



## Foam Extrusion and Thermoforming of NatureWorks® Bio-Polymer

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# Introduction

- Foam development program initiated 4 years ago
- Engaged two development partners in North America
- Engaged engineering firm who specializes in equipment design for foam extrusion
- Investment of several million dollars in research and development and materials

**Objective:** Develop a NatureWorks bio-polymer suitable for use in an amorphous foam meat tray comparable to existing polystyrene trays in properties and cost

## What is NatureWorks bio-polymer?

- Made from plants, an annually renewable resource.
- Reduces fossil fuel usage 68% versus PS.
- Reduces green house gas emissions nearly 100%!
- Carbon footprint additionally improved by the purchase of Renewable Energy Credits.

## Why NatureWorks bio-polymer?

Foam packaging made from  
**NatureWorks bio-polymer** allows  
brand owners, institutions and communities  
**TO DIFFERENTIATE**  
by offering  
environmentally friendly, renewably based  
packaging.

## Trends and drivers for foam packaging.

- Brand owners are looking for ways to differentiate.
- Foam packaging continues to be a viable solution because of its functionality.
- Foam packaging made from a renewable resource such as NatureWorks bio-polymer is well received.

***Sustainability is a key component of most companies' business philosophy***

## Targeted NatureWorks foam markets.

### Fresh Food Packaging - Complete

- Meat trays, produce trays, mushroom tills, egg cartons, etc.

### Food Service Ware – **In Development**

- Cups, bowls, plates, clamshells, lunch trays

# Technical Development

# Challenges for developing a NatureWorks foam grade resin

## Key differences

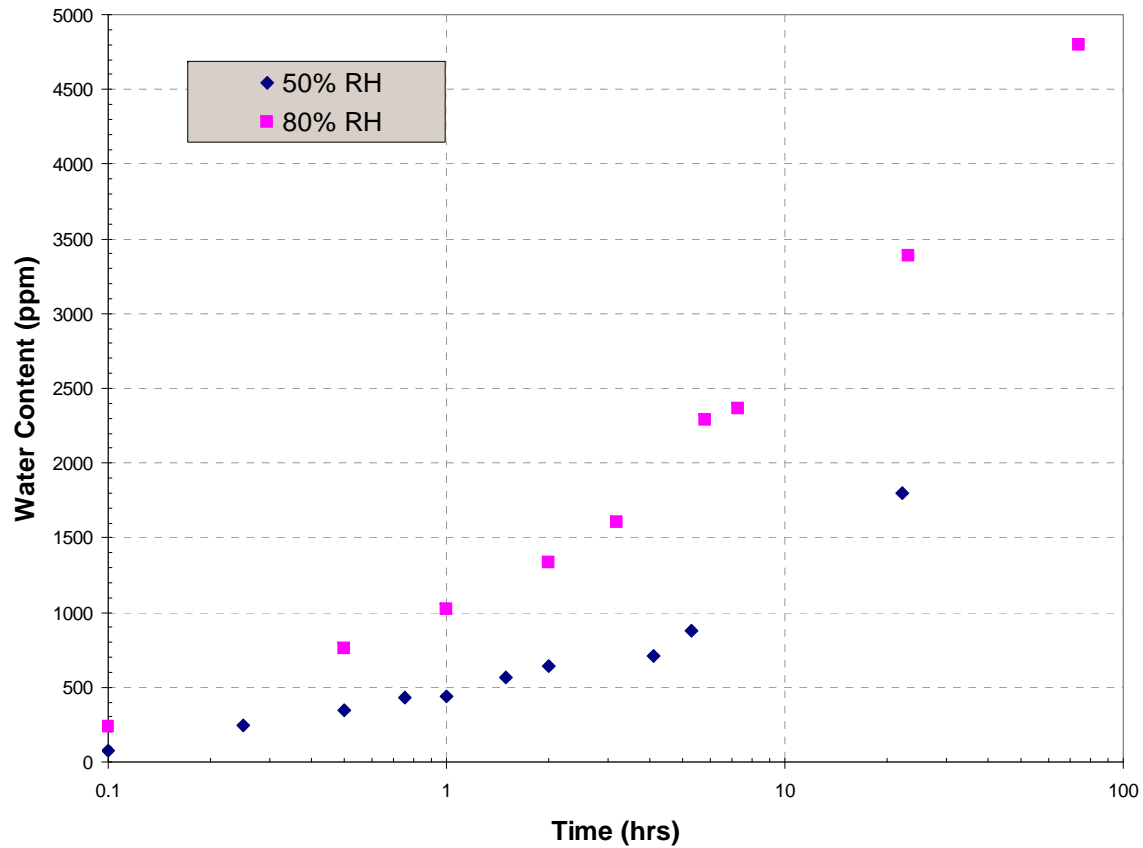
- Hydrolytic Degradation
  - All NatureWorks bio-polymers are subject to a loss in molecular weight due to hydrolysis if not dry prior to extrusion
- Linear Polymer
  - Foam expansion required an elastic component typically not observed in linear polymers
- Lower Glass Transition Temperature
  - Higher post extrusion cooling rates, or longer cooling times are required to stabilize foam

## Hydrolytic Degradation

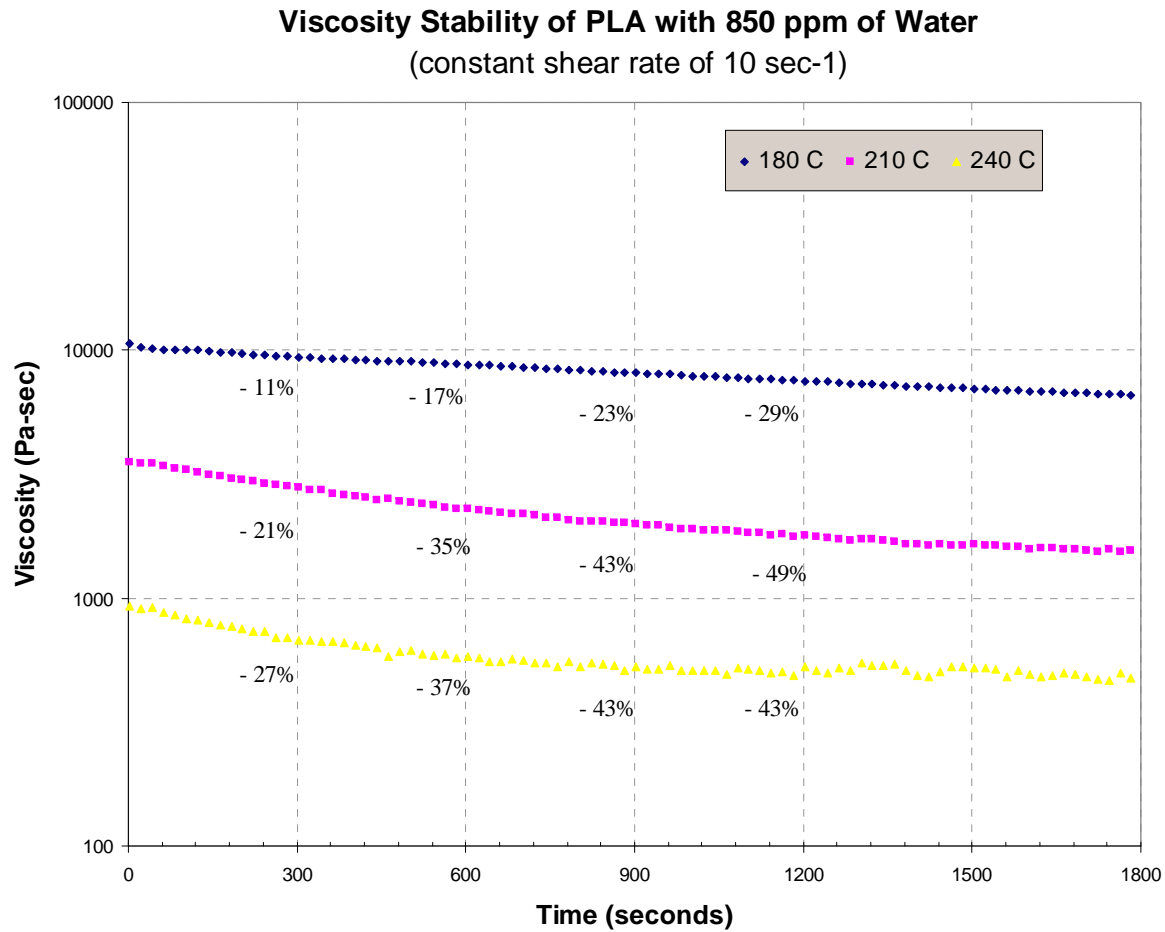
- Much like a polyester, lactic acid based polymers will hydrolyze in the presence of water at temperatures above  $T_g$
- Includes all extrusion
  - Virgin resin fed to primary extruder
  - Flake repelletization
  - Scrap resin fed to primary extruder

# Moisture Pickup of Lactic Acid Polymers

Water Pickup of Crystalline PLA Pellets

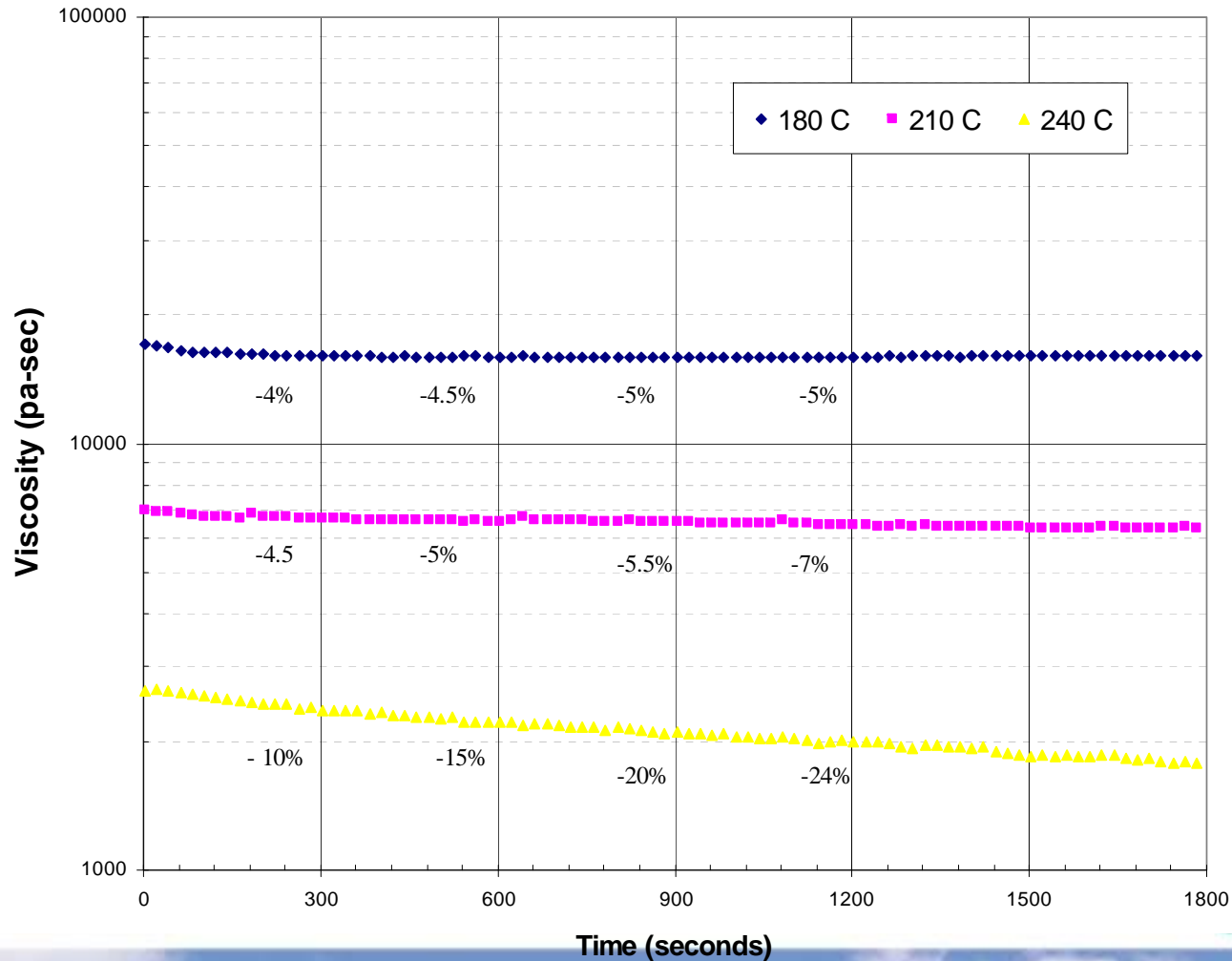


# Viscosity Stability of Linear Lactic Acid Polymers in the Presence of Water at Temperature



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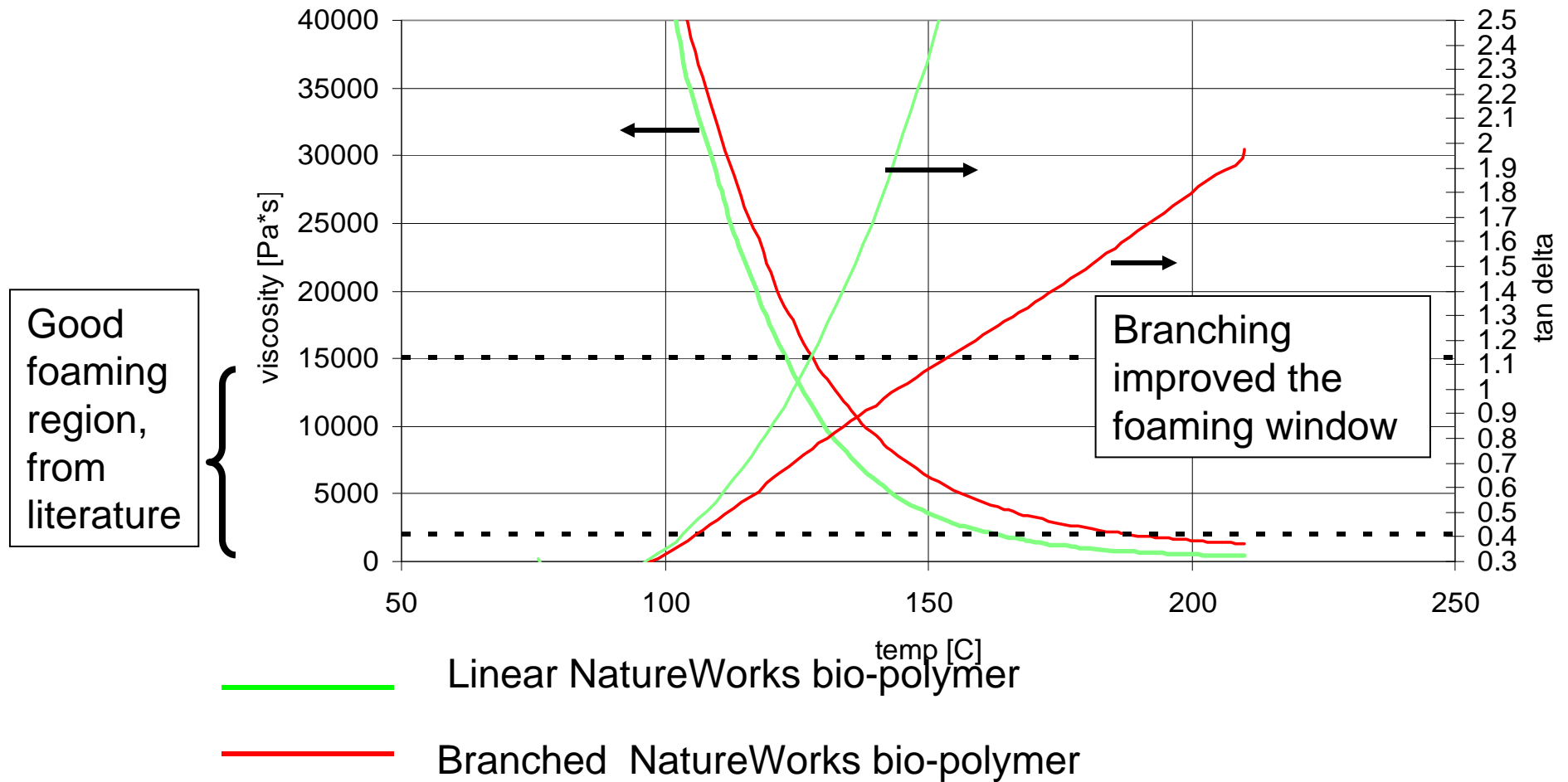
Viscosity Stability of PLA with < 100 ppm Water  
(constant shear rate of 10 sec<sup>-1</sup>)



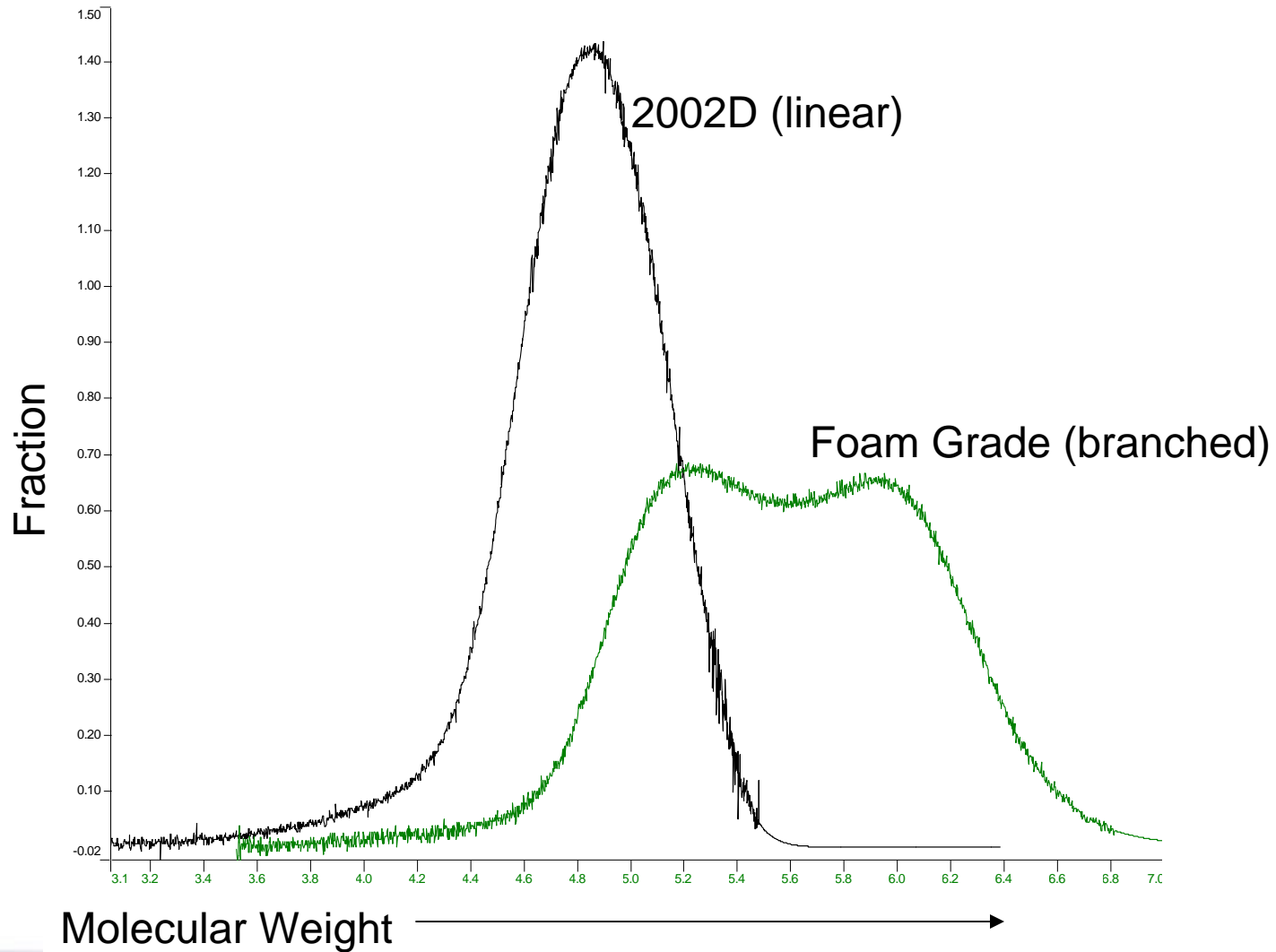
## Secondary Extrusion

- Standard packaging NatureWorks bio-polymer grades have no elastic properties
  - Limited foam expansion
  - Bubble collapse
- Necessitated the development of resin grade with elastic properties suitable for foaming
  - Chemical modification through the use of branching agents

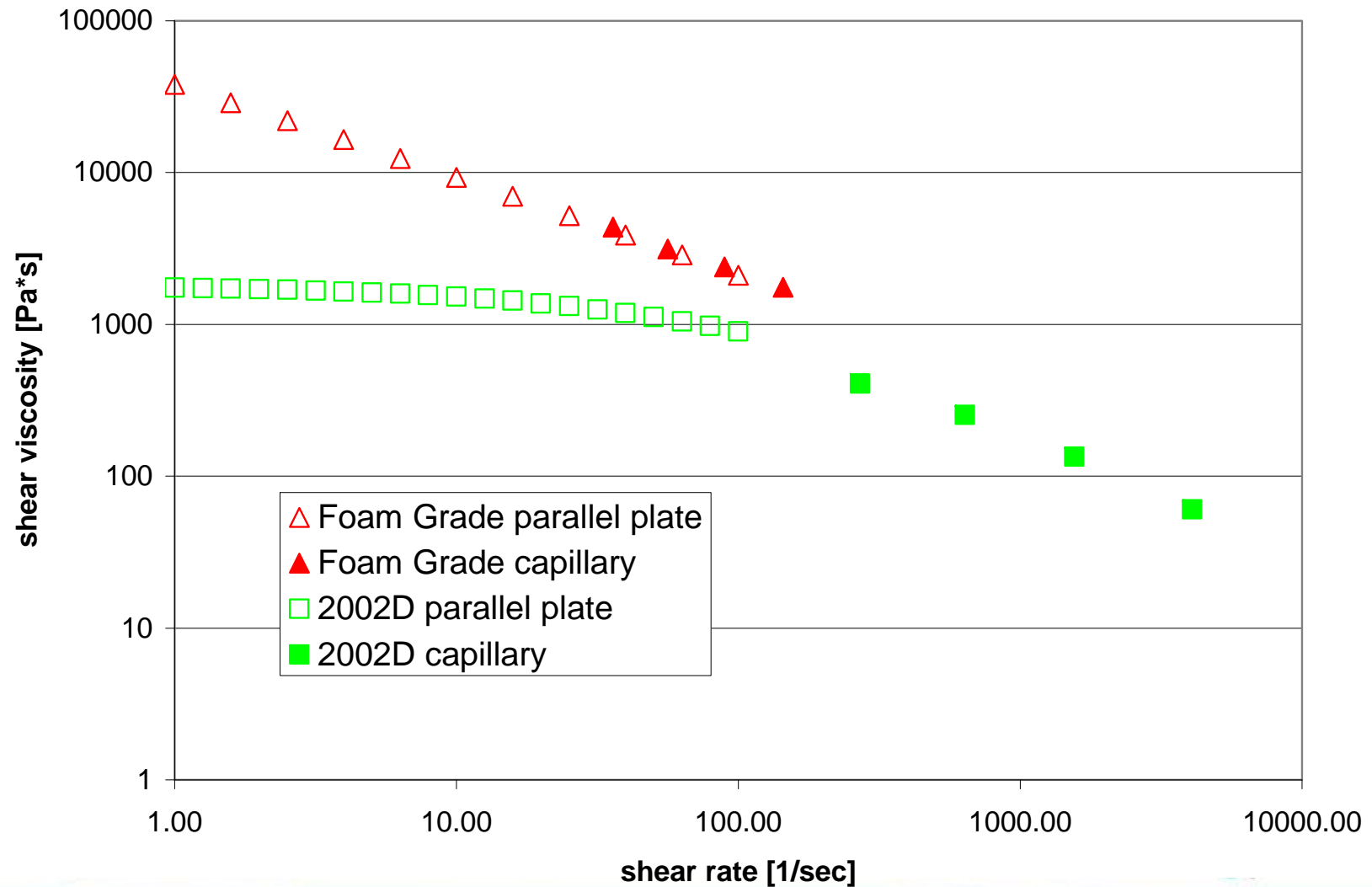
# Rheology Window for Foaming



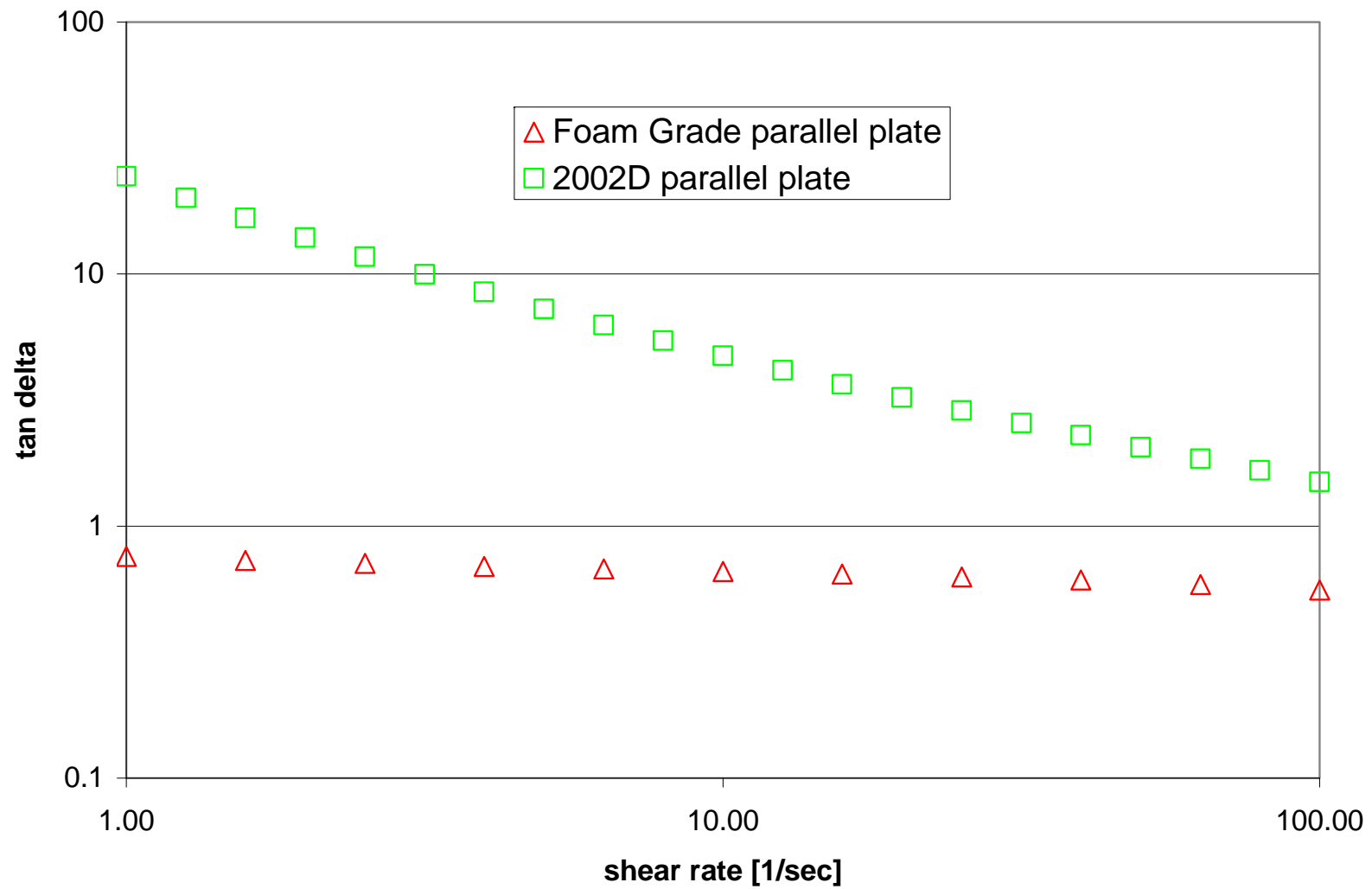
# Molecular Weight Distribution NatureWorks bio-polymers



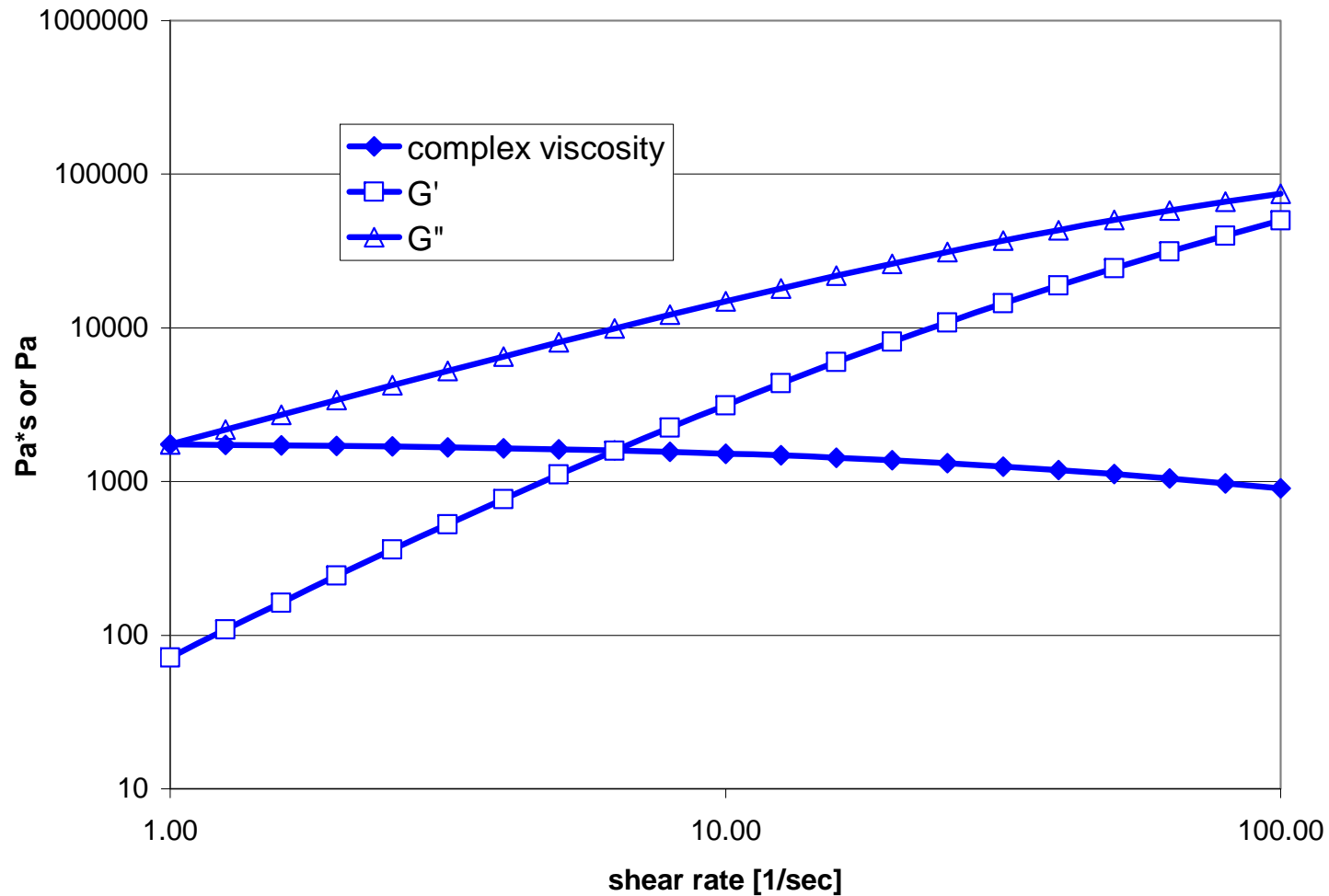
# Parallel Plate and Capillary Rheology



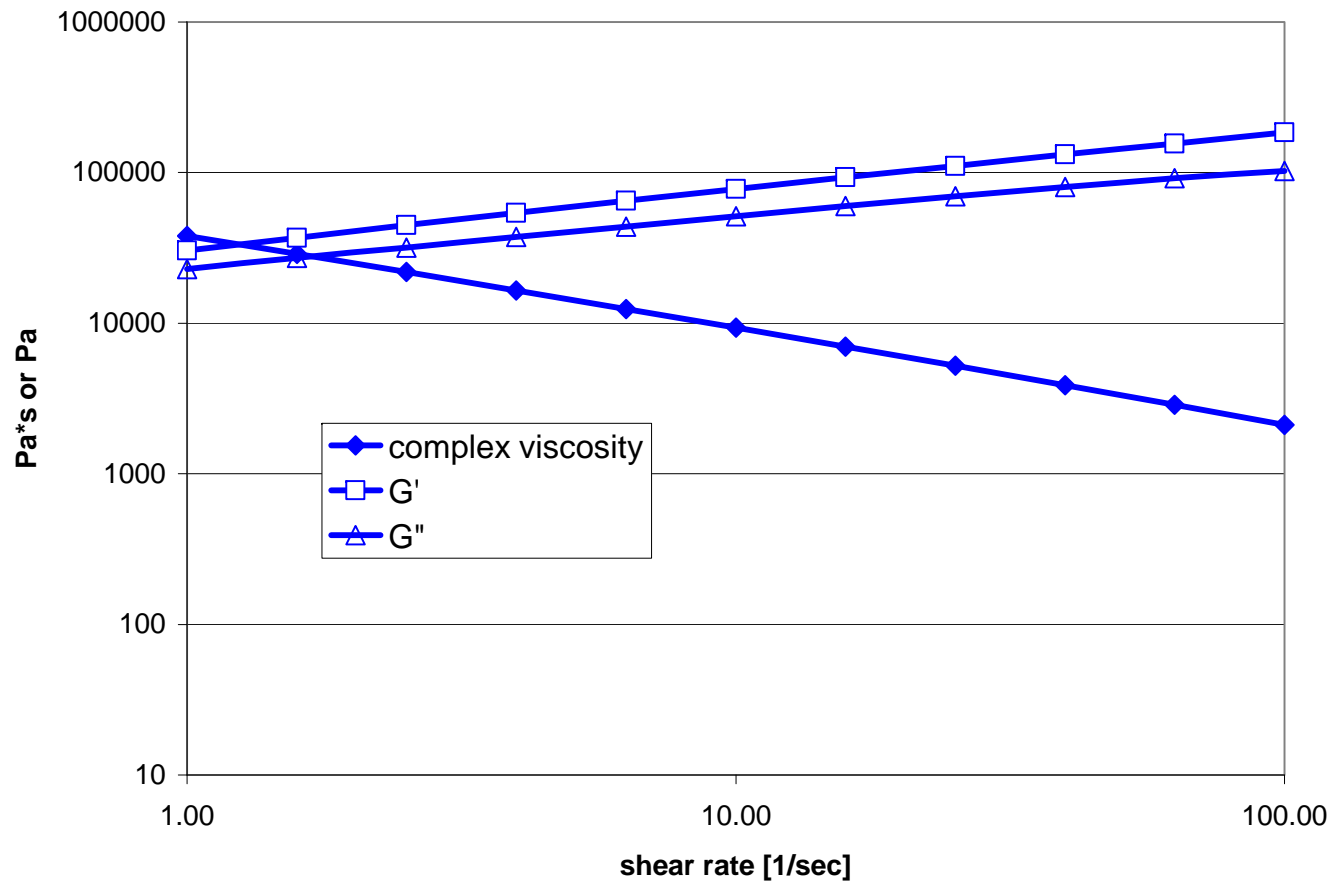
# Parallel Plate Data



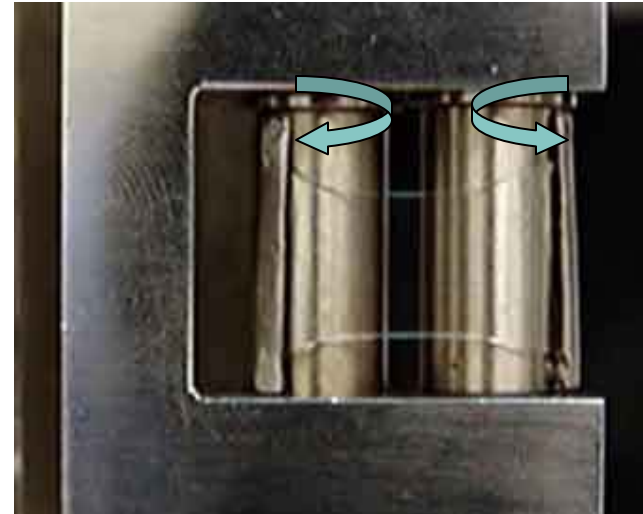
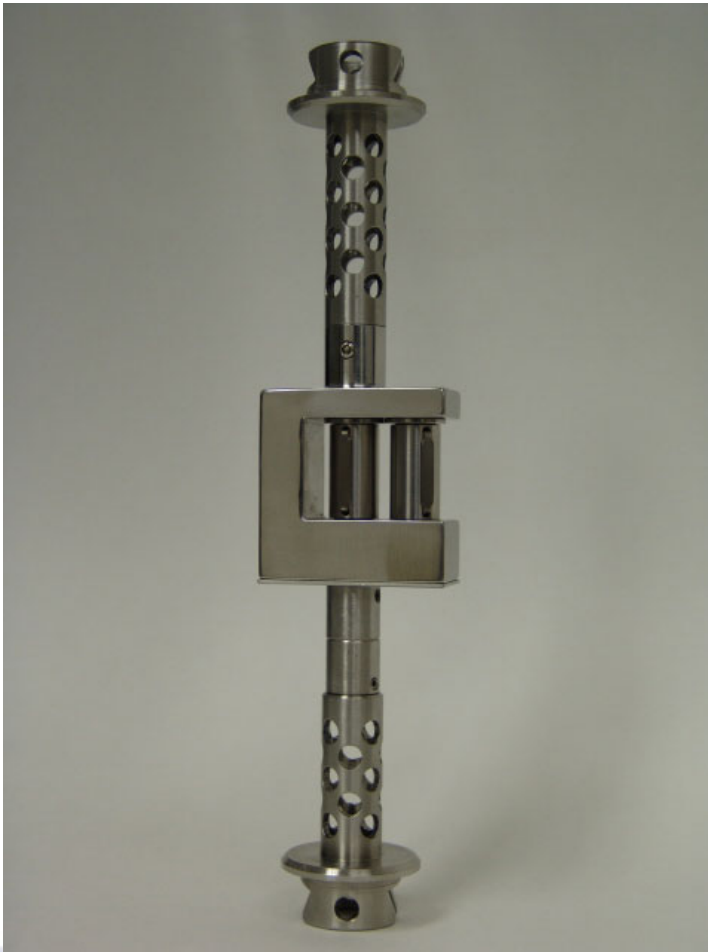
# Rheology of Linear NatureWorks bio-polymers (2002D)



# Rheology of NatureWorks Foam Grade

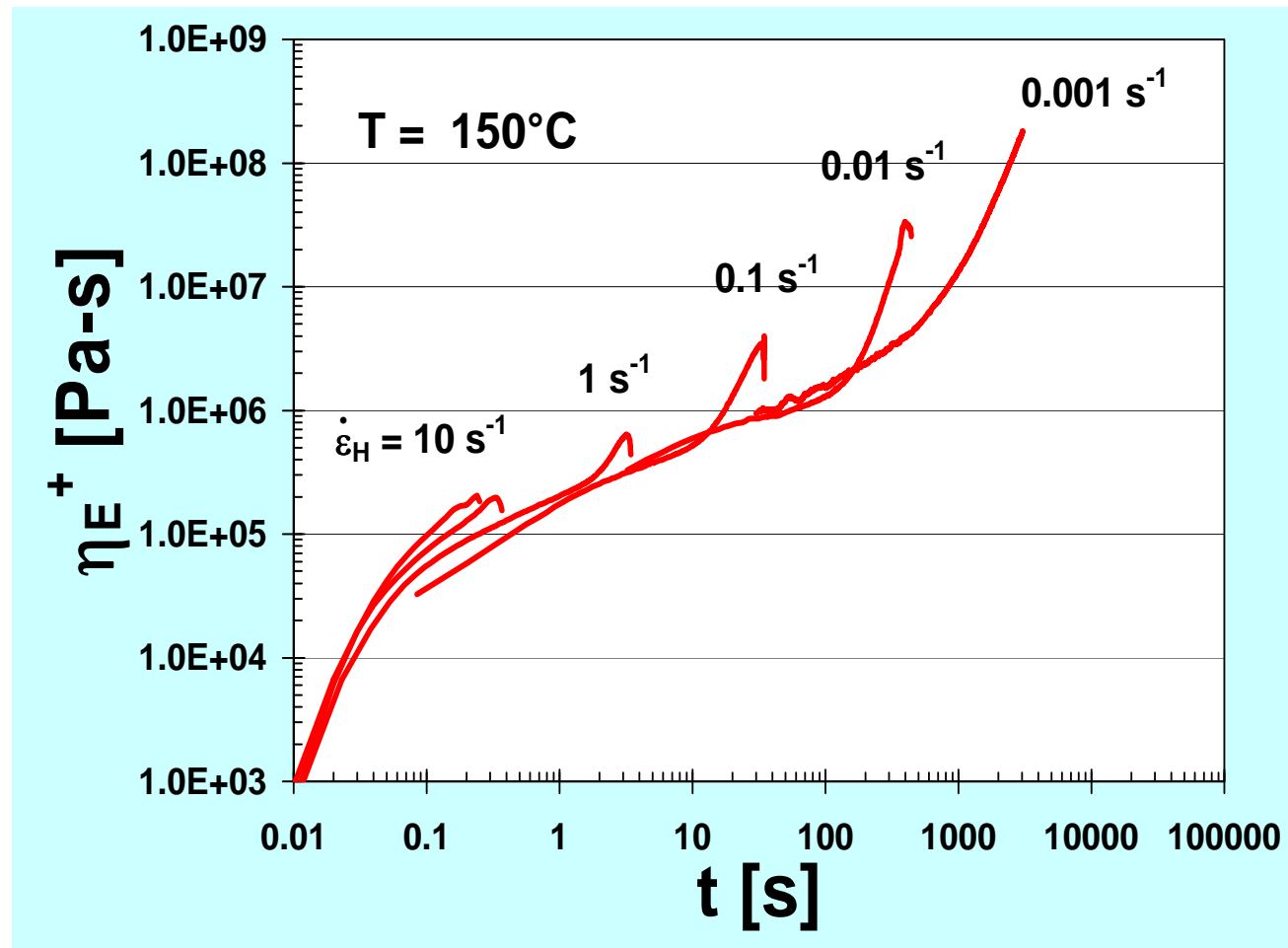


Model SER-HV-A01 from Xpansion Instruments  
coupled with a TA Instruments/Rheometrics ARES

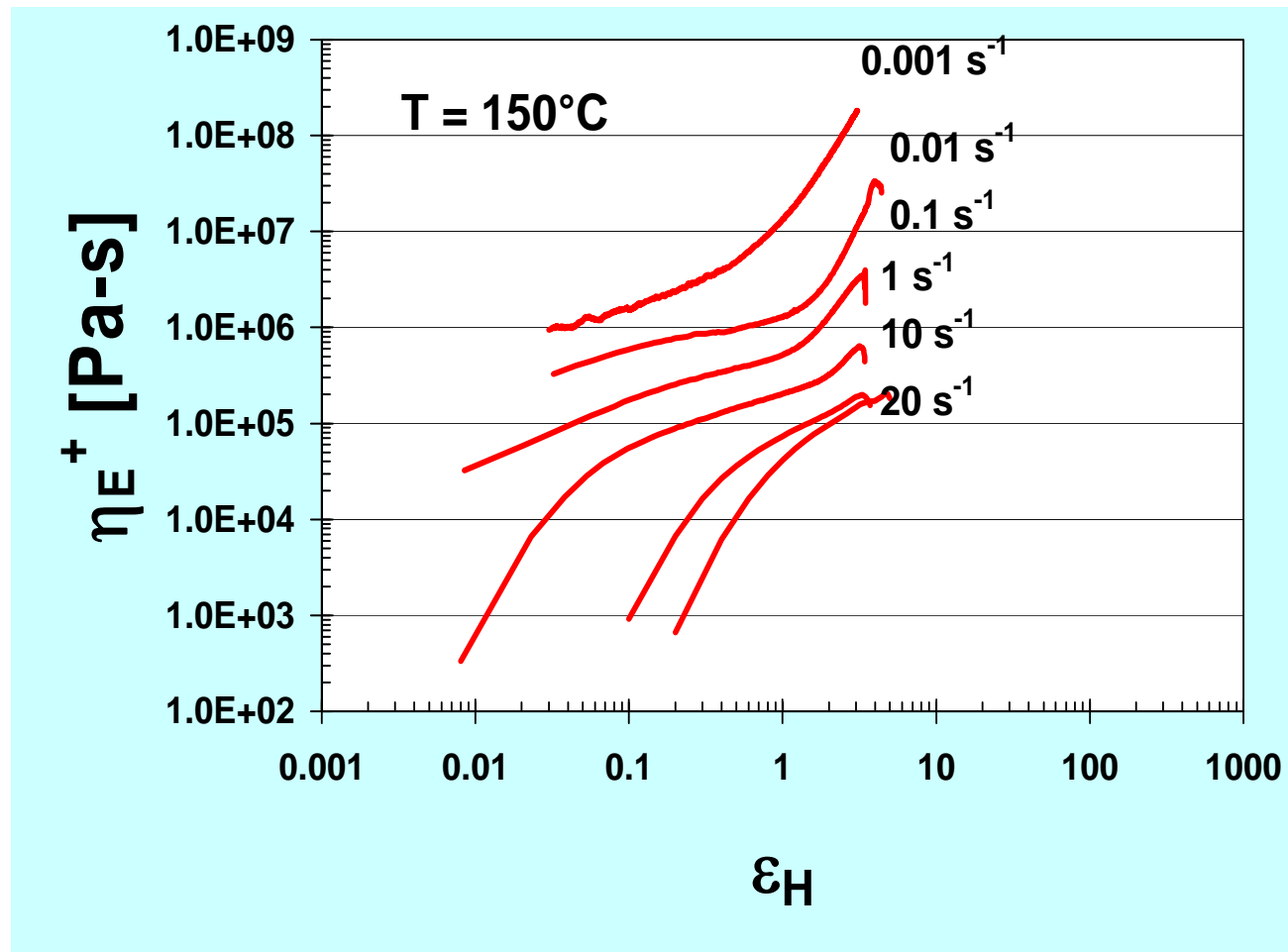


Dual cylinder design allows for  
constant Henky strain  
measurements

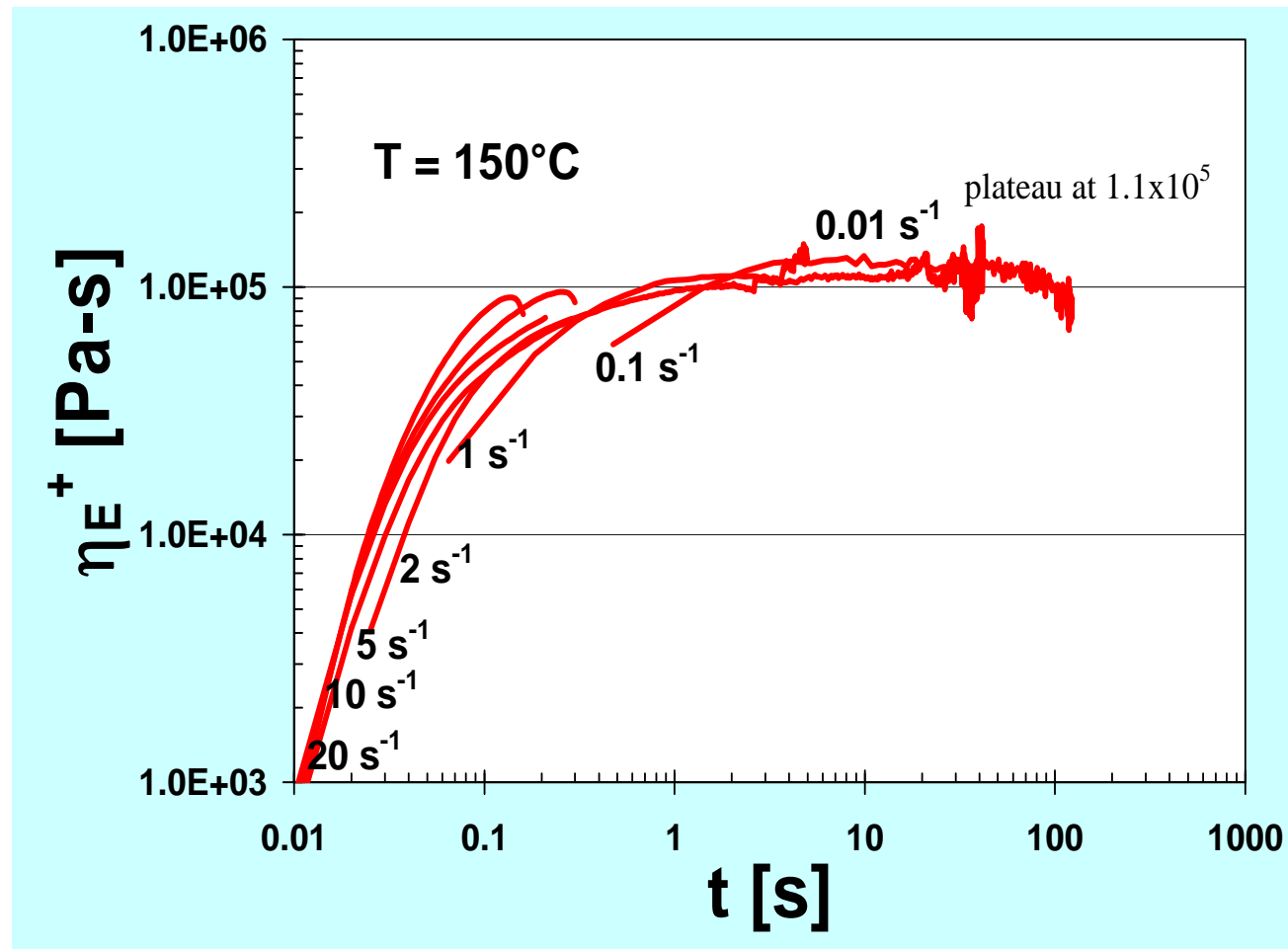
## NatureWorks Foam Grade (branched)



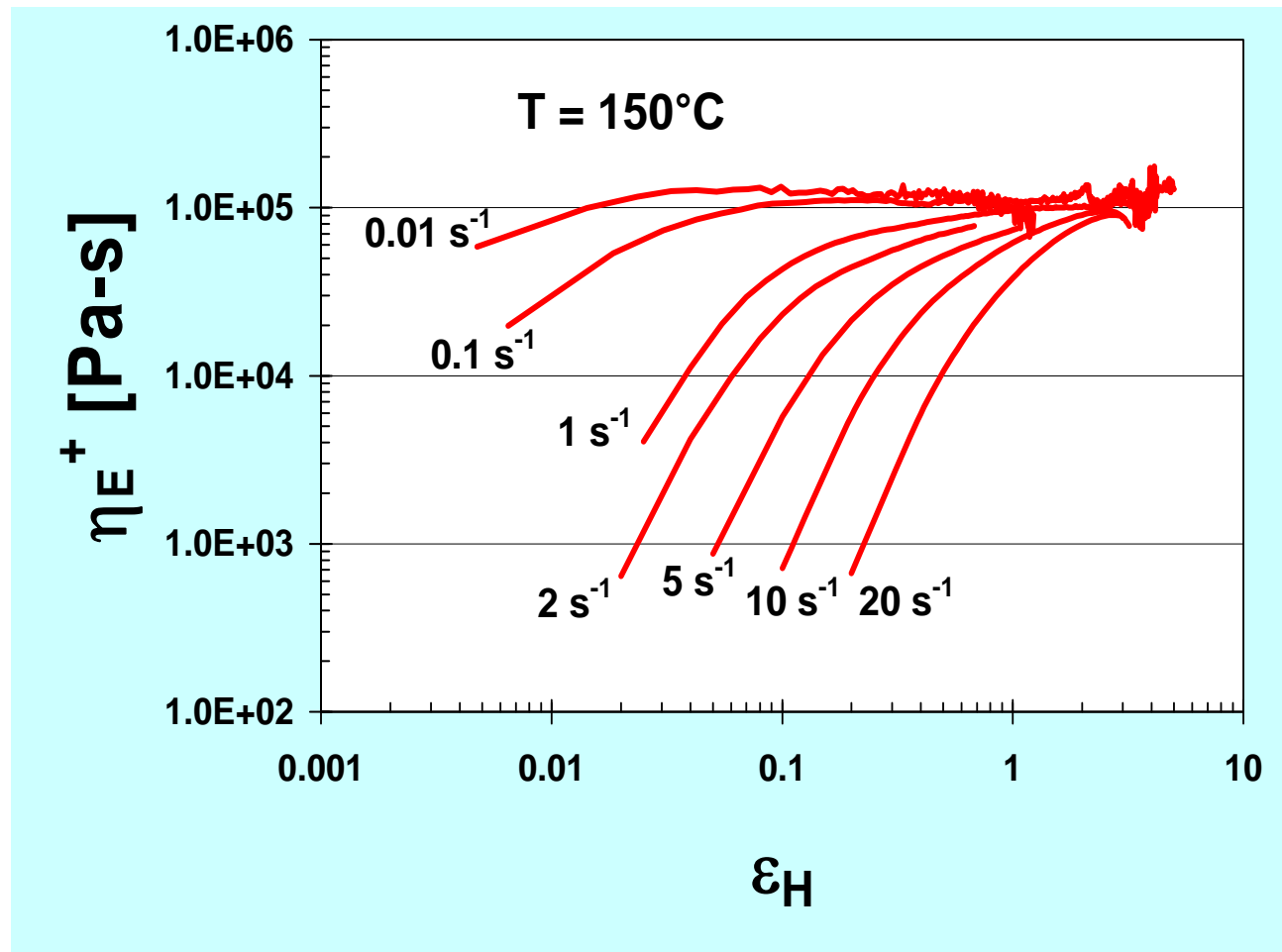
## NatureWorks Foam Grade (branched)



## NatureWorks 2002D (Linear)



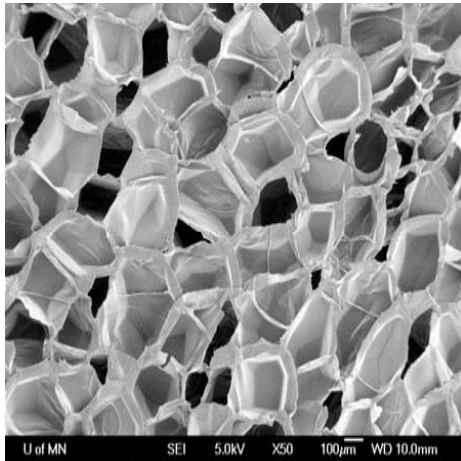
## NatureWorks 2002D (Linear)



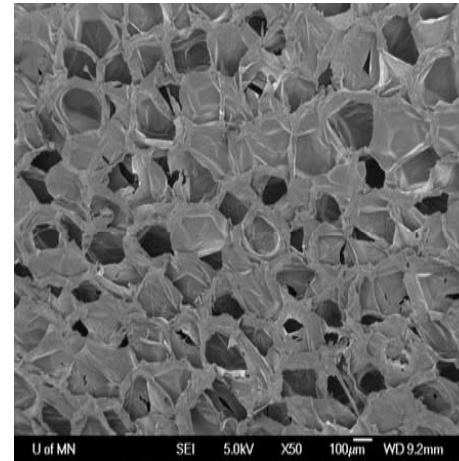
## Results

	<b>NatureWorks 2002D (Linear)</b>	<b>NatureWorks Foam Grade (Branched)</b>
<b>Lowest Achievable Density</b>	0.21 g/cc (13.1 pcf)	0.04 g/cc (2.5 pcf)
<b>Heaviest Gauge Achieved</b>	1.6 mm (65 mils)	5.4 mm (212 mils)
<b>Highest Closed Cell Count</b>	30%	98%

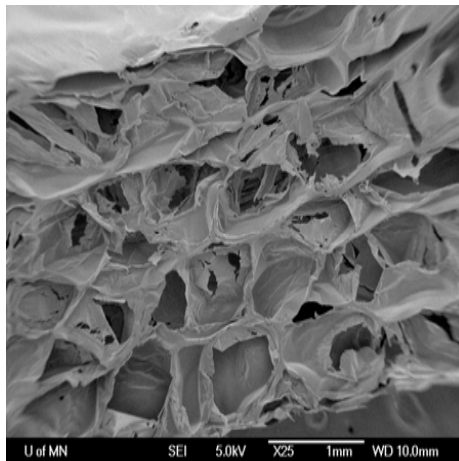
# NatureWorks Foam Grade vs. Polystyrene



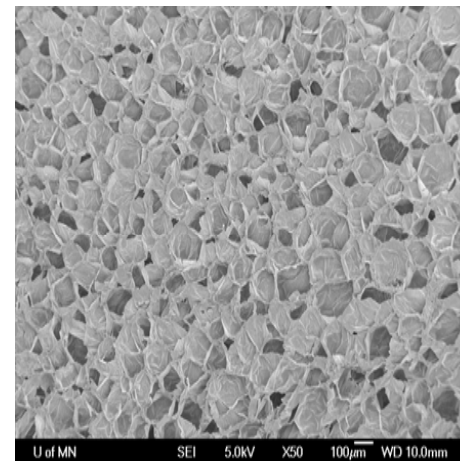
Commercial  
PS Foam  
Tray  
99% CC  
At 50x



Commercial  
PS Foam  
Tray  
99% CC  
At 50x



NatureWorks  
Foam Grade  
66% CC  
25x



NatureWorks  
Foam Grade  
98% CC  
50x

# Conclusions on NatureWorks Foam Grade Resin Rheology

- Elastic component significantly increased
- Bimodal molecular weight distribution results in resin that has expansion characteristics similar to polystyrene
- Shear viscosity increased compared to standard foam grade polystyrene necessitating use of low shear secondary screw

# Thermoforming

- Standard polystyrene foam tooling can be used
- Cycle times equivalent or slightly longer depending upon part and specifics of tooling construction
- Forming temperatures slightly lower than polystyrene

## Food Contact

- FCN letter obtained for current formulations for use in room temperature and below foods
- Allowed uses
  - Meat trays
  - Produce trays
  - Egg cartons

## Conclusions

- Foam with mechanical properties equivalent to standard PS packaging foam can be produced from NatureWorks bio-polymers
- Extrusion process required modifications to equipment consistent with the differences between polystyrene and NatureWorks bio-polymers
- Thermoforming process is essentially equivalent to polystyrene foam thermoforming

# NatureWorks Foam Trays



- Real
  - Introduced in May 2007 in limited markets
- Right
  - Properties match PS trays
  - Potential to be economically competitive with PS trays
- Renewable
  - Made from annual renewable corn