7/9/11 layer blown film lines - Which are the most suitable applications?

It's the age old question... "Which came first, the chicken, or the egg"? Are 7/9/11 layer films lines being sold because they are needed for a product, market or economic reason, or because they are the newest and latest equipment technology?

Through the years, film manufacturing has evolved from monolayer films to multilayer films for a variety of reasons. The confluence of machining technology, equipment development, computer technology, process development, polymer chemistry, economic forces, market needs, and education all came together over time to yield what we now know today as modern coextrusion. This is true across the entire spectrum of polymer film production, including blown film, cast film, double bubble, oriented cast sheet and extrusion coating. The technology developed by Roberto Colombo (Turin, Italy) **[1]** in 1958, Walter Schrenk (Bay City, Michigan, USA) **[2]** in 1967, and many others has forever changed film manufacturing, and the markets which they serve.

Three and even five-layer films have been common for many years, and are commonly used in a number of packaging applications all around the world, either as stand-alone films, or as part of a lamination to another film or foil. Film structures such as shown in Figure 1 are commonly used for food and non-food packaging either as they are, or as laminations with oriented films. Until now, these 3-layer and 5-layer films have taken full advantage of coextrusion technology, machinery development, polymer properties, and have satisfied market needs.

So, how did we go from one to three and five layer films to 7, 9, and 11-layer films? What is driving the market to films with more and more layers? It seems all the major manufacturers are offering 7, 9, and 11 layer machines. The big question is why? Is there a real benefit to be gained from the additional capital expenditure, or is it marketing hype?

Introduction

All films offer certain properties that make them desirable for various end uses **[3]**. These properties include:

- Product protection
- Puncture and abuse resistance
- Vapor barrier
- Moisture barrier
- Grease barrier
- Light barrier
- Printability
- Heat seal
- Hot tack
- Machinability

Monolayer films have traditionally been used for the most simple applications, such as agricultural film, construction films, and garment bag films. Very few new lines are sold today as monolayer lines, if for no other reason than for increased output and flexibility of product capability. In fact, surveys show that sales of mono-layer blown film lines have fallen to less than 4% today, whereas the sales of 5/9/11-layer lines has grown to about 30% of the market today **[4]**. The remainder of the lines sold today are 3-layer lines, whose market share has fallen from about 75% in the year 2000 to about 60% today. Clearly, the trend is to purchase equipment capable of coextruding more and more layers. There are many benefits of multilayer films, as shown in Table 1 below.

Table 1. Benefits of Multilayer Films **[4, 7]**

- Improved physical properties
- Optimization of film structures for specific applications
- Improved Gelbo flex resistance (reduced flexural failures)
- Reduced layer thickness of expensive resins
- Improved barrier properties
- Controlled respiration (O_2 & CO_2 transmission)
- Use of new polymers
- Thinner, stronger films
- Combining incompatible polymers in one step
- Improved gloss
- Additional attributes, such as anti-fog, anti-block, COF, two-sided color
- Reduced cost
- Quick response of new product structures as new applications are developed

A complete review of all these benefits is beyond the scope of this article. However, if we focus only on barrier properties, the benefits that 7/9/11-layer coextrusion offers become obvious. While EVOH is a very effective oxygen barrier material, its drawbacks are that it is stiff, relatively difficult to process, possesses poor moisture vapor barrier properties, and is expensive. Table 2 below shows the oxygen transmission values of various polymers.

Table 2 - Oxygen Transmission Rate of Various Polymers, [5]

POLYMER	OTR @ 20°C, 65%RH (cm^3 20µ / m^2 day atm)	GAS BARRIER
27 Mol% Ethylene EVOH	0.2	Excellent
44 Mol% Ethylene EVOH	1.5	
PVDC	2.6	
PA	38	Fair
PET	54	
HDPE	2300	Poor
PP	3000	
PC	5000	
PS	8000	
LDPE	10000	
EVA	18000	

As can be seen on Table 2 above, the oxygen transmission rate of 27 Mol% ethylene vinyl alcohol resin is 50,000 times less than traditional LDPE, so that a very thin layer of EVOH provides excellent oxygen permeability. The modulus of elasticity shows that thinner layers of material are more flexible than thicker layers **[6]**, so improved Gelbo flex resistance is anticipated with thinner layers of stiff materials. Also, it can be seen in Table 2 that the oxygen transmission rates of polyamide and polyester films are similar. This means that the possibility exists for polyamides, which are inherently tough and stiff, to be substituted for polyesters in multilayer films, for its oxygen transmission rate and stiffness, thereby producing a finished lamination in the one-step blown film process. This is but one advantage of multilayer coextrusion. As machinery technology developments allow for more and more layers to be coextruded, more and more properties and uses of blown film are being discovered.

What are the advantages of a 3 or 5 layer line over 7/9/11 layer lines?

To be sure, 3- and 5-layer films are not going to disappear anytime soon. The installed base of these machines is very large, and the adhesive laminators that they feed is likewise so large, that it is difficult to imagine these lines disappearing. In addition, 3- and 5-layer lines are perfectly suitable for commodity, non-barrier products such as institutional liners, T-shirt bags, garment bags, stretch films, construction film and agricultural films. They also require less capital outlay, less floor space and ancillary equipment such as material handling, so the overall cost of the equipment is less. In those applications requiring some degree of barrier properties, especially those that are adhesively laminated to metallized films, 5-layer structures as shown in Figure 1 are more than adequate for many applications.

Three-layer film blown lines are capable of either a 2-layer or 3-layer structure, in the form of an A/B/A or A/A/B structure, by simply using the same material in 2 extruders. These structures are commonly used as frozen meat and fish packaging films, frozen vegetable bags, cereal liners, forming webs, Modified Atmosphere Packaging (MAP) for fresh cut produce and poultry, boil-in bags, and much more **[3]**. Three-layer film capability also provides the option to "bury", or sandwich in between, a low-cost material or post-industrial waste in the middle layer to reduce cost, or to bury a pigmented layer between two layers of virgin polymer to reduce cost, increase gloss, or meet regulatory requirements.

It has long been recognized that 3-layer films have limits, such as with oxygen barrier, or print quality. To solve this issue, many 3-layer films were used as part of an adhesive lamination to reverse-printed films to achieve higher quality structures, either to other 3-layer films, or to metallized-oriented films and foil for improved barrier properties.

Conventional wisdom would say that if three layers are good, five layers must be better. Though this is not necessarily true, it can be said that five layers can offer more options and flexibility over 3 layers. Figure 1 shows a typical 5-layer film structure, showing a core layer of EVOH as a barrier layer, inner and outer layers of LLDPE, and "tie" or adhesive layers to join together the otherwise incompatible LLDPE & EVOH. This structure is ubiquitous today, and is used in many applications.

Figure 1 - Typical 5-Layer Coextruded Structures

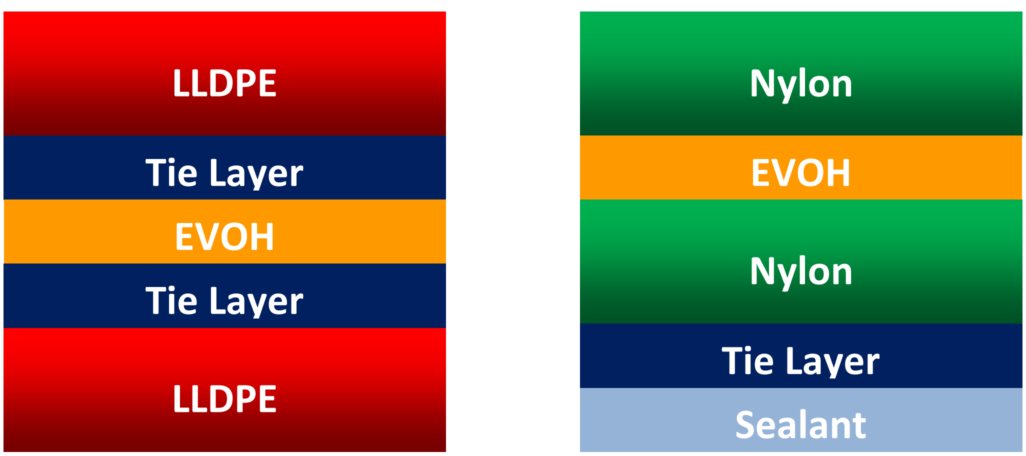


Fig 1A. Typical frozen food structure

Fig 1B. Typical processed and cook-in meat structure

For the many basic package structures, a 5-layer film obviates the need for an adhesive lamination step. Figure 2 shows a typical 5-layer coextrusion blown film line. Some might argue that the modulus of oriented PP & PET films are greater than unoriented nylon films, and that laminations are superior to unoriented blown films, and that the film structure shown if

Figure 1B above is inadequate for many packaging applications. However, careful examination of data **[6]** shows that the secant modulus of nylon is greater than polypropylene and about 10% less than PET. This difference is easily replaced by the traditionally thicker nylon abuse layer, and in practice, nylon-based packages exhibit good toughness and stiffness.

Figure 2. A traditional 5-layer coextrusion blown film line showing a nested spiral die, air ring and bubble. Courtesy Alpine American.

What are the benefits of 7/9/11 layer lines over 3- or 5-layer lines

Given what we know today, 5-layer structures are limited as to their performance and cost saving ability. From a simple cost standpoint for example, whereas the structure in Figure 1A is an [LLDPE – Tie – EVOH – Tie – LLDPE] structure, a 7-layer structure can utilize a lower-cost LLDPE in the second layer and an expensive, high-performance metallocene LLDPE as the skin layer, which has superior hot tack and heat seal properties. This structure, [mLLDPE – LLDPE – Tie – EVOH – Tie – LLDPE – mLLDPE] shown in Figure 3A below, optimizes performance and cost, and is used for milk packaging.

Alternatively, if improved barrier properties and toughness are desired, an [LLDPE – Tie – Nylon – EVOH – Nylon – Tie - mLLDPE] structure can be made with a 7-layer die, shown in Figure 3B. This structure is used as a lidding film with excellent barrier properties and gloss. If ethylene vinyl acetate (EVA) is substituted for the mLLDPE layer in this previous structure, the film can be used as a thermoformable cheese tray, shown in Figure 3C. The point made here is that more layers offers the package designer more options.

Figure 3. 7-layer structures for various applications and uses

Fig. 3A Cost reduction over the 5-layer analog

Fig. 3B High barrier lidding structure

Fig. 3C Thermoformable cheese tray

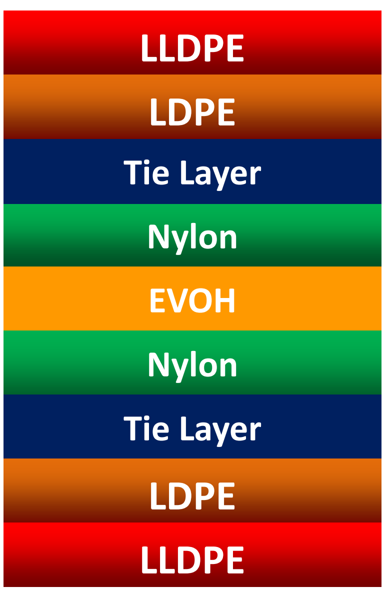
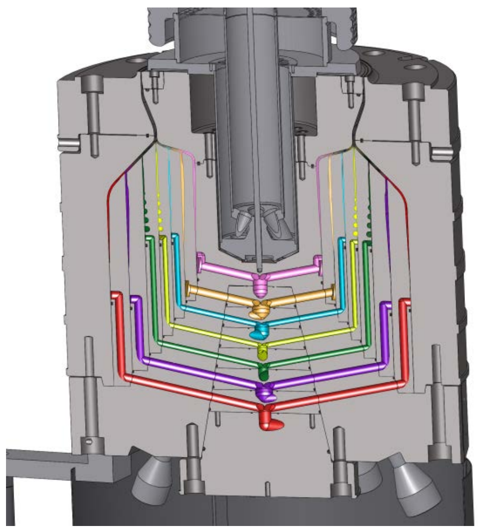


Fig. 3D 9-layer rigid, high barrier structure using cost/performance optimized PE resins

Fig. 3E 11-layer retortable, high-barrier structure using cost/performance optimized PP and copolymer PP resins

In the final analysis, the application determines the performance requirements, which in turn determine the function requirements. The ability to split an expensive sealant layer into two layers, one of which is less expensive, reduces the cost of the overall film and package. Assuming a single line that can produce 362 kg/hr x 22 hours/day up time x $0.0272/kg = $380,000/year savings **[7]**. This is achieved by substituting lower cost resins in a 9-layer structure as compared to a 7-layer structure. Figure 4 shows a schematic of a 7-layer die.

Figure 4. A cross-section of a 7-layer, nested spiral, blown film die. Courtesy Gloucester Engineering



In some parts of the world, some resins are simply not available, so substitution becomes a necessity. Moving to 9-layers gives further flexibility to the blown film manufacturer without sacrificing film properties. According to David Nunes, President of Alpine American in Boston, Massachusetts, USA, "There are dozens, perhaps more than 100, 7-layer blown film lines in use today. They offer the converter excellent flexibility in terms of product structure, asymmetric layer ratios, and film properties".

It is estimated that there are less than fifty (50) 9-layer lines in use in the world today, and 11-layer blown film lines are basically brand new entrees into the market place, so little practical information exists to report on today. It is envisioned that 11 layer structures will provide the ultimate in flexibility in terms of structures that can be made, with advances, asymmetric barrier structures being the target market. One technical source envisions a structure as shown in Figure 3 for use as a retortable pouch with superior barrier properties to be made on 11-layer blown film lines **[4]**. One configuration for an 11-layer blown film line is shown in Figure 5. It is readily discernible that manufacturing space becomes more and more crowded as the number of extruders is increased, creating a challenging operational and maintenance environment.

Figure 5. A 11-layer blown film line. Courtesy Alpine American

While none of the major manufacturers report any sales, or even the development of, a 13-layer die, a small development company in South Carolina, USA has been working on a 77-layer die which uses nano-technology via a series of layer-splitting rings to produce films of superior strength.

According to Henry Schirmer, CEO at BBS Corporation in Spartanburg, South Carolina, USA, "It has been shown that it is feasible to produce blown film configurations with up to 77 layers using our new Layer Sequence Repeater (LSR). This technology allows the polymer molecules to align without stress in a nanolayer film structure. This provides many advantages, such as increased blow-up ratio in blown film, higher orientation ratios on biax film lines, higher strength films, thinner films, and also improved clarity". Mr. Schirmer, who is author or co-author of nearly 100 patents, further indicates that "Nanolayer coextrusions of nylon 6 and EVOH can be made with higher-than-standard blow-up ratios on a blow film line, which yield high-strength, crystal-clear film, overcoming a present limitation of standard coextrusions of those two materials"**[8, 9,10]**.

Nano-layer films are truly novel and exciting. Because the surface contact area within a nano-layer melt is so great and the mass is so small, instantaneous air quenching reduces crystallinity in a similar manner to water quenched films and high clarity is the result. Even DSC polymer signatures have been altered with nylon/EVOH combinations consistent with forming a co-polymer between these 2 active polymers, which is nothing short of miraculous.

Are there any alternatives to advanced multilayer blown film lines?

While there is a lot of technical merit to 7/9/11-layer blown film lines, the market will have to sort out the utility of this new technology. Until then, there is a very large installed base of 3- and 5-layer blown film lines, dozens or more oriented film machines, vacuum metallizers, adhesive laminators and extrusion laminators that, when taken together, can produce any combination of bulk layers, barrier layers, adhesives and sealants to satisfy any need without any further capital expenditure. And while not as Green or environmentally friendly perhaps as a single-step blown film operation, cost is quite often a driving factor in any product design or market category.

Conclusion

Technology exists today to produce blown films with up to 77 layers. The most common number of coextruded layers in use today is 3 layers, with a trend to 5- and 9-layer films. As machinery advances are made, new product structures are created to fulfill various market needs. A balance will be struck between cost of new capital equipment required to makes 7/9/11-layer films, and the benefit derived from doing so. The competition is not necessarily another machine supplier, or from a lower cost producer, but from another technology that can laminate unlike films to produce similar structures, namely adhesive lamination and extrusion lamination. These technologies have coexisted for many years, and are likely to do so for the foreseeable future.

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