Substrates for Flexible Packaging

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Substrates and Their Properties

Less Common Substrates

Paper

- Properties
  - Biodegradable
  - Recyclable
  - Variety of coatings available
  - Excellent deadfold
- Cons
  - Often used with plastics
  - Typically requires coating
  - Poor product shelf life

Metal (Aluminum) Foil

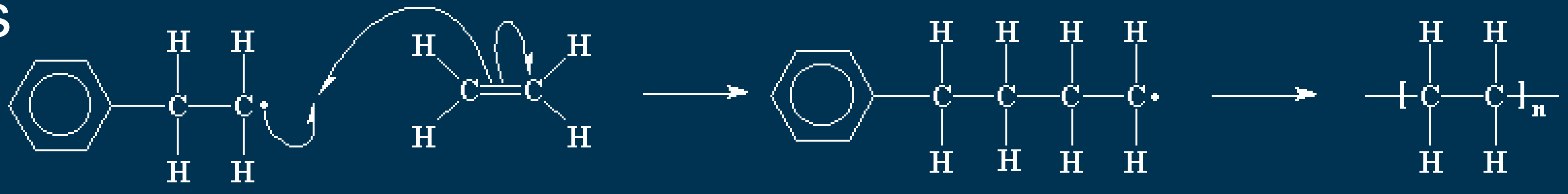
- Properties
  - Best barrier properties
  - Best deadfold
  - Recyclable
  - Good reflector of Heat
- Cons
  - Fragile/Brittle
  - Typically used with plastics/paper
  - Prone to pinholes

Plastics (Polymers)

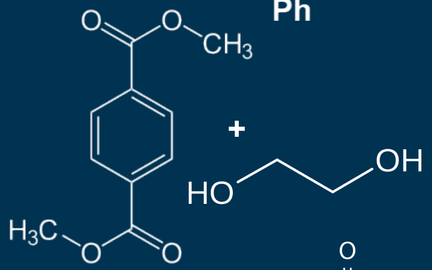
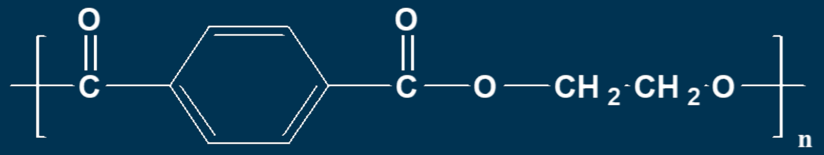
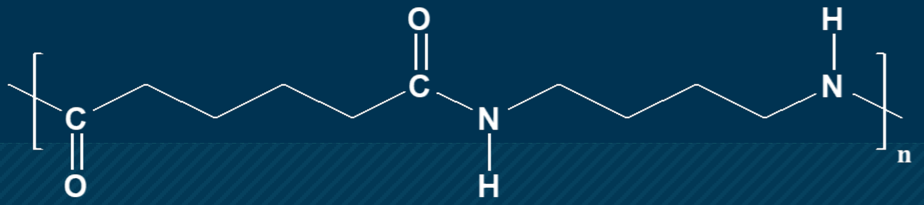
Most Common Substrates

What is a Polymer?

- Macromolecule made by linking monomers together.
- Can be "Homopolymers" or "Co-polymers"
- Polymerization Processes
  - Free Radical Processes
  - Coordination Catalysis
    - Ziegler-Natta Process
    - Metallocene Catalysis
  - Condensation Polymerization
- Polymers are high molecular weight



Common Polymers & Their Monomers

Polymer Name	Monomer(s)	Repeat Unit	Polymerization Reaction
Polyethylene PE	$CH_2{=}CH_2$	$[-CH_2-CH_2-]_n$	Ziegler-Natta
Polypropylene PP	$CH_2{=}CH(CH_3)$	$[-CH_2-CH(CH_3)-]_n$	Ziegler-Natta
Polyvinylchloride PVC	$CH_2{=}CH(Cl)$	$[-CH_2-CH(Cl)-]_n$	Free Radical
Polystyrene PS	$CH_2{=}CH(Ph)$	$[-CH_2-CH(Ph)-]_n$	Free Radical
Poly(ethylene terephthalate) PET			Condensation
Nylon 6,6			Condensation

Polyethylene (PE)

$$\left[CH_2 - CH_2 \right]_n$$

The most abundant polymer used today

Typical applications include bread bags, newspaper overwraps, sealant film for laminations, etc.…

LDPE

Low-Density PE

LLDPE

Linear Low-Density PE

HDPE

High-Density PE

Three primary types differentiated by branching within the polymer structure

Polyethylene (PE) $\left[-CH_2-CH_2-\right]_n$

LDPE

Low-Density PE

- Properties
  - Inexpensive
  - Decent Clarity/ Good Gloss
  - Soft/ very flexible
  - Heat Sealable
  - Fair moisture barrier
- Cons
  - Requires high levels of additives
  - Printability
  - Narrow heat seal range

LLDPE

Linear Low-Density PE

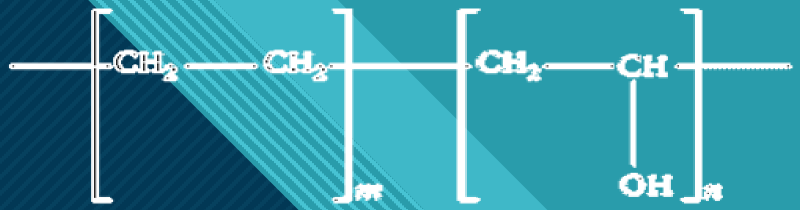
- Properties
  - Improved barrier properties to LDPE
  - Tougher than LDPE
  - Improved sealability to LDPE
- Cons
  - Reduced gloss/clarity to LDPE
  - More difficult to process compared to LDPE

HDPE

High-Density PE

- Properties
  - Improved stiffness to LLDPE
  - Tougher than LLDPE
  - Improved barrier properties to LLDPE
- Cons
  - Reduced gloss/clarity to LLDPE
  - Less printability
  - Less sealability

Ethylene vinyl alcohol (EVOH)



Ethylene Unit Vinyl Alcohol Unit

Typically used in multilayer films due to moisture sensitivity

Defined by the mole % of ethylene content. Grade affects barrier properties/extrusion temperatures

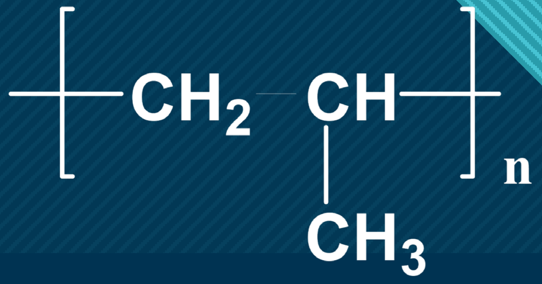
Properties

- Excellent transparency/gloss
- Excellent gas/aroma barrier properties
- Excellent oil/solvent resistance
- Anti-static properties

Cons

- Difficult to produce/expensive
- Moisture sensitive
- Can cause issues during recycling

Polypropylene (PP)



Second most abundant flexible packaging film

Primarily used in food packaging due to good strength

Properties

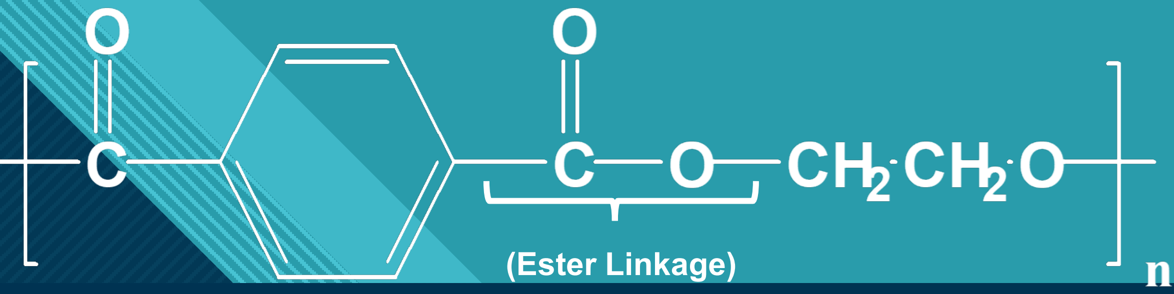
- Low cost
- High clarity and gloss
- Fair gas barrier
- Good moisture barrier
- Good mechanical properties
- Recyclable

Cons

- Static build up
- Poor tear propagation
- Susceptible to UV degradation
- Susceptible to oxidation

Polyethylene terephthalate (PET)

(Polyester)



Used for a variety of demanding applications due to chemical resistance/inertness

Typical applications range from microwaveable packaging, medical packaging, or safety window film

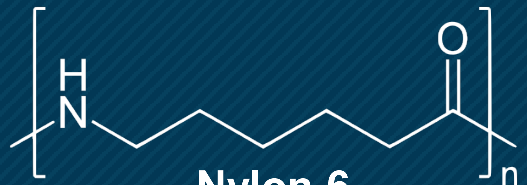
Properties

- Excellent clarity and gloss
- Excellent flavor, odor, and solvent barrier
- Moderate moisture barrier
- Excellent heat resistance
- High chemical resistance
- Recyclable

Cons

- High manufacturing cost
- Static generation
- Requires additives for biodegradability

Nylon (N or PA)
(Polyamide)



Nylon 6

or

Nylon 6,6

Excellent oxygen barrier properties but is carbon dioxide permeable

Primarily used for food packaging such as meat, fish, cheese, and dairy products to avoid ballooning

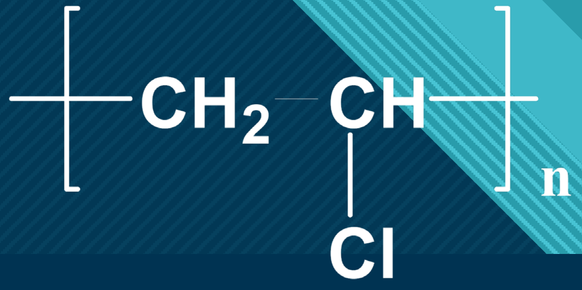
Properties

- Heat resistant
- Exceptional strength & toughness
- Good flavor and aroma barrier
- Excellent oxygen barrier, but CO_2 permeable
- Good chemical resistance
- Relatively easy to process

Cons

- Expensive
- Moisture sensitive
- Difficult/expensive to recycle

Polyvinylchloride (PVC)



Third most widely produced synthetic plastic

Primarily used in shrink sleeves, stretch wrap, tamper proof packaging, caps, and decals

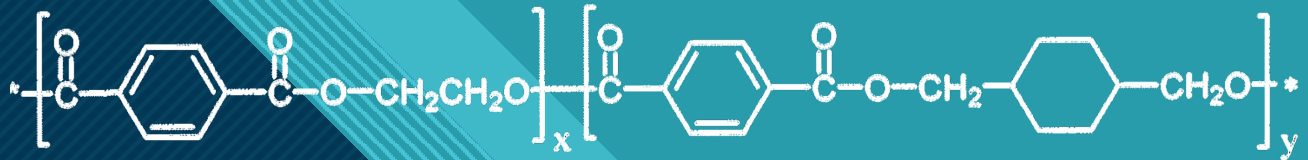
Properties

- Cost-efficient
- Good impact strength
- Soft & conformable
- Product resistance
- Oxygen permeable
- Abrasion resistance

Cons

- Sensitive to certain solvents
- Plasticizer levels can affect properties
- Environmental and health concerns

PET-G (Glycol modified PET)



ET Unit (PET Monomer) CT Unit

Excellent formability with good chemical resistance and durability

Typical applications are shrink sleeves, bottles, and pharmaceutical/medical device packaging

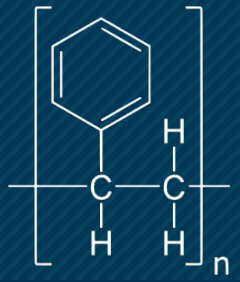
Properties

- Good clarity/ and excellent gloss
- Heat resistant
- Excellent mechanical properties
- Good chemical resistance
- Good gas/ decent moisture barrier properties
- Highest shrink percentage
- Recyclable

Cons

- Most expensive shrink sleeve material
- Static generation
- Difficult to recycle

Polystyrene (PS)



Excellent clarity and high gloss with excellent anti-static properties

Primarily used in shrink sleeves, tamper proof packaging, envelope windows, and protective films for screens

Properties

- Excellent transparency/gloss
- Excellent antistatic properties
- Inexpensive
- Breathable

Cons

- Poor impact strength
  - Copolymers can improve
- Poor chemical resistance
- Environmental concerns

Chemical Resistance

Chemical resistance plays a significant role in the ability of a film to maintain its integrity

Chemical Resistance of Common Substrates

Material	Dilute Acid	Dilute Alkali	Oils/Greases	Aliphatic Hydrocarbons	Aromatic Hydrocarbons	Halogenated Hydrocarbons	Alcohols
LDPE/LLDPE	4	4	2*	1	1	1	4
HDPE	4	4	2*	1	1	1	4
PP	4	4	2*	1	1	1	4
PET	4	2	4	4	2	2	4
PVC	4	4	3*	4	1	2*	3*
PS	2	4	2	4	1	1	1*

Rated on a 1-5 scale, 1 being poor and 5 being excellent. * Indicates the resistance is variable

Oxygen & Water Vapor Permeability

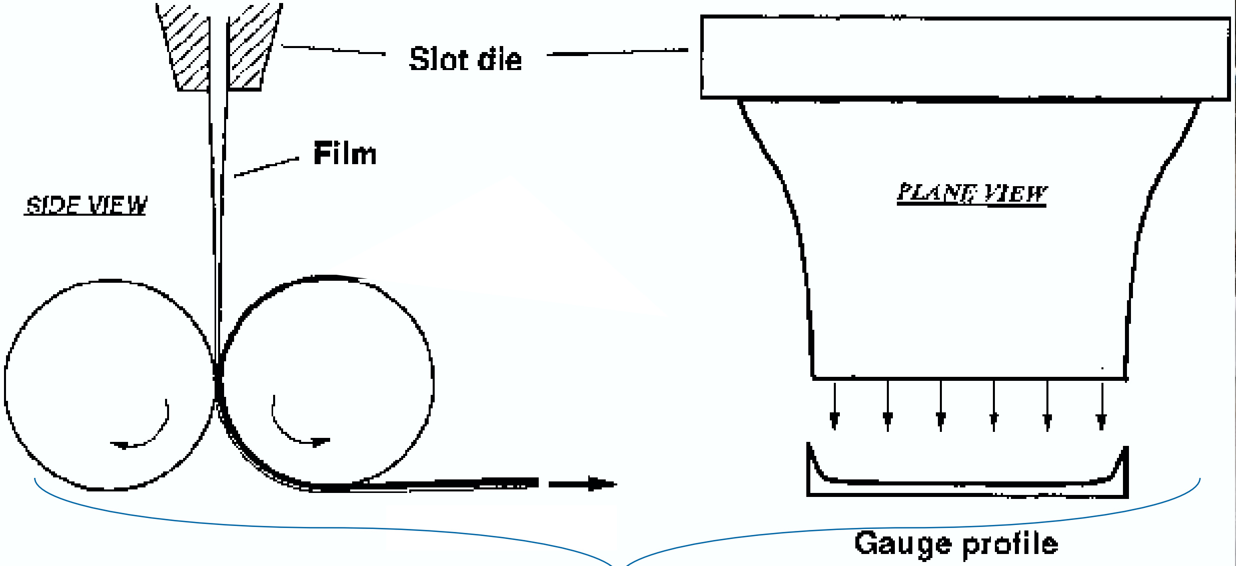
Oxygen and Water vapor permeability play a significant role in shelf-life of contents

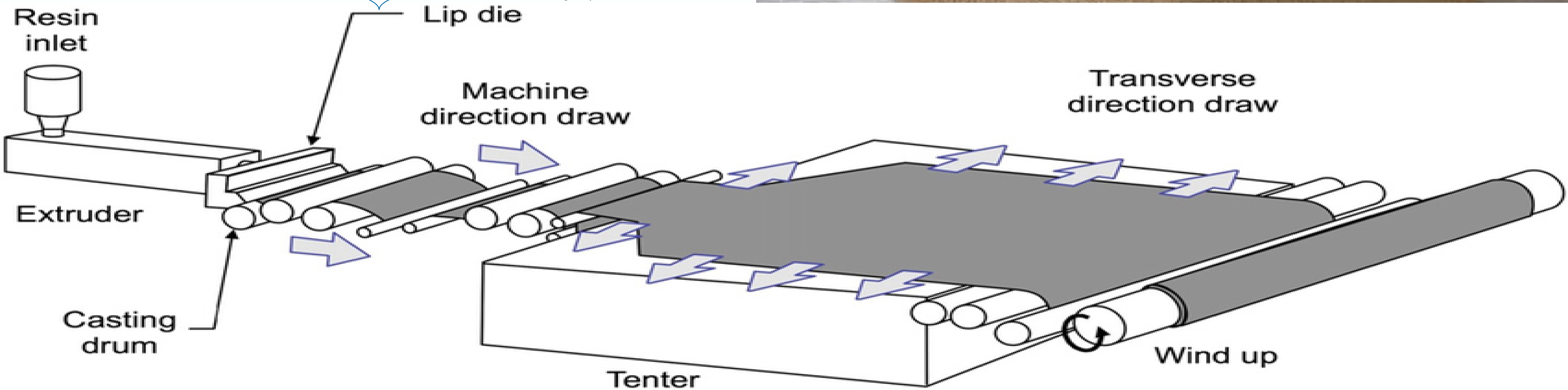
Barrier Properties of Common Substrates		
Material	MVTR (gm/100 sq. in./24 hours)	OTR (c.c./100 sq. in./24 hours/atm.)
Saran 1 mil	0.2	0.8-1.1
Saran HB 1 mil	0.05	0.08
Polyester 48 Ga.	2.8	9
50 M-30 PVDC Coated Polyester	0.4	0.5
Metallized Polyester 48 Ga.	0.05	0.08-0.14
Nylon 1 mil	19-20	2.6
Metallized Nylon 48 Ga.	0.2	0.05
PVDC-Nylon 1 mil	0.2	0.5
250 PVDC Cello	0.5	0.5
LDPE 2 mil	0.6	275
OPP .9 mil	0.45	80
PVC 1 mil	4-5	8-20
Polystyrene 1 mil	7.2	4,800

Other barrier properties can also affect the shelf-life and freshness of contents

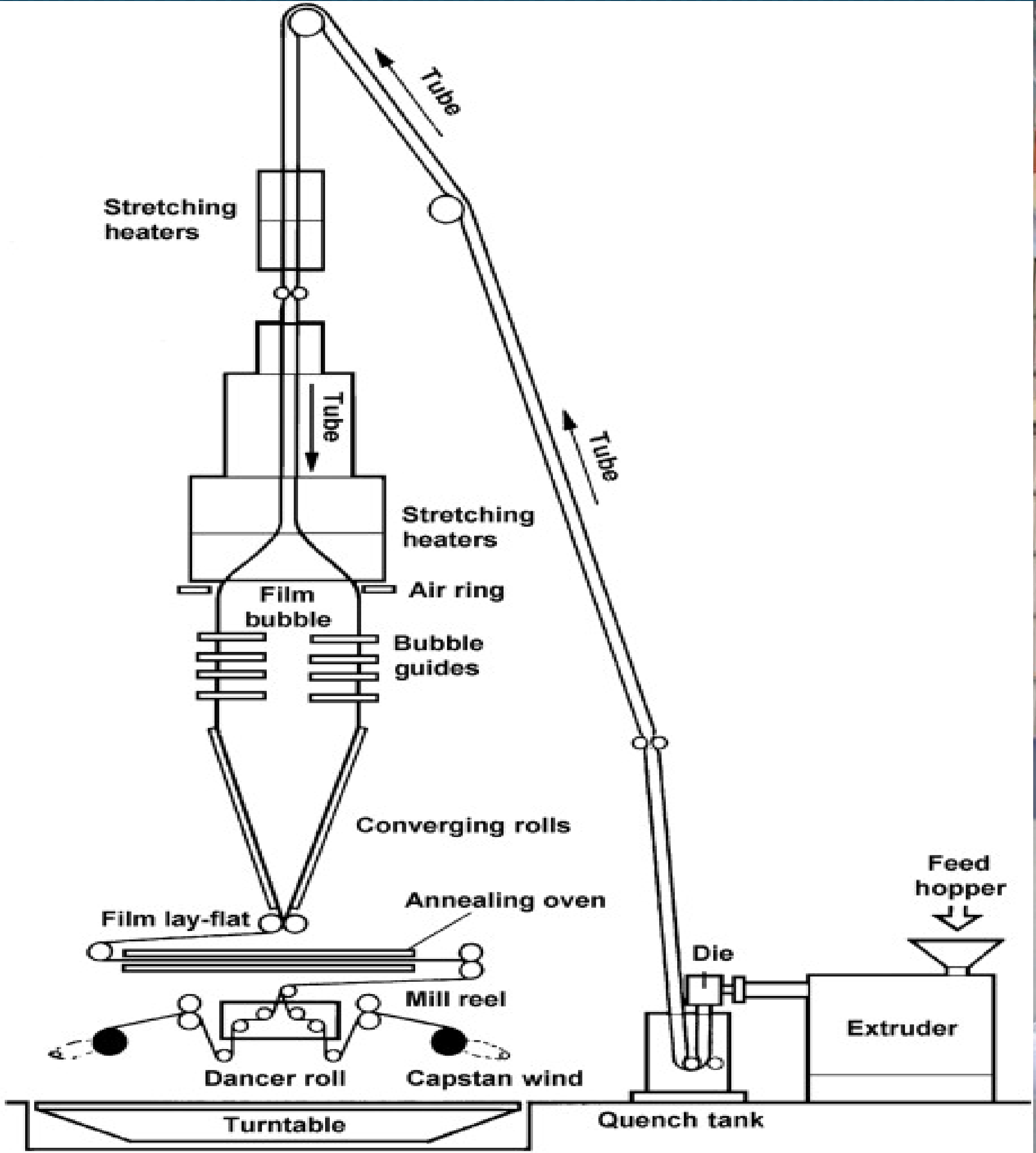
Film Production Methods

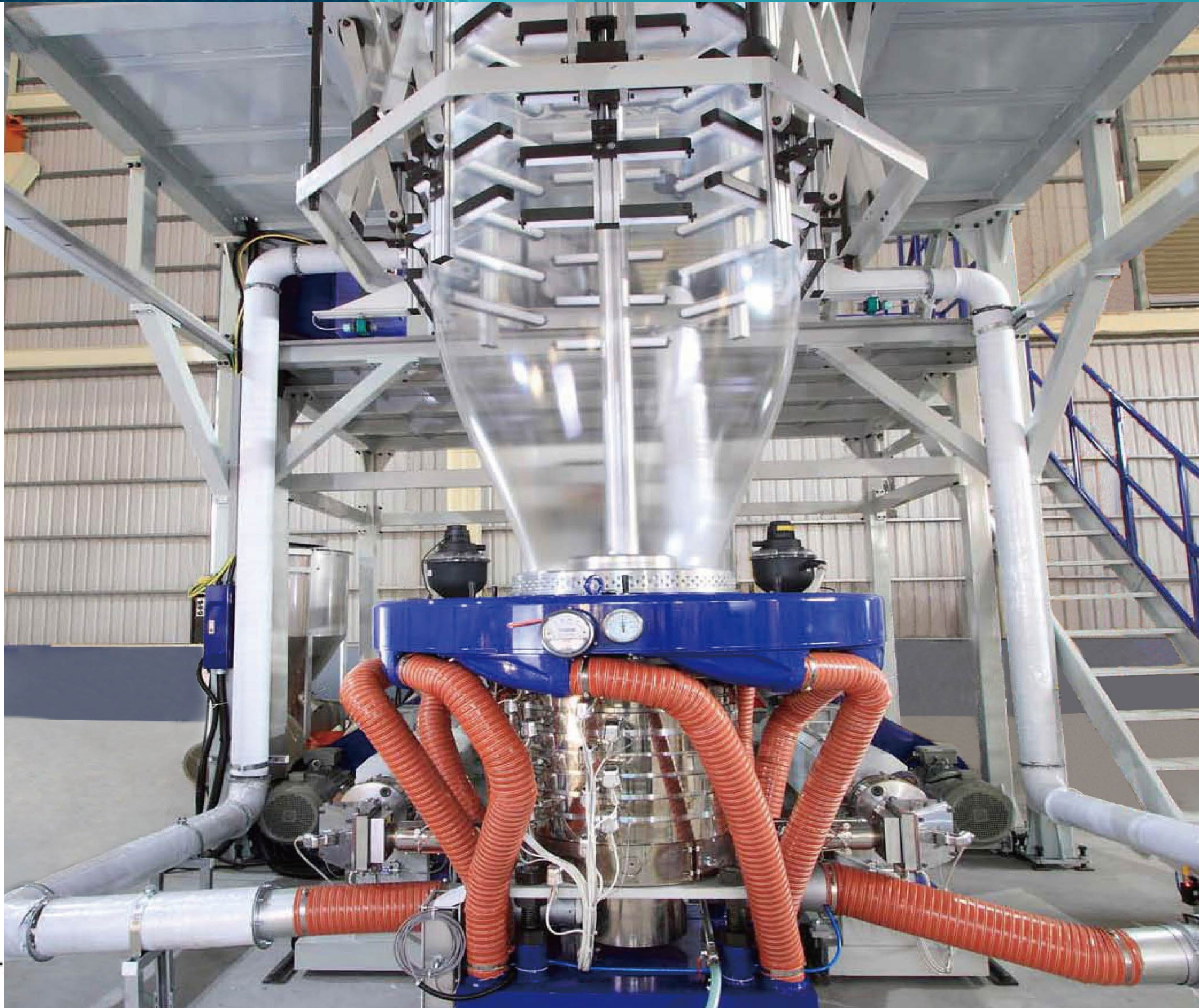
Cast Film Extrusion





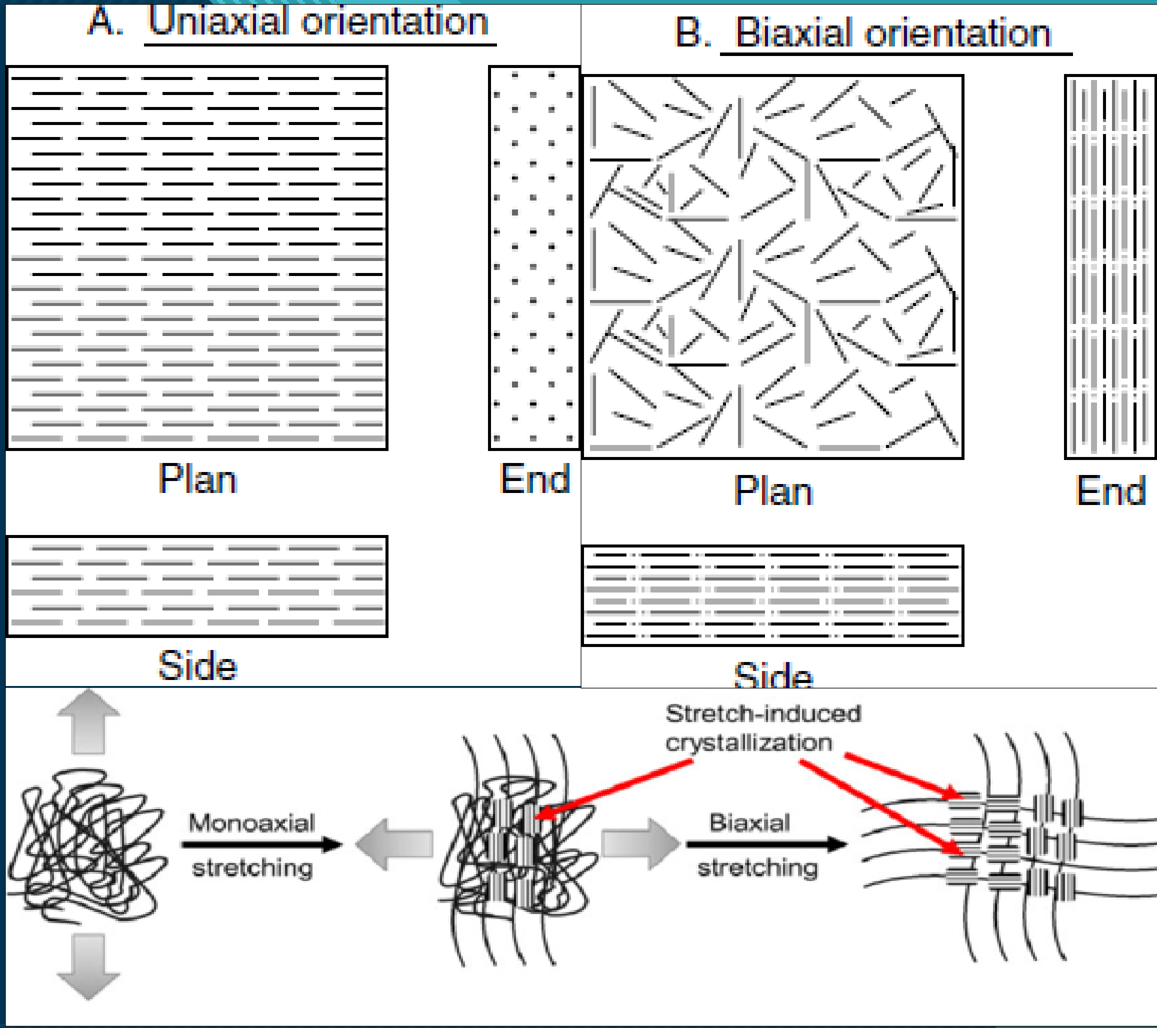
Blown Film Extrusion



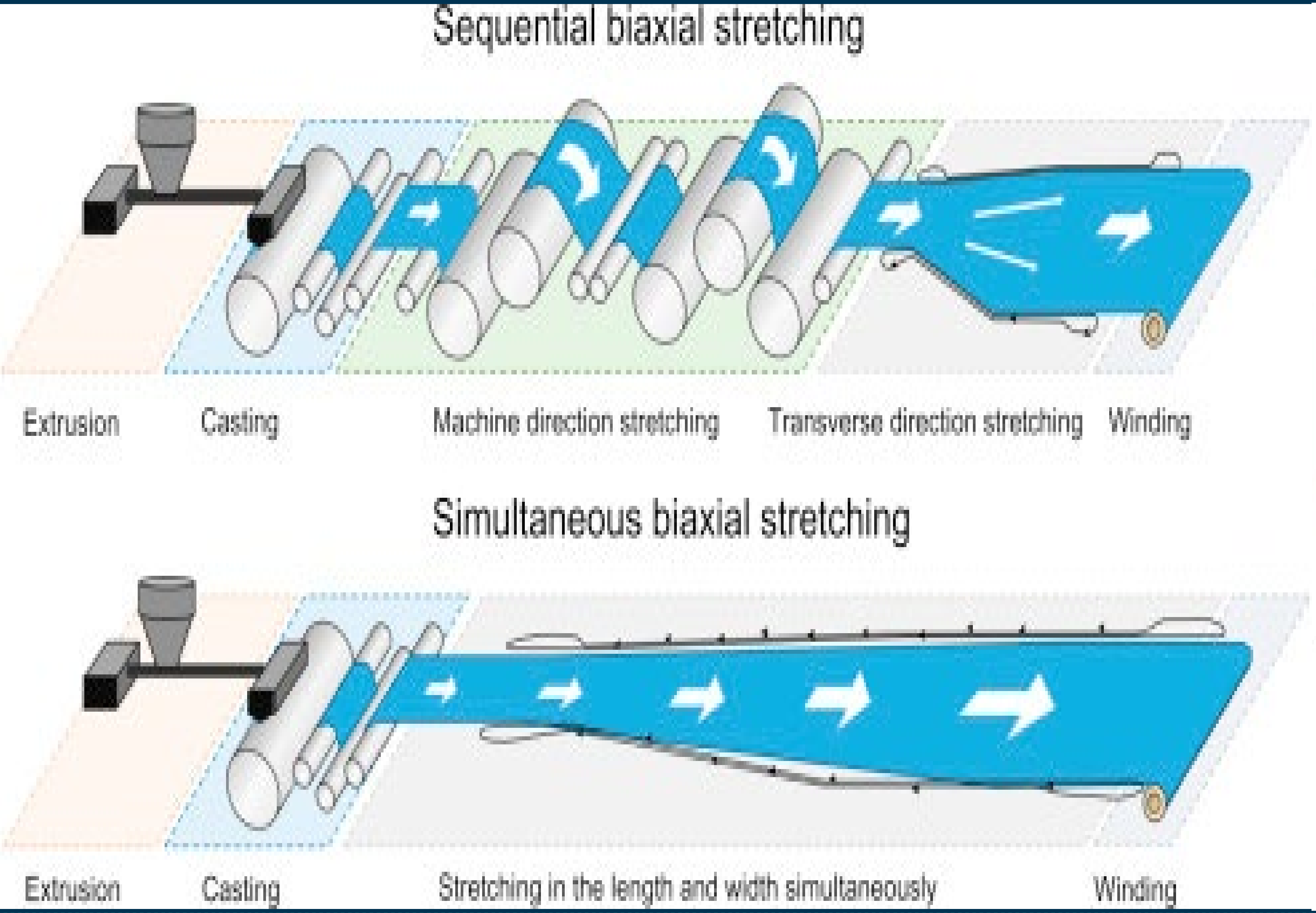


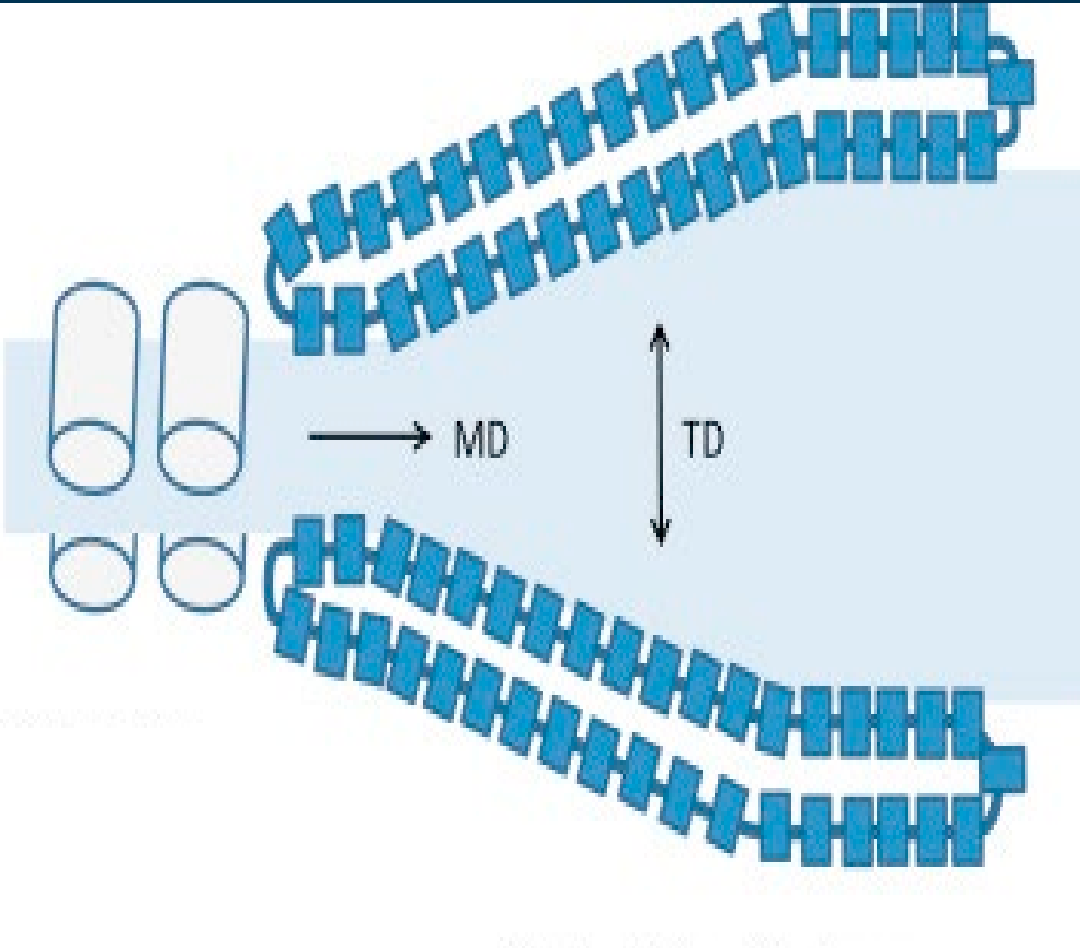
Oriented vs Unoriented Films

- Orientation is the arrangement of the internal film structure
- Orientation induces polymer crystallinity
- Orientation improves most film properties
- Monoaxial or Biaxial orientation is possible
- Annealing is necessary to produce non-shrink films.

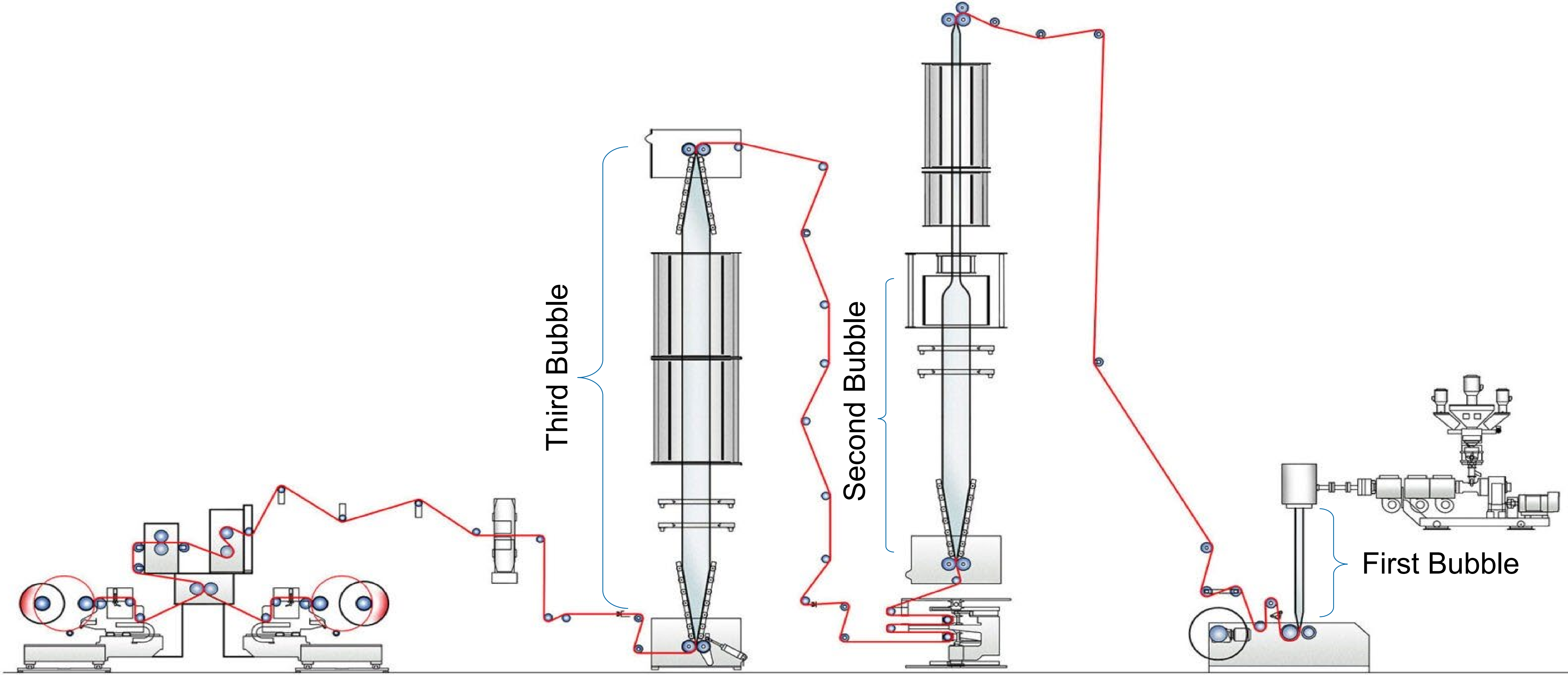


Orienting Cast Films





Orienting Blown Films (Triple Bubble Process Example)



Film Additives

Most packaging films contain a complex mix of additives to achieve various end use properties.

- Adjust coefficient of friction (COF)
- Adjust block resistance
- Reduce oxidation
- Antistatic (dissipating static charge)
- UV light (sunlight) protection
- Antifog
- Filler additives
  - Fibers
  - Nano particles (0.2 microns)
  - Cavitating agents

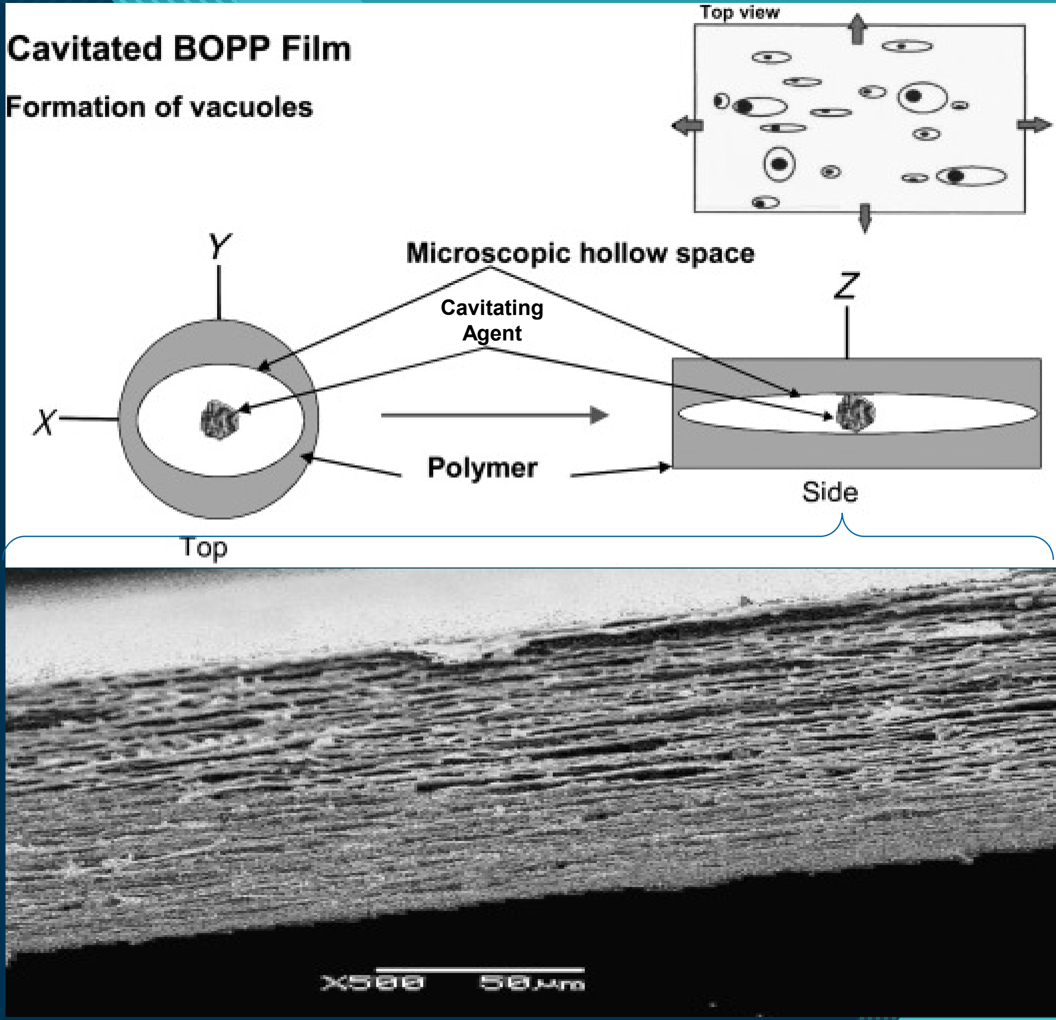
Cavitated Films

- Cavitating agents are added to core layer
- Biaxial orientation is necessary to create voids
- Cavitated films have unique properties

Cavitating agents are

- Incompatible film polymer
- Uniform particle size (usually 2-3 microns)
- Higher softening temperature than film polymer

Example: Calcium Carbonate ($CaCO_3$)

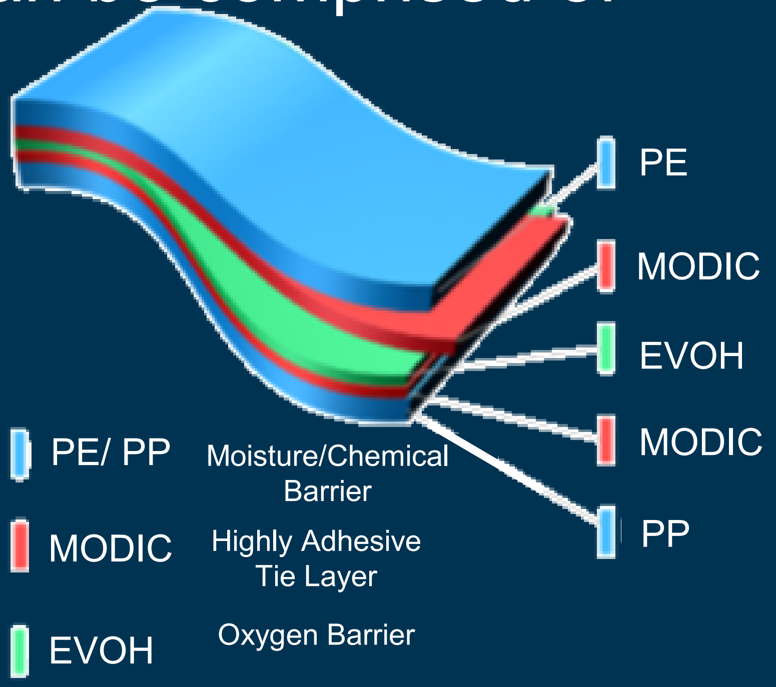


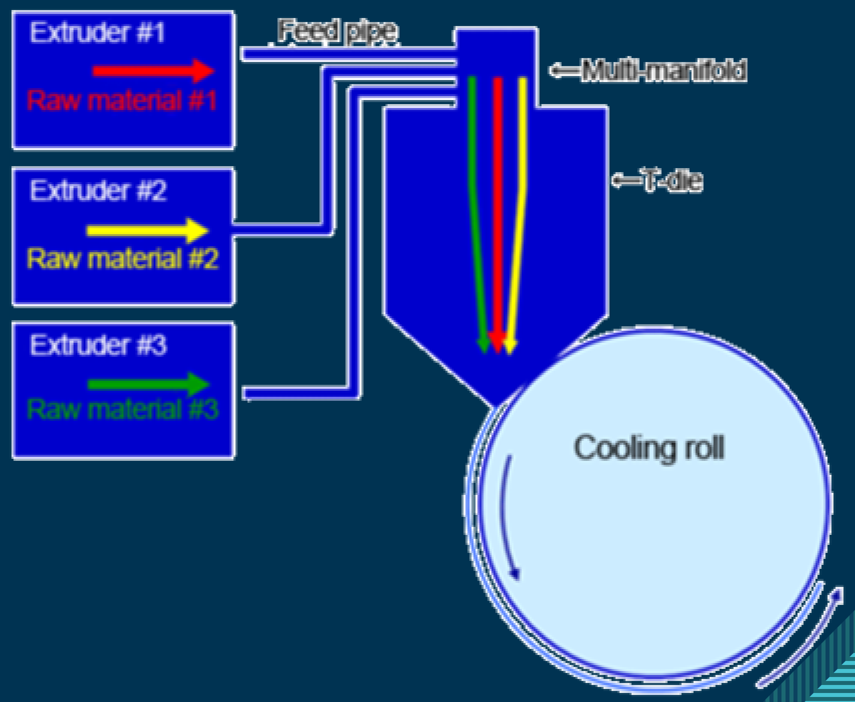
Multilayer Films

Coextrusion

Films can be coextruded as multilayer films.

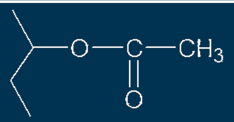
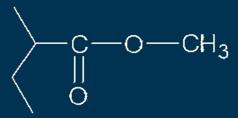
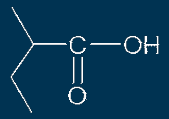
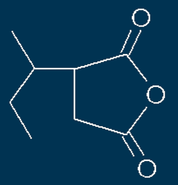
- A multilayer film can be comprised of different polymers
- Example:





Tie Layers

Coextruded dissimilar materials do not adhere well to each other, tie layers are used to prevent delamination of layers

COMMON TIE LAYER RESINS		
Compound	**Repeat Unit Structure**	**Adheres well to**
Ethylene-vinyl acetate (EVA)		HDPE, LDPE, PP, PS, PVDC
Ethylene-methyl acrylate (EMA)		HDPE, LDPE, PP, PS, PVDC
Ethylene-acrylic acid (EAA)		PA, PET, Ionomers, LDPE, EVA, EMA, Al
Ethylene-grafted-maleic anhydride (AMP)		PA, Al, EVOH, Cellulose

Lamination

Films can be combined after extrusion through lamination

- Lamination Methods
  - Adhesive
    - Solvent-based
    - Solventless
    - Water-based
  - Primer/Extrudate
- Films can be printed prior to lamination
- Bond strengths are typically lower than coextruded films

Surface Treatments of Films

Non-Printed Coatings

Coatings can be used to improve end-use properties

- Metallization (Aluminum)
  - Enhances gas/moisture barrier properties
  - Significantly increases opacity
  - Prone to oxidation
- Al_2O_3 & SiO_x
  - Enhances gas/moisture barrier properties
  - Maintains transparency
  - Microwaveable
  - Difficult for ink wetting/adhesion
  - Coating is brittle

Printed Coatings

- Polyvinylidene chloride (PVdC; Saran)
  - Improves barrier properties
  - Affects adhesion
- Acrylic
  - Improves barrier/resistance
  - Good heat sealability
  - Excellent COF control
  - Tendency to retain some solvents
- Additive Replacements
  - Antifog coatings, Slip Coatings (COF/Block Resistance), anti-static, etc..

Printability

Printability

Factors that Affect Printability

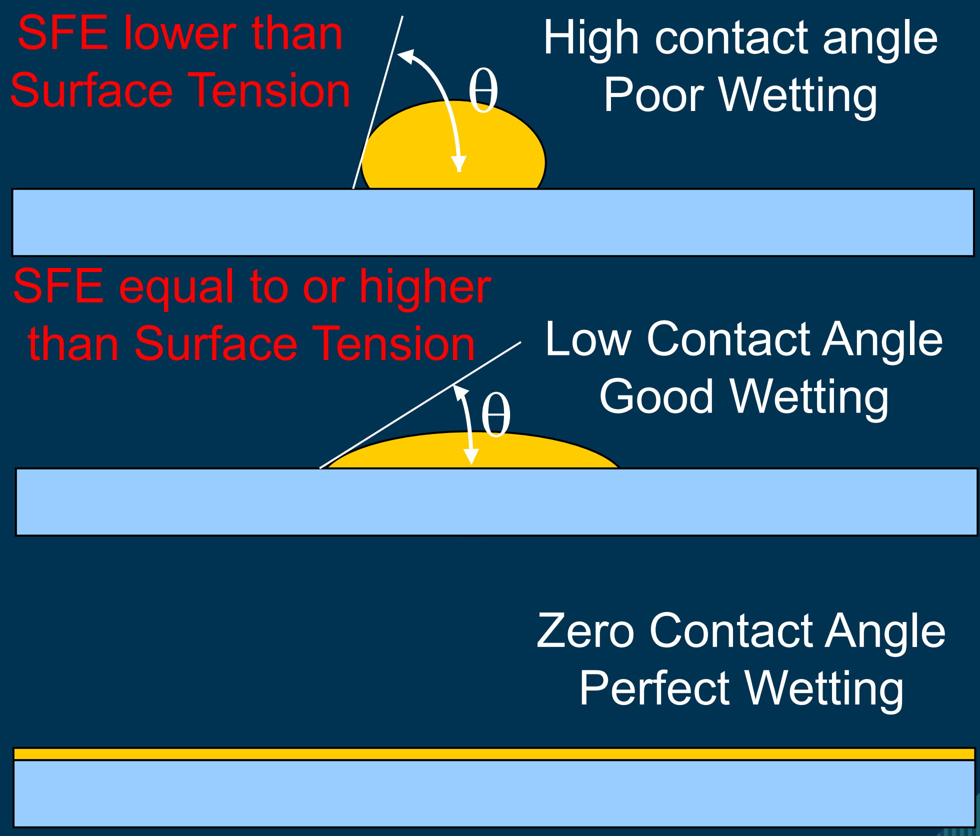
- Surface free energy (SFE) of the substrate

- Ink Properties
  - Surface tension of the ink
  - Rheology of the ink
  - Resolubility of the ink

Surface Free Energy (SFE) & Wetting

SFE is physically equivalent to surface tension. SFE describes solids whereas surface tension describes liquids.

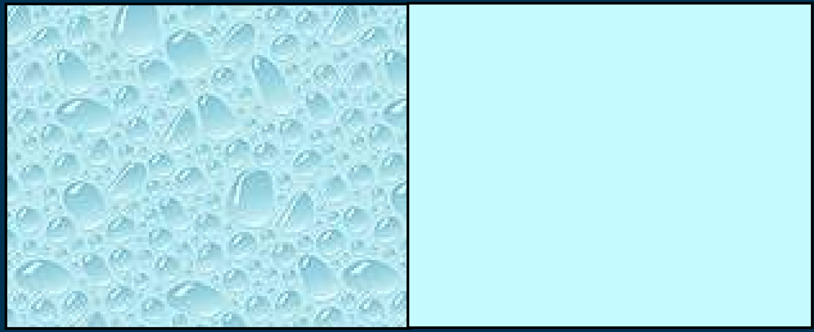
- Wetting is the ability of a liquid to spread on a solid surface
- Wetting occurs when surface tension is equal to or less than the SFE
- Wetting is necessary for good ink lay
- Contact angle is used to describe wetting



How is SFE Determined?

Dyne Solutions/ Dyne Pens

- Testing
  - Uses a series liquids with increasing surface tension
  - Solutions are applied and evaluated visually
  - The highest surface tension to wet out for a set time is the SFE
- Limitations
  - Only provides total SFE value
  - Solutions/Pens can become contaminated
  - Solutions/Pens expire



Poor Wetting Good Wetting

How is SFE Determined?

Surface Analyzer

- Testing
  - Instrument uses polar and non-polar liquids
  - Instrument measures contact angle of liquids
  - Provides total surface energy and fractions
    - Disperse fraction
    - Polar fraction
- Limitations
  - Instrument is expensive

Ways to Improve Surface Free Energy

Most treatment methods attempt to increase the polar fraction of SFE

- Corona (Air Plasma)
  - Both sides of the substrate are affected by corona treatment
- Atmospheric Plasma (Blown Ion)
  - Single side treatment is possible
- Flame Plasma
  - Treatment requires high temperatures
  - This method tends to have a longer effect
- Printed Primers

Why Treat Films?

- Ink needs lower dyne than substrate for wetting
  - Two factors have the most bearing on surface tension of liquid inks
  - Solvent
    - Solvent-based
    - Water-based
  - Additives
- Films lose surface energy with time
- Coated films cannot be corona treated
- Over corona treating can cause issues

Why Treat Films?

Dyne Comparison of Common Films		
Film	**Untreated Dyne**	**Treated Dyne**
PE	<30	~ 37-40
CPP	<30	~ 37-40
OPP	<30	~ 37-42
PET	~ 38-42	~ 48-50
ON	~ 38-42	~ 48-50
PVdC Coated OPP	35-45	-

Thank You