SOCIETY OF PLASTICS ENGINEERS
BLOW MOLDING DIVISION

WINTER 2004/05 Issue

THE INFLUENCE OF MELT RHEOLOGY ON THE SPECIFIC OUTPUT RATE OF BROAD MOLECULAR WEIGHT DISTRIBUTION POLYETHYLENES IN SINGLE SCREW EXTRUSION

by Rajendra K. Krishnaswamy, David C. Rohlfing, Ashish M. Sukhadia & Kevin R. Slusarz*

Chevron Phillips Chemical Company, LP
Bldg 94-G, Bartlesville Technology Center
Bartlesville, OK 74004
*** Davis-Standard Corporation, Pawcatuck (CT)**

Abstract

The extrusion (single-screw) characteristics of four broad molecular weight distribution (MWD), linear polyethylene resins are discussed with an emphasis on the output rate. Despite the high molecular weights of the subject polyethylenes, their broad MWD (*M*w/*M*n range: 10 to 60) does not limit the pressure and torque developed during extrusion. However, the specific output of the four polymers was quite varied. The dependence of the specific output on the melt rheology of the polymers is addressed; specifically, the shear-thinning extent of the melt in the metering section was found to influence output rate. The unique and counter-intuitive temperaturedependence of the shear-thinning character of one of the four polymers will also be addressed in relation to its extrusion characteristics. Lastly, a simple and quick method to evaluate the relative solids conveying efficiencies for various polyethylenes will be presented.

Background

Extrusion is the most popular process used to fabricate plastic parts. Product quality and production rate are the two most important aspects of the fabrication process. These are not only a function of the polymer and the extrusion parameters, but are also dependent on the interactions between the polymer and the details of the extruder and screw employed (1-4). Downstream of the pellet hopper, the extrusion process can, for the sake of simplicity, be divided into three major sections: (a)*?* Solids Conveying or Feed; (b) Compaction and Melting (c) Metering. In order to improve the physical properties of polyethylene (PE), it is typical to increase the molecular weight of the polymer for various applications. Increasing the molecular weight (and consequently the viscosity of the polymer) usually results in a resin that is somewhat more difficult to process as the extrusion pressure and torque on the screw become limiting factors. To overcome this, polyethylene resin producers usually broaden the molecular weight distribution (MWD) in addition to increasing the molecular weight. In this study, we report the processing behavior of four high molecular weight, broad MWD PEs. Specifically, the influence exerted by the melt rheology, solid frictional characteristics and melting capacities of these PEs on the output rate in single screw extrusion will be discussed. Our discussions are pertinent only to extruders with smooth-bore feed sections.

Experimental Section

Majority of the extrusion experiments were carried out using a 38 mm, 28:1 L/D Davis Standard single screw (smooth-bore feed section) extruder. A general-purpose screw with a Maddock mixing section was employed. These experiments were performed with a pipe die attached at the end of the extruder. Some extrusion experiments were also carried out using an instrumented 89 mm, 30:1 L/D Davis Standard extruder controlled with an EPIC III system. This extruder was equipped with seven pressure probes spaced evenly along the length of the extruder, a high-speed data acquisition system and a low-work barrier screw.

Results and Discussion

The molecular characteristics of the four polymers employed in this investigation are listed in the Table-1. The molecular weight distribution (MWD) of these polymers, as evident in their *M*w/*M*n values, is relatively broad. HDPE-C, with an *M*w/*M*n of about 15, is the narrowest MWD polymer among the PEs employed in this study. HDPE-D is the highest molecular weight polymer investigated here with an extremely broad MWD.

Figure-1 shows the dynamic mechanical characteristics (complex viscosity versus angular *ANTEC 2004 /* **173** frequency) of the four polymers measured at 210∞C. HDPE-A displays the lowest viscosity across the entire frequency range of measurement. HDPEC displays the highest viscosity at frequencies
greater than 50 s-1; however, HDPE-C approaches the Newtonian plateau at higher frequencies and has a lower low-shear viscosity compared to
HDPE-B and HDPE-D. HDPE-D displays very high low-shear viscosity; this is attributable to the very high molecular weight of this polymer. However, HDPE-D also displays a high degree of shear-thinning such that its high-shear viscosity is comparable to or less than that of HDPE-C. In general, the dynamic mechanical properties of these polymers are quite consistent with their molecularweight data.

continued on page 9

Chairperson's Message

Welcome to The Winter 2004 Newsletter

Chairman's message 01/21/05

Education, that is all there is to it! Go out and provide opportunities for anyone in the Blow Molding industry to learn and grow. This is our (SPE Blow Molding Divisions) simple mission. But how to reach the people who need or want the information? Let's look how this can be achieved.

Many of you may have attended our Annual Blow Molding Conferences. Attendance has been growing and from the reviews, this annual conference is becoming the one last vestige of technical interaction open to anyone interested in technology. Our next conference is to be held in Toledo, Ohio on October 12-13, 2005. We will have a dual path program which present information on both Packaging and Industrial applications. You will be able to find more information on our web site in the next few weeks.

We have tried to make our web site active and become a source of information. For those of you who have accessed www.blowmomdingdivision.org you have been able to access information from past Blow Molding Conferences, details on the programs the division offers and articles on Blow Molding technologies and techniques. We expect to add more information and hopefully a broad based FAQ section.

We have always supported the "Ask PIP" program through SPE and we get about two to three inquiries each week. This program allows anyone access to our divisions wealth of experience through questions and responses. The questions run from basic understanding to very involved blow molding operations.

As an investment in the future we also have sponsored specific educational scholarships from those at attending training at college level to employees of companies actively working in the industry. The University scholarships have provided students an opportunity to ensure they complete their education and hopefully become a member of Blow Molding industry. The workplace scholarships are relatively new but have given several industry employees needed training in a variety of technical areas.

Remember, all we do is to serve our industry and provide information to that industry. Use our resources, that are here to help you and your company perform at higher levels of efficiency. If you need help, contact us. If you can suggest additional programs for us to provide let us know. Just remember we are here to serve you!

Sincerely,
Ron Puvak
Chairman, Blow Molding Division, SPE

The Blow Molding Division Goes Electronic!

Your Board of Directors took a giant step at the Winter Meeting and voted to convert to electronic voting and also foregoing hard-copy for the upcoming newsletters. The Winter newsletter will be our last mailed edition.

The new slate of candidate directors will be posted on both the SPE website (www.4SPE.org/communities/divisions) as well as on our own website, www.blowmoldingdivision.org Voting buttons on our website will tabulate the vote.

The switch to posing the Newsletter on both web-sites follows the trend across all Divisions, being driven both by savings in printing and postage and the substantial advantages of color, etc.

WHY JOIN?

It has never been more important to be a member of your professional society than now. In the current climate of change and volatility in the plastics industry. Now, more than ever, the information you access and the personal networks you create can and will directly impact your future and your career.

Active membership in SPE:
*** keeps you current**
*** keeps you informed**
*** keeps you connected**

The question really isn't "why join?" but WHY NOT?

http://www.4spe.org/join/

A SPECIAL THANKS TO OUR SPONSORS

WITH YOUR SUPPORT YOU MAKE IT POSSIBLE TO PUBLISH THE SPE BLOW MOLDING DIVISION NEWSLETTER!!!

SPONSORS - COLOR ADDITIVES SUPPLIERS

QUICK NOTES.....

SPE Blow Molding Division wishes to Thank All of Our Newsletter Sponsors for their Tremendous Support THANK YOU!!!

Have a Technical Question/Problem & Need some Quick Expertise? ASK US Ron Puvak Chairperson at 724-482-2163 or email: rpuvak@agrintl.com OR Any of the Board of Directors listed on the back of the Newsletter

Become A Member Of The SPE Blow Molding Division Contact: Lew Ferguson at 609-368-7229 or email him at parisons@aol.com

SPONSORS - CONSULTANTS/TRAINING/LABORATORY

BOARD OF DIRECTOR'S MEETING

Minutes of the Board of Directors of the Blow Molding Division of SPE,

Meeting held at Holiday Inn, Clearwater Beach, Florida, 1-31-05 - 2-1-05.

- **Executive Meeting:**
- A short executive meeting was held to discuss people in the Chair positions.
- **Call to order at 8:15**
- BOD Members present: Bruce Thompson, Ron Puvak, Joe Altimari, Bob DeLong, Jonathan Meckley, Mark Heitker, Win Burrington, Bob Jackson, Lewis Ferguson, Dave Holliman, Gary Carr, Mark Barger, John Rathman, Janai Stepp, and Bob Fitch
- BOD Members Excused: Surendera Agarwal, Jack McGarry, and Gordon Williams
- Recognized Scott Steele as a visitor to the meeting
- Reading of Non-Disclosure/Non-Compete Statement
- Jack McGarry has resigned from the board
- Karim Amellal has resigned from the board
- **State of the Board (Structure of the BOD)**
- Committee Meetings were Productive
- List of Nominees looks long for BOD
  - Found new people at ABC 2004
- **Secretary's Report - Jonathan Meckley**
- There were no Changes to the minutes from Fall BOD Meeting
- Dave Holliman moved and Mark Barger seconded the move to accept minutes.
- **Treasurer's Report - Mark Heitker**
- Operating Fund Budget
  - Changes
  - $8,000 for Newsletter
  - $16,000 for Sponsorships
  - $2,000 for Councilor's Travel
  - $1,000 for Administrative Assistant
  - $2,000 for Dues Rebate
  - January 2006
  - $6,500 for Web Maintenance
- Bruce Thompson moved to Accept and Bob Jackson seconded the move, Board Accepted the Budget.
- Disbursement Fund Budget
  - Mark Heitker to Solicit funds from Captive Plastics & Milacron Greer
  - 1st Payment to SPE Foundation due at beginning of the Fiscal Year
  - Pay for Plastics Van as part of the ABC,
  - Bob Jackson moved to Accept and Dave Holliman seconded the move
  - The Board Accepted the Budget
- Grant Fund Budget
  - Bob Jackson moved to Accept and Joe Altimari seconded the move
  - The Board Accepted the Budget
- **Councilor's Report - Bob DeLong**
- SPE Recognizes the need to Change
- Dues Rebates will be back in January 2006
- Pinnacle Award has become the new Award Program
  - Replaces Star and Pride Awards
- Value for SPE Website
  - Web Based Training
  - Member only Section
- Increase in SPE Membership after several Years of Decline
- ANTEC
  - Only 10% of Membership Attends
  - Negotiated Chicago Attrition Rate from $160,000 to $70,000
  - No more than 30% of Papers will be from the Academics
  - Allow more Commercial Papers
  - Free Tutorials on Sunday Afternoon
  - Councilors voted down a proposal for Councilors to pay 1/2 of ANTEC Registration
  - Tim Wormer is President Elect
- **Nominating Committee Report - Bruce Thompson**
- Joe Altimari is not able to stand for Chair-Elect position.
- Ron Puvak will stay Chairman for another year
- Dave Holliman was nominated to Chair-Elect
  - Bob Jackson moved to Accept and Mark Heitker seconded the Nomination
  - The Board elected Dave Holliman
- Mark Heitker is moving to Educational Chair
- Mark Barger will be leaving the BOD after ANTEC 2005
- There are 4 open positions on the board
- **Education - Mark Barger**
- There are 5 applicants for Scholarships
- There are 13 applications for the Design Competition
- There is 1 approved for the Graham Workplace Scholarship
  - From Last Fall
- Blow Molding Educational Grant Program
  - Mark Barger will put out a draft proposal similar to The Thermoforming Division's for Educational Grants.
  - The grant will provide up to $4,000 per application
  - Will give priority to Universities that have Matching Grants
  - Evaluation of the grants will done at each board meeting
  - A motion for entering a grant proposal to establish a new program called the Blow Molding Educational Grant Program was made.
  - Mark Barger moved to Accept and Bob Jackson seconded the Nomination
  - The Board accepted the proposal
- There was discussion about finding other sources to upgrade University blow molding machines to ANSI/SPI B151.15-2003
- Larry Schult from Ferris State is taking a sabbatical to work at Bekum
- **Marketing - Bob Jackson**
- Gary Carr created a PowerPoint presentation for Membership evaluation
- Newsletter - Bob Delong
  - Would like to have only an Electronic Version of the Newsletter
  - Need to acquire Adobe Pro
    - Need $300 to Purchase
  - Costs for Printed Newsletter
    - $16,000 Budgeted for 3 printed newsletters
    - $3400 for editorial help
    - $750 for pdf file conversion
    - ~$12,000 for printing and postage
  - More than 60% of sections and divisions have Electronic Newsletters
  - There was an Advisor vote to move the newsletter to an Electronic Version after the next Newsletter
- Membership - Lew Ferguson
  - Primary Members 609
  - Secondary Members - 360
  - Total Members - 969
  - There are 40 new members
  - Lew Ferguson will make a list of lapsed Members
  - Divide them up amongst the board members
  - Board Members will call to see if they will rejoin
  - New Member Packet needs to be prepared & sent to Board Members
  - The AIM (Action in Membership) form needs to be sent
- **TPC - Surendra Agarwal (Jon Meckley)**
- ABC 2004 - Jon Meckley
  - $6,042.46 Net Profit
    - Split with National
  - $4531.85 Division Profit
- ABC 2005 - Scott Steele
  - Electronic Flier will be available 1 week after meeting
  - Possible Tour on the 11th
  - Two side by side sessions
    - Industrial
    - Packaging
  - Conference is in a new conference center
  - $350 conference fee
  - A motion for using the Graham Workplace Scholarship for up to $4,000 to get the students to the ABC was made
  - The motion was approved by the board

continued on Page 5

BOARD OF DIRECTOR'S MEETING

Continued from page 4

- ABC 2006 - Bob Jackson
- ABC 2007 - Surendra Agarwal
- Dave Holliman asked about having the ABC 2008 in Bartlesville
- ANTEC 2005 - Mark Barger
  - BOD Committee meetings on Wednesday Morning
  - BOD Meeting Wednesday Afternoon
- Awards Report - Dave Holliman
  - Lifetime Achievement
  - 5 Candidates were voted on to pare the list down.
  - Candidates will be put forward based on complete applications
  - Fellows Nominations
  - Mark Barger
  - Lew Ferguson
    - Honored Service Nominations
  - John Rathman
  - Bruce Thompson
  - Outstanding Board Member Service
  - Vote was taken

OLD BUSINESS:

- There was no Old Business

NEW BUSINESS:

- Additions to Marketing PowerPoint presentation
  - Information on the upcoming ABC's
  - Names of some Material and Machinery Suppliers

ADJOURNMENT:

- Motion to adjourn made by Bob Jackson
- The Board accepted the Motion

ANTEC 2005

Boston, Massachusetts
May 1-5, 2005

A Revolution in Plastics
Hynes Convention Center
&
Sheraton Boston Hotel

Lennie Kogut
Receives the 2004 Carrie Fox Solin Memorial Scholarship

Leonard V. (Lennie) Kogut III is the recipient of the 2004 Carrie Fox Solin Memorial Scholarship award. Lennie received the award from Dr. Larry Solin at the 2004 ANTEC in Chicago. Lennie is currently a Junior at Ferris State University majoring in Plastics Engineering. He is also the SPE Student Chapter President at Ferris. The Blow Molding Division offers its congratulations, and hopes to see Lennie at future Division events.

The 2004 memorial scholarship is supported by the Blow Molding Division and our corporate sponsor, Captive Plastics.

About the Blow Molding Division's Memorial Scholarship Program:

The SPE Blow Molding Division has been awarding university scholarships since 1991. To date over $160,000 has been awarded to deserving students enrolled in Plastics Engineering at eligible universities.

The Blow Molding Division's scholarship program seeks to reward outstanding candidate students currently enrolled in degreed undergraduate plastics engineering programs. The Division is particularly interested in identifying students that plan to pursue careers in the blow molding industry. Further information can be found at the Blow Molding Division and the SPE Foundation websites:
www.blowmoldingdivision.org
http://www.4spe.org/foundation/scholarships.php

We encourage our member companies to consider these scholarship recipients as a source of talent. We have identified these students as being top candidates within their field. Too often we lose these students to other fields within the plastic industry. Please consider these students upon graduation if your company has employment openings. We have two scholarship recipients completing their degrees in 2005. Andrea Leczynski will be graduating from UMASS Lowell, and Rachel Suffield will be graduating from Western Washington University. Both are obtaining degrees in Plastic Engineering.

SPONSORS - PROCESSORS

DICK SMITH
PRESIDENT
AGRI-INDUSTRIAL PLASTICS COMPANY
CUSTOM BLOWMOLDING
301 N. 22ND • P.O. BOX 950
FAIRFIELD, IOWA 52556
(515) 472-4188

SPONSORS - MACHINE EQUIPMENT & BUILDERS

AgrTopWave
QUALITY TESTING SYSTEMS
FOR PLASTIC CONTAINERS AND PREFORMS
ON-LINE & LABORATORY EQUIPMENT
AgrTopWave, LLC
P.O. Box 149
Butler, PA USA 16003-0149
Phone: 724 482-2163
Fax: 724 482-2767
E-mail: sales@agrtopwave.com
www.agrtopwave.com

BEKUM AMERICA CORPORATION
Blow Molding Machines and Complete Systems
P.O. Box 567
1140 W. Grand River
Williamston, MI 48895-0567
Phone. 517-655-4331
Fax 517-655-4121
E-mail: sales@bekumamerica.com
Website: www.bekumamerica.com
BEKUM

SPONSORS - MACHINE EQUIPMENT & BUILDERS

ABC 2005

The 2005 annual Blow Molding Conference is set for Oct 11-13th. Our venue will be the Convention Center in downtown Toledo, Ohio. Toledo? You may be scratching your head and getting ready to dismiss the location, but you will be missing out on a great event in a good location if you do.

The conference will feature two separate programs in one. In addition to speakers who will be giving an overview of the blow molding industry, we will have programs directed at industrial and technical parts blow molding, as well as and alternative program directed to packaging. We will cover extrusion blow molding, stretch blow molding, materials, and decorating. There will also be tours through local manufacturing and technical facilities. The schedule of presenters, topics and activities is presently being set and the complete program will be available on the blowmoldingdivision.org website as soon as possible.

Toledo is conveniently located in the heart of the plastic processing industry and is serviced by the local airport, as well as being 50 minutes from Detroit Metro airport. Thirty-five percent of our membership should be able to drive to the conference making those corporate accountants happy. The convention center is located in the downtown area with access to good restaurants and hotels. If you have not experienced the world famous Tony Packo's Hot Dog, get ready for some serious Midwestern hospitality and heartburn. We promise not to make you stay through Saturday night.

PET Corner

Recently, I have received a spat of old questions again regarding the safety of PET containers. My neighbors all think of me as some kind of plastics expert, so I try not to disappoint them with my answers. The question goes something like, "Is it safe to microwave or freeze your PET packages? Don't they contain Dioxin?"

If you search the web, there is a very good document published by the EPA entitled "Questions and Answers about Dioxins", which you can read for yourself. Or, I might take a moment to summarize the relevant information for you.

Dioxins contain chlorine, by definition. The PET (polyethylene terephthalate) bottles used for soft drinks, water bottles and juices contain no chlorine. PET is made up of carbon, hydrogen and oxygen only, and has been demonstrated over many years to be nontoxic and contaminant-free. There is absolutely no way that dioxins can be leached from PET!

Dioxins are naturally contained in many common food products, and they are known to be found particularly within fatty foods. Experts seem to agree that the natural levels of exposure are not harmful, but most testing of foods that purports to detect dioxins, fails to recognize that the levels detected are natural to the food and have nothing to do with the packaging.

Dioxins are not contained naturally even in plastics that contain chlorine, such as PVC (polyvinyl chloride). Rather, dioxins are produced upon combustion and incineration of such plastics that contain chlorine. This has been known for many years and the EPA has placed stringent requirements on incineration in order to minimize the production and emission of dioxins during incineration. Certainly some dioxins are produced and emitted as a result of incineration, but the fact is that dioxins have gradually been reduced in our atmosphere over the last ten years. High heat exposure by itself does not produce dioxins. Most reports of such studies are scientifically inaccurate and misleading but they are sensational, which is sure to breed illogical conclusions by uninformed individuals.

When you are confronted with questions like this by your friends and neighbors, it is always in our best interest to answer factually and with some confidence that yes, our plastic packaging industry is very well controlled and safe. My kids drink from the same bottles you do, which is all that I really need to say.

Scott Steele
Plastic Technologies, Inc.

SPONSORS - FEEDSCREW

SPONSORS - MOLD BUILDERS

VISIT THE
SPE BLOW MOLDING
DIVISION WEBSITE :

http://www.blowmoldingdivision.org

ON THE LIGHTER SIDE.....

The Dictionary: ***What engineers say and what they mean by it ...***

A number of different approaches are being tried
We don't know where we're going, but we're moving.
Extensive effort is being applied on a fresh approach to the problem
We just hired three new guys; we'll let them kick it around for a while.
Preliminary operational tests are inconclusive
The darn thing blew up when we threw the switch.
The entire concept will have to be abandoned
The only guy who understood the thing quit.
Modifications are underway to correct certain minor difficulties
We threw the whole thing out and are starting from scratch.
Essentially complete.
Half done.
We predict...
We hope to God!
Drawing release is lagging.
Not a single drawing exists.

SPONSORS - STATISTICAL PROCESS CONTROL SOFTWARE

SPONSORS - USED MACHINERY

SPONSORS - MATERIAL ADDITIVES/SUPPLIERS

THE INFLUENCE OF MELT RHEOLOGY ON THE SPECIFIC OUTPUT RATE OF BROAD MOLECULAR WEIGHT DISTRIBUTION POLYETHYLENES IN SINGLE SCREW EXTRUSION

continued from Cover

TABLE 1:

Resin ID	M_w (kg/mol)	M_w/M_n
HDPE-A	200	28
HDPE-B	320	33
HDPE-C	250	15
HDPE-D	500	58

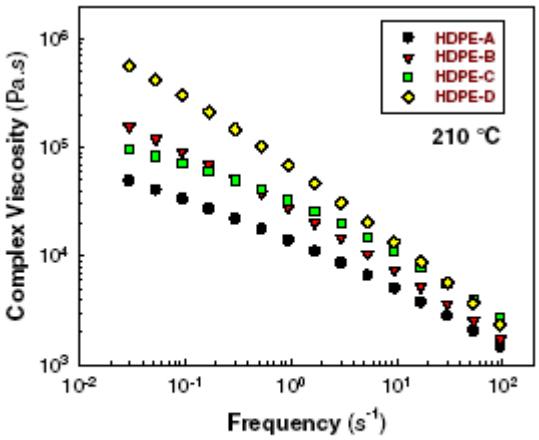

Figure-1: Dynamic mechanical properties of the subject polyethylenes.

Figure-2 shows the volumetric output rate (@ 104 rpm on the 38 mm extruder) for the four subject polymers. These data were collected at an extrusion set temperature of 230 ∞C. The output rates rank as follows: A > B > C > D. It is clear that the output rates of the subject PEs is considerably different even though the extrusion pressures and torque they generate are moderate. Therefore, our objective is to elucidate the principal causes for the observed differences in output rate.

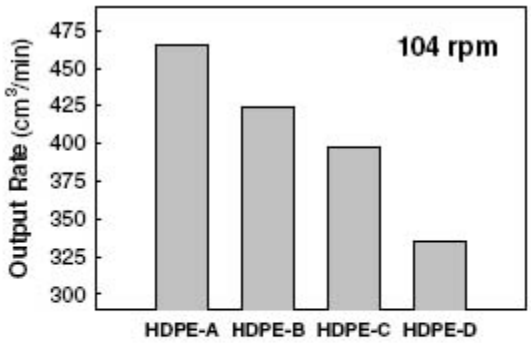

Figure-2: The output rate of the subject polyethylenes during single screw extrusion at 104 rpm.

Many investigators have compared the extrusion behavior of polypropylene (PP) to that of PE and attributed the substantially lower specific output of PP to its relatively inefficient melting rate (5, 6). The substantially higher melting temperature and the larger change in heat capacity (.Cp) across the melting process for PP compared to PE adequately explain the inefficient melting rate of PP in single screw extrusion (7, 8). Investigation of the melting characteristics indicate that the peak melting temperatures and the enthalpies of melting for the subject HDPEs are not that different. This means, the .Cp of the melting process for the four PEs is quite similar in magnitude. Further, the flow activation energies estimated from melt rheology measurements at various temperatures for the subject polymers are very similar. Therefore, we assume a negligible influence exerted by the melting capacity of these polymers on the ultimate output rate in single screw extrusion. Consequently, differences in the output rate for the subject PEs is driven largely by the efficiencies of the solids conveying and the metering sections of the extruder.

The metering section of an extruder has been reasonably well characterized; specifically, momentum and mass balance of the metering section provides relatively simple equations that predict the output rate of an extruder as a function of screw and extruder geometry, screw rpm and the melt rheology of the fluid. Despite the simplifying assumptions involved in such derivations, the trends indicated by such models have been very useful in studying extrusion. The equations developed for a non-newtonian power-law fluid at isothermal conditions indicate that the output rate is a function of the limiting power-law slope, ***n*** (1, 2,9). Stated explicitly, the output rate increases with ***n***, all else being constant. In order the address the influence exerted by the power-law slope on the output rate in our extrusion experiments, the highrate shear rheology of the subject polyethylenes were measured in a capillary rheometer. The limiting ***n*** parameter for the HDPEs was estimated by fitting the high rate capillary data to the powerlaw equation; the data points after the onset of melt instability (melt fracture) were excluded from the fitting.

In Figure-3, the extrusion output rate for thefour HDPEs is plotted as a function of the limiting ***n*** and screw rpm. In this plot, it is clear that the output rate is a function of the power-law slope and the trend is consistent with previously reported experimental results and theoretical prediction (1,2, 9). The output rate decreases as the degree of non-newtonian (shear thinning) character of the melt increases. Further, this dependence on ***n*** becomes systematically more significant as the screw rpm is increased.

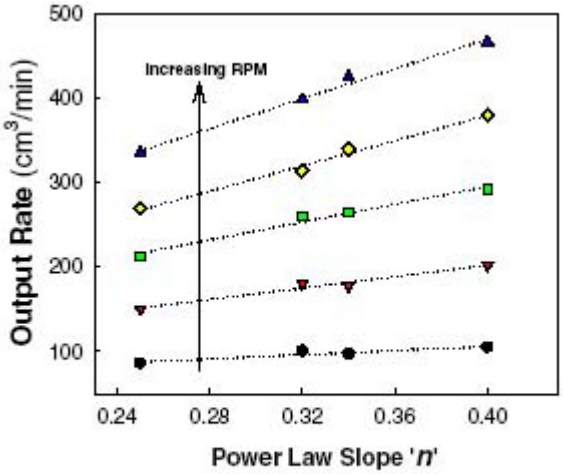

Figure-3: Output rate plotted as a function of power-law slope at various rpm.

In Figure-4, the ***n*** parameter for the HDPEs is plotted as a function of measurement temperature. For HDPE-A, HDPE-B and HDPE-C, ***n*** increases with increasing temperature. This makes intuitive sense as the melt approaches Newtonian character with increasing temperature. However, for HDPE-D, ***n*** decreases slightly with increasing temperature. This counter-intuitive observation for HDPE-D may be attributed to its very high molecular weight and its consequent extreme shear thinning character. With the extrusion output rate being dependent on ***n***, and the counter-intuitive dependence of ***n*** on temperature for HDPE-D, we decided to carry out extrusion experiments at multiple temperatures. Extrusion experiments were performed at 170 ∞C, 200 ∞C and 230 ∞C. At 170 ∞C, the output rate of HDPE-Dis greater than that of HDPE-B; this is contrary to previous observations made at higher temperatures. However, this trend is consistent with the ***n*** forHDPE-D being greater than that of HDPE-B at this temperature. Further, this trend reverses at 230 ∞C; at higher temperature, the output rate of HDPE-D is considerably lower than that of HDPE-B. At 200∞C, the output rates for HDPE-B and HDPE-D are quite similar. The extrusion pressure was observed to systematically decrease with increasing temperature for both polymers, with HDPE-D displaying a larger magnitude of pressure change.

continued on Page 10

THE INFLUENCE OF MELT RHEOLOGY ON THE SPECIFIC OUTPUT RATE OF BROAD MOLECULAR WEIGHT DISTRIBUTION POLYETHYLENES IN SINGLE SCREW EXTRUSION

continued from Page 9

The output rate of HDPE-B increased with extrusion temperature; this is consistent with the pressure gradient and power-law slope trends. However, in the case of HDPE-D, while the extrusion pressure decreases significantly with increasing temperature, the output rate remains constant. Perhaps, the counter-intuitive shearthinning character of HDPE-D is countering the decreased pressure drop, the net result of which is a temperature-independent output rate. Thus far, having assumed a negligible influence exerted by the melting capacity of the polymers on the ultimate output rate, we have analyzed the extrusion data primarily from the metering section perspective. However, it is well known that the solids conveying section can also exert a substantial influence on the ultimate output of an extrusion process. In general, high frictional forces between the pellet bed and the barrel wall and low frictional forces between the pellet bed and the screw surface promote solids conveying. Many experimental and theoretical methods to characterize the frictional forces between a solid pellet bed and a metal surface to evaluate the frictional forces relevant to solids conveying in an extruder exist (10-16).

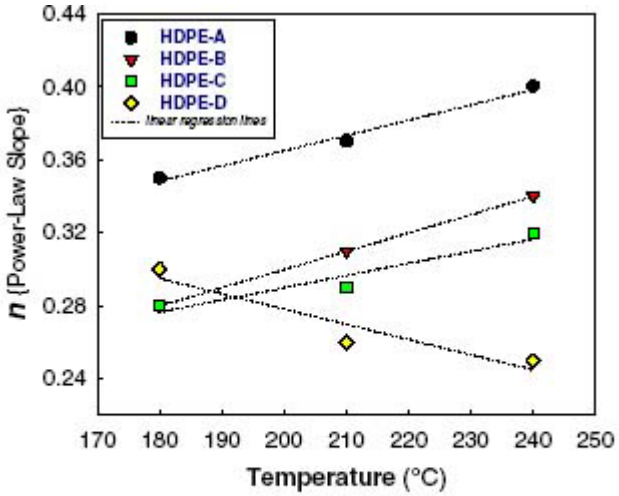

Figure-4: Power-law slope plotted as a function of measurement temperature for the subject polyethylene.

In this report, we first present a rather unsophisticated method to evaluate the relative solids conveying efficiency of the subject PEs. Essentially, the extrusion experiments discussed thus far were repeated by removing the pipe die. In other words, the polymer melt is being conveyed through the extruder with minimal backpressure.
For instance, the maximum pressure developed during this experiment was well below 300 psi. We, therefore, designate the output rate thus obtained as the "pseudo-drag" rate for the polymer in the given extruder. This pseudo-drag rate was found to be independent of extrusion temperature for all the subject PEs as well as a couple other narrow-MWD PEs. Therefore, we contend that this pseudo-drag rate is a means, albeit a crude one, to gauge the efficiency of the solids conveying section. This pseudo-drag rate for HDPE-A, HDPE-B, and HDPE-C are quite similar.

Conclusions

In this study, the single screw extrusion characteristics of four high-molecular weight, highdensity polyethylenes are discussed with an emphasis on the output rate. Despite the high molecular weight of the subject HDPEs, their broad MWD and the consequent broad distribution of melt relaxation times renders them to be adequately shear-thinning melts such that the pressures developed during nominal extrusion operations is moderate. In other words, the extrusion of these polymers is not limited by the pressure they develop. However, the specific output rate of these HDPEs is quite different. We have analyzed the extrusion output data from the perspectives of the solids conveying, compression and the metering sections of an extrusion process.

The melting characteristics of the subject HDPEs were found to be quite similar; this prompted us to neglect the influence exerted by the melting capacity of the extrusion process on the ultimate output rate.
The output rate of the four HDPEs was found to depend on the limiting power-law slope, ***n***,estimated from high shear-rate capillary rheology. Specifically, the output rate increases with ***n***, with a stronger dependence evident at higher screw rpm. In other words, the specific output decreases as the extent of shear-thinning increases. This is consistent with the equations developed from a momentum balance across the metering section that indicates a "favorable" velocity profile for the flow between the rotating screw and the stationary barrel for fluids with a larger ***n*** (1, 2, 9). Further, ***n*** was observed to increase with increasing temperature for all but one of the four HDPEs investigated suggesting an approach to Newtonian behavior with increasing temperature.

However, the shearthinning character of HDPE-D (the highest molecular weight and broadest MWD HDPE) displayed a counter-intuitive trend with ***n*** decreasing slightly with increasing temperature. This anomaly appeared to influence the extrusion behavior of the polymer as well. Specifically, while the output rate of HDPE-B increased considerably with increasing extrusion temperature, the output rate of HDPE-D was insensitive to extrusion temperature despite a systematic decrease in extrusion pressure. This observation also reemphasized the role of melt rheology in the metering section on the specific output rate in single screw extrusion.

In order to address the influence exerted by the solids conveying section on the ultimate output, extrusion experiments were carried out without a die. In these experiments, the polymer was extruded under minimal, almost insignificant, back-pressure. The output rate measured under this condition was referred to as the "pseudo-drag" rate.
The pseudo-drag rate of the polymers was found to be independent of temperature, suggesting that it is related to the solids conveying rate. While the pseudo-drag rate for HDPE-A, HDPE-B, and HDPE-C were very similar, the pseudo-drag rate for HDPE-D was considerably lower. This suggested inefficient solids conveying for HDPE-D compared to the other polymers. This crude, yet simple, measure of solids conveying efficiency was subsequently verified by following the pressure profile within the extruder using a highlyinstrumented extruder. Essentially, the very high molecular weight of HDPE-D was probably responsible for lowering the frictional forcesbetween the solid pellet bed and the barrel wall, thus lowering the efficiency of the solids conveying section relative to the other HDPEs investigated.

Acknowledgements

The authors would like to acknowledge useful discussions with John Christiano (Davis-Standard), Jim Keesling (Chevron Phillips) and Prof. Garth Wilkes (Virginia Tech). The authors are also grateful to Jerry Stark, David Higbee & Barbara Lewis for performing most of the experiments.

References

(1) C. I. Chung, "*Extrusion of Polymers:Theory & Practice*", Hanser Gardner, Cincinnati,(2000).
(2) J. M Dealy & K. F. Wissbrun, *Melt Rheology & its Role in Plastics Processing: Theory & Applications*, Chapman & Hall, New York (1995).
(3) D. G. Baird & D. I. Collias, *Polymer Processing: Principles & Design*, John Wiley & Sons, New York (1998).
(4) J. -F. Agassant, P. Avenas, J. -Ph. Sergent & P. J. Carreau, *Polymer Processing: Principles & Modeling*, Oxford University Press, New York (1991).
(5) C. Y. Cheng, *Proceedings of the SPE ANTEC*, pg 34 (1988).
(6) C. Y. Cheng, *Proceedings of the SPE ANTEC*, pg 98 (1995).
(7) D. W. Van Krevelen, Properties of Polymers, Elsevier, Amsterdam (1992).
(8) B. Wunderlich, Macromolecular Physics, Vol-3: Crystal Melting, Academic Press, New York (1980).
(9) M. L. Booy, *Polymer Engineering and Science*, **21**, 93 (1981).
(10) C. I. Chung, *Society of Plastics Engineers Journal*, **26**, 32 (1970).
(11) D. I. Marshall and I. Klein, *Polymer Engineering and Science*, **6**, 191 (1966).
(12) C. I. Chung, *Polymer Engineering and Science*, **15**, 29 (1975).
(13) D. E. McClelland and C. I. Chung, *Polymer Engineering and Science*, **23**, 100 (1983).
(14) W. H. Darnell and E. A. J. Mol, *Society of Plastics Engineers Journal*, **12**, 20 (1956).
(15) M. A. Spalding, K. S. Hyun and K. R. Hughes, *Proceedings of the SPE ANTEC*, pg 191 (1996).
(16) K. S. Hyun and M. A. Spalding, *Proceedings of the SPE ANTEC*, pg 211 (1997).

SPE BLOW MOLDING DIVISION
NEW MEMBERS
November 2004 - January 2005

NAME	COMPANY or LOCATION
Sameer Saha	Rochester, NY
Tuomin Liu	Canuck Compounders Inc.
Joseph Mecca	Marubeni America
Shengmei Yuan	DuPont Engineering Polymers
M Reza Mirsaeian	Iran Techno Systems Co Ltd.
Rene R. Sanchez	Gambro Renal Products
David Yenor	Pinckney, MI
Steve C. Stieben	Houston, TX
Brad Dickman	SC Johnson & Son Inc.
Steve Kenyon	Raleigh, NC
Kevin Alexander	Amco Plastic Materials
R Keith Brower	Consolidated Container Co.
Mike Savard	Husky Injection Molding Systems Ltd.
Jim Brost	MPC Inc.
Amit Shai	Log Plastic Products (1993) Ltd.
Al Lund	Church & Dwight
John K. Frazier Jr.	Plastipak Packaging
Blake Jack McCoy	Cleveland, OH
Ajit Bhat	Norcross, GA
Jayson T. Humble	Delta Systems Inc.
J. Eric Scott	Douglasvile, GA
Delfin Rega Villar	A Coruna, SPAIN
Moreno Minghetti	Techne Spa
Ronald C. Fisher	Goldmark Distribution Inc.
Mary L. Hughe-Olson	Constar Intl Inc.
Julie Savchenko	P & G
Thomas H. Ellis	Harmon Becker Automotive Systems
Kim Thiara	Acetronic Industrial Controls
Grace M. Garcia	Ertess Plastic Industries

NAME	COMPANY or LOCATION
Inshan Rasool	SM Jaleel & Company Limited
Lloyd G. Martin	Consolidated Container Company
Gerardo D. Morales	Regio Molders SA De CV
John G. Brace	Polymer Institute
John Steadman	Aquapurge Ltd.
Ronald Lintz	Chilton Products
Bradley Adams	Ring Container Technologies
Paul Trainor	Entropex
Sadanand Hanagodimath	Western Cans Pvt Ltd.
Peter J. Wentzel	Utrecht, NETHERLANDS
Steven R. Priest	Setco Inc.
Norkamal Jaafar	Klang selangor MALAYSIA
Shaun D. McNair	Sterling Heights, MI
Ajmal Beg	CRP Group Ltd.
Peter H. Todd	Todd & Associates Inc.
Luis Campos	Soluna SA
Richard Nolen	Hollo Blow Molding
Dale P. Werle	Plastic Solutions Company LLC
Brent Evans	Liochem
Russell Rl Fenton	Fenton Weber & Jones Packaging Inc.
Tricia McKnight	Society of Plastics Engineers
Debra Ravetto	Society of Plastics Engineers
Stephen E. Tarnell	Tarnell Company
Alfonso Diez-Gutierrez	Tapones Y Articulos De Distribucion
Rani L. Daley	Mitsui
Scot M. Sholler	Torrance, CA

SPONSORS - FEEDSCREW

SOCIETY OF PLASTICS ENGINEERS BLOW MOLDING DIVISION
BOARD OF DIRECTORS 2004 / 2005

SOCIETY OF PLASTICS ENGINEERS, INC.
Blow Molding Division
14 Fairfield Drive, Brookfield, Connecticut 06804

The Blow Molding Division Newsletter is brought to you through the support and help of our sponsors.

BULK RATE
U.S. POSTAGE
PAID
Permit No. 6
Edison, NJ

Dated Material