
Constant Target Output (26 kg/hr) through 0.8 mm Die Gap



Bar Graph 4 : Effects of PPA on Extruder Energy Consumption
Constant Target Output (26 kg/hr) through 0.8 mm Die Gap



Bar Graph 5 : Effects of PPA on Extruder Output
Constant Target Die Pressure (22 MPa) through 0.8 mm Die Gap

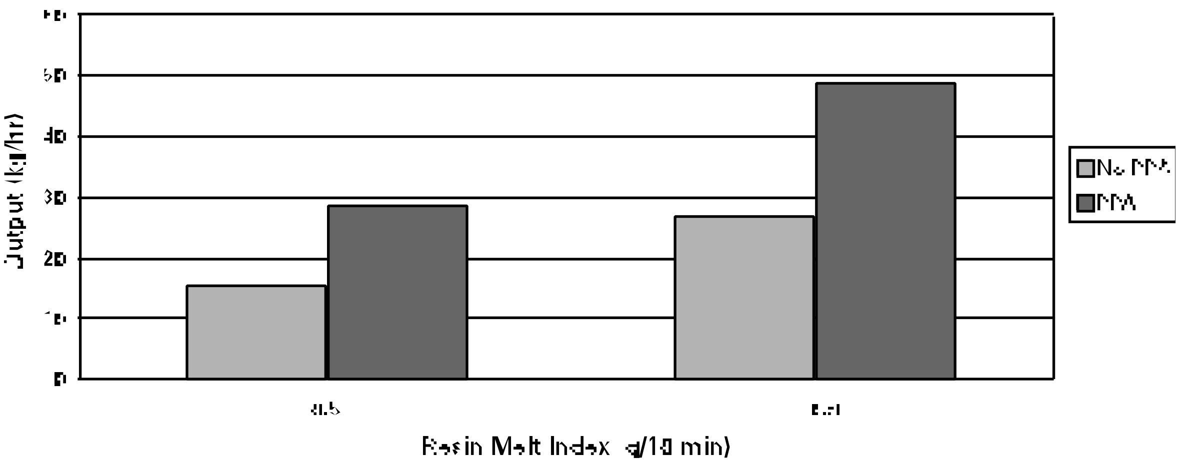
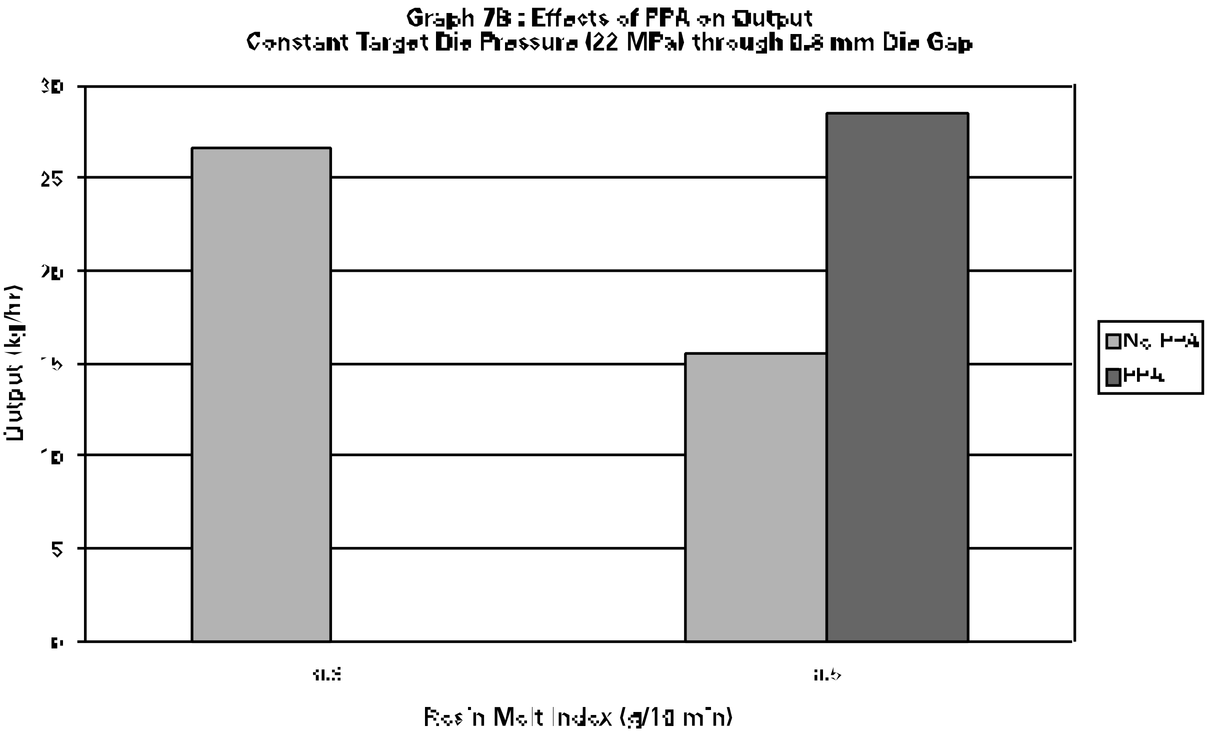


Table 7A: Physical Properties Comparison Between 0.5 MI and 0.9 MI LLDPE

MELT INDEX		g/10 min	0.5	0.9	0.5 vs 0.9+
DIE GAP		mm	0.8	0.8	0.8
FILM THICKNESS		µm	15	15	15
TENSILE STRENGTH	MD	MPa	31.1	27.3	12%
(ASTM D882)	TD	MPa	22.5	21.3	5%
ULTIMATE ELONGATION	MD	%	521	634	-22%
(ASTM D882)	TD	%	617	708	-15%
SECANT MODULUS	MD	MPa	184.9	152.1	18%
(ASTM D882)	TD	MPa	220.0	176.0	20%
ELMENDORF TEAR	MD	cN	121.6	66.0	46%
(ASTM D1922)	TD	cN	382.0	262.4	31%
DART IMPACT (ASTM D1709)		g	406	198	51%
HAZE (ASTM D1003)		%	25.1	21.7	14%
TRANSMITTANCE (ASTM D1003)		%	94.2	94.9	-1%

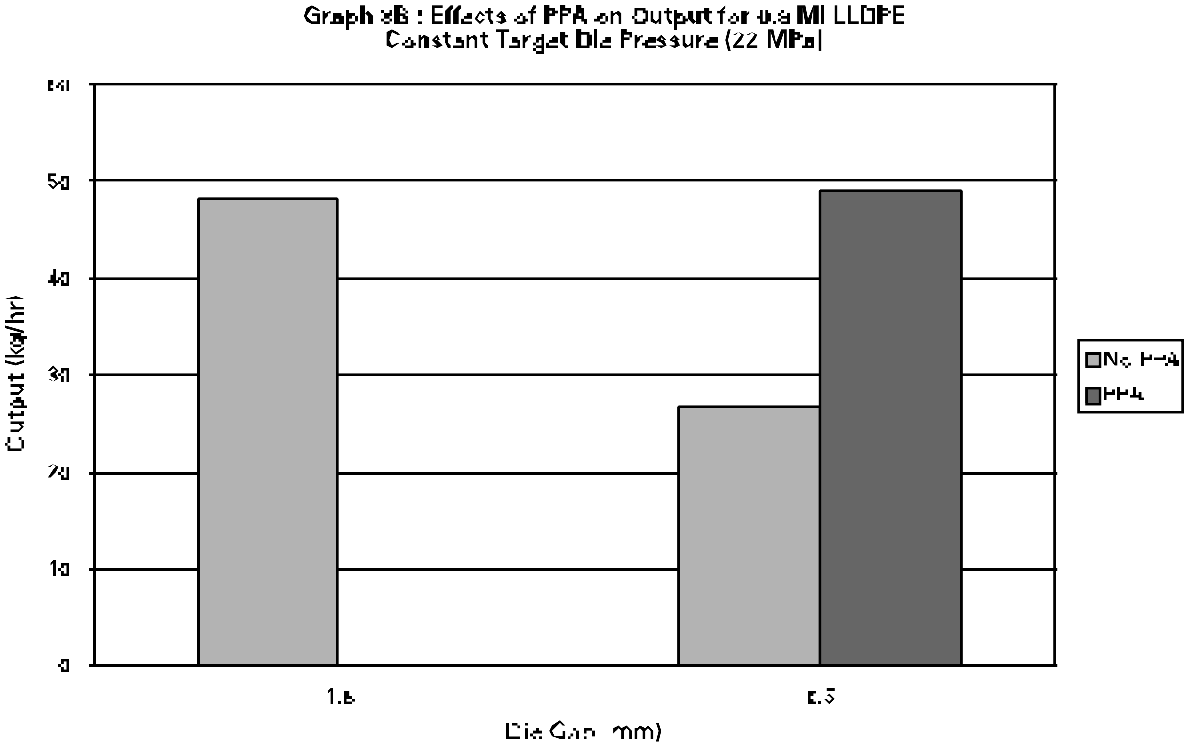
(+0.5 vs 0.9 Data is calculated as: [(0.5 MI-0.9 MI)/0.5MI]


Graph 7B : Effects of PPA on Output
Constant Target Die Pressure (22 MPa) through 0.8 mm Die Gap

In this example the 0.5 MI LLDPE, with the presence of a PPA, can yield outputs higher than the 0.9 MI LLDPE without PPA.

Table 8A: Physical Properties Between 0.8 mm and 1.6 mm Die Gaps.

MELT INDEX		g/10 min	0.9	0.9
DIE GAP		mm	1.6	0.8
FILM THICKNESS		µm	8	8
TENSILE STRENGTH	MD	MPa	30.2	28.3
(ASTM D882)	TD	MPa	19.6	20.2
BALANCE			*1.54*	*1.40*
ULTIMATE ELONGATION	MD	%	337	428
(ASTM D882)	TD	%	631	641
BALANCE			*0.53*	*0.67*
SECANT MODULUS	MD	MPa	117.6	124.7
(ASTM D882)	TD	MPa	131.4	154.6
BALANCE			*0.89*	*0.81*
ELMENDORF TEAR	MD	cN	16.0	32.0
(ASTM D1922)	TD	cN	198.0	230.4
BALANCE			*0.08*	*0.14*
DART IMPACT (ASTM D1709)		g	112	136
HAZE (ASTM D1003)		%	23	19.4
TRANSMITTANCE (ASTM D1003)		%	95.4	95.3


Graph 8B : Effects of PPA on Output for 0.9 MI LLDPE Constant Target Die Pressure (22 MPa)

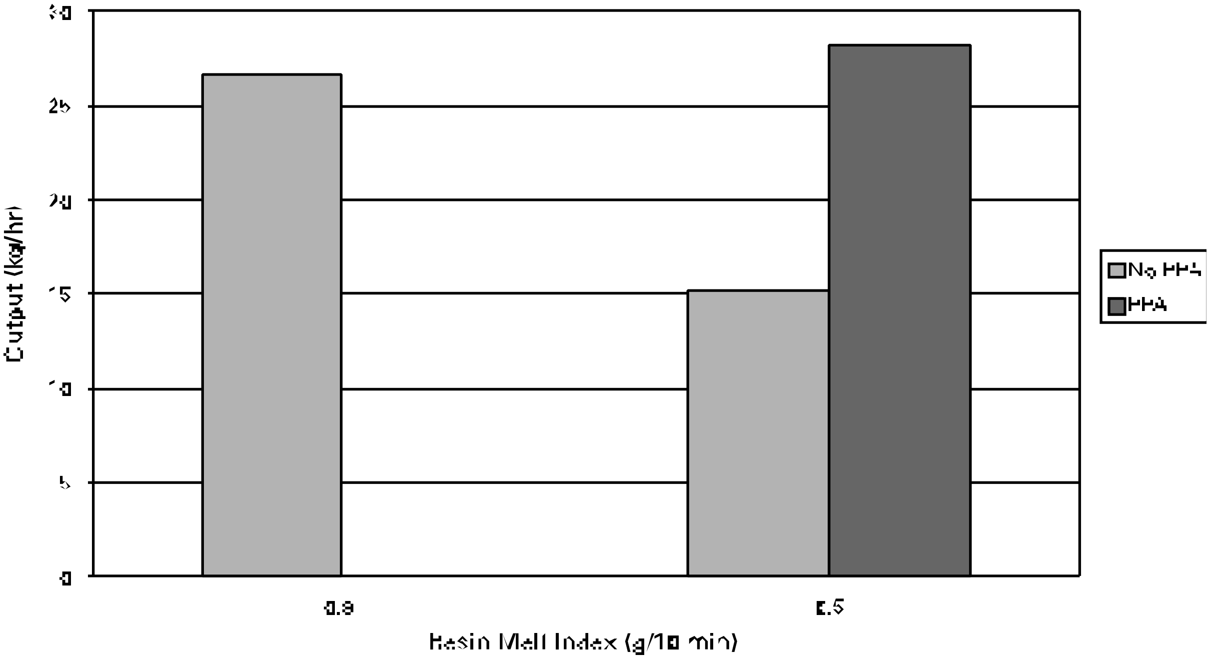
NOTES: In this example the 0.9 MI LLDPE, with the presence of a PPA and extruded through a 0.8 mm die gap, can yield the same output as the 0.9 MI LLDPE without PPA extruding through a 1.6 mm die gap.

Table 9A: Physical Properties Comparison Between 0.5 MI and 0.9 MI LLDPE

MELT INDEX		g/10 min	0.5	0.9	0.5 vs 0.9+
DIE GAP		mm	0.8	0.8	0.8
FILM THICKNESS		µm	8	15	8 vs 15
TENSILE STRENGTH	MD	MPa	34.9	27.3	22%
(ASTM D882)	TD	MPa	23.3	21.3	9%
ULTIMATE ELONGATION	MD	%	368	634	-72%
(ASTM D882)	TD	%	664	708	-7%
SECANT MODULUS	MD	MPa	177.4	152.1	14%
(ASTM D882)	TD	MPa	207.1	176.0	15%
ELMENDORF TEAR	MD	cN	32.0	66.0	-106%
(ASTM D1922)	TD	cN	214.4	262.4	-22%
DART IMPACT (ASTM D1709)		g	204	198	3%
HAZE (ASTM D1003)		%	22.5	21.7	4%
TRANSMITTANCE (ASTM D1003)		%	94.1	94.9	-1%

+ 0.5 vs 0.9 Data is calculated as [(0.5 MI-0.9MI)/0.5 MI]

Graph 9B : Effects of PPA on Output
Constant Target Die Pressure (22 MPa) through 0.8 mm Die Gap



In this example the 0.5 MI LLDPE, with the presence of a PPA, can yield outputs higher than the 0.9 MI LLDPE without PPA.

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