Flexible Plastic Packaging
Part Two – Manufacturing

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Plastic Films

Conceptually, making a thin polymer film is an easy proposition - just melt one or more polymers, force the melt through a long, narrow opening, freeze the extruded melt into a solid film, and wind it into a roll. Like most important things, there is a rich and extremely varied menu of material and process variables that offer the opportunity to create widely differing useful films. The opportunities—and the devils—are in those variables.

Film making processes

- Extrusion
- Cast Film
- Air-Cooled Blown Film
- Water Quench Blown Film

In this presentation we will concentrate more on Air - Cooled Blown Film Process.

Blown Vs. Cast film extrusion

- In cast film extrusion the thickness variation is minimum and hence the gauge control is better compared to that in a blown film process. The rapid quenching of film in case of cast film offers a significant advantage in the improvement of the film properties related to the rate of quenching.

- The stiffness and clarity of cast film is superior compared to a blown film. Output of the Cast film lines are higher, however machinery cost & operative costs are much higher compared to blown film.

Blown Vs. Cast film extrusion

- Blown film process however offers some distinct advantages in processing of the film. ts ability to give films of varying widths by merely changing the blow up ratio and the ease of changing the die makes blown film process popular.
- Blown film due to its biaxial orientation gives balanced properties of the film in Machine & Transverse direction. Moreover the recent developments in the processing equipment viz. computerized thickness control mechanisms have offset the earlier disadvantages when compared to cast film process.
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Blown Vs. Cast film extrusion

- However, the market forces, the producer's needs and capital costs are the basic factors influencing the selection of one process over another

Blown Film Process

- The blown film extrusion system is, in fact, one of the most complex and sensitive of all plastics processing technologies.
- An operator can become so familiar with a given film line that problems are solved intuitively, but training new personnel or bringing a new line on stream may raise difficulties.
- However, anyone familiar with blown film extrusion knows this simplified explanation is less than half the story.

Approach

Reviewing the blown film extrusion process can prepare you to handle these problems.

Blown Films

The tubular blown film process is efficient and economical, and can produce a magnificent array of products — from a light gauge, clear converter film to heavy gauge construction film, which when slit and opened, may measure 40 feet or more in width.

Blown Film Process Basics

- The elements of the process **(Figure 1)** include the resin pellets which are fed through a hopper into an extruder. Here, heat and friction convert the pellets to a melt which is forced through an annular or ring-shaped die to form a tube.
- The tube is inflated to increase its diameter and decrease the film gauge. At the same time, the tube is drawn away from the die, also to decrease its gauge. The tube, also called a “bubble,” is then flattened by collapsing frames and drawn through nip rolls and over idler rolls to a winder which produces the finished rolls of film.

Blown Film Process Basics

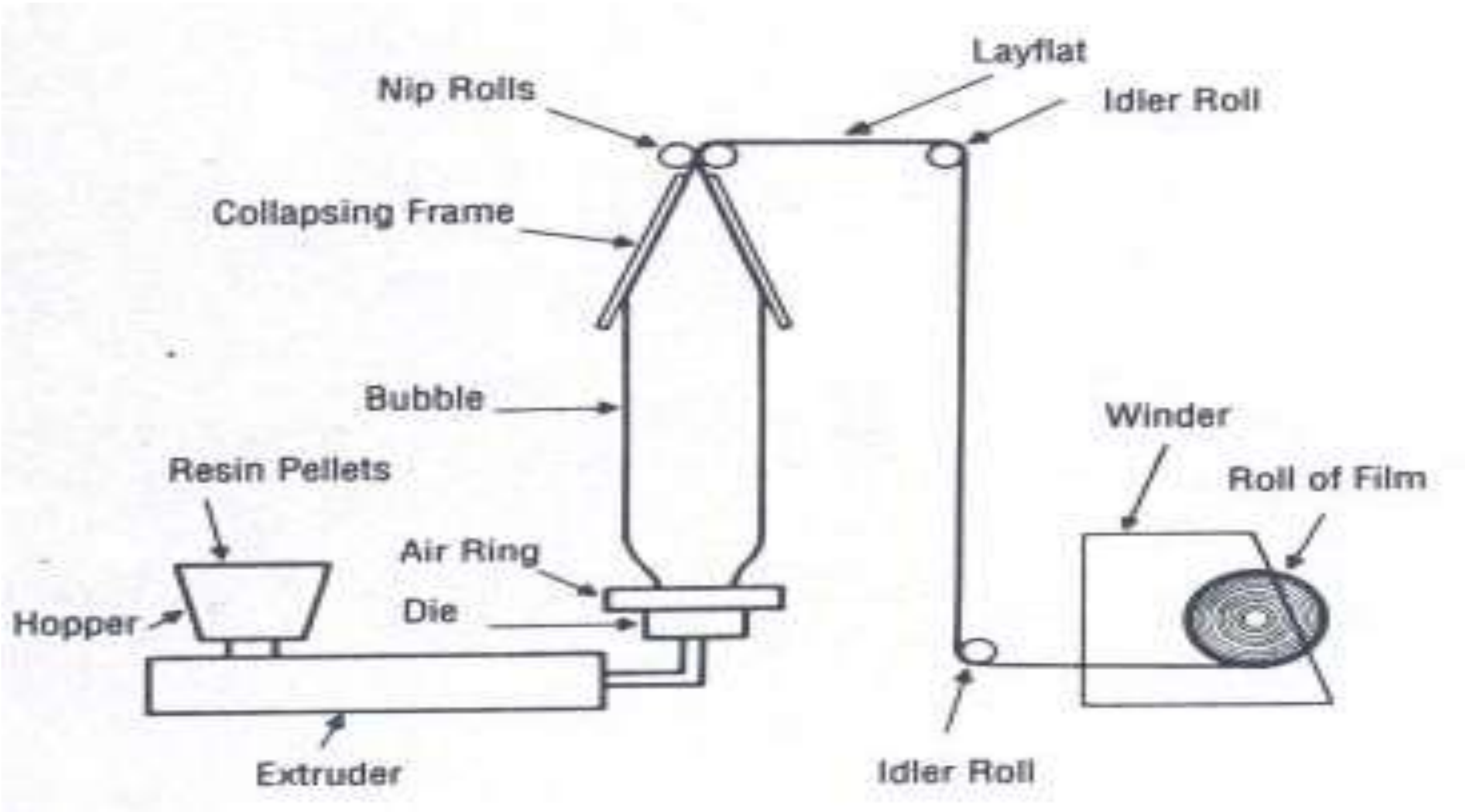

Fig 1

Blown Film Process Basics

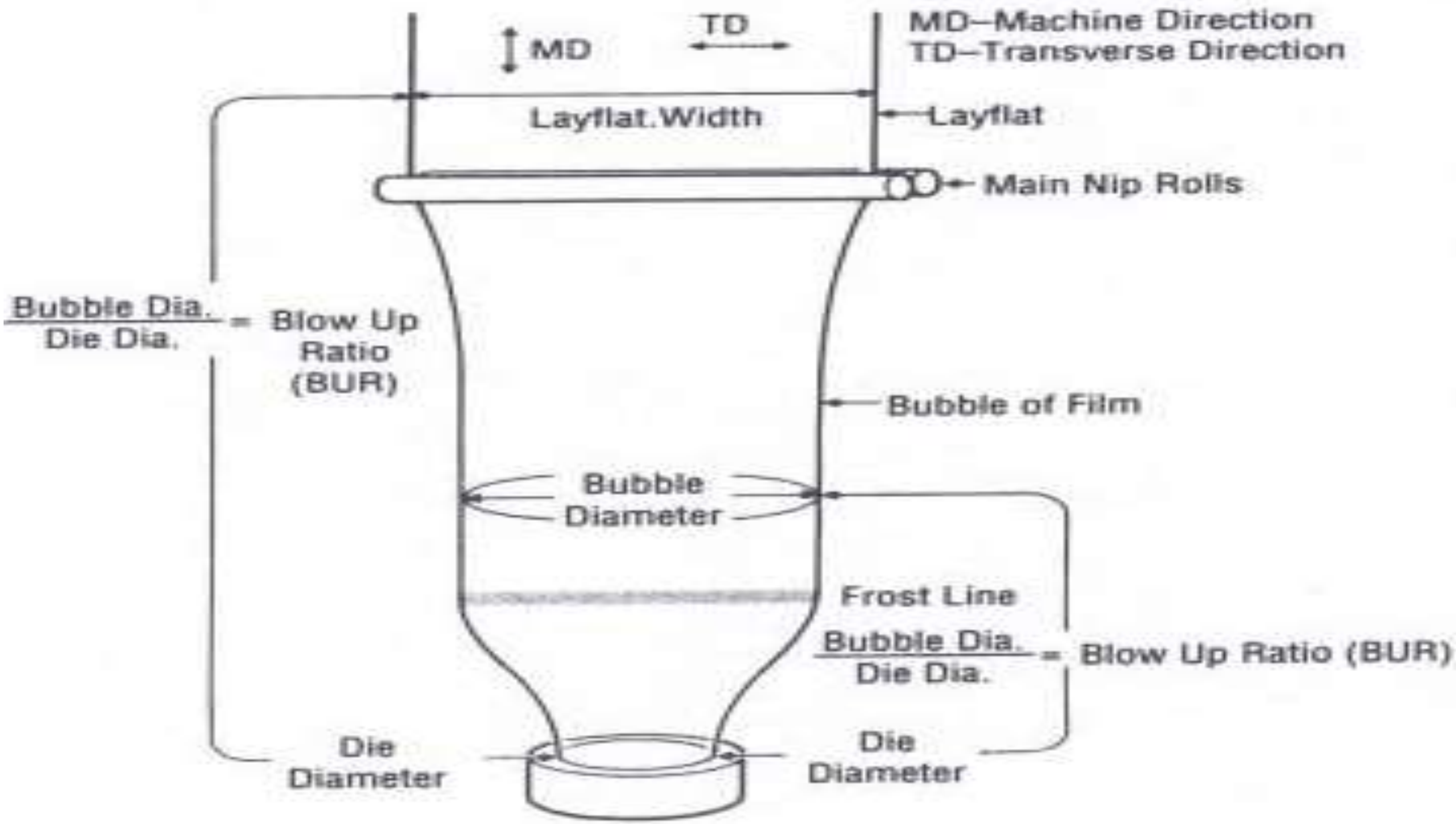

Fig 2

Blown Film Process Basics

- Even though practice does not always follow theory, theory can help explain many of the problems encountered in extruding polyethylene into blown film.
- More of the problems in blown film extrusion take place in the section of the tube illustrated in **Figure 2** — from within the die to the far side of the nip rolls — than in any other portion of the line.

Mono & Multilayer Blown Films

- Monolayer Blown Films are predominantly used for Secondary Packaging such as carry bags, T Shirt bags etc
- Multilayer co-extruded Blown Films are used for primary packaging for food products.
- Most of the films produced by SMEs under this program are monolayer hence we will duel more on monolayer, however let us understand what multilayer co-extruded films offer.

Why Multilayer Films Are Superior To Monolayer Films In Packaging

- Co-extrusion is a process to manufacture multilayer structure by the simultaneous extrusion of two or more polymers.
- It has been observed that a single polymer cannot meet the packaging requirements of properties such as high impact, high stiffness, good sealability, optical properties, barrier properties etc. However, a multilayer structure offers a good blend of properties.
- Co-extrusion gives the processor the flexibility in choice of characteristics that are required to be built into the film as required, by use of different polymers.
- The feel of the bag, high strength, and increased gloss for better printability, improved optics, and enhanced sealability can all be tailored for a particular application.

Mono VS Co-extruded Multilayer Films

- The ability to combine the superior properties of different polymers, allows the use of higher loading of master batch without affecting sealability, and this results in lower production cost of the film composite.
- The output rates of individual layers in a multilayer die are very much lower than for equivalent size of single layer die. This results in reduced shear rate and longer resistance times in the die spirals, leading to better homogeneity and additional relaxation of melt. Hence, the inherent benefit of Co-extrusion is the improvement of film quality.

Oxygen & Moisture Barrier

Oxygen and Moisture are the two elements which cause lot of damage to the product packed in the film.

Influence of moisture causes:

- Agglomeration of powders,   Stickiness in product
- Loss of nutritive value , Bitter taste
- Loss of crispness in baked/dried foods,
- Hydraulic rancidity etc.

Influence of oxygen (even in small quantities) causes:

- Change in color, Formation of off-taste
- Vitamin degradation, Change in Aroma
- Oxidation Rancidity

All these can be eliminated by using a multilayer film structure which gives excellent moisture & oxygen barrier properties

Film properties : Multilayer (3-layer) v/s Monolayer

Film property, Unit	Monolayer film LDPE, 50 micron	Multilayer, 3-layer film LL/LD/LL 30 micron	Benefit (%)
Yield Tensile strength MD, MPa	9.5	12.3	+ 29.5
Yield Tensile strength TD, MPa	9.0	13.0	+ 44.0
Ultimate Tensile stress MD, MPa	26	28.2	+ 8.0
Ultimate Tensile stress TD, Mpa	21	27.4	+ 30.0
Ultimate Elongation MD, %	245	415	+ 69.0
Ultimate Elongation TD, %	650	745	+ 14.6
Specular Gloss, %	60	65	+ 8.3
Tear Resistance MD, g/mil	38	50	+ 31.5
Sealability property	Moderate	Excellent	improved

Studies indicate that a three layer film of same polymer can increase the tear, dart & drop strengths by as high as 25 - 30 % over those of an equivalent thick film made in single layer. This improvement allows the film to be down gauged (i.e. lower thickness) while still maintaining the product strength and abuse resistance. This results in raw material savings up to 35 - 40 %. The above table clearly illustrates the same.

Monolayer Blown Films

Blown Film Industry

- The blown film extrusion system is one of the most complex and sensitive of all the plastics fabricating technologies and it presents many inherent difficulties. In addition, the surging demand and its dynamics are exerting various challenges to sustain on part of plastic manufacturing industry.

- Plastic manufacturing industry is facing operational, economic and environmental issues.

Issues

- The operational issues include low labor productivity, low scale of production, obsolete machinery. Strong processing industries in neighboring countries which results in higher competitive cost of manufacturing.

- The economic issues are fluctuating crude oil prices, higher cost of production for end user.

- The environmental issues are mainly attached with flexible packaging plastic. Customer pressure is resulting in banning this versatile material in production and use.

Process

- Blown film extrusion is tedious and complex process.
- The typical process variables are screw diameter, screw speed rpm, barrel temperature, die diameter, die gap, bubble height, bubble perimeter, etc.
- The requisite mechanical properties at the end of the process are tensile strength, tear strength, shrinkage, haze and gloss, etc.
- The open market intense cost competition and environmental drivers are compelling the optimization of these process variables to maximize output and minimize material consumption and energy.

Blown Film Extrusion Process Variable

- The typical cost structure in plastic processing is
  - 70% raw material,
  - 5-15% labor and
  - 15 to 25% energy.
- The raw material estimated losses at material handling, scrap rates, setups and purging were estimated at 1.5 – 3 %.
- There is also material degradation because of excessive heating and recycling.

Energy Consumption

In terms of energy consumption, major energy requirement for blown film extrusion process is the electricity to drive the extruder screw motor. Significant energy is also used to drive cooling fan motors and lesser amount is required for winder equipment as below.

Energy Consumption in Blown Film Extrusion

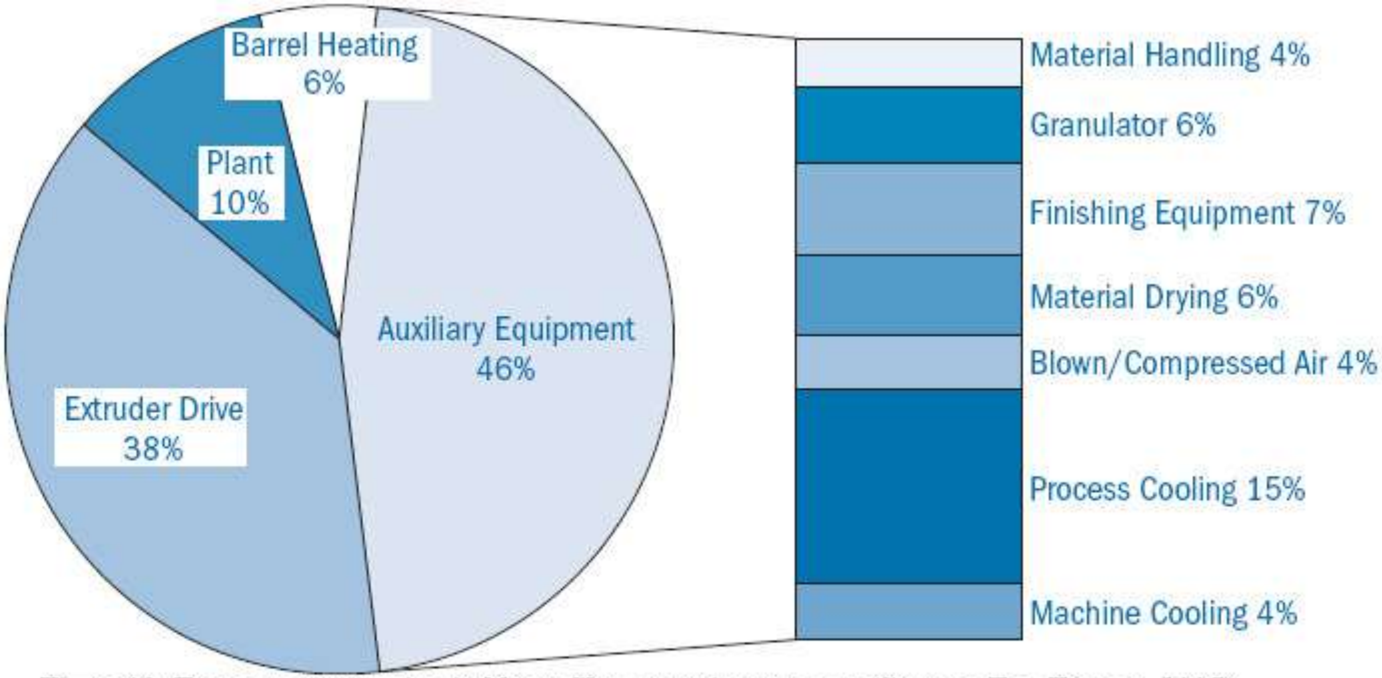

Figure02. Energy consumption in blown film extrusion process (Source: Eco-Energy, 1997)

LCA Studies

- **LCA studies are conducted worldwide, which are prima facie source of average energy consumption in blown film extrusion process.**
- **American plastic film manufacturers required energy in the range of 5.87 to 6.51 MJ for manufacturing one kilogram of plastic films (PE Americas (2008), Life Cycle Services (2007).**
- **Australian plastic film manufacturers require 10.2 to 10.5 MJ for processing one kilogram plastic film (Ross and**
- **Evans, 2003).**
- **Indian plastic film processing consumes 11.4 to 31.42 MJ of energy for processing same plastic films (Nayak and Swain (2002), Ghosh (2004)).**

How much is your energy consumption?

It is necessary to do energy audit.

The Recent Developments across Film Manufacturing and its Implementation

- **Innovations in terms of recent research are not incorporated in practice. For instance,**
  - **blend selector for heat shrinkage packaging,**
  - **instabilities and multiplicities in isothermal blown film extrusion,**
  - **melt rheology analysis,**
  - **effect of polymer processing additives.**
- **Tools for optimizing flexible packaging are**
  - **innovative die design,**
  - **energy efficiency at blown film extrusion process.**
- **Large and medium scale companies adopt recent technologies like**
  - **stack dies,**
  - **internal bubble cooling, oscillating take-off, thickness profile control, gravimetric blending and dosing.**

The Recent Developments across Film Manufacturing and its Implementation

- There is huge gap between blown film extrusion processes practiced by large, medium, small companies.
- The major factor is technology. However, each segment is following different production practices depending on technical expertise and experience. It creates lot of technological independent difference.

The Recent Developments across Film Manufacturing and its Implementation

- The variable outcomes of such difference are varied energy consumption, material consumption, throughput and product quality. Knowing the variation for extrusion process in various countries and plastic film manufacturing companies classified according to size, there is variation in the performance outcomes.
- Hence, to improve the performance in all aspects, **BENCHMARKING** is done for best practices

BENCHMARKING

- **Units of Analysis:**

Blown film extrusion process viz pallet feeding unit, extruder unit, die unit, bubble cooling and stabilizing unit, bubble take-off unit and film winding unit.

- **Variables of Analysis:**

Material consumption and waste creation, energy consumption, process based product quality, labor productivity and unwanted outputs (environmental).

BENCHMARKING

- Each dependent variable is analyzed focusing independent process variables for its cause and effect using ‘fishbone diagram’.
- The commonality in process variables are identified and benchmarked for blown film extrusion process.
- Lastly, best practices are reviewed for each process variables to reduce precision gaps in independent variables across the industry.
- **Boundaries of Work:** The work excludes technology advancements, etc.

IDENTIFICATION OF BEST PRACTICES

Fishbone Diagram of Blown Film Extrusion Process and its Analysis:

- The main dependent parameters for process analysis are material and resource consumption, energy consumption, throughput, product quality and unwanted environmental effects.
- The horizontal main bone of fishbone diagram depicts blown film extrusion sub-processes. The main branches are sub-process variables. The fishbone diagram is shown in next slide.

Fish Bone Diagram

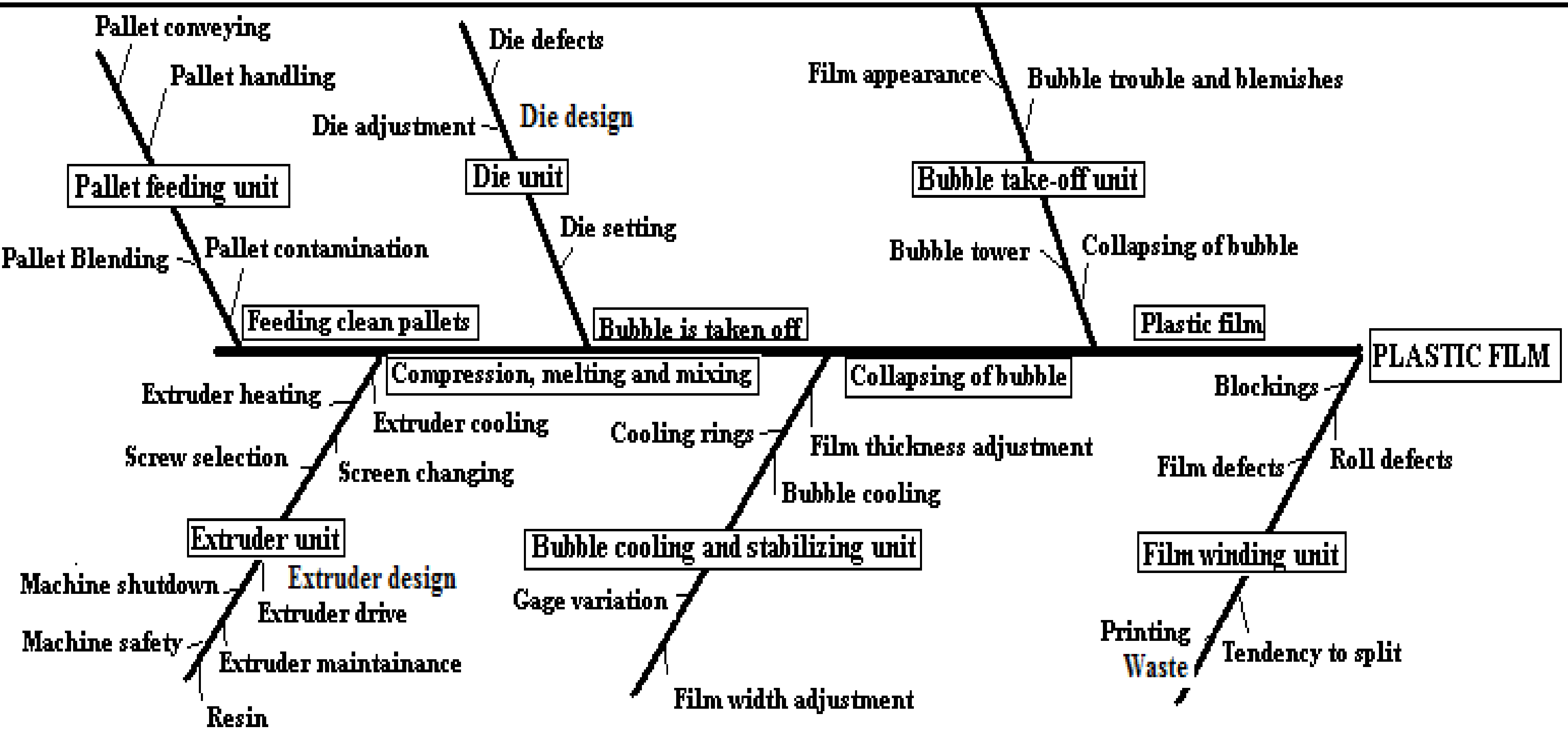

Figure04. Fishbone diagram for blown film extrusion process (Variables: Energy / Material consumption, Throughput, Product quality)

LDPE

- LDPE is the most friendly material for blown film processing.
- Melts are pseudo-plastic and hence melt viscosity is not high.
- Motor-loads for extruder motor are low.
- Extruder screw with L/D 24 can also give adequate output.
- Stress thickening elongational viscosity:
  - Leads to bubble stability, the blow-up ratio can go high without melt rupture (upto 4)
  - Makes it possible to process materials of lower MW (higher) MFI also
- LDPE is useful to improve the bubble stability of LLDPE, when mixed.
- Extruder with screw L/D 24 can be used to process 70:30::LDPE:LLDPE blend.

LLDPE

- LLDPE melts are less pseudoplastic as compared to LDPE melts, so viscosity at processing temperatures is high.
- Extruder motor loads are higher, with metallocene LLDPE motor loads are still higher due to narrow MWD & still less pseudoplasticity of melt.
- Screw with higher L/D and designs to enhance output (e.g. Barrier screw) have to be used to ensure steady supply of melt to the die.
- Elongational viscosity is stress thinning:
  - To ensure high elongational viscosity at the melt stretching rates employed the molecular weight is high (MFI 2 or less)
  - Blends with LDPE employed to ensure avoiding melt rupture & bubble stability. (Trends to use LDPE as less as possible below 30 % in order to take advantage of lower prices of LDPE)
- Incorporation of even 10 % of LD in LL improves transparency as well as gloss of films (with mechanical properties at acceptability level.), improvement in bubble stability & decrease in motor loads.

HDPE

- Generally HM-HDPE films are used. (HD films go as middle layers in three layer constructions with outer layers of LLD+LD)
- HM-HD grades are bimodal. High MW fraction, being sluggish in crystallization leads to large number of lower melting crystallites with tie molecules & low MW fraction giving large high melting crystallites.
- For desirable crystallization and desirable orientation of crystalline & amorphous zones, bubble shape is of wine-glass.
- Orientation of the crystallite lamellae & tie molecules perpendicular to MD leads to better strength along TD, improving tear strength along TD
- Films with high crystallinity are more hazy.

Structure development during processing…

- Usually when PE melt is cooled it would lead to spherulitic structures (e.g. in injection moulding & thick extrudates)
- When melt is shaped & cooled and simultaneously stretched the crystalline and amorphous structures get formed as well as oriented.
- The degree of crystallinity attained depends on rate of cooling as compared to rate of crystallization of individual polymers.
- Under the elongational flow-field below frost line the crystalline zones formed as well as the tie molecules get oriented to enhance strength.
- During manufacture of PE films by blown film extrusion the crystallization as well as orientation takes place in molten state.
- The orientation is dictated by the MD stretching and blow-up ratio.

Structure development in LDPE films..

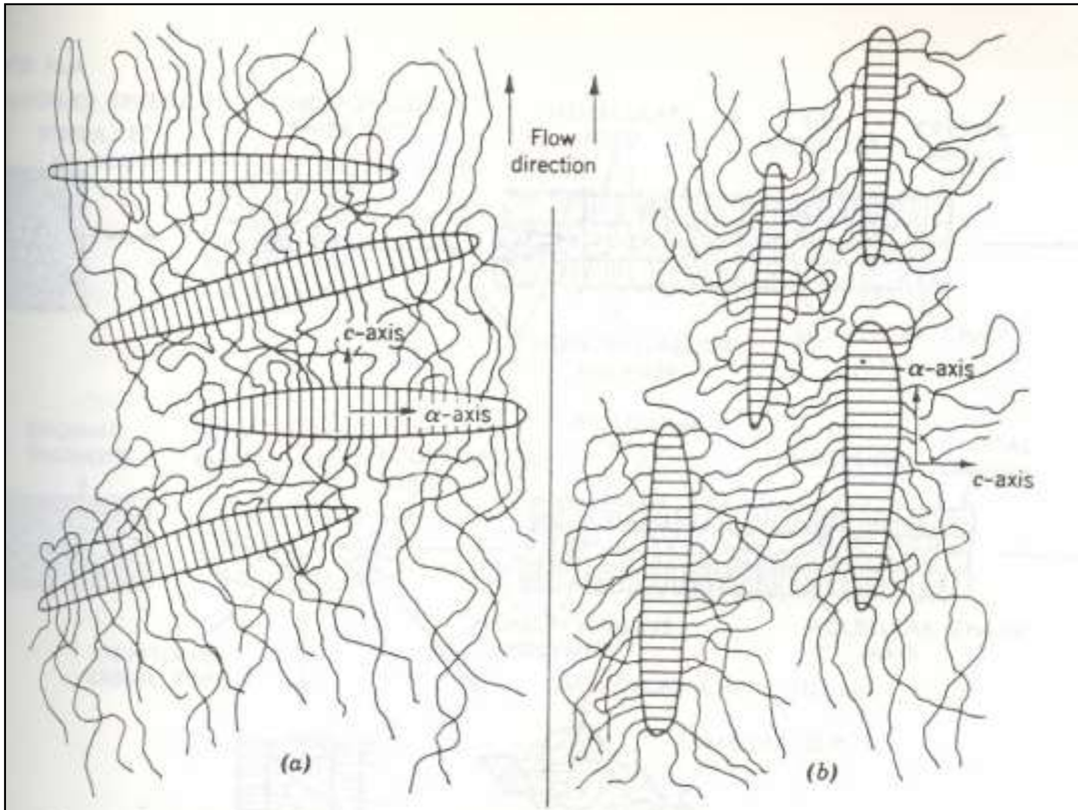

Fig. 2.2.4. - Alignment of crystallites in (a) cold drawn polyethylene and (b) extruded film

Fig (b) represents the structure of LDPE Blown films

Structure development in Linear PE films

- Morphological studies of HDPE films prepared by different haul-off speeds & blow-ratios carried out.
- Row nucleated lamellae perpendicular to machine direction formed during crystallization under stress.
- As haul-off speed increased lamellae became more perfect in in perpendicular direction & dimension of lamellae increased in that direction.
- α axes of lamellae were perpendicular to MD.
- Schematic presentation in next slide…

Structure development in Linear PE films

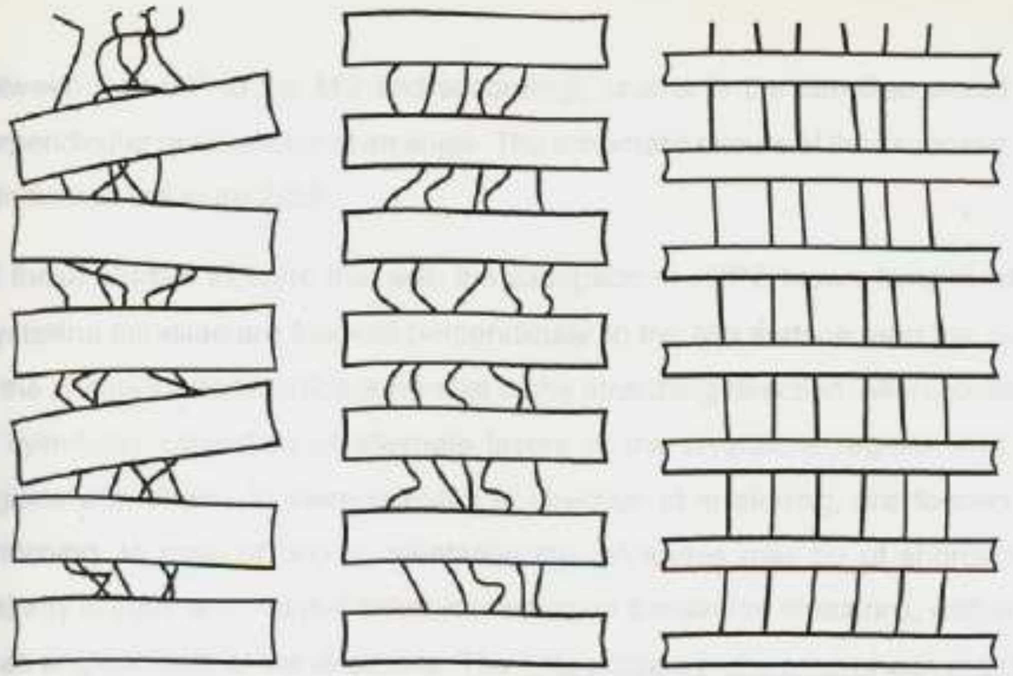

Fig. 2.2.7. - Orientation of lamellae with increase in haul off ratio

Structure development in HDPE films with changing MD stretching.

Prevention Checklist

For the Operator

When you go on shift or take over another line, do you

"stop, look, listen and feel?"

- Many elements of a properly designed, installed and adjusted blown film line remain trouble-free for a long time. Other parts may need repair often. Most malfunctions show up quickly in the form of some defect in the film.

LOOK

- Are the resin, additive and recycle
- systems correctly adjusted and functioning properly?
- Are the melt temperature pressure gauges and temperature controllers functioning?
- Are there any temperature over- or under-rides?
- Are bubble shape and frost line normal?
- Are there any wrinkles in the web?
- Is the trim too narrow or too wide?
- How does the roll look on the winder?

LISTEN

- How do the extruder drive system, resin feed system, barrel cooling pumps, relays and treater sound? Any variations in sound can be an indication of trouble. If you become familiar with sounds of the line in operation, many times you can stop a problem from becoming a larger one, if not prevent it altogether.

FEEL

- Is there excessive heat or vibration in the extruder transmission and drive bearings?
- Is the air chiller functioning in the air ring?
- Are water cooling lines cool, warm or hot?
- Is the web tension too tight or too loose?
- How hard is the roll across the face?

Additives in film grades

- **Antioxidant** :

They are incorporated in Polyethylenes to prevent thermo-oxidative degradation during manufacturing, processing and end-use.

- **Antiblock Agent** :

LLDPE films have a tendency to bind itself during roll formation, which is aggravated if temperatures of film and winding tensions are too high. To prevent the blocking, antiblocking agent is added to polyethylene.

Additives in film grades

- **Slip Agent** :

LLDPE films tend to have somewhat tacky surfaces and hence a high coefficient of friction (COF). Slip agents are added to reduce COF and improve the machineability of films on FFS machines.

- **Polymer Processing Aid (PPA)** :

It reduces the shear stresses in the barrel and the die, thus eliminating the surface defects such as melt fracture and shark skin effect. Processing aid also reduces the back pressure and motor load on the extruder.

Important Film Properties

- Dart Impact strength
- Tensile properties
- Tear strength
- Coefficient of friction
- Hot tack strength
- Heat seal strength
- Haze
- ·Gloss

DART IMPACT STRENGTH (ASTM D 1709)

Impact strength of film is determined by measuring the loss in kinetic energy of a free falling dart as it penetrates a film specimen.

Impact strength is indication of the balance of film properties in both the direction.

TENSILE STRENGTH AND ELONGATION (ASTM D 882)

- Tensile strength and elongation of film is measured using a tensile test machine. Film samples must be tested in the direction of maximum orientation and in the cross direction.
- Tensile properties are another indication of the mechanical strength and toughness of the film.

PROPAGATION TEAR RESISTANCE (ASTM D 1922)

- It is measured using a calibrated pendulum apparatus commonly known as the Elemendorf tear tester.
- Propagation tear resistance is another indicator of measure of the balance of the film properties in both directions.

COEFFICIENT OF FRICTION (COF)

- It is a measure of the resistance offered by a film surface when in contact with other film/metal surface. COF determines how the film will perform on packaging machines.
- The COF value depends on the amount of slip additive present in the resin.

HOT TACK STRENGTH

- “Hot tack strength” is an excellent measure of the ability of a film to form a strong heat seal and to withstand mechanical stress which might be applied to the still molten seal during packaging operations.
- Hot tack strength is usually determined at various sealing temperatures and the results described in graphical form.

HEAT SEAL STRENGTH

- Heat seal strength is the tensile strength of seal at ambient temperature.
- A test specimen of film is heat sealed (in the cross direction) under standard sealing conditions, and the force required to peel the cold seal apart is measured.

Hot Tack & Heat Seal Testing

HAZE

- Haze is the measure of clarity of a film. It is the scattering of light within or at the surface of a nearly clear specimen responsible for cloudy appearance seen by transmission. In other words, haze is the ratio between diffused light transmittance and total light transmittance. 0% haze indicates a perfectly clear transparent material and 100% haze indicates an opaque material.

GLOSS (ASTM 523)

- Gloss is measurement of light reflected at the specular angle, the angle equal and opposite to the angle of light hitting the sample. For most gloss measurements, light is directed on to a sample at 60° from the perpendicular. The percent of light that is reflected at the specular angle (-60°) is reported as the gloss. 60° is the most commonly used gloss angle.

Haze & Gloss Meter

Thank You