Message from the TPC of Extrusion Division for ANTEC 2011

ANTEC is the largest annual technical conference in the plastics industry. Every year, thousands of polymer scientists and process engineers gather together to update each other in their latest research findings. It is through these meetings that ideas are cultivated, information is exchanged and friendships are formed. The Extrusion Division has eight great sessions planned for ANTEC 2011! We are covering the areas of Twin Screw Extrusion for Compounding and Reactive Extrusion, Simulation and Application sessions in Single Screw Extrusion, Dies, Extrusion for Pharmaceuticals, a session dedicated to New Technologies, and lastly a session where you can meet with present and past members of the SPE Extrusion Division Board of Directors. We will have a review of several past best papers to see what we have learned since, and an interactive panel discussion.

We are privileged to have three keynote speakers this year: Professor Dilhan M. Kalyon from Stevens Institute of Technology will be speaking on Twin Screw Extrusion of Complex Fluids on Monday morning; Professor Peng Wang from the University of Rhode Island will be introducing an exciting new field for polymer engineers — Pharmaceutical Extrusion on Tuesday morning; Dr. Joseph Dooley from the Dow Chemical Company will be speaking on Experimental and Numerical Modeling of the Coextrusion Processes on Tuesday afternoon.

Don’t forget our SPE Extrusion Division Awards and Business Meeting Tuesday night starting at 5:30p.m. Hors d'oeuvres and refreshments are on us! It will be great to mingle with friends and colleagues with wine and food! We look forward to seeing you there!

Michelle Curenton
Technical Program Chair, Extrusion Division for ANTEC 2011
Top 5 Reasons to Attend ANTEC

1. **Broaden Your Understanding of the Plastics Industry** - Attend sessions exploring the full spectrum of the plastics industry. ANTEC is the place to gain exposure to developments and people from throughout the entire industry.

2. **Network** - Meet with fascinating, informed and creative colleagues from around the world to share insights from a broad range of disciplines and industries within plastics.

3. **Visit with Exhibitors** - Walk the tradeshow floor and talk with representatives from leading companies who offer solutions for your business.

4. **Understand the Impact of New Technology** - Confer with the plastics industry's leading experts to learn what new technologies and techniques are being developed today.

5. **Build New Skills** - ANTEC offers seminars, workshops and other forums for people of all levels within the plastics industry. Take advantage of one or more of our special sessions to enhance your skills and increase your knowledge.

The Extrusion Division launch of the first Extrusion Wiki in early 2009 has met with broad acceptance. Board of Directors Member Michelle Curenton was instrumental in developing the Wiki. The Extrusion Wiki will allow you to search a vast database of information concerning extrusion as well as being able to submit additional content.

Check it out by clicking [here](#)!
## Keynote Speakers

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<td><strong>TWIN SCREW EXTRUSION OF COMPLEX FLUIDS - CHALLENGES AND OPPORTUNITIES</strong></td>
<td>Prof. Dilhan M. Kalyon Stevens Institute of Technology</td>
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<td>8 a.m.</td>
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<tr>
<td><strong>Tuesday Morning</strong></td>
<td><strong>PHARMACEUTICAL EXTRUSION – AN EXCITING NEW FIELD FOR POLYMER ENGINEERS</strong></td>
<td>Prof. Peng Wang Stevens Institute of Technology</td>
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<td><strong>Tuesday Afternoon</strong></td>
<td><strong>EXPERIMENTAL AND NUMERICAL MODELING OF THE COEXTRUSION PROCESS</strong></td>
<td>Dr. Joseph Dooley Dow Chemical Company</td>
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### Extrusion Division Wine and Cheese

Come network with your colleagues at the **Extrusion Division Wine and Cheese Reception** on Tuesday afternoon, May 3!!
### Monday AM — Twin Screw Extrusion - Compounding — M9

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<tr>
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<td>RESIDENCE STRESS DISTRIBUTIONS IN TWIN SCREW EXTRUDERS</td>
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<td>INFLUENCE OF WOOD FLOUR CONTENT ON MECHANICAL PROPERTIES AND MORPHOLOGY OF EXTRUDED FOAMED WOOD PLASTIC COMPOSITES</td>
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<td>10:00</td>
<td>EFFECT OF THE PROCESSING VARIABLES ON THE MECHANICAL PROPERTIES AND MORPHOLOGY OF PP/MODIFIED CLAY NANOCOMPOSITES</td>
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<td>Lee, Patrick C.</td>
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<td>MODELING OF ANISOTROPIC POLYMERS DURING EXTRUSION</td>
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<td>INVESTIGATION OF THE EXPANSION BEHAVIOR OF PE-LD FOAMED WITH CO2</td>
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## ANTEC Program
**Tuesday — May 3, 2011**

### Tuesday AM: Twin Screw Extrusion - Reactive — T7

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<td>CONTINUOUS POLYMERIZATION USING A TWIN-SCREW COMPOUNDER</td>
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<td>UV-INITIATED REACTIVE EXTRUSION OF POLYPROPYLENE</td>
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<td>NATURAL FIBRE PULPING AND REFINING USING TWIN SCREW EXTRUSION</td>
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### Tuesday AM: Extrusion for Pharmaceuticals — T8

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<td>EFFECTS OF SCREW CONFIGURATION ON THE DISSOLUTION BEHAVIOR OF INDOMETHACIN IN EUDRAGIT® E PO SOLID DISPERSIONS</td>
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<td>HOT MELT MIXING OF INDOMETHACIN AND SOLUPLUS® FOR ORAL DELIVERY</td>
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### Tuesday PM: Single Screw Extrusion - Simulation — T27

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<td>AN ENGINEERING APPROACH TO THE CORRECTION OF ROTATIONAL FLOW CALCULATIONS FOR SINGLE-SCREW EXTRUDERS - EQUATION CORRECTION</td>
<td>Spalding, Mark</td>
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<td>LATERAL STRESS AND DENSITY OF PET RESIN WITH RE-CYCLE</td>
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<td>ONE DIMENSIONAL MELTING IN SINGLE-SCREW EXTRUDERS</td>
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<td>SIMULATION OF MICROPELLETIZING MECHANISMS</td>
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## ANTEC Program
### May 3 (Cont’d) - May 4, 2011

### Tuesday PM
**Moderator:** Steve Schick - Teel Plastics

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<td>PRODUCING MICROLAYER BLOWN FILM STRUCTURES USING LAYER MULTIPLICATION AND UNIQUE DIE TECHNOLOGY</td>
<td>Dooley, Joseph</td>
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<td>Andersen, Paul</td>
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<td>3:00</td>
<td>ELECTRONICALLY TIMED GEAR PUMPS</td>
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<td>Gryczan, Matthew</td>
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### Wednesday AM
**Moderator:** Michelle Curenton - SoloCup Company

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<td>A COLLECTION OF PREVIOUS BEST PAPERS AND WHAT ADVANCEMENTS HAVE BEEN MADE SINCE...</td>
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<tr>
<td>9:30</td>
<td>WHY BECOME A MEMBER OF SPE AND EXTRUSION DIVISION BENEFITS</td>
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<td>10:00</td>
<td>PANEL DISCUSSION</td>
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Extrusion Dies Industries, LLC

EDI is an international supplier of flat extrusion and coextrusion die systems for the full range of film, sheet, extrusion coating, fluid coating, and strand pelletizing applications. Its subsidiaries, EDI Precision Dies (Shanghai) Co., Ltd in China and EDI GmbH in Germany, provide rework, sales, and technical services.
In Memory of  
Ed Steward (1950-2011)

It is with great sadness that American Kuhne announces that Ed Steward passed away on Saturday, April 9th from an unexpected heart attack. As the co-founder and Vice President of Process Technology, Ed’s technical contributions as well as his friendship and sense of humor will be greatly missed at American Kuhne.

In January, 1997 Ed co-founded American Kuhne with his good friend and colleague, Bill Kramer along with Peter Kuhne, President of Kuhne GmbH in St. Augustine, Germany. Prior to that he was employed at the Davis Standard Corporation for 24 years as the Chief Process Engineer. His responsibilities included screw design and application engineering along with processing related tasks that insured extrusion systems would meet the designated performance goals. Ed had been a member of the Society of Plastics Engineers since 1973 and was recognized as a Fellow Of The Society in May 2006. Ed also received the Bruce Maddock Award from the Society of Plastics Engineers Extrusion Division in recognition of his contributions to single screw extrusion in May 2004.

Ed’s educational experience included a Bachelor of Science degree in Mechanical engineering from the University of Connecticut. Ed has written numerous papers for various extrusion societies and publications on screw design and related topics. These included general screw performance, data acquisition for screw design, screw wear, co-extrusion articles, vented extrusion and grooved feed extrusion.

Ed was a devoted husband to his wife Rita, deeply involved in his church, an accomplished golfer and tennis player, as well as an overall sports enthusiast. In addition to his high performance Steward Barrier Screws, he was well known for his gentle demeanor and outstanding sense of humor.

Services will be held at the Old Mystic Baptist Church, 151 Shewville Road, Old Mystic, CT 06355, on April 30, 2011 at 1:00 PM. In lieu of flowers, the family requests that donations in his memory be directed to the Church. Ed will be greatly missed by his family, friends, colleagues, and customers.

William Kramer, President  
American Kuhne, Inc.  
401-326-6212  
bkramer@americankuhne.com
Feeding of Color Concentrates into the Molding or Extrusion Process

Keith A. Larson
Colortronic North America, Inc.

There are many reasons to consider using color concentrates in your facility, and adding them directly into the feed throat of your injection molding machine or extruder:

- Reduced material cost
- Reduced virgin resin cost
- Simpler inventory control
- Quick mold changes
- Improved process control
- Better, and faster, process flexibility

Accurate metering of color concentrate, or any other additive, is critical to the quality of the end product in any molding or extrusion process. Inaccurate feeding can result in:

- Color variations
- Excess cost
- Diminished physical properties
- Inaccurate additive inventory

The following elements need to be considered when selecting the proper feeder for your application:

- Actual running rate of all your processes.
- Ratio of cycle time to recovery time (injection molding applications).
- Desired additive rate.
- Minimum acceptable additive level to produce a good product.

Physical characteristics of the additive material

A properly designed feeding system will feed consistently through the desired feed range. Specific styles of feeders operate differently, and each has its own advantage – the trick is selecting the best combination for your application!

BACKGROUND

Most plastic processors started using pre-colored material because it was easy to handle, and simple to control in their plant. However, this convenience comes at a price because pre-compounded material costs more than coloring your own material in-house.
In recent years, many processors have switched to coloring their own material in-house for a variety of reasons. There are many reasons to consider using color concentrates, or other additives, in your facility, and adding them directly into the feed throat of your injection molding machine or extruder:

- Reduced material cost compared to pre-colored, or pre-compounded, material (typically $0.25 to $0.30 per pound).
- Reduced virgin resin cost by buying in larger quantities, i.e. truck load or railcar (typically $0.05 to $0.10 per pound).
- Simpler inventory control – reduced amount of high usage materials to keep track of – store common virgin resins and smaller containers of color concentrate.
- Quicker mold changes – change cooler feeder hopper “on the fly”.
- Improved process control by introducing the additive directly into the feed throat, especially when compared to off-line batch blending.
- Flexibility to modify color shades – add more or less color as the end customer deems necessary.
- Reduced lead time to make a color change to a product – do not need to get the colored compound from a third party – they color it in-house.
- Ability to purchase color concentrates at various pigment loading levels to better control their process.
- Ability to tint parts to a translucent shade rather than an opaque color.
- One less heat history since the color concentrate is not heated an additional time in the compounding process.

All of these advantages can add up to a significant improvement in your process. Once you factor in all of the issues, you will decide that adding these materials in-house will also make sense for your operation.

**SELECTING AN ADDITIVE FEEDER**

Once you decide to add color concentrate, or any other additive, directly into your molding machine or extruder, accurate metering of the additive is critical to the quality of the end product you produce. Inaccurate feeding can result in:

- Color variations in the final product.
- Excess cost in the product by using more color concentrate, or additive, than necessary.
- Diminished physical properties if too much color is added, i.e. failed parting lines in a blow molded part.

Inaccurate control of additive inventory.

The following elements need to be considered when selecting a feeder for your application:

- Minimum and maximum continuous running rate of your process.
- Ratio of cycle time to recovery time of the shot in injection molding applications.
- Additive feed rate (let down ratio), as well as minimum acceptable level to produce a good product.
- Physical space limitations of the existing process, i.e. height, width, weight capacity, etc.
- Orientation of existing equipment, i.e. drying hoppers, loaders, etc.
Feeding of Color Concentrates into the Molding or Extrusion Process
(Cont’d)

Physical properties of the virgin material and the additive, including:
- Bulk density (weight)
- Particle shape – pellet, micro pellet, powder, etc.
- Particle or pellet size
- “Flowability” of the material

Selecting a Feeder

Understanding the minimum and maximum continuous running rates of your process is very important when trying to size any kind of feeding equipment. Low rates on start-up are not an issue, but if you plan to run a broad range of continuous output rates, you need to take all of them into account when sizing a feeder. Most feeders can easily handle a turn-down range of 10:1 between the highest and lowest rates, and some designs have a broader range. Changing the feed screw or disc will usually cover the entire range, but it must be considered up front when specifying the feeder.

The ratio of “cycle time” to “recovery time” of the shot in injection molding applications must also be considered, because the screw is only rotating and feeding additive material during the recovery phase of the molding cycle. If you assume a 5 second recovery and a 15 second cycle time, the feeder needs to feed the entire amount of the additive, with the virgin material, in one-third of the time, so the feeder needs to be sized for three times the actual feed rate. This is important to understand or the feeder will be undersize, and will not achieve the desired cycle time.

The desired additive rate, as well as the minimum acceptable level to produce a good product, is your single biggest opportunity to reduce the cost of the part. Many processors over-color the product because the feeder, or blending process, is inconsistent, and the part cannot fall below the minimum color spec. A more accurate feeder allows you to reduce the amount of color used and maintain the color specification. An example is listed below:

Assumptions:
- 2% color on a 100 lbs./hr. application
- Five day, 24 hour operation
- 0.5% overfeed (2.5% vs. 2%) to ensure color match
- $5.00 / lb. color or additive (conservative estimate)
- Operating time, overfeed and additive price are conservative – many numbers are larger, making payback quicker

Return on Investment (ROI):
- 0.5 lb./hr. x 24 x 5 days = 60 lbs./week savings
- 60 lbs. x $5.00 / lb. = $300/week savings
- $3,250 digital dosing feeder ÷ $300 weekly savings =
- 10.83 week payback (1 week payback with a $50.00/lb. additive)
- Payback in less than three months at $5.00 /lb.!!
- An easy decision in this day of rising material costs!!

Physical characteristics of the additive material, including density, particle size and particle shape can affect the end result of your finished product. Dissimilar materials are harder to mix consistently.
and will also separate if they are mixed too much. A feeder that feeds the additive directly into the throat of the molding machine or extruder is the most accurate, because you minimize the risk of contamination, inconsistent feeding and material separation.

**Feeder Types**

Additive feeders are available from many suppliers, and in many different configurations. Common designs include:

- Augers, or screws
- Dosing discs
- Vibratory
- Bulk solids pumps

*Volumetric* and *gravimetric* versions of the feeder designs

**Auger Feeder**

*Auger, or screw, feeders* have been the most prevalent design in recent years, and they offer a broad feeding range that is easily modified. However, they must be operated in the middle of their feeding range, or they will not be very accurate. The mechanical design of the screw creates a pulse that makes the feeder very inaccurate at low rates, often alternating between feeding and not feeding when the screw turns very slowly. If the proper speed is maintained, their accuracy is acceptable to many processors, especially for lower cost additives, or maybe even metering regrind back into the process.

Multiple units can easily be configured to introduce two or more components, or easily change back and forth between two additives, i.e. different colors.

**ADVANTAGE:** Low cost

**DISADVANTAGE:** Varying feed rates, leading to poor accuracy
Application: A blow molder is making air ducts for automobiles. All of the components are molded black, and use a lot of regrind. Therefore, he only needs to color a small amount of virgin material for each part.

An auger feeder does a good since his color consumption is very low.

Digital dosing disc feeders utilize a horizontal or vertical disc that looks like a bicycle sprocket to consistently feed materials at all speeds. The rate is increased by changing the size or number of the pockets, or the speed of the motor. These feeders can precisely meter most powder and pellet materials at rates as low as 50 grams per hour!
ADVANTAGE: Extremely accurate feeding

DISADVANTAGE: Slightly higher price

Application # 1: A medical molder needed to accurately dispense 0.5 gram shots of an expensive polymer into a molding machine.

Fifty shots were recorded with a range of 0.496 to 0.504, with an average of 0.5016 grams
Feeding of Color Concentrates into the Molding or Extrusion Process

(Cont’d)

Application # 2: A custom molder needed to consistently meter very low percentages of blue color concentrate to lightly tint a medical component – existing auger feeder could not accurately feed the material consistently, resulting in varying tint levels in the molded part.

The shot size was very small (8 grams), and the let down ration was less than 0.5%

A digital dosing feeder solved the problem.

Vibratory Feeder

**Vibratory feeders** are good for pelletized, and friable, materials. They have a high turn-down ratio, often as broad as 100:1. The drawback is that they do not work well with some materials, especially those with inconsistent particle shapes, like regrind. They fill a need, but are not usually the best choice for a precision color or additive feeder. They are better suited for higher percentage additives, i.e. glass fiber bundles, re-pelletized material, etc.

**ADVANTAGE:** Lower cost

**DISADVANTAGE:** Inconsistent feeder accuracy, especially with dissimilar particle size

**Application:** A custom compounder needed to feed glass fiber bundles into a second downstream port on his compounding line.

A vibratory feeder did the job without damaging the fragile glass fiber bundles.
Bulk Solids Pump

Bulk solids pumps are another feeding alternative that offer some of the advantages of the disc feeding technology. The feeder utilizes positive displacement action to feed free flowing materials with good accuracy, offering uniform discharge, consistent volume and gentle handling.

The BSP feeders have vertical rotating discs that create a product lock-up zone, conveying the material smoothly from storage the hopper to the discharge outlet, achieving true linear mass flow.

Utilizing a simple design and the principle known as “lock up”, the material in the feeder is moved together in true positive displacement, producing excellent linearity and breakthrough accuracy levels.

With only one moving part, the compact feeder is cleaned in seconds, making it ideal for applications with frequent material changes.

They are also available in a variety of sizes, and are a good choice for many free-flowing materials at higher feed rates.

**ADVANTAGE:**
Improved accuracy with many materials

**DISADVANTAGES:**
- Slightly higher price
- Larger physical size
Volumetric vs. Gravimetric Feeders

Most of the feeders described above are available from several suppliers in both volumetric and gravimetric models. Gravimetric models will be more expensive, but offer the advantage of inventory tracking.

Volumetric models are calibrated (with an off-line scale) during setup to feed a given rate and are left alone. Auger versions are typically accurate in the range of +/- 3 to 5%, and can be as bad as 10% with inconsistent material particle size. Digital dosing disc models are in the +/- 0.5 to 1% range. They usually need to be re-calibrated for different bulk densities when materials are switched, i.e. black vs. white color concentrate.

Gravimetric versions use a load cell to weigh all of the additive material that passes through the additive hopper, and are usually accurate to +/- 1 to 2%. However, even though the weighing system provides the inventory tracking, the feeding device ensures the consistency of the feed rate.

In most applications, a more accurate feeder, i.e. dosing disc style, in volumetric mode will produce better results than an auger feeder in gravimetric mode, since the feed rate is much more consistent. This is especially true at feed rates below 2 lbs./hr.

Summary

A properly designed feeding system will feed your additive materials consistently through your desired feed range. The correct feeder will result in a better quality product and savings in your operation. A volumetric dosing disc feeder is probably your best choice for precise metering, while a gravimetric feeder may be the better option if inventory tracking is more important to you.

Specific styles of feeders operate differently, and each has its own advantage – the trick is selecting the best combination for your material and application!
Feeding of Color Concentrates into the Molding or Extrusion Process
(Cont’d)

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An Experimental Study of the Flow of an Encapsulated Polymer Melt Through a Unique Blown Film Die
(Antec 2001 Best Paper)

Joseph Dooley, Steve Jenkins and John Naumovitz
The Dow Chemical Company, Midland, MI

Abstract

Many polymers are extruded through blown film dies to produce monolayer and multilayer films. The most popular style of die in use today to produce blown films is the spiral mandrel die. This type of die can be used effectively for many polymers but cannot easily be used with thermally sensitive materials due to long flow paths and large surface areas that can lead to polymer degradation. This paper will discuss a new, unique blown film die technology in which a thermally sensitive polymer is encapsulated with a less sensitive material and processed into a blown film. Experimental data will be shown on the viscosity of encapsulated melts and the unique flow patterns in the die.

Introduction

Many polymers are extruded through blown film dies to produce monolayer and multilayer films. The most popular style of die in use today to produce blown films is the spiral mandrel die (1). This type of die can be used effectively for many polymers but cannot easily be used with thermally sensitive materials due to long flow paths and large surface areas that can lead to polymer degradation.

Coextrusion is a common method used for producing multilayer blown films. Coextrusion is a process in which two or more polymers are extruded and joined together in a feedblock or die to form a single structure with multiple layers. This technique allows the processor to combine the desirable properties of multiple polymers into one structure with enhanced performance characteristics. The coextrusion process has been widely used to produce multilayer sheet, blown film, cast film, tubing, wire coating, and profiles (2-7).

This paper will discuss a new, unique blown film die technology in which a thermally sensitive polymer is encapsulated with a less sensitive material and processed into a blown film. Experimental data will be shown on the viscosity of encapsulated melts and the unique flow patterns in the die.

Background

Two styles of coextrusion are illustrated in Figure 1. This figure shows a planar layered structure on the left and an encapsulated structure on the right. The encapsulated structure can be produced using a feedblock similar to the one that is shown schematically in Figure 2. This diagram shows a feedblock attached to the end of an extruder pumping polymer A from the left into a transfer pipe. The pipe feeds the feedblock that radially encapsulates polymer A with a layer of polymer B. This encapsulated structure then flows downstream maintaining the layered structure.

Figure 3 shows why encapsulation technology can be important for thermally sensitive materials. This figure shows a representation of the velocity profile in a tube for a monolayer and an encapsulated material. The left side of the figure represents the velocity vectors in parabolic flow in a tube. The right side of the figure shows how in an encapsulated structure, the core material is confined to the higher velocity areas of flow and will have a shorter average residence time. Since degradation of thermally sensitive materials is normally a function of time and temperature, a shorter average residence time would produce less degradation.

As was described earlier, most commercial blown film lines use a style of die called a spiral mandrel. In this type of
die, the melt stream is split into several streams and spiraled around a central mandrel in order to produce a film that is uniform in thickness. This essentially produces thin overlapping layers of polymer at the exit. This style of die is not suitable for an encapsulated structure because the melt stream division and layering would disrupt the encapsulation structure.

Since a spiral mandrel die is not suitable for an encapsulated structure, a crosshead style die was used in this study. In a crosshead style die, a distribution manifold similar to that used in a coathanger sheet die is wrapped around in a circle such that the ends touch forming a tubular exit. When an encapsulated structure, similar to what is depicted in Figure 1, is fed to a standard crosshead die, the flow geometry changes it experiences are shown in Figure 4. The encapsulated structure shown in the top of the figure is compressed in one direction and stretched in the other direction and then wrapped around the central mandrel such that the ends meet, as is shown in the bottom of the figure.

The difficulty with this structure is that when the ends of the encapsulated structure come together at the back of the manifold, the skin layers join together but the core materials do not touch. If the core material is a barrier polymer and the skin material is not, this type of structure would produce a film in which the barrier properties at the weld line are significantly worse than those in the rest of the structure.

One unique solution that produces a tubular structure with uniform barrier properties is shown in Figure 5. The left side of this figure shows a structure produced by a standard crosshead die while the right side of the figure shows a structure produced by a unique die in which the ends of the channels have been overlapped (8). Figure 6 shows an enlargement of just the joining area of the tubular structure in which the barrier layer has been overlapped. Path A represents the flow path of a gas permeating straight through the skin material and the barrier core layer. Path B represents the flow path of a gas permeating just through the non-barrier skin material in the overlap area. By knowing the relative barrier properties of the skin and core materials, the overlap structure can be designed such that Path A and Path B produce equivalent barrier properties. This style of die would produce a tubular film with equal barrier properties around the film.

One of the difficulties in designing a tubular die for distributing an encapsulated melt is determining the rheology of the encapsulated structure. The purpose of this work was to experimentally measure the rheology of an encapsulated structure and to use that information to design a tubular die for producing a film with uniform barrier properties with a thermally sensitive core material.

**Experimental**

Several commercially available resins were used in these experiments: a high impact polystyrene resin (HIPS), a low density polyethylene resin (LDPE), a polyvinylidene chloride barrier resin (PVDC), all three manufactured by The Dow Chemical Company, and an ethylene vinyl acetate copolymer (EVA) manufactured by DuPont. The rheological properties of the polystyrene and polyethylene resins were shown previously (9).

Two types of experiments were run in this study. The first series of experiments were run to determine the viscosity of coextruded encapsulated structures. The second series of experiments were run to determine the flow patterns of encapsulated melts through different die geometries.

The coextrusion line used in this study for determining the viscosity of an encapsulated coextruded structure consisted of a 63.5 mm (2.5 inch) diameter, 21:1 L/D single screw extruder and a 31.75 mm (1.25 inch) diameter, 24:1 L/D single screw extruder. These extruders were attached to a feedblock that was designed to produce coextruded structures consisting of a core layer encapsulated by a skin layer. The layered structure consisted of a 10% skin layer and a 90% core layer. Attached to the exit of the feedblock was a transfer line in which pressure transducers had been inserted at specific lengths down the pipe as is shown in Figure 7. The pipe had a diameter of 9.5-mm (0.375 inch) with a distance of 107 mm (4.2 inches) between the transducers.
For the rheology experiments, the coextrusion line was run with the two extruders pumping at set flow rates and temperatures until steady-state conditions had been reached. At this condition, the pressures from the three transducers were recorded along with the measured total flow rate and temperature. This procedure was repeated at several different flow rates and temperatures so that the viscosity of the encapsulated structure could be determined at different shear rates.

The coextrusion line used for examining the interface location in coextruded structures consisted of a 31.75 mm (1.25 inch) diameter, 24:1 L/D single screw extruder and a 19.05 mm (0.75 inch) diameter, 24:1 L/D single screw extruder. These extruders were attached to a feedblock that was designed to produce coextruded structures consisting of a core layer encapsulated by a skin layer. The layered structure consisted of a 30% skin layer and a 70% core layer. Coextruded structures were made using the same material in each extruder with different colored pigments added to each to allow determination of the interface location in the structure.

Attached to this feedblock were dies containing channels with a teardrop shaped cross section and a coathanger style die manifold with a rectangular shape. These channels were described previously in detail (9-10). Both die channels had approximate lengths of 61 cm.

For a typical experiment, the coextrusion line was run for 30 minutes to ensure that steady-state conditions had been reached. The experiments were run at a temperature of 215 °C and an extrusion rate of 2.5 kg/h, which would give a wall shear rate in the range of 1 to 10 s⁻¹. Variable depth thermocouples were used to measure the temperature of each melt stream just prior to their entering the feedblock. This was done to ensure that the melt temperature of each stream was the same as they entered the feedblock. When steady state was reached, the extruders were stopped simultaneously and the coextruded material was cooled while still in the die channel, solidifying the material. After it had cooled to room temperature, the polymer “heel” was removed from the die and cut into 25.4 mm (1 inch) sections to expose the cross-sectional faces along the die. These faces were studied by obtaining digital images with a video camera and an appropriate magnification lens. This procedure allowed the major deformations of the interfaces to be examined.

**Results**

The experimental setup shown in Figure 7 was run with LDPE resin to validate that the rheological data produced by this apparatus would correlate with data generated by standard capillary rheometers. Figure 8 shows the viscosity vs. shear rate data generated for the LDPE resin using the three different combinations of pressure transducers (P1-P2, P2-P3, and P1-P3). As the figure shows, all three combinations produced similar curves. These data also correlated very well with data generated by a capillary rheometer.

This apparatus was then used to measure the viscosity of an encapsulated structure consisting of a skin layer of EVA on a core layer of PVDC, as well as monolithic structures of the individual components. These data are shown in Figure 9. At the test conditions used, the PVDC core resin had the highest viscosity, the EVA skin resin had the lowest viscosity, and the encapsulated structure had an intermediate viscosity between the core and skin resins.

These viscosity data were then used to design a die manifold with the ends of the channels overlapped. Special care was taken in choosing the shape of the distribution manifold channels. Previous work (11-18) has shown that die channel shape is a critical factor in producing coextruded structures with uniform layers, especially for highly viscoelastic materials. This is illustrated by the images in Figure 10. These images show an encapsulated structure containing HIPS in both layers flowing down a teardrop shaped channel. The image on the left shows the encapsulated structure near the entry of the channel while the image on the right shows the structure near the exit of the channel. Note the large deformation of the white core layer as it flows down the channel. If the white material was a barrier material, this large amount of deformation would produce a film structure in which the barrier properties would not be uniform throughout the film.
An encapsulated melt of HIPS was also extruded through an experimental die manifold with a rectangular cross-sectional shape. The results of this experiment are shown in Figure 11. This figure shows cross-sectional cuts at intervals of 102 mm (4 inches) from near the entry of the manifold on the left to near the end of the manifold on the right. Note that the black encapsulating material becomes a larger proportion of the area of the manifold as it flows down the manifold. At a distance of approximately 508 mm (20 inches) down the 610 mm (24 inch) manifold, the entire cross section is composed of black skin material only. This implies that the majority of the material in the overlap area of a crosshead die would be composed of the skin material using this specific die geometry. This illustrates the importance of the shape of the die manifold when running an encapsulated structure.

Using the results of all of the above experiments, a large-scale die manifold was designed for an EVA/PVDC encapsulated structure with an overlapped weld line. This manifold was used as the central layer in a five layer blown film die to produce a coextruded film structure in which uniform barrier properties were produced in all areas of the film.

**Conclusions**

A unique multilayer coextrusion blown film die has been developed using encapsulation technology to protect the thermally sensitive barrier layer material. This die uses a technique of overlapping the ends of the core layer distribution manifold in a crosshead style die to ensure uniform barrier properties throughout the film. The key to scaling this technology to large-scale dies is the use of appropriate die channel geometry to maintain proper layer uniformity as the encapsulated material flows through the distribution manifold.

**References**


Keywords: Blown film, coextrusion, encapsulation, die design.
An Experimental Study of the Flow of an Encapsulated Polymer Melt Through a Unique Blown Film Die

(Continued)

Figure 1. Types of coextruded structures.

Figure 2. Schematic diagram of a coextrusion feedblock for producing an encapsulated structure.

Figure 3. Flow of monolayer and encapsulated materials in a tube.
An Experimental Study of the Flow of an Encapsulated Polymer Melt Through a Unique Blown Film Die
(Continued)

Figure 4. Geometry changes experienced by an encapsulated melt flowing into a crosshead style die.

Figure 5. Comparison of an encapsulated melt in a standard crosshead die and a die in which the ends of the channels have been overlapped.

Figure 6. Flow paths through an overlapped structure that would produce equivalent barrier properties.
An Experimental Study of the Flow of an Encapsulated Polymer Melt Through a Unique Blown Film Die (Continued)

Figure 7. Viscosity measurement apparatus for coextruded structures.

Figure 8. Viscosity data produced for a LDPE using different pressure transducer combinations.

Figure 9. Viscosity data for individual components and for a coextruded encapsulated structure.
An Experimental Study of the Flow of an Encapsulated Polymer Melt Through a Unique Blown Film Die
(Continued)

![Image of entry and exit of a teardrop channel for an encapsulated structure.]

**Figure 10.** Layer interface location at the entry and exit of a teardrop channel for an encapsulated structure.

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