Kinetic Nucleators maximize cell distribution in foam extrusion
1. Why Use Chemical Foam?
2. CFA types
3. Modern CFA Expectations
4. Nucleation - *What are we looking for?*
5. The Importance of Solubility
6. New Data (Application Case Studies)
7. Conclusions
Why Use Foam?

- Reduces Cost
  - Less Material Consumption
- Reduces Weight
- Eliminates Sink Marks
  - Improved Printing on Flat Surfaces
- Easily Scalable
  - Stable and Repeatable
  - Simple Process, Easy to Feed
- Easy Startup Cost
  - Easy to use Additive
  - No Modifications to Equipment Needed

- Improves Thermal Insulation
- Improves Sound Insulation
- Higher Production Efficiency
  - Lower Processing Temperatures
  - Faster Cycle Time
  - Reduces Machine Energy

_Shutoff nozzles are a benefit in Injection Molding_
Foaming Agent

(Blowing Agent) A substance which is capable of producing a cellular structure via a foaming process in a variety of materials that undergo hardening or phase transition, such as polymers and plastics.

Two technologies:

Physical Blowing Agent

(Gas Injection) Cellular structure created by injecting gas in a super critical state directly into the barrel through equipment modifications.

For high and medium density foams, gases utilized are usually $\text{N}_2$ or $\text{CO}_2$.

[Image: Gas Injection shown]

Chemical Blowing Agent

(Chemical Foaming Agent, CFA) Cellular structure created by a chemical reaction and heat during the plasticating process.

Gas generated is usually $\text{CO}_2$, $\text{N}_2$, or a combination for high-to-medium density foams.

$\text{N}_2$ And/or $\text{CO}_2$
Primary CFA Types

Exothermics

Azodicarbonamide (ADC) : Creates Nitrogen and Ammonia, generates heat upon decomposition.

- 50 years of use in rubber and plastics
- Slow gas diffusion rate - Positive for some applications and negative for others
- Rapid and Robust gas expansion
- $N_2$ is not as soluble in olefins and styrenes as $CO_2$
- ADC has recently been added to SVHC list

Endothermics

Carbonate / Acid Blends (SAFOAM®) : Creates $CO_2$ and water, absorbs heat.

- 30 Years of use in Thermoplastics
- Rapid gas diffusion rate – Faster crystallization times due to $CO_2$ being a plasticizer
- Slow, controlled gas release
- $CO_2$ is more soluble in the polymer melt than $N_2$
Expectations of Modern CFA

• Early CFA Technology:
  • 400-500 micron cells were common and acceptable in commodity parts
  • High gauge variability and process challenges
  • Closed-and-Open cells
  • ADC is most common worldwide; Challenges due to potential toxicity
  • No longer acceptable for use in food packaging, children’s products

• Modern CFA Technology:
  • Process Friendly formulations – “Value Added” formulas for easy processing
  • Uniform cell structure = more consistent physical properties, better surfaces
  • Customers seek 200 microns cells and below, more Closed-Cell content
  • Fine Cell structure = better retention of physical properties like impact strength and elongation at break
What is Nucleation?

• Foam Nucleation is the point at which the physical separation of solid, liquid, and gas occurs.
• Physical nucleators can provide a good “seed point” for gas bubble formation and growth.
Gas Solubility

Gas solubility is the gas absorption into the polymer melt. Different resins, process, method of gas delivery and the gas itself will determine solubility and homogeneity. CO$_2$ and N$_2$ are the most common chemical blowing agent gasses used and are the topic of these tests.

**Carbon Dioxide (CO$_2$)**
- Smaller molecular size (3.6 angstroms) which helps to permeate other materials
- Polarized molecule which allows it to interact with other materials
- More soluble in plastics
- Generally gives finer cells
- Better surface appearance
- Shorter cycle times

**Nitrogen (N$_2$)**
- Larger molecular size (3.8 angstroms) which allows the gas to stay inside other materials
- Non-polarized molecule
- Has a high vapor pressure that can help quickly fill a mold
Foam Nucleating Agents

Nucleating agents are used to create a starting point from where a cell can form as gas comes out of solution. A closed-cell structure is crucial in keeping mechanical properties and part characteristics.

A closed cell structure is evidence of consistency in processing. In order to maintain mechanical properties like impact strength, tensile strength and elongation-at-break, the goal is usually to achieve the smallest closed cell structure possible.

Minerals like talc and calcium carbonate are the most commonly used physical nucleators. A higher number of nucleation sites will yield smaller cells and more rapid cell expansion.
New Kinetic Nucleator (KN)

• A particle nucleator that improves component dispersion by creating turbulent flow along boundary layer.

• Reedy Chemical Foam & Specialty Additives is the exclusive provider of Kinetic Nucleators for foamed thermoplastics.
A laminar flow is typical in extrusion processing. Talc is commonly used to create nucleation sites. Over time, talc will build up on the screw, the barrel walls and the die, which requires thorough cleaning often with greater frequency than a non-foamed process.

Introduction of Kinetic Nucleator improves mixing and component dispersion along the boundary layer. This creates smaller and more evenly dispersed cells overall allowing for more efficient use of the same volume of gas.
HDPE Extrusion Case Study

**HDPE: Bapolene 3255, MI 8.0, Density 0.960**

Extruder: 1.25” single screw, 30:1 L/D, 3:1 compression ratio.

CFA Endo Blend: 0.50% by weight of a sodium bicarbonate/citric acid blend.

Nucleated samples contained 0.25% by weight of K-nucleator.

**Extrusion profile:**

<table>
<thead>
<tr>
<th>ZONE 1</th>
<th>ZONE 2</th>
<th>ZONE 3</th>
<th>ZONE 4</th>
<th>CLAMP</th>
<th>HEAD</th>
<th>DIE</th>
</tr>
</thead>
<tbody>
<tr>
<td>345°F</td>
<td>385°F</td>
<td>385°F</td>
<td>355°F</td>
<td>345°F</td>
<td>320°F</td>
<td>320°F</td>
</tr>
<tr>
<td>174°C</td>
<td>196°C</td>
<td>196°C</td>
<td>179°C</td>
<td>145°C</td>
<td>160°C</td>
<td>160°C</td>
</tr>
</tbody>
</table>

Melt Temp at clamp:
362°F (183°C)

Melt Pressure:
2250 psi (155 bar)
## HDPE Extrusion Case Study

<table>
<thead>
<tr>
<th>CELL RANGE (MICRONS)</th>
<th>NOMINAL SIZE (MICRONS)</th>
<th>DENSITY (G/CC)</th>
<th>DENSITY REDUCTION</th>
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<tbody>
<tr>
<td>60-120</td>
<td>100</td>
<td>0.533</td>
<td>44.5%</td>
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**Endo blend**

<table>
<thead>
<tr>
<th>CELL RANGE (MICRONS)</th>
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<th>DENSITY (G/CC)</th>
<th>DENSITY REDUCTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>50-160</td>
<td>105</td>
<td>0.464</td>
<td>51.7%</td>
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</table>

**Endo Blend + Reedy KN**
Polypropylene Rod Extrusion

Polypropylene: Exxon PP4712E1, 2.8 MFI
1.25” single screw extruder, 30:1 L/D, 3:1 compression ratio.

Chemical Foaming Agent (CFA) Endo Blend: 0.36% by weight of a sodium bicarbonate/monosodium citrate blend. An equal weight of mineral oil was used to coat the pellets with the additives.

All nucleated samples contained 0.36% by weight of nucleator.

- Talc particle size: 1 micron
- Calcium carbonate particle size: 1 micron
- Reedy KN: 30 micron

Melt Temperature: 380°F at the clamp
Melt Pressure: 1850 psi

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<td>420°F</td>
<td>395°F</td>
<td>370°F</td>
<td>350°F</td>
<td>340°F</td>
<td>350°F</td>
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Extrusion profile:
## Polypropylene Rod Extrusion

<table>
<thead>
<tr>
<th>SAMPLE</th>
<th>CELL RANGE (MICRONS)</th>
<th>NOMINAL SIZE (MICRONS)</th>
<th>DENSITY (G/CC)</th>
<th>DENSITY REDUCTION</th>
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</thead>
<tbody>
<tr>
<td>CFA</td>
<td>50-130</td>
<td>100</td>
<td>0.837</td>
<td>8.1%</td>
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<tr>
<td>CFA + CaCO$_3$</td>
<td>30-100</td>
<td>80</td>
<td>0.754</td>
<td>17.2%</td>
</tr>
<tr>
<td>CFA + Talc</td>
<td>30-135</td>
<td>100</td>
<td>0.694</td>
<td>23.8%</td>
</tr>
<tr>
<td>CFA + Reedy KN</td>
<td>30-100</td>
<td>85</td>
<td>0.675</td>
<td>25.9%</td>
</tr>
</tbody>
</table>

### Images

- CFA
- CFA + CaCO$_3$
- CFA + Talc
- CFA + Reedy KN
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<td></td>
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<tr>
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No Foam

CFA + Talc

Cells to the edge

CFA + Reedy KN

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Similar cell size; still not reaching edge

Same conditions yield ~9% greater density reduction
Interesting Discoveries:

The relation of physical particles size to cell size in the finished part

- PP foamed with KN yielded smaller cells and lighter weights.

- Regarding particle size of the nucleator, smaller particles typically yield smaller cells. In this case the smallest cells were generated while using a particle 30 times larger than common. This is due to KN’s unique morphology. It generates a greater number of nucleating sites by creation of turbulence in the flow inside the barrel and as it exits.

<table>
<thead>
<tr>
<th>Particle Type</th>
<th>Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Talc particle size</td>
<td>1 µm</td>
</tr>
<tr>
<td>Calcium carbonate particle size</td>
<td>1 µm</td>
</tr>
<tr>
<td>K-Nucleator™</td>
<td>30 µm</td>
</tr>
</tbody>
</table>
Real world Examples: HIPS Extrusion

Multilayer: ABA Structure with Foamed “B” Layer


Established foam process, weight reduction 23-27%

Addition of KN, with no process changes, 32%

Unanticipated findings: Gauge variation went from 12.5% down to 1.7%!

Better mixing of the formula and CFA allowed better heat distribution and more efficient use of the gas generated by the CFA.
Injection Molding – CORE BACK Process with TPO (Automotive Application)

Incumbent CFA 4% Loading
(Actual CFA content 10,000 ppm)

Reedy CFA 1.7% + KN 0.4% Loading
(Actual CFA content 4,000 ppm)

In this trial, the Kinetic Nucleator made more efficient use of the CO₂ gas generated by the CFA (No Direct Gas).

This allowed the same density and cycle time with half the LDR of the standard CFA.
Physically blown low density foam

Nucleated with Talc

Goal:
Improve cell distribution, density reduction and cost

Observations:
Introduction of KN resulted in larger, coarser cells versus Talc. Surface quality was also affected.

Possible causes:
• Inadequate pressure to enable Kinetic spinning
• Pressure loss at transfer?
• Too much gas?
• Further testing is needed for low density markets
Conclusions

• Particle morphology and “tumbling” action in the barrel create the benefits of gas distribution and formula blending.
• Clear benefits of Kinetic Nucleator™ are realized in Chemical Foaming Agent applications. Markets including pipe, profiles and sheets are primary users of CFA.
  • Greater density reduction in HIPS sheet.
  • Greater gauge control in profile & sheet extrusion
  • Lower LDR in TPO Injection Molding

• Further work is needed to prove viability in very low density processes.