Some of the Important Design Requirements of a Machine Direction Orientor (MDO) Machine

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Key Words

MDO, Draw Ratio, Rate of Draw.

Abstract

Machine Direction Orientation (MDO), has been practiced, with varying success, for decades. The dramatic improvements in film clarity, stiffness, barrier, and tensile strength has been documented since the 1950's. In the past few years' companies have begun to commercialize this technology in an ever-increasing rate. Until recently, with a few exceptions, the machine used to MDO the film has changed very little. In this paper, a short overview will be presented discussing some of the important facets of the MDO machine, and how they affect the orientation process, and ultimately, the final film properties.

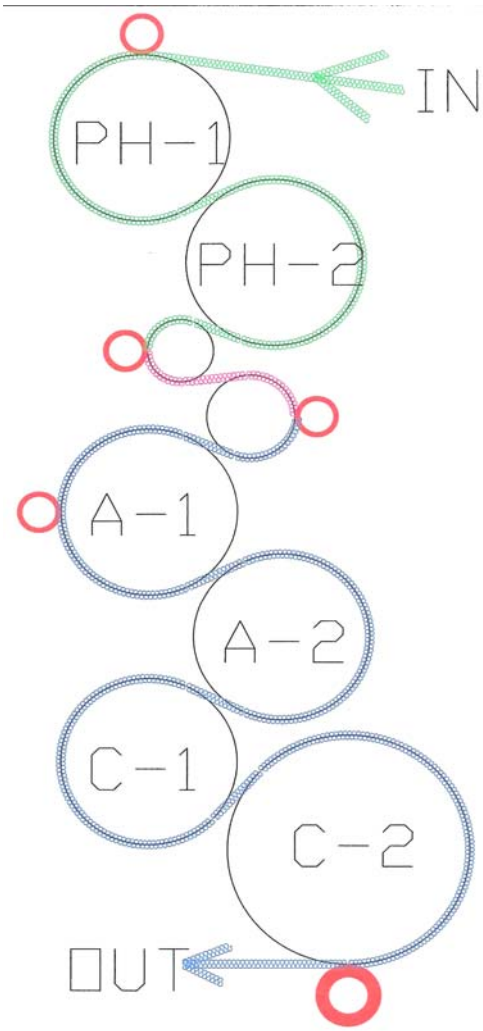
Introduction

Machine Direction Orientation (MDO), involves the uniaxially stretching of film, or sheet, to improve physical and barrier properties.

Machine Direction Orientation is being practiced in a wide variety of film applications. The growth of the use of this technology is rapidly increasing. This is due to the dramatic improvements in film properties such as Optics (haze and gloss), Tensiles, Stiffness (Secant Modulus), Dead fold, and Oxygen, Moisture & Grease barrier.

Most major OEM's today are building MDOs. With a few exceptions, the basic design of the MDOs being built has not changed. And the basic theory of operation is much the same, almost regardless of the materials being oriented, or the desired final properties.

The Basics of a Machine Direction Orientor



There are four main steps or parts of an MDO. Below each step is explained.

Preheat:

On the sketch these are the rolls labeled PH-1 & PH-2. Their function is to uniformly raise the temperature of the film to orientation temperature, And to do this without putting hard wrinkles into the film.

The first Preheat roll (P1), also acts as a nip for tension control of the web coming into the MDO.

Drawing:

These are the rolls between PH-2 and A-1.

After the film is up to the desired orienting temperature, it is stretched across a pair of draw rolls. These are smaller in diameter than the preheat rolls so that the distance between the tangent points is less. The gap between these rolls is usually adjustable. The film is stretched as much as 10:1 or more in this section.

Annealing:

The third section of an MDO is the Annealing Rolls. This section heat sets the film, and "locks" the property changes from the orientation into the film. It also controls how much the film will shrink back when later exposed to heat. This is done on rolls A1 & A2 in the sketch.

Cooling:

The last section of an MDO is the cooling portion (rolls C-1 and C-2). In this area the film is cooled back to near ambient.

Parts of an MDO Line, and The Effects of Their Design on Operations and Film Properties

Unwind:
(If the MDO is out of line.)

The unwind can be very simple; however a more sophisticated unwind system can improve the economics of the MDO process. This is due mainly to the ergonomics of changing rolls. The following things should be taken into account just as one would on a slitter:

- The unwind should be capable of handling the largest roll that is anticipated that will be made for the MDO. If you are making your own film, this would be the largest roll your winders can produce.
- Some sort of braking system is helpful in getting the film into the MDO without wrinkling.
- How will the feed rolls be safely and quickly changed.

Preheat Section of the MDO:

The function of the Preheat section of the MDO is to uniformly heat the film, or sheet, to the desired orientation temperature, and to do this with out wrinkles, or damaging the surface of the film.

When the film is heated it expands. In some cases 15% or more. This "extra" volume, or width, must go somewhere. If the film is heated too fast on a given roller this expansion can cause wrinkles. Often these wrinkles can be pulled out, but if the are "pressed in", they can leave a mark in the film after orientation, or can even cause a break off between the draw rolls. If the film wrinkles on the rolls, these areas are often not heated completely to the desired orientation temperature. This can cause uneven stretching in the draw station.

Heating the film slowly over several Preheat rolls can eliminate this problem. It also assures that your feed film to the draw station is the same temperature. If it is not it can cause different physical properties and/or optics across the web, and, in extreme cases, cause a break off.

Draw Station, or Orientation Rolls:

It is in the draw station, or between the draw rolls, that most of the orientation of the film takes place. This must be done at controlled and uniform temperatures, with the correct gap, draw ratio, and rate of draw (acceleration across the gap). If all of these things are

not taken into consideration, the film properties will not be optimized, and may prevent the desired film to be made at all.

Many (not all), film properties continue to improve the more you stretch them. Thus one normally wants the maximum Draw Ration the film can handle. This is done by heating the film up as much as possible, and then stretching it to the point just before it breaks.

Typically you want to orient the film across as narrow of a gap as possible. If the gap is too wide, on many materials, you will have too much neck-in, or the heavy edges will come further into the web, forcing you to have to take more trim than otherwise necessary. This has an adverse effect on operating yields.

The gap cannot be set too tight, or the Rate of Draw (the acceleration of the film across the gap, or dv/dt), will exceed what the film structure can handle, and the web will break. The energy the motors on the rolls puts into the film is affected by the draw ratio, line speed, and rate of draw. This difference in the energy imparted into the film can affect the physical properties. As the line speed is increased, the gap will need to be adjusted to maintain the same Rate of Draw.

Another thing often done in the design of the Draw Station is to make the draw rolls smaller in diameter than the other rolls in the MDO. This is to reduce the tangent-to-tangent distance the film must travel. Again to reduce neck-in and/or heavy edges.

If the Rate of Draw is too low, the film may stretch non-uniformly in the machine direction. This is sometimes called “Striping”. If the gap is too wide it may be necessary to orient the film at an undesirably high draw ratio. Or it could even prevent the web from being oriented all without breaking.

When the MDO is laced up it is necessary to get a rope, or balled up piece of film, through the machine. To facilitate this the draw gap needs to open an inch or so. It is possible on to hand feed the film through tight gaps, however this can cause safety concerns, and can result in serious injury.

Because, of the above mentioned items, it is nice to know what the draw gap is at all times. This is often done with a read out on the control screen. It is also helpful when trouble shooting a process problem on the orientor, or initially developing an MDO product, to have the ability to adjust the gap while orienting film at operating speeds.

Sometimes it is desirable to have multiple draw stations. This second orientation can either be performed immediately after the first draw, or further downstream. Both approaches can have advantages.

If the film is oriented a second time immediately after the first orientation, the second draw station is placed right after the first one. Drawing the film twice can permit some films to be oriented to a higher ratio. This can result in further improvement in film properties.

If the second draw station is placed further down stream in the MDO, the film can be annealed before it is stretched again. Or the film can be stretched at two different temperatures. This can be useful if you have a coextrusion with resins of different melting points, or draw temperature requirements.

Nipping the Film in the Draw Section:

There are two standard ways to nip film. One is with the film being pressed between a rubber roll and a steel roll while it travels straight through the nip point with little or no wrap in either roll. This like the Primary nip on Blown Film lines. This type of nip arrangement is adequate for the Draw rolls for many films.

A second nip arrangement is the "S-wrap". In this case the web wraps the rubber roll 180 degrees or more, before reaching the nip point. This permits the film to be laid down flat against the steel roll. This can be helpful in preventing wrinkles, and is sometimes necessary when the nip rolls begin to wear.

Annealing Section:

This portion of the machine has been given the least amount of attention in the past, but it can prove to be one of the most important parts of the MDO process. A poorly designed Annealing section can destroy much of the improvements put into the film in the Draw Station. It can have severe negative effects on quality, and the resulting negative economic impact.

It is in the Annealing Section of the MDO that the oriented film is heat set, or stabilized. This is mostly a function of time and temperature. Not annealing the film long enough will cause it to shrink back more when it is heated up again. Like when it is heat sealed for instance. Film with inadequate annealing time will shrink back when it is heat sealed, and this can cause weak seals, or even "pucker lanes" in the seal, causing leakers.

Annealing the film also can reduce the amount of post shrinkage the film has after it is wound into a roll. This shrinkage is an exponential function, and takes several days to near completion. If the film is not annealed enough, and/or wound too tight (see winding below), the edges can become baggy, or even crush the core.

As a general rule, MD oriented film should be annealed as hot as possible. This is usually the same temperature as it is stretched, since this is usually has hot as the film can get without sticking to the rolls. The film should also be annealed as long as possible. In the machine this translates into more roll surface contact time. The film is moving very fast (1000 to 1500 ft/min. or more), in this part of the MDO. Thus the annealing section of the machine should have several large diameter rolls.

Cooling:

It is the function of the cooling section of the MDO to uniformly cool the oriented film to near ambient temperature, and to do this without wrinkles, or damaging the film surface.

The web is shrinking as it cools. Thus the film should be step cooled to minimize the chance of getting wrinkles. The cooling section of the MDO usually has a couple large diameter rolls, or several smaller diameter rolls.

Miscellaneous Equipment (Treaters & Profile Gauges):

Treaters are often needed to treat the film after it is oriented.

The post orientation gauge profile is a very useful piece of information when deciding how much trim to take. This is because the web gets thicker as you move from the center of the web to the edge. A gauging system can take a lot of the guesswork out of where to set your knives, and can speed the setting up of an order. It can also be useful in troubleshooting.

Rewinder:

The choice of the wrong rewinder can be the source of many years of problems with scrap, rework, and customer complaints. Film that has been MD oriented has its own set of winding requirements.

Because of the post shrinkage of MD oriented film, and the thicker edges, it is necessary to wind as much air into the finished roll as possible to give the film room to shrink over time. The ability to gap wind, at low tensions, and high line speeds, will save the processor from facing problems with crushed cores and baggy edges.

The rewinder purchased should be among the top of the line made. Saving money here will only cost you money latter.

Conclusion:

The proper consideration of the final film properties and types must be considered when designing, or selecting a design, of a Machine Direction Orientor. There is a good deal more involved in the orientation process, and the machine that must perform it, then just heating the film up as hot as you can, stretching it, then cooling it back down for winding.

If the machine is not properly designed, it will not be able to optimally provide the final film properties, or quality, that are desired, and some of the resulting profits will be lost.

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Presented by:

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MDO Engineering, Inc.

& our MDO Partner: Windmoeller & Hoelscher Corp.

Introduction

Machine Direction Orientation (MDO), of film, is being practiced in a rapidly increasing rate.

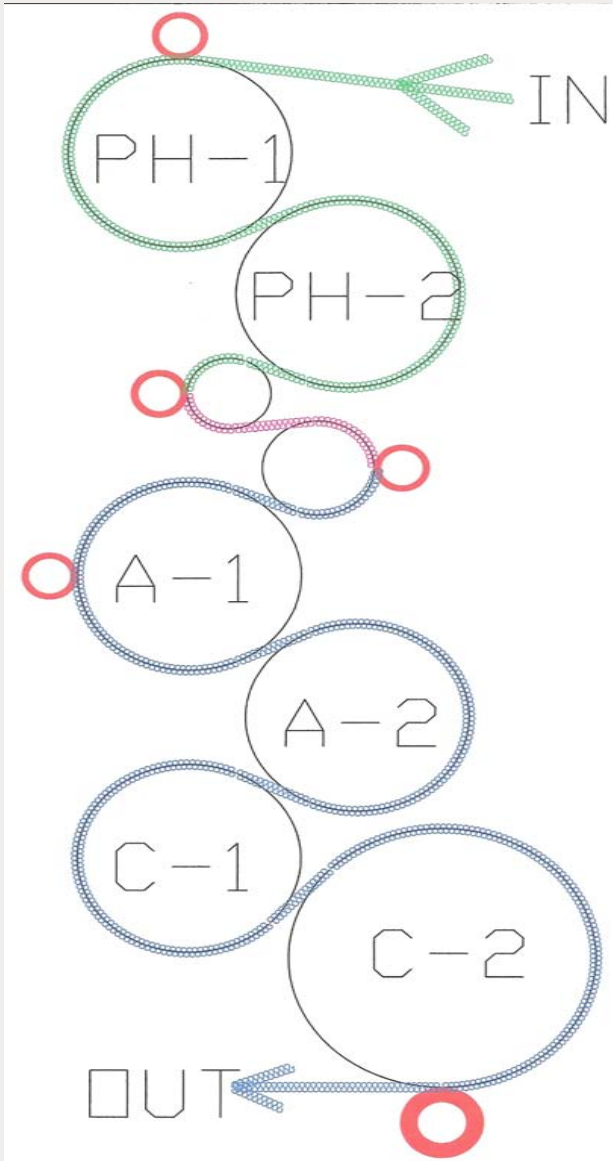
Nearly every OEM has an MDO to sell.

Most of the MDOs look very much the same, and have changed very little from the 1960's.

This paper will discuss some of the important facets of an MDO & what to look for when buying one.

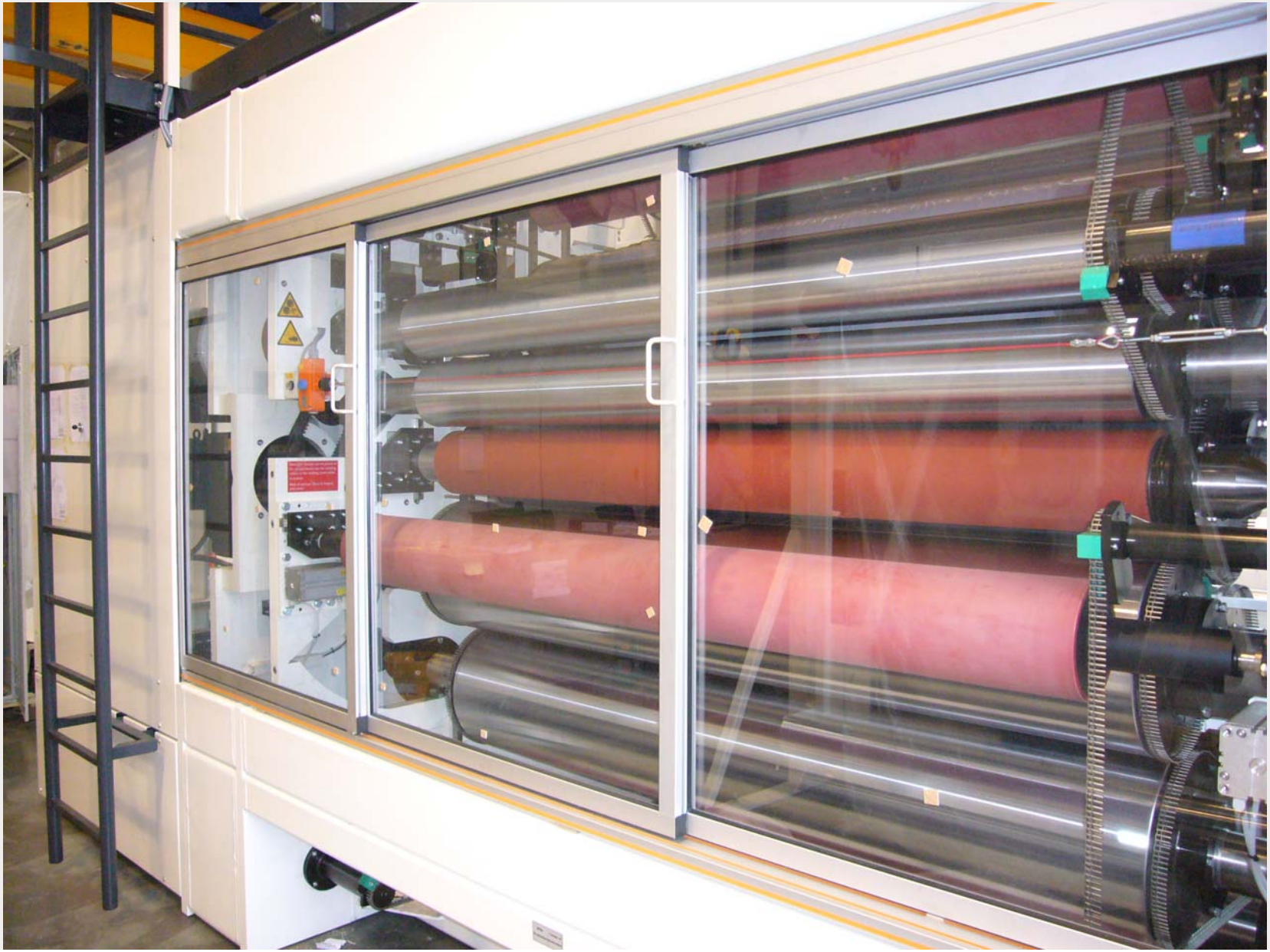
This paper will also cover some of the property improvements that film, or sheet, achieve when they are run through the MDO process.

Basics of an MDO



- The Film is First Heated to Drawing Temperature on several Pre-Heat Rolls.
- The Film is then Stretched Between Smaller Diameter Rolls.
- It is then Annealed or Heat Set.
- And Finally Cooled Down to Near Ambient.

Commercial MDO



Properties of Machine Direction Oriented Films:

- The following properties can be improved when a film is oriented in the machine direction. Detailed data for some of the properties follows.

- Optics: Clarity, Haze and Gloss.
- Tensiles: Increase in break strength.
- Controlled shrink levels.

Properties of Machine Direction Oriented Films:

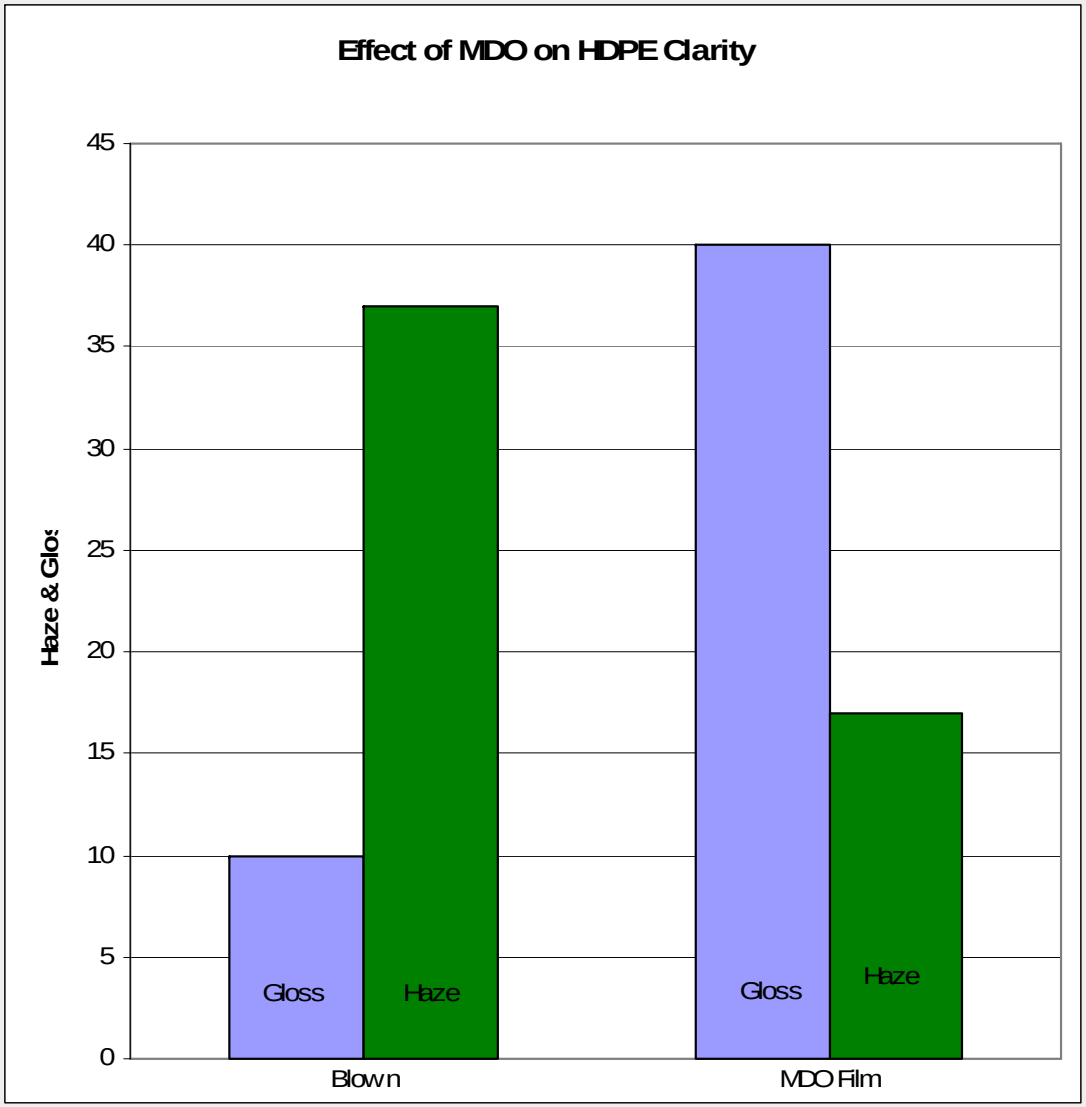
continued

- Stiffness: Secant Modulus can increase from 2X to 3X in both TD and MD directions inclusively.
- Barrier: Both Oxygen and Water Vapor.
- Dead fold & Twist Retention.
- Film “toughness”, and ability to with stand puncture and heavy loads.

A Few Examples:

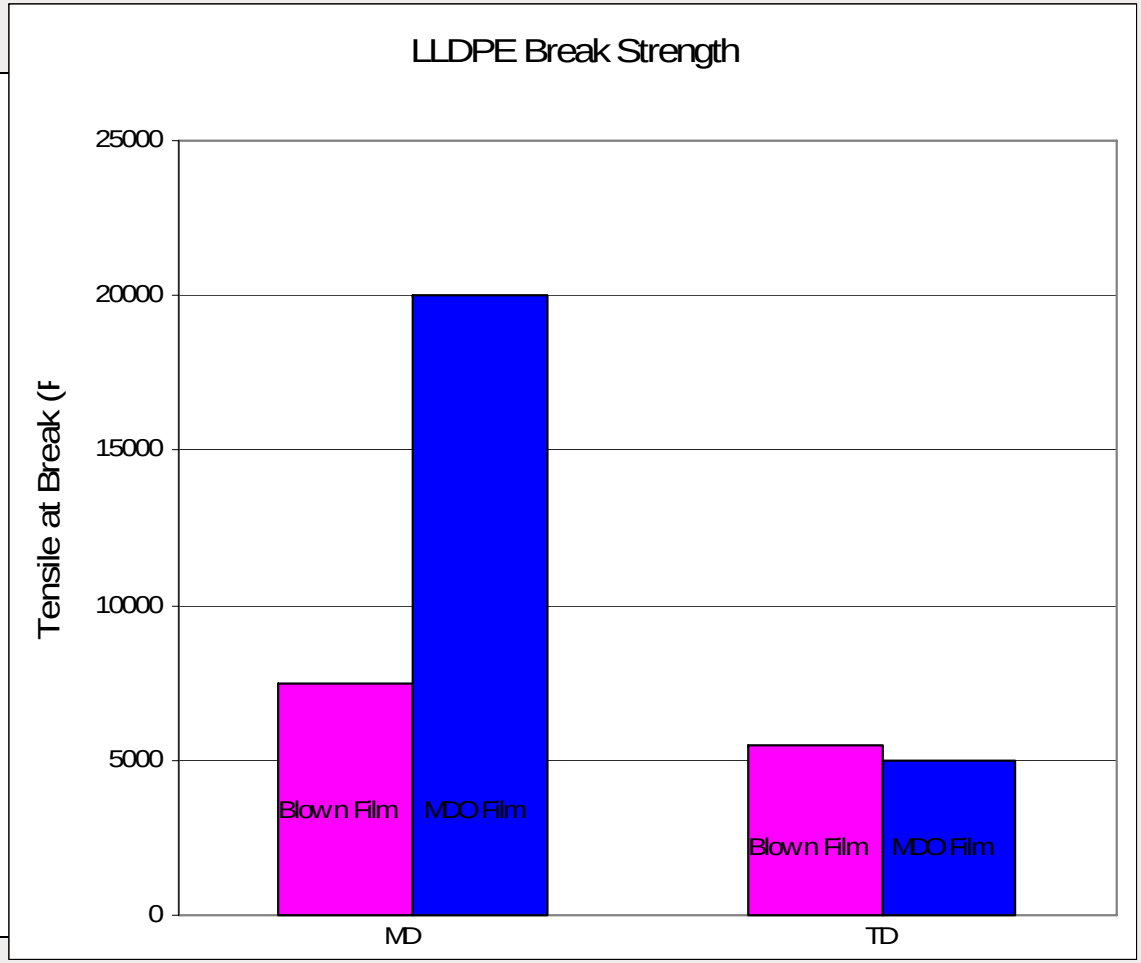
Optics: Haze and Gloss.

- 2X Improvement in Haze for HDPE.
- 3X Improvement in Gloss for HDPE.
- Graph is for 2.0 MI HDPE.
- Similar Improvements for LLDPE.

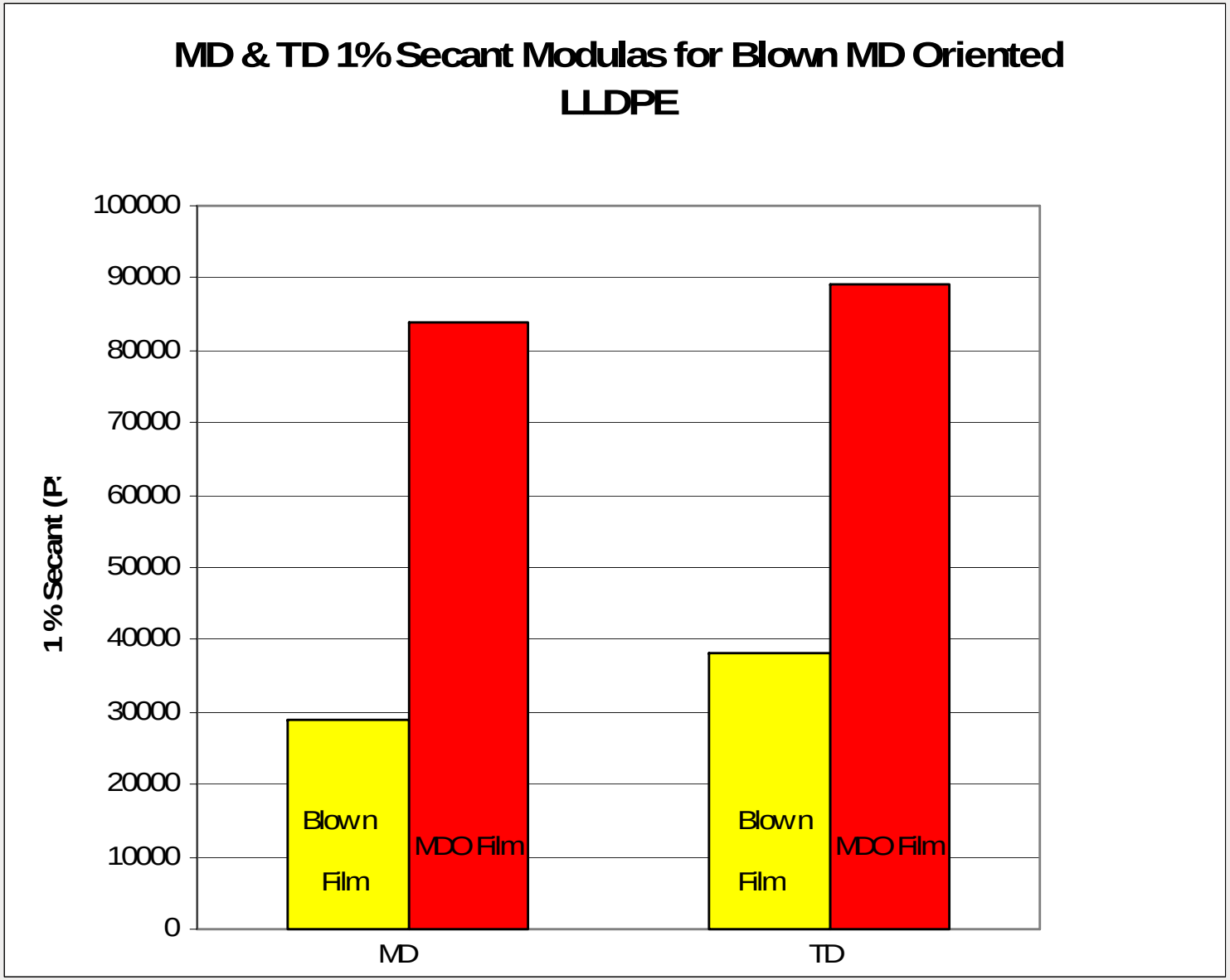


Tensiles: Increase in Break

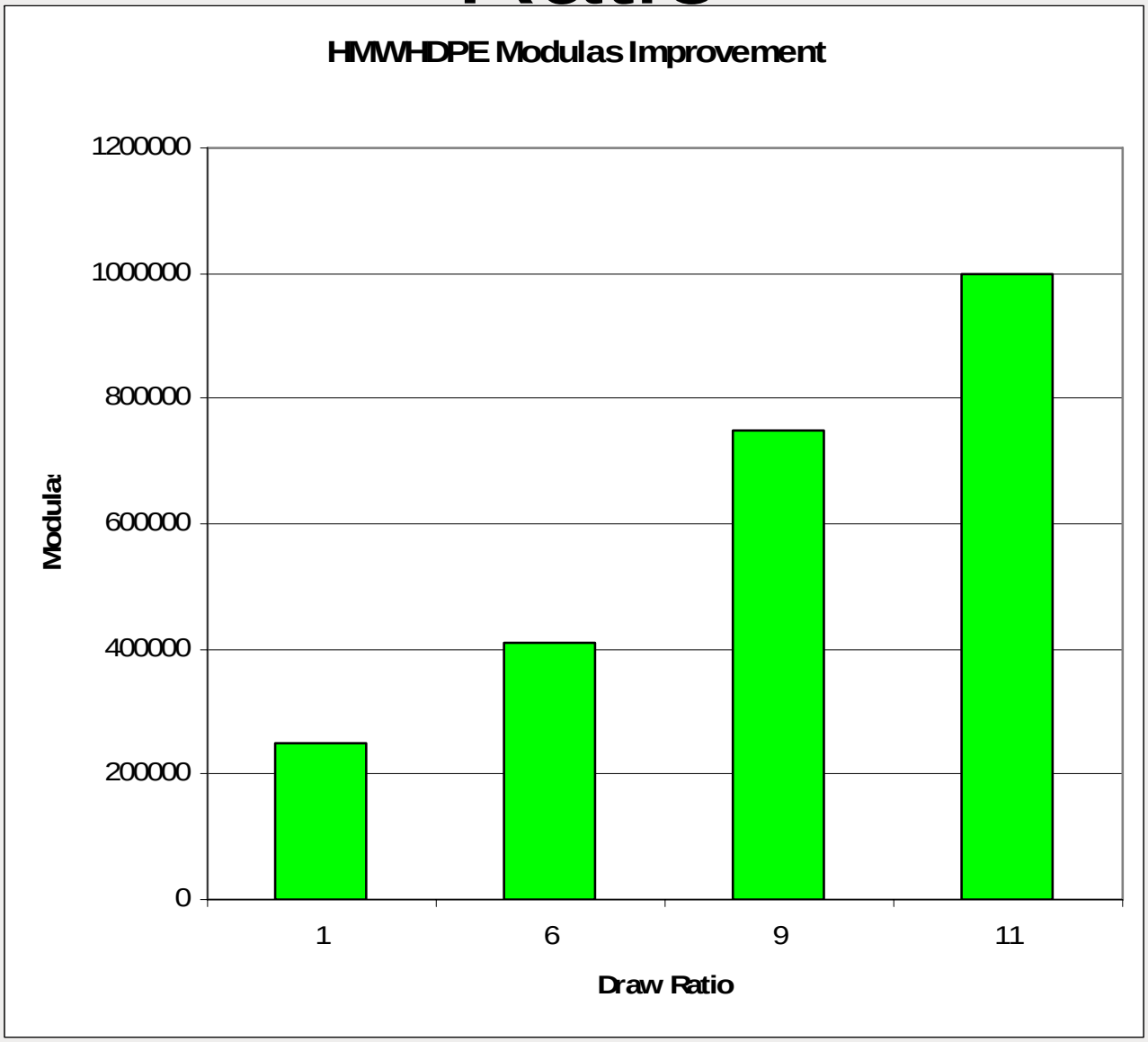
- Nearly 3X Improvement in MD Break Strength.
- Marginal loss in TD Break Strength.
- Unlike With HDPE, MDO-LLDPE Elongates in the TD so the MD Tensiles can kick in and “Toughen” the package.



Stiffness: Secant Modulus

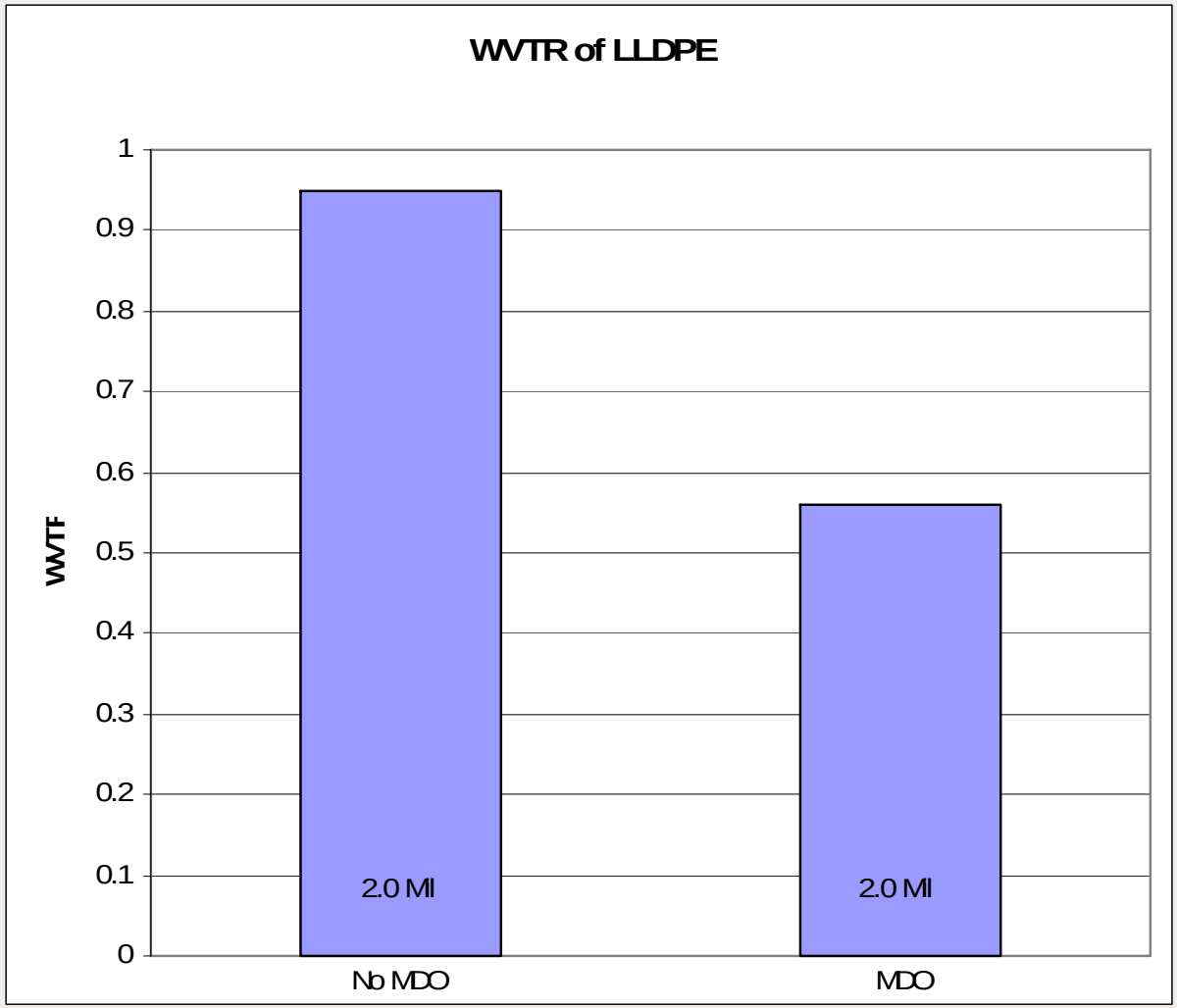


Modulus of HDPE vs. Draw Ratio

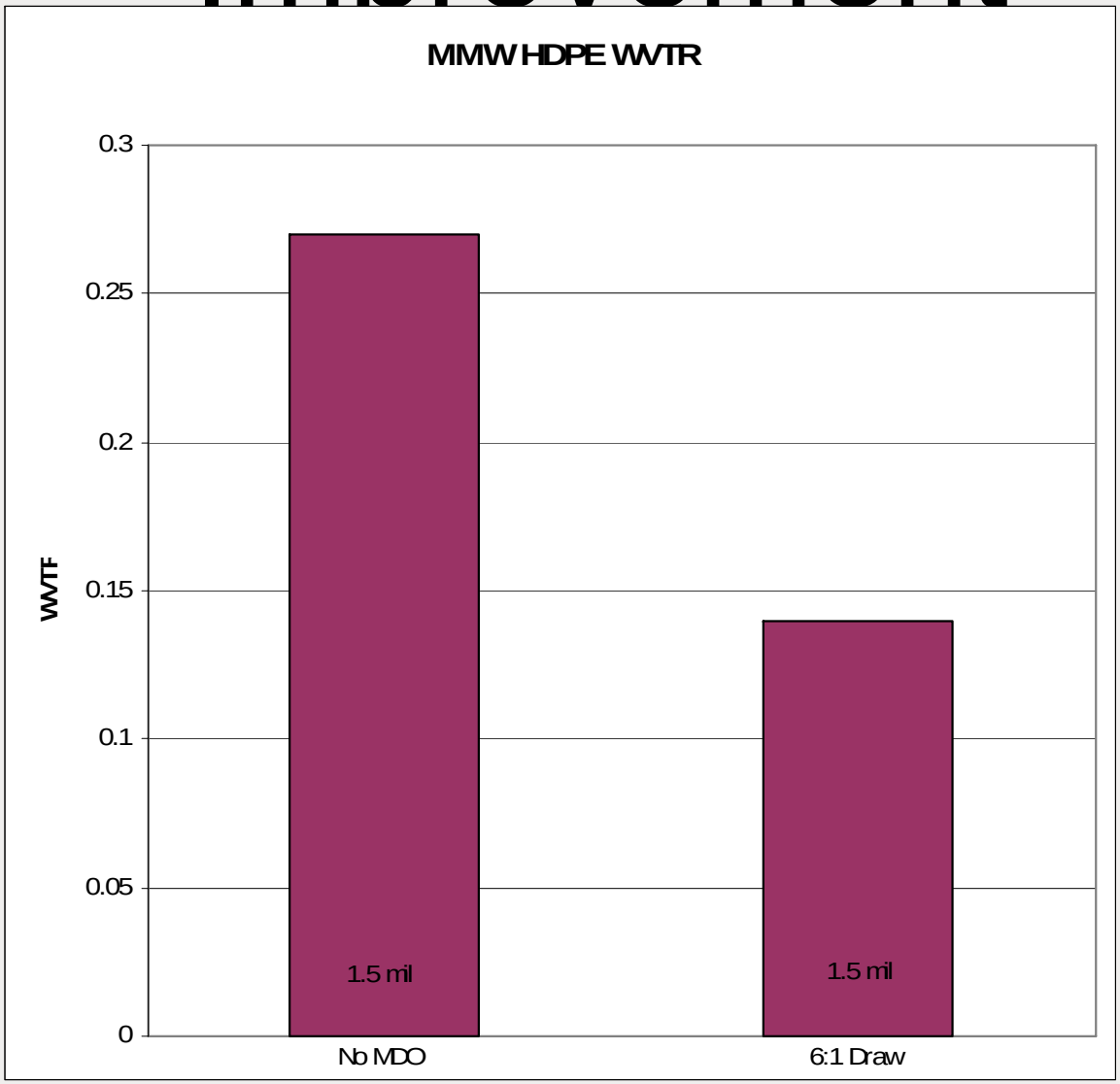


Barrier: Both Oxygen and WVTR

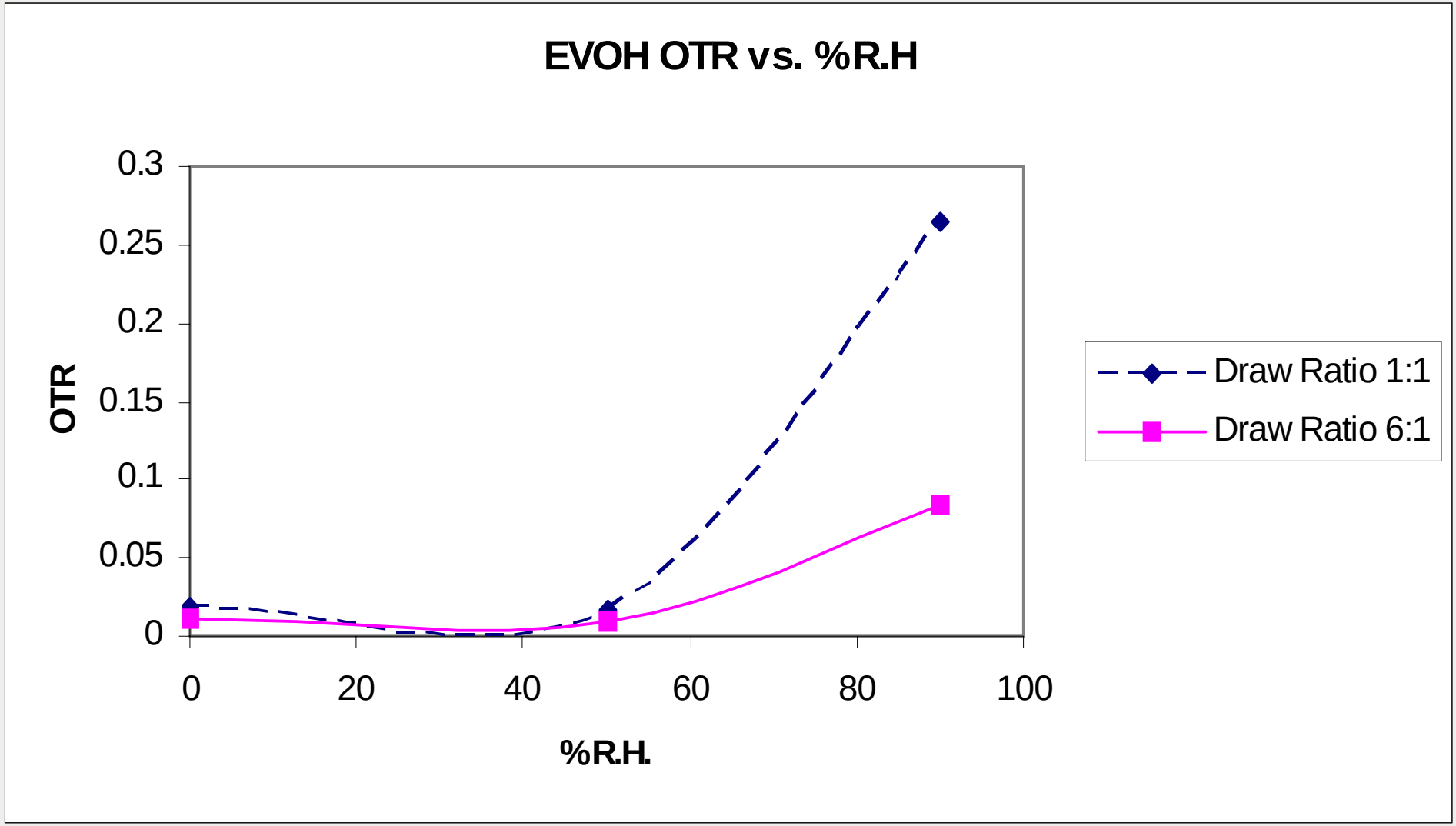
- Double Moisture Barrier of HDPE
- Double Barrier of LLDPE



HDPE Barrier Improvement



Oxygen Barrier vs. R.H. for EVOH



Summary of Property Improvements from MDO

- Films are stiffer.
- Films have Better Gloss, Clarity and Haze.
- Films Have Much Higher Tensiles.
- MDO LLDPE is Much Tougher.
- The Barrier of the Film is Doubled, or More.
- Shrink Properties can be Controlled over a Wide Range.

A Few Applications for MDO Film

- Stand up Pouch.
- In Mold Labels
- Shrink Wrap
- Draw String
- Cereal and Cracker Wrap.
- Sealant Webs.
- Twist Wrap.

- Tapes and Ribbon.
- Frozen Food Packaging.
- Barrier Packaging.
- Trash Bags and Liners.
- Heavy Duty Bags.
- Lamination Replacement
- To Name a Few….

Components of an MDO Line

- Unwind (If MDO is Not In-Line).
- Preheat Section.
- Draw Station or Orientation Rolls.
- Annealing Section.
- Cooling Section.
- Miscellaneous Equipment: Treaters & Thickness Measuring System.
- Rewinder.

Unwind

- Handle Large Rolls
- Braking System.
- Safety & Roll Handling Ergonomics.
- Requirements similar to Slitter.
- Does not need to be Fancy.

Preheat Section:

- Uniformly Heat Web.
- Without Hard Wrinkles.
- Film Expands when Heated & Must go Somewhere.
- Heat Web Slowly over Several Rolls.
- Wrinkles or Non-Uniform Web Temperature can cause poor Optics or Inconsistent Physicals.

Draw Station

- This is where most of the orientation happens.
- Web temperature must be Controlled & Uniform, in *both* the MD & TD.
- As shown earlier, Draw Ratio is important.
- As is the gap between to Draw Rolls.
- Rate of Draw (dv/dt, or the acceleration of the web across the gap), is also Important!
- With an increase in the line speed, the gap should be adjusted to maintain the same rate of draw.
- Accurate Speed Control.

Second Draw Station

- Sometimes it is desirable to have a second draw station.
- This Draw Station can be Immediately after the first station.
- Or it can be further down stream in the MDO.
- There are Potential Advantages of both.

Nipping in the Draw Station

There are two Commonly employed methods of nipping the web in the Draw Station.

The first, and most common, is the standard nip. Similar to what is used in the Primary nip of most Blown Film lines.

The second is an “S-Wrap” nip.

Both can have their advantages.

The Annealing Section

- Annealing Can Effect Properties and Quality.
- Can destroy much of the Improvements put into the film in the Orientation Section.
- Effects & Can Control Shrinkage.
- Can help Prevent Crushed cores or Baggy Edges.
- Usually the Film should Annealed as hot and as long as Possible.

Cooling Section

- Uniformly Cools Web to near Ambient Temperature.
- The Film Shrinks Because of the Temperature Change.
- Web needs to be cooled without Wrinkling.

Miscellaneous Equipment

- Treater.
- Thickness Measuring System.
- Film is Thinner in the Center of the Web, and Gets Thicker as you move Toward the Edges.
- Knowing the Film Thickness Profile Helps Quickly Locate the Correct Place to Trim the Edges.

Rewinder

- Film Shrinks over several Days.
- Need Loose Wind to Allow Film to Shrink.
- If winding is too Tight the Web will get Baggy Edges.
- Can Also Crush Cores.
- A Good Winder, Which can Gap Wind, will Pay for itself in Preventing Customer Returns & Excess Edge Trim.

Conclusion

- *There is a Good Deal more Involved in the MDO Process than:*
- Getting the Web as Hot as you can.
- Stretching it as Much as you can.
- Then Cooling it Back Down for Winding.

- ***There is Also a Good Deal More to an MDO than Just a Stack of Heated and Driven Rolls.***

Thank You

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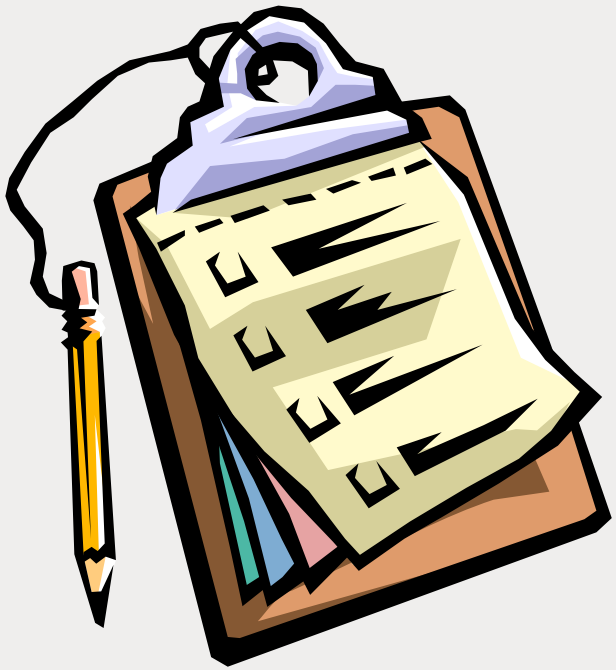

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