**Introduction**

CFC-12 is widely regarded as the preferred blowing agent for the manufacture of polystyrene foam sheet for a variety of products including thermoformed egg cartons, meat trays, and fast food containers. The success of CFC-12 as a blowing agent is due to its unique properties such as adequate solubility in the molten polystyrene resin, appropriate volatility, low order of toxicity, and non-flammability. Most importantly, the Food and Drug Administration has stated “they have no objection to the use of CFC-12 in the manufacture of food contact polystyrene foam containers.”

Concern over environmental issues such as ozone depletion and the greenhouse effect has focused attention on the use of large quantities of CFC-12. For this reason, the Freon® Products Laboratory evaluated the feasibility of producing polystyrene foam sheet with chlorofluorocarbon alternatives.

**Alternative Selection**

Several alternative compounds were evaluated as replacements for CFC-12 blowing agent. The selection criteria are as follows:

- **Non-Ozone Depleting**
  - Limit chlorine release into the stratosphere
  - Compounds containing hydrogen or no chlorine

- **Low “Greenhouse” Potential**
  - No unusually strong infrared radiation (IR) absorption
  - Compounds containing hydrogen

- **Toxicology**
  - No carcinogens or developmental toxins
  - Low acute toxicity

- **Physical/Chemical Properties**
  - Suitable for end use application

Two alternative compounds survived the initial screening process. Their volatility, environmental acceptability, toxicity, and cost were compared with those of CFC-12 (see **Table 1**). Upon review of the data, **DuPont™ Formacel® S–Food Grade** (HCFC-22), was selected as the most appropriate alternative blowing agent for polystyrene foam sheet. **Formacel® Z-2** (HFC-152a) is also an acceptable alternative blowing agent for this application, however it is flammable and significant plant and process modifications are required to allow its safe use. **Formacel® Z-2** contains no chlorine and has zero ozone depletion potential, so it is the best candidate in areas where ozone-depleting compounds are not allowed in this application (see “Safety and Handling of Formacel® Z-2: Thermoplastic Foam Extrusion Applications”).

**Formacel® Z-4** (HFC-134a) is not flammable, and its properties closely parallel those of CFC-12. **Formacel® Z-4** was however, not selected for this application because the projected cost of this compound would produce foam containers that are not cost competitive with similar containers produced from paper pulp of foam expanded with hydrocarbon blowing agents.
Table 1 – Properties of CFC-12 Blowing Agent and Possible Alternatives

<table>
<thead>
<tr>
<th>Compound</th>
<th>CFC-12</th>
<th>Formacel® S–Food Grade</th>
<th>Formacel® Z-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Formula</td>
<td>CCl₂F₂</td>
<td>CHCl₂F₂</td>
<td>CH₂CHF₂</td>
</tr>
<tr>
<td>Molecular Wt</td>
<td>120.9</td>
<td>86.5</td>
<td>66</td>
</tr>
<tr>
<td>B.P. °C</td>
<td>-29.8</td>
<td>-40.8</td>
<td>-24.7</td>
</tr>
<tr>
<td>Ozone Depletion Potential</td>
<td>0.1</td>
<td>0.055</td>
<td>0</td>
</tr>
<tr>
<td>Global Warming Potential (GWP)</td>
<td>(100 yr ITH. for CO₂, GWP = 1)</td>
<td>10,900</td>
<td>1,810</td>
</tr>
<tr>
<td>Flammable Limits in Air (vol %)</td>
<td>None</td>
<td>None</td>
<td>3.9 – 16.9</td>
</tr>
<tr>
<td>Toxicity Exposure Limits</td>
<td>1,000 PPM TLV (ACGIH)</td>
<td>1,000 PPM TLV (ACGIH)</td>
<td>1,000 PPM (AEL)</td>
</tr>
</tbody>
</table>

Evaluation Trials
Several trials were conducted using commercial equipment under typical production conditions. The tests were done to determine the functional acceptability of Formacel® S–Food Grade as an alternative blowing agent for polystyrene foam sheet. The data from a typical trial are summarized below.

Extruder = Commercial 4-1/2” x 6” Tandem Extrusion System
Die = 8” Diameter

<table>
<thead>
<tr>
<th>Extruder</th>
<th>CFC-12</th>
<th>Formacel® S–Food Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foam Extrusion Rate</td>
<td>774 lbs/hr</td>
<td>774 lbs/hr</td>
</tr>
<tr>
<td>Foam Density</td>
<td>6.09 lbs/ft³</td>
<td>6.07 lbs/ft³</td>
</tr>
<tr>
<td>BA Injection Rate</td>
<td>56.6 lbs/hr</td>
<td>36.2 lbs/hr</td>
</tr>
</tbody>
</table>

Trials were begun with extrusion equipment in operation using CFC-12. CFC-12 flow was turned off, and Formacel® S–Food Grade directed into the blowing agent metering system. The blowing agent injection rate was not changed initially with the switch to Formacel® S–Food Grade. As a result, the foam sheet became very thick and heavily corrugated. The Formacel® S–Food Grade injection rate was then slowly reduced over the next hour until foam density and sheet thickness returned to normal. An additional hour was allowed for extruder conditions to stabilize; then foam samples were taken for analysis.

In one trial, the blowing agent injection rate was reduced from 56.6 lbs/hr to 36.2 lbs/hr (an injection rate decrease of about 36 percent). Similar results were observed in other trials. The cost of Formacel® S–Food Grade is about 1.5 times that of CFC-12 on a per pound basis; however, the reduced blowing agent requirement yielded a finished product of almost equivalent cost.

Post-Expansion, Orientation Testing, and Cell Size Testing
Samples of foam sheet produced in trials with CFC-12 and Formacel® S–Food Grade were analyzed for post-expansion, orientation, and cell size. Post-expansion is determined by comparing the geometric volumes before and after heating. Orientation is calculated from the change in foam sheet machine and transverse dimensions.

Post-expansion was less with Formacel® S–Food Grade due to its more rapid diffusion from foam. Compensation can be made for this by extruding the polystyrene sheet at a greater thickness but same basis weight (lower density), thus supplying a sufficient volume of foam to fill the thermoformer mold.

Foam produced with Formacel® S–Food Grade exhibited more orientation (i.e., more shrinkage in the machine and transverse directions), than foam made with the CFC-12. Cells in Formacel® S–Food Grade expanded foam were slightly coarser than cells in similar density foam produced with CFC-12.

FDA Acceptance of Formacel® S – Food Grade
In September 1987, DuPont and members of the foamed polystyrene industry submitted extensive data to the Food and Drug Administration (FDA) requesting a letter of no objection to the use of Formacel® S in the production of polystyrene foam for use in food-contact applications. These data demonstrated that the blowing agent diffuses out of the foam in the course of the normal storage period for finished articles and that only trace levels, if any, of Formacel® S may reasonably be expected to be present in food under typical food-service use conditions. In response to DuPont and industry requests, the FDA issued letters on December 24, 1987, indicating that HCFC-22 (Formacel® S) does not require FDA clearance as a food additive in the production of foamed polystyrene products intended for the food-service industry (hamburger containers, plates, cups, etc.) since the data submitted indicate that Formacel® S residues in the diet would be far less than 1 part per billion.

This FDA decision to allow the use of Formacel® S in fast food containers only met part of the foam polystyrene industry’s need for an environmentally acceptable alternative to CFC-12. FDA advised that more data would be required before they could rule on the use of Formacel® S for food packaging products such as meat and poultry trays, egg cartons, etc., which are exposed to food for longer periods. Consequently, an extensive program was implemented at DuPont to generate data required by the FDA for all food packaging applications.

Upon review of these preliminary data, DuPont decided that a highly purified grade of Formacel® S would be required in polystyrene food packaging applications because of the potential of extended food exposure to the polystyrene foam. DuPont
worked to improve the quality of Formacel® S and established a high purity standard for the product. This highly purified grade of Formacel® S was trademarked Formacel® S–Food Grade.

DuPont filed with the FDA a Generally Recognized as Safe (GRAS) affirmation petition containing technical efficacy, diffusion, residue and toxicity data on Formacel® S–Food Grade for use in polystyrene food packaging applications in late February 1988.

In March 1988, the FDA accepted for filing DuPont’s petition for the use of Formacel® S–Food Grade in all polystyrene foam sheet applications. As a result, DuPont began marketing Formacel® S–Food Grade for all polystyrene applications on April 1, 1988.

**Product Specification Certified by DuPont**
Formacel® S–Food Grade conforms to tighter product specifications (99.92% purity) than Formacel® S (99.80% purity). Only products meeting the Formacel® S–Food Grade specification can be used in food packaging under the FDA GRAS petition outlined above. Specification sheets for both Formacel® S and Formacel® S–Food Grade are available from your DuPont representative.

In order to guarantee the specification of the Formacel® S blowing agent products purchased, DuPont will provide product analysis and certification of each shipment of Formacel® S–Food Grade to ensure customers that it conforms to tight product specifications.

**Foam Monitoring Program**
Under the FDA GRAS petition, food can contact only those polystyrene food containers which contain a maximum of 5 parts per million (ppm) Formacel® S–Food Grade at the time of use.

DuPont is developing a foam monitoring program designed to help customers determine if their polystyrene food packaging products made with Formacel® S–Food grade meet these requirements. It is recommended that customers work with DuPont to assess the blowing agent content in their foam and to develop an ongoing foam monitoring program. This foam monitoring program is only required for food packaging items such as meat trays and egg cartons. It is not required for food service packaging applications such as hamburger containers.

**Product Availability**
Formacel® S and Formacel® S–Food Grade blowing agents are available in several locations throughout the U.S. and Canada. Contact your DuPont representative for additional shipping information.

**Summary**
Formacel® S–Food Grade was selected as the most promising of the alternative compounds for evaluation in the manufacture of polystyrene foam sheet for the following reasons:

- It is a cost-effective replacement due to its lower molecular weight (86.5 versus 120.9 for CFC-12) and greater efficiency.
- It is environmentally acceptable; it has low ozone depletion and greenhouse potential ratings; and it has negligible photochemical reactivity.
- It is commercially available.
- It does not require FDA clearance as a food additive when used in the manufacture of fast food service items such as hamburger containers.
- It can also be used in the manufacture of food packaging items such as meat trays and egg cartons.