

# A Comparison of the Physical Properties [and their causative factors] of Froth vs. Pour Foams

John Murphy

*Foam Supplies Inc*

*4387 N Rider Trail*

*Earth City, MO 63045*

## ABSTRACT

Today the urethane panel producer is faced with the angst of changing yet again to an alternate foam blowing agent. Since HCFC-22 has been phased out, many panel manufacturers are faced with the difficult decision of either staying with a froth type blowing agent [HFC-134a], or transitioning to a liquid [or near liquid] alternative such as pentane, water, HFC-245fa, or ecomate®.

This paper will try to facilitate that decision by examining the pertinent factors affecting foam flow, compressive strength, as well as other physical properties. Effects of mold temperature, orientation, packing, & speed of reaction will be examined.

## WHY STAY WITH A FROTH FORMULATION?

Why does one use a froth formulation in the first place? Froth foams employ a very low boiling material [boiling much below room temperature], as either the sole blowing agent, or as a co-blowing agent. This low boiling effect allows the product to emerge from the mix-head of a foam unit with a shaving cream consistency. CFC-12 and HCFC-22, among others, have frequently been used as frothing agents in the past.

Froth formulations have long been used because they allow the formulator several advantages:

1. Little to no heat is required in the mold;
2. The mold does not have to be 'tight' – that is, the mold pieces do not have to be of such close tolerance as to prevent liquid leaks. This is because the formulation, when frothed, appears to have a higher viscosity and will not leak from loose fitting molds.
3. Some also claim a more even density distribution in the mold;
4. Supposed better flow;
5. Potentially less shrinkage; and
6. Perhaps a better thermal conductivity.

One of the major disadvantages to using froth formulations are that they require pressurized foam dispensing equipment [but that can often be bought/leased from the foam supplier]. Then using foam equipment will give more accurate shots, more uniform mix, and minimize waste [whether frothing or not]. Our studies will employ low pressure foam equipment.

Of course, much depends on the physical and chemical properties of the frothing agent itself. For instance, its boiling point, its level of solubility in the formulation, its molecular weight, and its gas pressure in the formulation are all important criteria. Additionally, its cost becomes an issue. And environmental impact is now a mitigating factor as well.

It is our intent to look at the physico-chemical properties of some of these agents, pitted against certain existing liquid blowing agents, to try to come to grips with the best, most environmentally benign solution to change over.

- First we will look at the properties of these BAs [Table 1] and some of the liquids that might replace them.

- We should make comparison to these other BA materials in the same formulation [to compare solubility, effect on reactivity, density potential, and packing required].
- Finding the optimal molding conditions required for each type of BA [liquid v froth] seems crucial. How do mold temperature, orientation, packing, and free rise density affect flow, density gradient and cell orientation?
- Next, a comparison of some of the physical properties of these foams would be warranted.
- And finally, a comparison of these properties versus foam economics might be in store.

## BLOWING AGENT CONSIDERATIONS

In the first table we look at some important properties of previous and current frothing agents in comparison to some liquids currently on the market. Three factors are paramount for a good blowing agent: its **boiling point**, its **solubility** in the resin system, and to determine its effective density potential, its **molecular weight**. Of course, a frothing agent could be used as the sole blowing agent, or in conjunction with a liquid BA to achieve desired properties.

**Table 1: Blowing Agent Properties**

| Blowing agent      | CFC-12 | HCFC-22 | HFC-134a | HFC-152a | HFC-245fa | nC5 | ECOMATE |
|--------------------|--------|---------|----------|----------|-----------|-----|---------|
| MW                 | 120.9  | 86.5    | 102      | 66.5     | 134       | 72  | 60      |
| Boiling Pt, C      | -29.8  | -40.8   | -26.2    | -25      | 15.3      | 36  | 31.5    |
| Therm Cond         | 10     | 11      | 13       | 13       | 12.2      | 15  | 10.7    |
| GWP <sub>100</sub> | 8500   | 1700    | 1300     | 140      | 950       | 11  | 0       |
| ODP                | 1      | 0.055   | 0        | 0        | 0         | 0   | 0       |

As one removes halogen from the blowing agents they become increasingly more flammable [Table 2]. Experience and recent studies<sup>1</sup> have shown that a blowing agent requires at least 60 wt percent halogen to approach being non-flammable at STP. The higher the halogen content the safer the material from a flammability sense, but the more dangerous it is to the environment [ODP & GWP], and the more expensive it becomes, not only from a cost basis but also from a MW sense as well - since blowing agents are used on a molar basis.

**Table 2: Flammability Properties**

| Blowing Agent      | HFC-134a | HFC-152a   | ecomate | n-pentane | c-pentane |
|--------------------|----------|------------|---------|-----------|-----------|
| MW                 | 102      | 66         | 60      | 72        | 70.1      |
| %F                 | 75%      | 58%        | 0%      | 0%        | 0%        |
| BPt, C             | -26.2    | -25        | 31.5    | 37        | 49        |
| Flash Pt, C        | NONE     | <b>-50</b> | -19     | -40       | -37       |
| LFL                | NONE     | 3.9        | 5       | 1.4       | 1.1       |
| UFL                | NONE     | 16.9       | 23      | 7.8       | 8.7       |
| Heat of Combustion | NONE     | -17.4      | -16.2   | -49.7     | -46.9     |

From the data in Table 2 one can see that ecomate has much less potential to burn than do the hydrocarbons, n-pentane and c-pentane. In fact, it has flammability characteristics **better** than HFC-152a.

Ecomate has higher flash point, a higher LFL [50,000ppm v 39000ppm], and lower heat of combustion. Ecomate can be formulated into polyol systems having Flash Points for the compounded system >35 C, which make them safe for shipment without Red Placards.

With regard to frothing agents, the environmentally mandated removal of CFC-12 and HCFC-22 leaves us with products that are less solubilizing to urethane foam ingredients: HFC-134a and HFC-152a. In fact as the halogen content decreases in a fluorocarbon, the solubility of the hydrocarbon base decreases as well. A loss in solubility generally means a greater loss of that BA to the atmosphere upon foaming [expensive and environmentally hurtful]. In addition, it requires finding polyols that are more soluble [and sometimes less capable of meeting stringent requirements such as flammability and/or dimensional stability].

## STUDY PARAMETERS

For the initial study, we selected a current production formulation designed around HCFC-22 and then substituted on a molar basis with HFC-134a [a frothing type BA, BP -26.2C] and with ecomate [a liquid BA, BP 31.5C] [see Table 3]. While many other BAs might have been used, we felt that these materials could give a good indication of what the various substitution types [liquid v gas] might afford.

The formulation chosen normally has BA present in both the polyol component and in the isocyanate component as well. Rather than compounding blowing agents into both components [increased labor and potential solubility issues], and/or risking blowing agent separation by forcing the additional quantity into the polyol component, we elected to utilize the formulation with BA quantity of the polyol component solely, thus giving a higher than normal densities to the foams produced.

**Table 3: Froth formulation used in study**

| J121-               | 1          | 2          | 3          |
|---------------------|------------|------------|------------|
| Polyol blend        | 90.3       | 90.3       | 90.3       |
| Surfactant          | 1.5        | 1.5        | 1.5        |
| PC8                 | 0.7        | 0.7        | 0.7        |
| water               | 1.5        | 1.5        | 1.5        |
| HCFC-22             | <b>6.0</b> |            |            |
| ecomate             |            | <b>4.2</b> |            |
| HFC-134a            |            |            | <b>7.1</b> |
|                     | 100.0      | 98.2       | 101.1      |
| RATIO               |            |            |            |
| A                   | 100        | 100        | 100        |
| B                   | 92.55      | 90.85      | 93.55      |
| GEL, sec            |            | 58 - 62    |            |
| Free Rise DENS, pcf |            | 2.3 - 2.4  |            |

Two things to note about the formulation: 1) it was originally designed for R-22, and the other BA substitutions were merely **drop-in replacements** without any formulation adjustments; 2) **economics**: the use of ecomate required 30% less than R22 and is less expensive than this BA. The use of R134a required 18% more material than R22, [and 70% more material than ecomate] while being much more expensive.

Since we were utilizing two frothing agents [22 and 134a], the component viscosity and cream times were incapable of being measured. The gel time on all the systems were targeted around 60 seconds w/o any adjustment of catalyst, and all foams were demolded at 20 minutes. A Lanzen mold [2000 x 200 x 50 mm] oriented in either the vertical or horizontal position, and heated to either 80F or 95 F was used for the study.

**Table 4: Conditions of Lanzen Mold Packing Trials**

| Material                 | Pack | Orient | Temp, °F |
|--------------------------|------|--------|----------|
| J121-1<br><b>R-22</b>    | MFD  | V      | 80       |
|                          | 10%  | V      | 80       |
|                          | 15%  | V      | 80       |
|                          | 20%  | V      | 80       |
|                          | MFD  | H      | 80       |
|                          | 10%  | H      | 80       |
|                          | 15%  | H      | 80       |
| J121-2<br><b>ECOMATE</b> | MFD  | V      | 80       |
|                          | 10%  | V      | 80       |
|                          | MFD  | H      | 80       |
|                          | 10%  | H      | 80       |
| J121-3<br><b>R-134a</b>  | MFD  | V      | 95       |
|                          | 10%  | V      | 95       |
|                          | MFD  | H      | 80       |
|                          | 10%  | H      | 80       |
|                          | 10%  | H      | 95       |
|                          | 15%  | H      | 95       |

The foam equipment consisted of separate pressurized tanks for each of the compounded B components and the uncompounded isocyanate components, connected to a 15 ppm SLUG gun with 25 ft of 1/2" hose. Component materials were approximately ambient [80F], and the panels made according to the conditions in Table 4. Ratios of the guns were adjusted to give a uniform index, and permitting the same molar amount of BA.

Two each 20 second shots were initially made to determine the free rise density of each system. Table 5 demonstrates that the systems were quite close in initial free rise density [~2.3 pcf].

**Table 5: Free Rise Density - BOX [12"x 12" x 16"] Pours**

| BOX<br>POURS  | WT,<br>grams | SHOT,<br>sec | g/sec | lb/sec | FRD         |
|---------------|--------------|--------------|-------|--------|-------------|
| <b>J121-1</b> | 2324         | 20           | 116.2 | 0.256  | <b>2.34</b> |
| <b>J121-2</b> | 2316         | 20           | 115.8 | 0.255  | <b>2.38</b> |
| <b>J121-3</b> | 2362         | 20           | 118.1 | 0.260  | <b>2.32</b> |

Shots were then made to determine the minimum fill density [MFD] of that particular system at the temperature and orientation prescribed. After this MFD had been established for the particular system at a prescribed orientation and mold temperature, at least one shot at 10% over-pack [MFD \* 1.10] was made. In many cases, 15% and 20% over-pack shots were made. All shots were made at a point 7" from one end of the Lanzen mold in the side of the mold.

After demolding, overall density of the panel was obtained, then the panels were cut into ~8" x 8" x 2" plaques, then density, and compressive strengths obtained in the length, width and thickness directions of the panels to determine the density gradient and the cell orientation along the panel.

**Thermal conductivity measurements were obtained immediately after demolding on certain panels. This will be data for another paper.**

## RESULTS OF STUDY

The obvious first thing one notices when cutting open froth foam is the irregular cell structure: large bubbles intermixed with normal foam cell structure. This was true with both the froth agents used, R-22 and R134a. It is caused by the higher vapor pressure of these gases, in their rush to escape the foam.



**Figure 1: R-22, ecomate and R-134a blown foams – Free Rise Density**

The Lanzen panels were made according to the outline in Table 4. Although the free rise densities were nearly identical, the minimum fill density for the ecomate system was higher than the froth agents [Tables 6-8].

This is not the norm for ecomate! Since it lowers viscosity more than most materials, it normally has better flow than most liquid BAs. This demonstrates that **ecomate, like most other materials, simply cannot be dropped into a formulation and be expected to out perform the other materials.** In this case, ecomate is being substituted into a froth optimized formula – where the froth initially fills 30-40% of the cavity before reactivity begins, and which has extra catalyst to accommodate the chilling effect of the BA evaporation. Both of these mechanisms tend to make a liquid blown system lock up prematurely, i.e., give a foam with higher density.

Because of this, formulations J121-4 and J121-5 were introduced who's polyol mixes had been changed to eliminate the amine polyol to better accommodate liquid BAs. System J121-5 had a free rise density of 2.24 pcf to more nearly match that of the other systems. System J121-4 [Table 8A] is a commercial system with a free rise density of 1.6 pcf. They both have more uniform density distributions, similar to R-22 and R134a [Figs 8-9].

It is not usually sufficient to just fill a panel [minimum fill density] since concomitant shrinkage generally occurs. We go to over-packing to resolve this tendency to shrink. This increases the density of the foam. So what we really are looking for is the minimum fill density without shrinkage. This can often be accomplished by higher cross-linking in the foam, earlier green strength, or both.

Since the free rise densities of the foams investigated here were as high as one would normally expect to have in a normal packed part, there was no residual shrinkage in any of the foams - even at minimal fill.

**Table 6: Minimum Fill Density w R22**

| <b>J121-1</b> |      | <b>R-22</b> |      |           |         |        |
|---------------|------|-------------|------|-----------|---------|--------|
| FRD =         |      | 2.34        |      |           |         |        |
| panel         | mass | DENS        | pack | shot time | TEMP °F | ORIENT |
| 1             | 1036 | 3.13        |      | 9         | 80      | V      |
| 2             | 1077 | 3.43        | MFD  | 9.4       | 80      | V      |
| 3             | 1176 | 3.55        | 10   | 10.3      | 80      | V      |
| 4             | 1174 | 3.55        | 10   | 10.3      | 80      | V      |
| 5             | 1229 | 3.71        | 15   | 10.8      | 80      | V      |
| 12            | 1255 | 3.79        | 20   | 11        | 73      | V      |
| 7             | 1063 | 3.21        | MFD  | 9.2       | 80      | H      |
| 9             | 1063 | 3.21        | MFD  | 9.2       | 80      | H      |
| 10            | 1067 | 3.22        | MFD  | 9.2       | 80      | H      |
| 11            | 1066 | 3.22        | MFD  | 9.2       | 80      | H      |
| 6             | 1174 | 3.84        | 10   | 10.3      | 80      | H      |
| 8             | 1227 | 3.71        | 15   | 10.6      | 80      | H      |

**Table 7: Minimum Fill Density w ecomate**

| <b>J121-2</b> |      | <b>ecomate</b> |      |           |         |        |
|---------------|------|----------------|------|-----------|---------|--------|
| FRD =         |      | 2.38           |      |           |         |        |
| panel         | mass | DENS           | pack | shot time | TEMP °F | ORIENT |
| 2             | 1357 | 4.32           |      | 11.9      | 80      | V      |
| 3             | 1424 | 4.30           | MFD  | 12.5      | 80      | V      |
| 4             | 1568 | 4.74           | 10   | 13.8      | 80      | V      |
| 5             | 1553 | 4.69           | 10   | 13.8      | 80      | V      |
| 7             | 1442 | 4.36           |      | 12.5      | 80      | H      |
| 8             | 1434 | 4.33           | MFD  | 12.4      | 80      | H      |
| 9             | 1567 | 4.73           | 10   | 13.6      | 80      | H      |
| 10            | 1557 | 4.70           | 10   | 13.6      | 80      | H      |
| 11            | 1400 | 4.23           |      | 12.3      | 95      | V      |
| 12            | 1417 | 4.28           | MFD  | 12.5      | 95      | V      |
| 13            | 1548 | 4.68           | 10   | 13.7      | 95      | V      |
| 14            | 1553 | 4.69           | 10   | 13.7      | 95      | V      |
| 15            | 1568 | 4.74           | 10   | 13.7      | 95      | H      |

**Table 8A: Low Density ecomate system**

| <b>J121-4</b> |          | 1.6 pcf     |      |      |      |
|---------------|----------|-------------|------|------|------|
| FRD           |          |             |      |      |      |
| shot          | duration | orientation | temp | fill | DENS |
| 12            | 6.9      | H           | 95   | MFD  | 2.39 |
| 4             | 7.6      | H           | 95   | 10%  | 2.58 |
| 8             | 7.9      | H           | 95   | 15%  | 2.69 |
| 11            | 8.3      | H           | 95   | 20%  | 2.83 |

**Table 8: Minimum Fill Density w R134a**

| J121-3 |      | R134a |      |           |         |        |
|--------|------|-------|------|-----------|---------|--------|
| FRD =  |      | 2.32  |      |           |         |        |
| panel  | mass | DENS  | pack | shot time | TEMP °F | ORIENT |
| 1      | 724  | 3.03  |      | 6.3       | 95      | V      |
| 2      | 1006 | 3.04  | MFD  | 8.7       | 95      | V      |
| 3      | 1112 | 3.36  | 10   | 9.6       | 95      | V      |
| 4      | 1108 | 3.35  | 10   | 9.6       | 95      | V      |
| 5      | 1104 | 3.33  | 10   | 9.6       | 95      | H      |
| 10     | 1058 | 3.20  | MFD  | 9.1       | 80      | H      |
| 11     | 1153 | 3.48  | 10   | 10.1      | 80      | H      |
| 12     | 1167 | 3.53  | 10   | 10.1      | 80      | H      |
| 13     | 1165 | 3.52  | 10   | 10.1      | 80      | H      |
| 14     | 1157 | 3.50  | 10   | 10.1      | 80      | H      |
| 15     | 1157 | 3.50  | 10   | 10.1      | 95      | H      |
| 16     | 1220 | 3.69  | 15   | 10.5      | 95      | H      |

## DENSITY DISTRIBUTION

To have good physical properties in a finished foam part, one would expect to have a uniform density distribution across the finished part. We investigated density distribution in our panels [Table 9]. The panels were cut into 10 equal pieces along the long axis, starting at the fill end [A] and proceeding to the vent end [J]. Data for 'J' pieces were not included in the tables. The results were then graphed.

### R-22

Note in Figure 2 that the density of the vertical pour is fairly uniform across all the panels, with a peak forming between 70-80% of fill and then density falling off dramatically at the end of the panel. The peak formed is pushed back and lessened with packing, but not eliminated until 20% over-pack. Also note the density decline at the panel end is a result of gelling of the foam locking the panel [causing the peak], then stretching to fill – thus producing a lower density at the end of the panel. This effect will be seen for most of the foams investigated here.

In the horizontal mode [Fig 3] the density distribution of the R22 system is much flatter [more uniform] than seen in the vertical position, suggesting that perhaps not as much packing is required in this position.

But R22 is now history in the US, so how does 134a compare?

### HFC-134a

HFC-134a is not as uniform in density distribution as is R-22 [Figs 4-6]. Packing seems of little utility in fixing the situation. In fact, it seems that packing may exacerbate the uniformity of density across the length of the panel. Temperature seems to make very little difference in minimum fill density

Why is this so? Two factors come into play: Heat of vaporization and solubility. First, not only is the boiling point of R-22 is lower than that of R-134a [-40.8°C v -26.2°C respectively], but its heat of vaporization is higher as well [233.95 KJ/kg v 215.9 KJ/kg for R-22 and R-134a respectively] which means that upon evaporation, R22 will have a greater cooling effect than R-134a. This means even though 134a

is a gas, it locks up quicker than foams blown with R-22 because it does not have the same cooling potential. Secondly, the solubility of R-22 is greater than that of R-134a so the viscosity of the mixture will be higher for 134a, and this additional viscosity will impede flow.

## **Ecomate**

Let's look at ecomate. One can see from the following figure [Figure 7] that the foam blown with ecomate locked up excessively and early. This cannot be a mechanism of the blowing agent itself because blowing agents have very little to do with reactivity other than an intrinsic cooling effect. Certainly, froth foams obscure Cream Time, because the frothing agent begins to foam as soon as the material sees a decrease in pressure – immediately as it leaves the gun. This evaporation causes an immediate drop in foam temperature, which will cause a slowing of reactivity. To compensate for the cooling, a froth formulation generally uses a large portion of amine polyol.

Without the cooling effect of a frothing agent, a liquid blown foam would react rapidly and experience premature gelation. This would be the case using any liquid BA in this formulation.

Because of this premature lock-up, density distribution is much wider for these initial liquid ecomate panels. The foams made locked up at 40-50% of fill, then stretch their way to the end of the panel. In the vertical orientation panels were nearly identical, regardless of mold temperature. The horizontal mode produced similar distribution, exemplifying the lock up and stretch mechanism noted above.

To overcome the formulation imposed bias against liquid BAs, another formulation [J121-5] was made without the high amine polyol content. This formulation had a free rise density of 2.24 pcf, and a minimum fill density of 3.03 pcf. The Density Distribution is much improved, and quite like that of HFC -134a as expected [Figure 8].

We also took a commercial ecomate system [J121-4] which has a FRD of 1.6pcf and determined its density distribution in various panels in both horizontal and vertical orientations, with equal success [Fig 9].

## **CELL ORIENTATION**

In addition to density distribution, another criterion that can affect physical properties is cell orientation. Strength, dimensional stability, and thermal conductivity can be dramatically affected by cell orientation. This is not to be confused with cell size. Normally the cells in urethane foams are egg shaped, to somewhat spherical. Froth foam will have larger blow-holes [caused by the rapid release or evaporation of the frothing agent] mixed in with the normal fine cells found in liquid blown foams.

To assess the cell orientation of the foams produced in this study, compressive strengths were run on specific pieces out of the panels [sections B, E, I] which were labeled Front, Middle, and End respectively. The data were obtained in the Length, Width, and Thickness directions of the panel independent of pour orientation. This data obtained are captured in Table 10. The panel number is listed, then the pour conditions for that panel. For instance, MV80 means [Minimum Fill, Vertical, 80F], while 10H80 would be [10% Pack, Horizontal, 80F].

So what does this show us? It is easier to see graphically [Figs 10-16]. While all the data has been graphed, there is not enough space to include them all in this paper. We can say the following, however:

- Compressive strength depends upon cell orientation
- Elongated cells always appear stronger along their long axis.
- Thermal conductivity is better across the smaller cell direction [there are more effective insulating cells in this direction per unit distance].



**Table 9: Density Distribution of panels - from Fill End to Vent End**

| DENSITY |       | FILL END |      |      |      |      |      |      | VENT END |      |
|---------|-------|----------|------|------|------|------|------|------|----------|------|
| 121.1   |       | A        | B    | C    | D    | E    | F    | G    | H        | I    |
| R22     | PANEL | 10       | 20   | 30   | 40   | 50   | 60   | 70   | 80       | 90   |
| MFD V80 | 2     | 3.26     | 3.22 | 3.24 | 3.24 | 3.25 | 3.27 | 3.31 | 3.34     | 3.24 |
| 10% V80 | 3     | 3.56     | 3.54 | 3.57 | 3.57 | 3.57 | 3.56 | 3.64 | 3.56     | 3.48 |
| 15% V80 | 5     | 3.70     | 3.71 | 3.71 | 3.70 | 3.70 | 3.74 | 3.80 | 3.78     | 3.68 |
| 20% V80 | 12    | 3.77     | 3.83 | 3.81 | 3.83 | 3.83 | 3.80 | 3.79 | 3.79     | 3.73 |
| MFD H80 | 7     | 3.24     | 3.23 | 3.24 | 3.25 | 3.24 | 3.21 | 3.24 | 3.22     | 3.18 |
| 10% H80 | 6     | 3.55     | 3.55 | 3.55 | 3.54 | 3.53 | 3.55 | 3.59 | 3.58     | 3.58 |
| 15% H80 | 8     | 3.83     | 3.74 | 3.72 | 3.71 | 3.71 | 3.71 | 3.72 | 3.74     | 3.67 |
|         |       |          |      |      |      |      |      |      |          |      |
| 121.2   |       | A        | B    | C    | D    | E    | F    | G    | H        | I    |
| ECOMATE | PANEL | 10       | 20   | 30   | 40   | 50   | 60   | 70   | 80       | 90   |
| MFD V80 | 3     | 4.58     | 4.52 | 4.48 | 4.43 | 4.36 | 4.27 | 4.19 | 4.18     | 4.16 |
| 10% V80 | 4     | 5.02     | 4.97 | 4.91 | 4.85 | 4.78 | 4.71 | 4.64 | 4.58     | 4.49 |
| 10% V80 | 5     | 5.05     | 5.01 | 4.92 | 4.85 | 4.75 | 4.64 | 4.54 | 4.48     | 4.39 |
| MFD V95 | 12    | 4.54     | 4.49 | 4.46 | 4.41 | 4.34 | 4.25 | 4.19 | 4.18     | 4.18 |
| 10% V95 | 13    | 4.94     | 4.88 | 4.84 | 4.80 | 4.76 | 4.67 | 4.58 | 4.52     | 4.45 |
| 10% V95 | 14    | 4.97     | 4.91 | 4.87 | 4.84 | 4.78 | 4.69 | 4.59 | 4.53     | 4.45 |
| MFD H80 | 8     | 4.54     | 4.51 | 4.53 | 4.50 | 4.44 | 4.32 | 4.22 | 4.17     | 4.11 |
| 10% H80 | 10    | 5.00     | 5.00 | 4.93 | 4.93 | 4.84 | 4.68 | 4.58 | 4.50     | 4.38 |
|         |       |          |      |      |      |      |      |      |          |      |
| 121.3   |       | A        | B    | C    | D    | E    | F    | G    | H        | I    |
| R134a   | PANEL | 10       | 20   | 30   | 40   | 50   | 60   | 70   | 80       | 90   |
| MFD V95 | 2     | 3.08     | 3.06 | 3.08 | 3.09 | 3.08 | 3.12 | 3.15 | 3.16     | 3.12 |
| 10% V95 | 4     | 3.28     | 3.38 | 3.46 | 3.48 | 3.46 | 3.42 | 3.47 | 3.41     | 3.24 |
| MFD H80 | 10    | 3.22     | 3.23 | 3.21 | 3.19 | 3.18 | 3.21 | 3.23 | 3.24     | 3.24 |
| 10% H80 | 12    | 3.53     | 3.58 | 3.60 | 3.62 | 3.63 | 3.61 | 3.58 | 3.54     | 3.45 |
| 10% H95 | 5     | 3.31     | 3.33 | 3.33 | 3.40 | 3.42 | 3.43 | 3.42 | 3.39     | 3.31 |
| 10% H95 | 15    | 3.40     | 3.49 | 3.50 | 3.55 | 3.62 | 3.63 | 3.58 | 3.61     | 3.49 |
| 15% H95 | 16    | 3.60     | 3.70 | 3.70 | 3.79 | 3.80 | 3.81 | 3.79 | 3.73     | 3.67 |
|         |       |          |      |      |      |      |      |      |          |      |
| 121-5   |       | A        | B    | C    | D    | E    | F    | G    | H        | I    |
| ecomate | PANEL | 10       | 20   | 30   | 40   | 50   | 60   | 70   | 80       | 90   |
| MFD     |       | 3.07     |      |      |      |      |      |      |          |      |
| 12% H80 |       | 3.44     | 3.45 | 3.41 | 3.48 | 3.45 | 3.61 | 3.57 | 3.51     | 3.25 |
| MFD     |       | 3.33     |      |      |      |      |      |      |          |      |
| 7% H80  |       | 3.47     | 3.61 | 3.60 | 3.60 | 3.57 | 3.54 | 3.55 | 3.39     | 3.33 |
| 12% H80 |       | 3.59     | 3.69 | 3.74 | 3.73 | 3.77 | 3.72 | 3.75 | 3.64     | 3.54 |
| 19% H80 |       | 3.94     | 4.08 | 4.17 | 4.08 | 4.00 | 4.03 | 4.02 | 3.93     | 3.85 |

| 121-4 ecomate |    | A    | B    | C    | D    | E    | F    | G    | H    | I    |
|---------------|----|------|------|------|------|------|------|------|------|------|
| PANEL         |    | 10   | 20   | 30   | 40   | 50   | 60   | 70   | 80   | 90   |
| MFD H95       | 12 | 2.10 | 2.20 | 2.30 | 2.36 | 2.55 | 2.57 | 2.59 | 2.49 | 2.26 |
| 10% H95       | 4  | 2.43 | 2.48 | 2.48 | 2.54 | 2.57 | 2.58 | 2.61 | 2.59 | 2.43 |
| 15% H95       | 8  | 2.46 | 2.53 | 2.60 | 2.67 | 2.70 | 2.76 | 2.73 | 2.65 | 2.57 |
| 20% H95       | 11 | 2.59 | 2.65 | 2.72 | 2.78 | 2.86 | 2.91 | 2.91 | 2.74 | 2.71 |
| MFD V80       | 6  | 2.18 | 2.22 | 2.34 | 2.47 | 2.56 | 2.65 | 2.62 | 2.47 | 2.32 |
| 10% V80       | 7  | 2.50 | 2.58 | 2.57 | 2.67 | 2.75 | 2.80 | 2.77 | 2.69 | 2.49 |
| 20% V95       | 9  | 2.63 | 2.65 | 2.69 | 2.74 | 2.82 | 2.86 | 2.81 | 2.75 | 2.57 |
| 25% V95       | 10 | 2.82 | 2.86 | 2.92 | 2.97 | 3.05 | 3.05 | 3.02 | 2.95 | 2.75 |

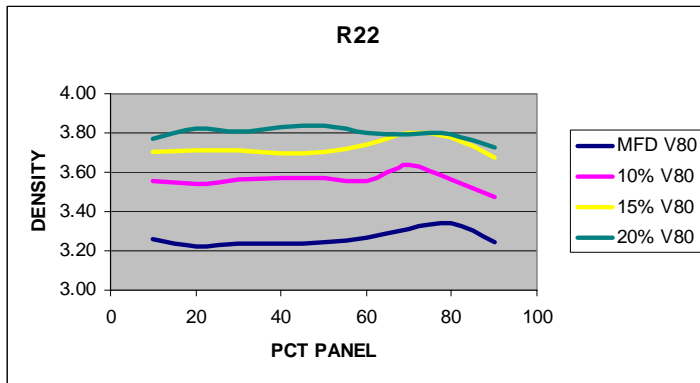


Fig 2: R22 Density Distribution - Vertical 80F mold

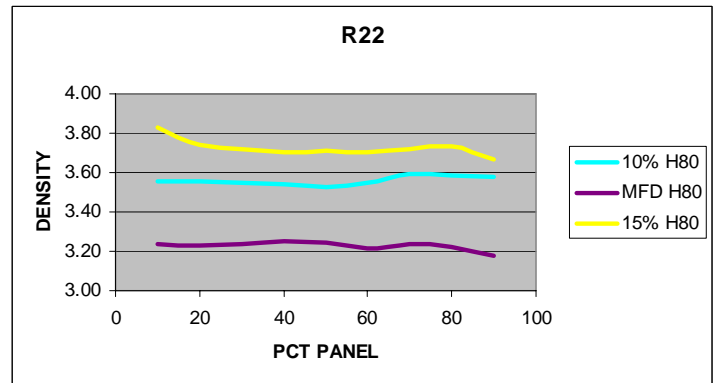


Fig 3: R22 Density Distribution - Horizontal 80F

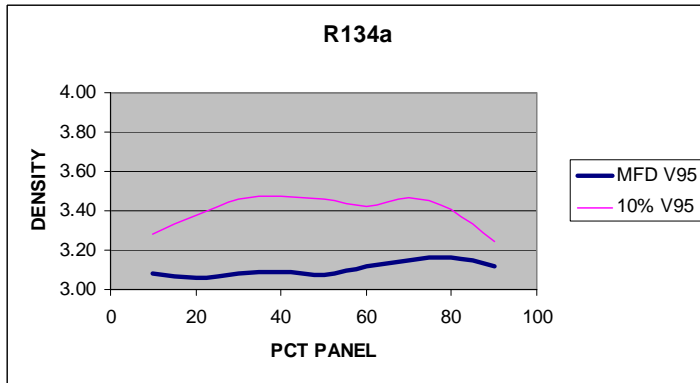


Fig 4: Density Distribution - R-134a Vertical 95 F

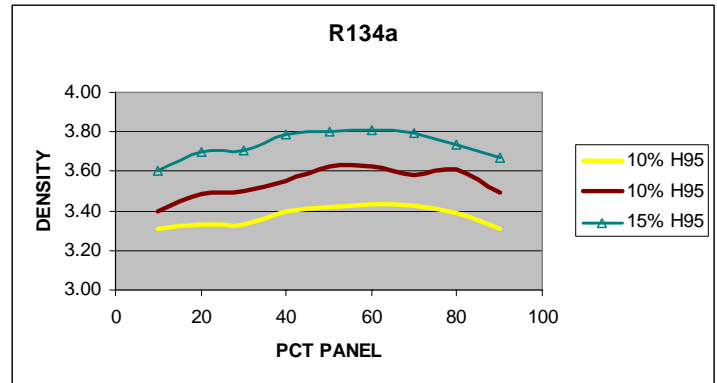


Fig 5: Density Distribution - R-134a Horiz 95F

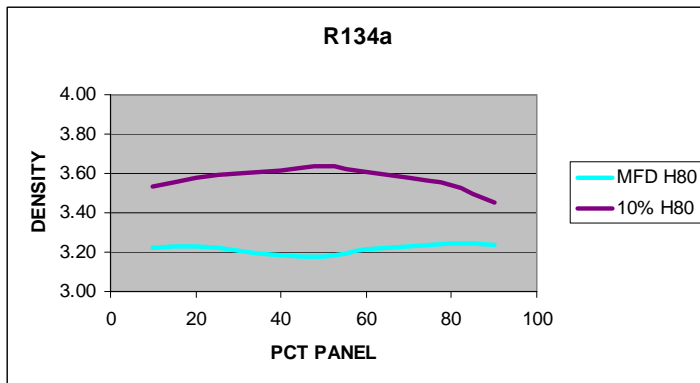


Fig 6: Density Distribution - R-134a Horiz 80F

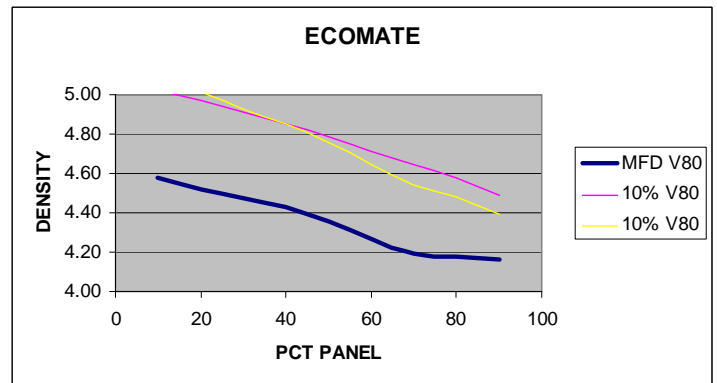


Fig 7: Density Distribution - Ecomate Vertical 80F

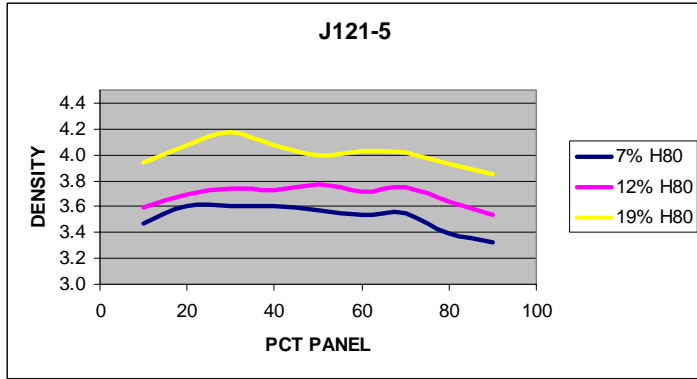


Fig 8: J121-5 Horz w/o Amine Polyol

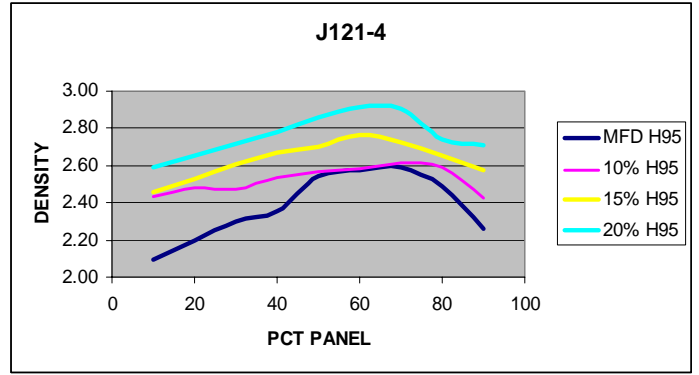
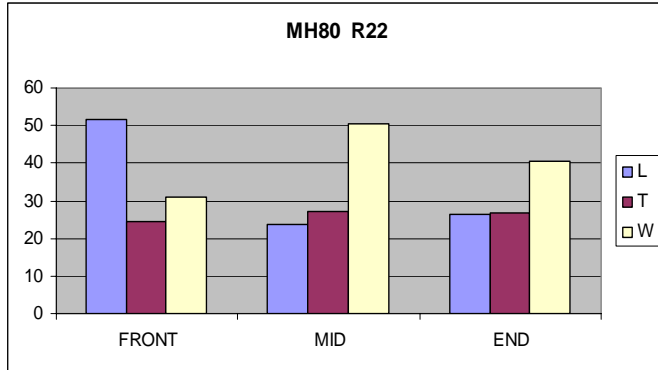


Fig 9: J121-4 Low Dens System

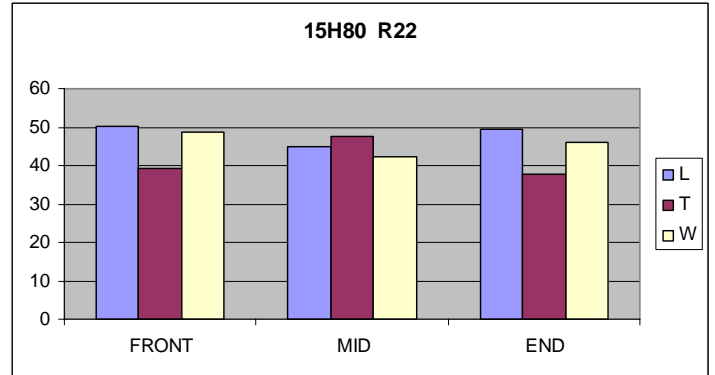
Table 10: Cell orientation of specific Panels

|   | <b>R-22</b> | FRONT | MID | END | <b>ecomate</b> | FRONT | MID | END | <b>R134a</b> | FRONT | MID | END |
|---|-------------|-------|-----|-----|----------------|-------|-----|-----|--------------|-------|-----|-----|
| L | 1-2         | 48    | 47  | 38  | 2-8            | 78    | 77  | 59  | 3-2          | 47    | 44  | 30  |
| T | MV80        | 30    | 27  | 23  | MH80           | 41    | 29  | 40  | MV95         | 25    | 25  | 23  |
| W |             | 35    | 33  | 40  |                | 61    | 65  | 59  |              | 28    | 28  | 28  |
| L | 1-3         | 53    | 51  | 37  | 2-10           | 83    | 83  | 54  | 3-4          | 42    | 49  | 34  |
| T | 10V80       | 38    | 34  | 33  | 10H80          | 45    | 43  | 43  | 10V95        | 34    | 34  | 27  |
| W |             | 45    | 30  | 44  |                | 70    | 78  | 70  |              | 38    | 36  | 35  |
| L | 1-5         | 59    | 53  | 43  | 2-3            | 85    | 80  | 49  | 3-10         | 50    | 47  | 41  |
| T | 15V80       | 43    | 39  | 33  | MV80           | 45    | 46  | 39  | MH80         | 24    | 29  | 25  |
| W |             | 49    | 38  | 49  |                | 64    | 68  | 62  |              | 34    | 32  | 34  |
| L | 1-12        | 48    | 55  | 44  | 2-4            | 90    | 77  | 40  | 3-12         | 49    | 50  | 39  |
| T | 20V80       | 39    | 40  | 34  | 10V80          | 55    | 58  | 49  | 10H80        | 33    | 31  | 35  |
| W |             | 49    | 45  | 46  |                | 72    | 72  | 71  |              | 42    | 46  | 37  |
| L | 1-7         | 51    | 24  | 26  | 2-5            | 92    | 77  | 58  | 3-5          | 47    | 38  | 38  |
| T | MH80        | 24    | 27  | 27  | 10V80          | 46    | 53  | 49  | 10H95        | 35    | 3   | 35  |
| W |             | 31    | 51  | 41  |                | 71    | 78  | 69  |              | 39    | 41  | 40  |
| L | 1-6         | 54    | 50  | 38  | 2-12           | 85    | 81  | 46  | 3-15         | 45    | 45  | 39  |
| T | 10H80       | 36    | 37  | 38  | MV95           | 49    | 45  | 29  | 10H95        | 34    | 40  | 40  |
| W |             | 45    | 46  | 45  |                | 62    | 65  | 58  |              | 38    | 44  | 36  |
| L | 1-8         | 50    | 45  | 50  | 2-13           | 87    | 74  | 57  | 3-16         | 44    | 44  | 43  |
| T | 15H80       | 39    | 48  | 38  | 10V95          | 59    | 57  | 54  | 15H95        | 36    | 38  | 11  |
| W |             | 49    | 42  | 46  |                | 71    | 79  | 73  |              | 45    | 51  | 48  |
|   |             |       |     |     | 2-14           | 85    | 76  | 61  |              |       |     |     |
|   |             |       |     |     | 10V95          | 59    | 62  | 52  |              |       |     |     |
|   |             |       |     |     |                | 73    | 83  | 71  |              |       |     |     |

To obtain optimum physicals it is wise to get the foam cells in a foamed part oriented 1) in the same direction, and 2) in the direction which gives optimal properties throughout the panel or part. For example, with the R-22 blown foam [MH80], there is elongation in the length direction in the front panel, but before mid-panel that changes to elongation in the width direction in the horizontal minimum filled panel. At 10 - 15% packing the cells are nearly spherical, and consistent in properties [Figures 10-11].

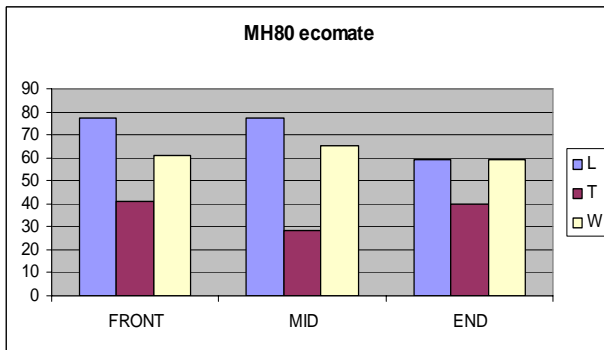


**Figure 10: Horizontal R-22 system - MFD**

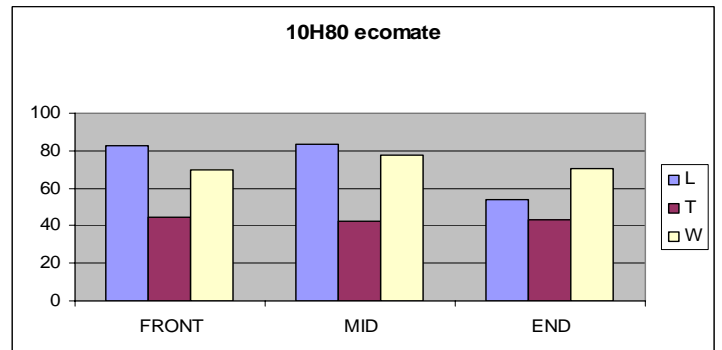


**Fig 11: Horizontal R-22 system - 15% Pack**

With ecomate blown panels, the cells of the minimum filled panel are slightly elongated thru mid-panel then become spherical. At 10% pack, they are spherical mid-panel and slightly elongated at either end suggesting that less packing might be in order [Figs 12-13].



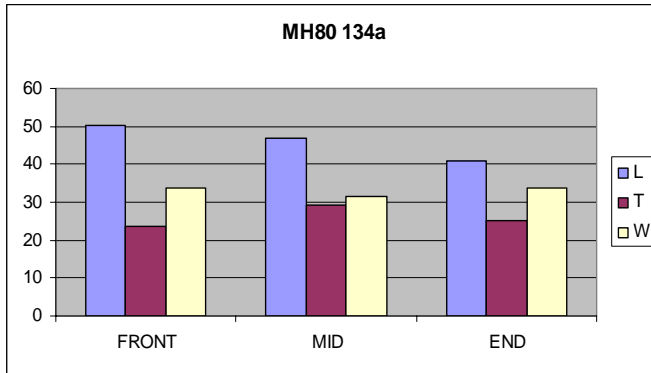
**Fig 12: eco Horizontal Panel - MFD**



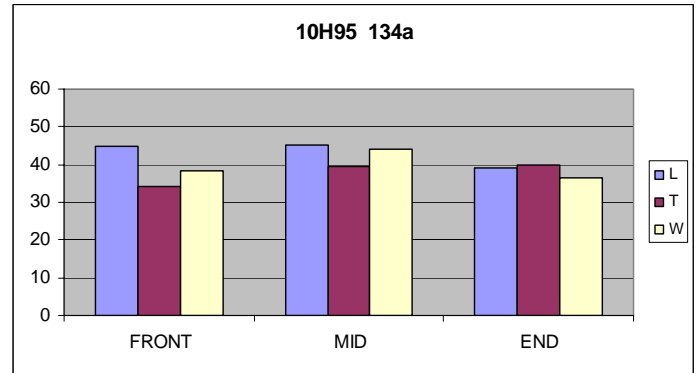
**Fig 13: eco Horizontal Panel - 10% Pack**

With R-134a [Figs 14-15], a horizontal panel made at minimum fill density shows elongation in the length direction across the entire panel. It requires both 10% packing and additional heat [95 F] to get nearly uniform cells throughout the panel. This is unusual because normally froth foam does not require a warm mold.

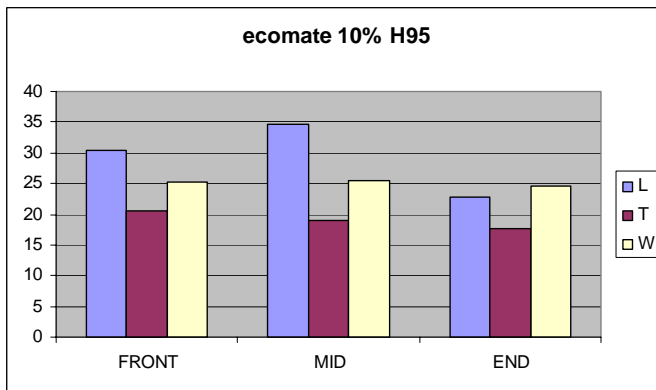
The objective is not to get spherical cells throughout the panel but to produce a product with uniform properties across the panel. This assures you and your customer that the parts produced are consistent throughout, and giving him the product he thought he was buying.



**Fig 14: Horizontal 134a Panel – MFD**



**Fig 15: Horizontal 134a Panel – 10% pack & 95 F**



**Fig 16: Horz J121-4 Low dens ecomate panel – 10% pack**

## ECONOMICS

Froth foam blowing agents are more expensive for several reasons:

- They are fluorochemicals. The cost of fluorochemicals will always cost more than the ethers, esters, or hydrocarbons from which they are made. The cost depends directly on the number of F molecules used.
- The cost of the foam equipment could be more expensive, especially the high pressure tanks used if that cost is passed on from the formulator.
- The cost of shipping the high pressure tanks is more than shipping drums.
- The molecular weight of a fluorochemical is generally higher than a hydrocarbon or ecomate, thus they are more costly on a mole basis than are the liquid BAs.
- There is a higher loss percentage when using a froth BA over a liquid [ $\sim 8\%$  v  $3\text{--}4\%$  respectively]
- The cost to the environment is also high.
  - Halogen containing species will always be less environmentally benign than ecomate. For example, HFC-134a with a MW of 102 requires 1.7 times more material than ecomate to blow the same density foam. Multiplying that times the GWP value of 1300 for 134a gives us a CO<sub>2</sub> equivalents value of over 1 metric tonne savings for each pound of ecomate conversion [Table 11]. The same can be said for converting from 245fa to ecomate.
  - This value does not include the additional loss due to higher vapor pressure.

**Table 11: Environmental cost of using HFCs**

|         | MW  | norm | GWP <sub>100</sub> | CO2 e |
|---------|-----|------|--------------------|-------|
| ecomate | 60  | 1    | 0                  | 1     |
| 134a    | 102 | 1.7  | 1300               | 2210  |
| 245fa   | 134 | 2.23 | 950                | 2122  |

## CONCLUSIONS

- Liquid blowing agents are different than Froth blowing agents.
  - They have lower heats of vaporization – they cool less!
  - They typically require tighter molds – especially foaming in a vertical position
- However
  - They can have better density distribution and better flow in molds
  - They have similar properties.
- All formulations require optimization!
  - Froth foams require an expensive amine polyol or more catalyst to overcome cooling effect.
- Froth foams have greater vapor loss than liquids - bad for the environment
- Froth foams will cost more than liquids
  - The cost of the equipment is more expensive, especially the high pressure tanks
  - There is greater vapor loss with a froth = higher price per finished part.
  - The cost of fluorochemicals will always exceed that of the ethers, esters or hydrocarbons they are manufactured from, and depend directly on the number of F molecules used.
  - Halogen containing species will always be LESS environmentally benign than Ecomate.
- Ecomate use instead of HFC-134a [or HFC-245fa] can save the environment 1 metric ton of CO2 equivalents for every pound of ecomate used.

## BIOGRAPHY

John A. Murphy

John received his BS in Chemistry in 1965. During his 35 years researching urethanes he has worked for [among others] ARCO Chemical and Elf Atochem, where he introduced HCFC-141b to the industry. Currently employed by FSI, he is responsible for New Product Development -Ecomate.



---

<sup>1</sup> Kondo, S, Urano, Y, Takizawa, K, Takahashi, A, Tokuhashi, K, and Sekiya, A. 2005. "Flammability Limits of multi-fluorinated compounds" *Fire Safety Journal*, February 2006, Pages 46-56