

Myths and Facts surrounding Long Term Ageing of Foam Insulation

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ABSTRACT

Many factors influence the thermal efficiency [λ value or k-factor] one obtains with foams blown with any of the commercial physical blowing agents. Factors affecting a product's thermal efficiency depend on, but are not limited to, the blowing agent itself – such as the blowing agent's molecular weight, its boiling point, and its solubility in the foam matrix. Other factors depend on formulation parameters such as catalyst levels which affect speed of reaction and fineness of cell structure. Yet others depend on the mixing efficiency of the equipment used to process the foams. Finally, a great deal of the contribution depends on the amount of protection the foam receives from its immediate environment - ranging from exposed foam to foam enclosed within impermeable facers.

The long term aging of foams has always been filled with myth and controversy. This has been true for every blowing agent that has been commercialized. We will try to dispel some of the myth with the results of several long term aging studies, run on ecomate® and other commercial BAs.

In one study, the 5 year drift of insulation values was monitored by long term thermal value changes in comparison to unit efficiency over that span of time. This comparison pits ecomate blown foams against those made with R-134a.

AGEING – Myth or Fact?

The “fact” of Foam Aging [loss of thermal insulation efficiency with time] seems certain. Many prestigious research labs [such as ORNLⁱ] have investigated the phenomenon. There have been many papers written on the subject over the years. Many countries, including the US [ASTM C-1303ⁱⁱ] and Canada [CAN/ULC S-770ⁱⁱⁱ], have adopted test methods on how to measure this change.

What are the consequences of this aging? It seems obvious that the thermal insulation value is critically important if one goes to the expense of putting urethane foam insulation in place...and the obvious consequence is that the insulation value that one had anticipated is slowly dissipating!

So if foams age, why do they age? **The common belief is that the blowing agent [BA] diffuses out of the foam over time.**

While this may in part be true, this author believes it to be surrounded in MYTH. The purpose of this paper is to give various types of evidence to show that the perceived “aging” of foams centers upon the infusion of moisture laden air into the foam. **How does one effectively differentiate the effects of moisture infusion from those of BA diffusion?**

1. Anecdotal Evidence

Allow me to relate anecdotally an episode that happened to me many years ago. A sample of spray foam taken from a roof failure [coating had weathered off, allowing the foam to badly discolor and become laden with water] was tested for thermal conductivity. This apparent 2.5 pcf [40Kg/m³] foam tested at $k = 0.25$ [36mW/mK]. The

foam was then placed in a 100 F [38 C] oven for a week to dry it out, and it retested at 2.0 pcf [32 Kg] and with a k-factor of 0.11 [15.8 mW/mK]. Exactly what it had been the instant it was manufactured!

This strongly suggested that *CFCs have a much harder time getting out of foam than do moisture and atmospheric gases in permeating into the foam simply due to the relative size [MW] of each*. In fact, our industry warns against placing foams below grade level specifically because of the potential uptake of moisture into the foam.

2. Lab Experiments

To make the above incident less anecdotal, foams were made which were blown with 134a, processed through a 30 ppm SLUG gun [a low pressure dispensing unit], poured into a 22" tall by 22" diameter [or 4.84 cu ft.] metal cylinder. The resultant foam core, having a density of 1.74 pcf, [27.8kg], was cut into 4 ea 8"x8"x2" pieces without skins, to determine the thermal conductivity under various environmental conditions:

- One, aged at 25C / 50% RH – labeled **RT**
- Another aged at 25C, in a desiccator – labeled **DRY**
- A third aged at 25C under water – labeled **WET**, and
- The last, aged at 70C / 95% RH – labeled **HA** [humid aged]

After only 1 week, the DRY specimen had already stopped aging and assumed a flat slope [Figure 1], while the RT aged sample continued to climb. This suggests that the water in the air has a strong influence on thermal aging.

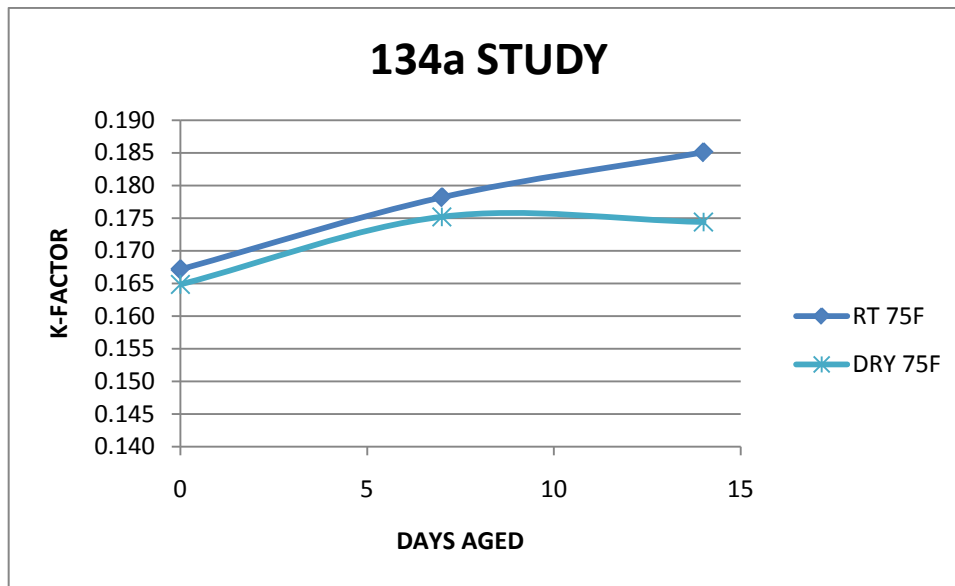


Figure 1: Comparison of same foam exposed to 25C, both dry and 50% RH

The HA sample took off at an even steeper slope, but after two weeks it too had begun to slow its aging rate [Figure 2]. Its density also began to climb, from 1.75 pcf. to 2.25 pcf. [28 to 36 Kg/m³] after one week.

Most telling of all was the WET sample, which was aged at room temperature under water – at the end of one week, its density had climbed to 12.6 pcf [202Kg]; a week later to 18.0 pcf [288Kg], and by the third week to 18.9 pcf [302Kg]. The thermal conductivity of this specimen had rocketed to 0.53[$\lambda=76$] [Figure 3] in only two weeks. This foam had not distorted in any fashion during the immersion.

This rapid change in thermal conductivity strongly suggests that the more water to which you subject foam, the worse you can expect its thermal conductivity to be.

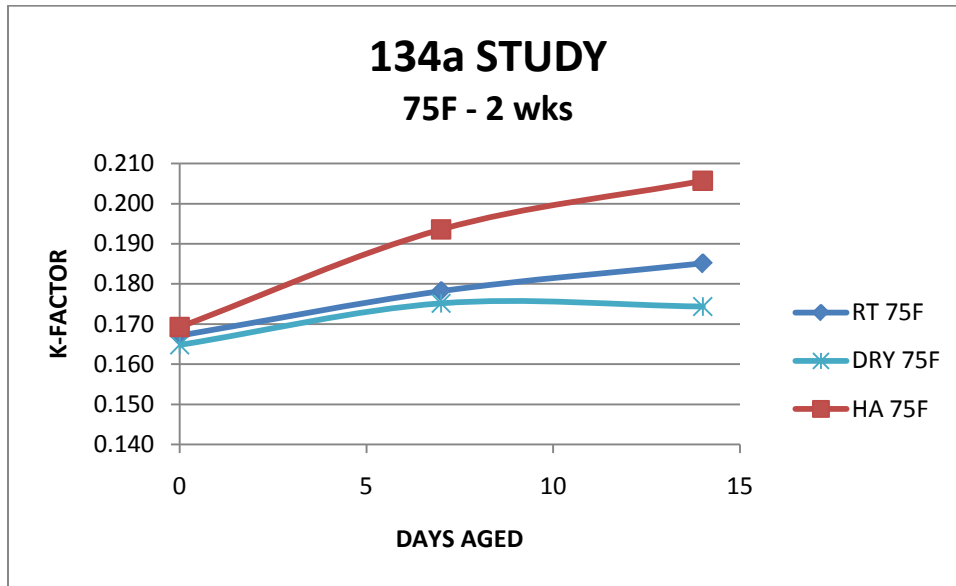


Figure 2: Same foam aged 2 weeks at various conditions – showing magnitude of Humid Aging

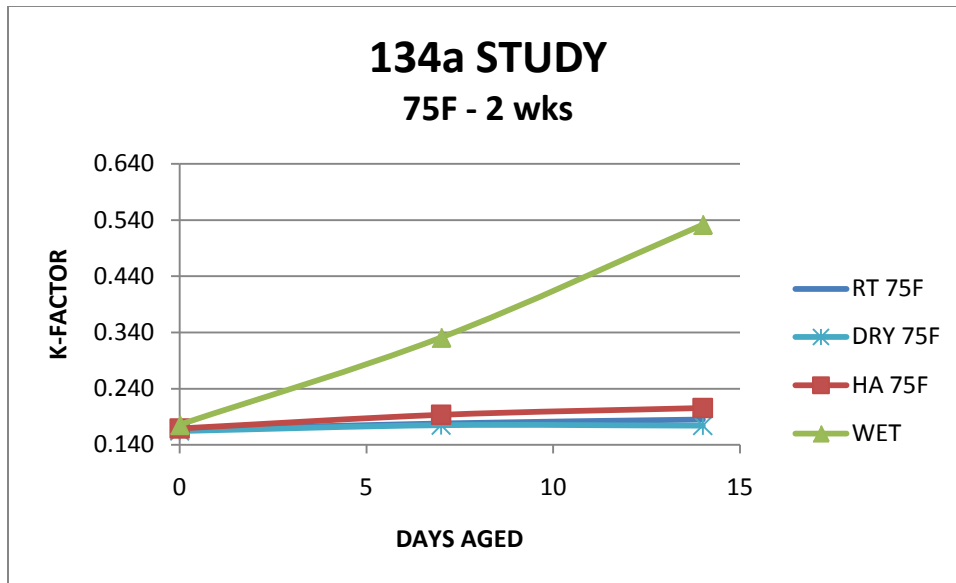


Figure 3: Same foam aged 2 weeks under various conditions – Showing magnitude of WET aging

To demonstrate the long term permanence of insulation value, an insulated shipping container, insulated with ecomate® blown pour foam on the 12th of July, 2002 was initially evaluated in the following manner: A block of dry ice was placed into the container and the lid closed and sealed with shipping tape. Ambient temperature was 21C. The temperature inside the box was measured with a thermocouple. The test was allowed to stabilize for one hour to reach stasis. The initial temperature was measured and the test recording began from here. The interior temperature was measured and recorded every 24 hours.

5 year retest [Jan 2008] – the Box from the original testing was stored in a warehouse for approximately 5 ½ years. It was re-tested in accordance with the original test method outlined above. The results of that testing are shown in **Figure 4**, which demonstrates that the ecomate blown foam maintained nearly the identical insulation capability that it had 5 ½ years earlier.

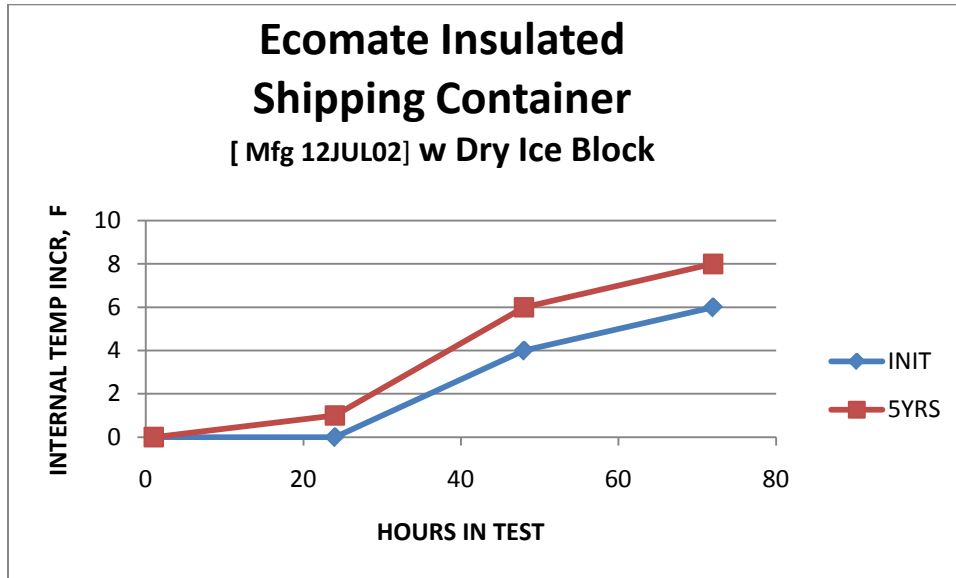


Figure 4: Temperature profiles of re-test of same Shipping Container aged over 5 years

3. Mathematical evidence

Let’s examine the practice of thin slicing to predict the aging of foam. A foam sample is cut into equal thin slices to mathematically determine the rate of blowing agent release - the thinner the slice, the faster the aging. Seems logical – thinner sections, with more surface area, beget faster diffusion. But diffusion of what, one might ask?

Physical blowing agents rely on their boiling point, their solubility in the polyol, and their gaseous thermal conductivity to be useful as BAs. They are used on a molar basis – equi-molar quantities will give the same density of foam.

Table 2: Molecular Weights and Boiling Points of some historic Blowing Agents

BA	MW	BP, C
CFC-11	137	23.7
HCFC-141b	117	32.2
HFC-245fa	134	15.3
HFC-365mfc	148	40
ecomate	60	32
CFC-12	121	-29.8
HCFC-22	86.5	-40.8
HCFC-142b	100.5	-9.3
HFC-134a	102	-26.2

But the molar weights of BAs have been quite different over the short history of PU foams [**Table 2**]. Their diffusion rates must be equally divergent. And if these liquids and /or gases are trying to get out of the foams, what

is trying to get into the foams? Atmospheric gases, of course! Graham's Law states that the rate of diffusion of given gases is inversely proportional to the square roots of their MWs. What are the atmospheric gases, what are their concentrations, and what are their MWs [See **Table 3**]?

The data in **Table 3** shows the gas composition of **dry air** at sea level, but it completely ignores the percentage of water vapor in this composition. This can be obtained from **Figure 5**, which suggests that there is between 2-2.5% in saturated air at RT at Sea Level. So, of all the common atmospheric gases, water is generally third in concentration and lowest in MW. At 50% RH and 25 C, the absolute humidity is 11.5 g/m3.

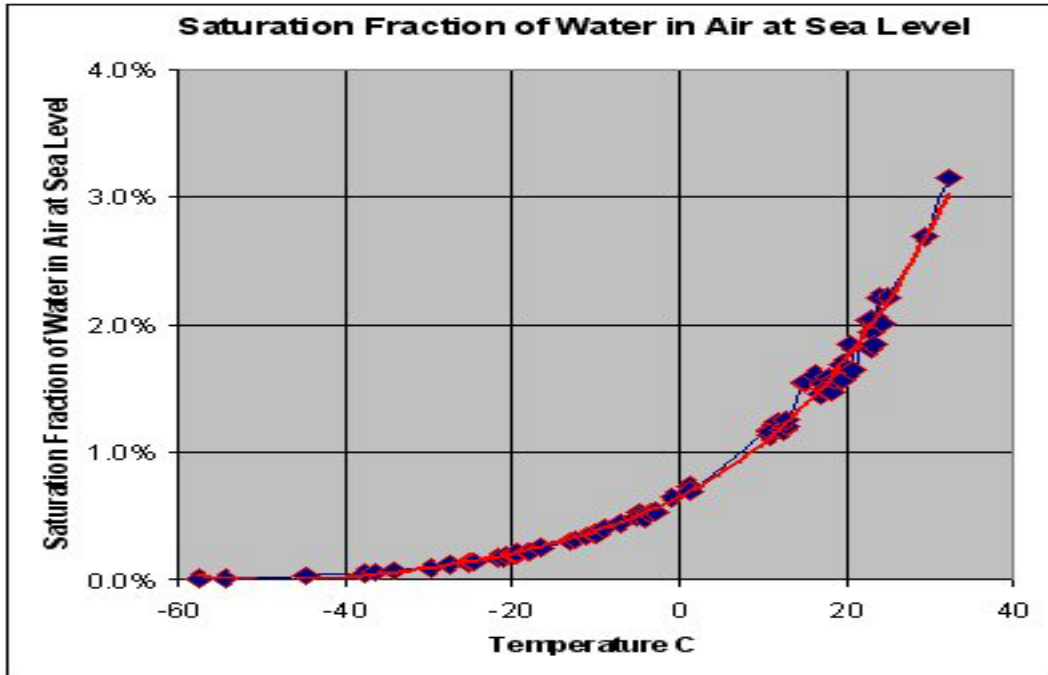


Figure 5: The Standard Fraction of Water in Saturated Air at Sea Level

Table 3: Standard Dry Air Composition

Gas	Form	% by Volume	% by Weight	Molecular Weight
- Nitrogen	N2	78.08	75.47	28.01
- Oxygen	O2	20.95	23.20	32.00
- Argon	Ar	0.93	1.28	39.95
- Carbon Dioxide	CO2	0.038 (2006)	0.0590	44.01
- Neon	Ne	0.0018	0.0012	20.18
- Helium	He	0.0005	0.00007	4.00
- Krypton	Kr	0.0001	0.0003	83.80
- Hydrogen	H2	0.00005	Negligible	2.02
- Xenon	Xe	8.7x10 ⁻⁶	0.00004	131.30

This means that water [MW=18], Nitrogen [MW=28], and oxygen [MW=32] are trying to get into the foam at the same time as the BA is trying to get out. **Nature always wants to reach a state of equilibrium!** Water, being the smallest of these, will also be the fastest to diffuse [according to the diffusion rate of Graham's Law]:

$$\frac{\text{Rate}_1}{\text{Rate}_2} = \sqrt{\frac{M_2}{M_1}}$$

Thus the diffusion rate of water = $\sqrt{(102/18)}$ = **2.38** times the diffusion rate of HFC-134a, and

The diffusion rate of nitrogen = $\sqrt{(134/28)}$ = **2.19** times the diffusion rate of HFC-245fa, for instance (see Table 4).

Table 4:		Graham's Law Diffusion				
		245fa	365mfc	134a	pentane	ecomate
	MW	134	148	102	72	60
Water	18	2.73	2.87	2.38	2.00	1.83
Nitrogen	28	2.19	2.30	1.91	1.60	1.46
Oxygen	32	2.05	2.15	1.79	1.50	1.37

But size isn't everything! There are many other parameters that must be considered, such as solubility in the polymer, fineness of cells, density of foam, Lambda value of the blowing agent, etc. - which means that **Fick's Law must be invoked** [a much more complicated calculation]. Some of these same parameters are what make smaller molecules as efficient an insulator as much larger molecules (For example, HCFC-141b [MW=117] is a much better insulator than HFC-245fa [MW=134]); or equal sized molecules considerably different from one another. For instance, 245fa [MW=134] is nowhere near as efficient as CFC-11 [MW=137].

4. Literature examples

How do we separate the changes brought on by water vapor infusion and those caused by blowing agent loss?

A paper published in 1986 by Baitinger^{iv}, et al, discussing the aging of PUR foams shows just that. In their study, they wrote:

“Thermal conductivity testing of the PUR production board was performed at two different laboratories using different test equipment and aging conditions. Canadian measurements were done on an ANACON k-factor Instrument; the faced boards sections were cut into six inch squares and the facers removed just prior to k-factor testing. For the accelerated aging, faced 18”x18” sections with edges exposed were stored in an oven for 28 days at 80 C.”

The US thermal conductivity tests were done in accordance with ASTM C518 using a Dynatech K-Matic Instrument. The board product samples were cut into one foot squares and the foil facers removed just prior to k-factor testing. For the six month ambient aging two 4’ x4’ boards (half sections) were stored in a well ventilated and heated/air conditioned area. The other 4’ x 4’ sections of each board were used for the initial k-factor measurements. The 1’ x 1’ squares with facers removed, used to obtain the initial values, were retested after 6 months storage for control purposes, These unfaced squares showed typical aging after 6 months while the faced board showed no significant change. These k-factor results are shown in table 5.”

**Table 5^o: Foil faced PU production board k-factor aging tests
in btu-ft/(hr)(ft²)(F)**

Sample	Initial	Canadian Test Conditions After 28
		Days, 80 C
Epoxy Coated Foil - PUR	0.128	0.128
ACR Coated Foil - PUR	0.128	0.129

Sample	Initial	US Test Conditions After 6 Months,
		70F, 50% RH
ACR Coated Foil - PUR	0.129	0.133
Foil facer removed		0.163

▪ Baitinger, et al

As stated by the authors, the samples aged in the 80 C oven one month did not drift. The ambient [70F/50%RH] materials stored with foil facers in place drifted only slightly, while the foams with Al facers removed fared poorly. This data clearly shows that if the foam board is kept dry, the increase in thermal conductivity is negligible. Thus, if a foam is exposed to moisture [even as low as 50% RH] its thermal conductivity will climb dramatically.

Is there documented proof that the Blowing Agent stay in the foam? Recent studies^v by AHAM [Table 6] have shown that fluorinated BAs do *not* leave refrigerators over the course of the refrigerator life time [15-20 years]. If the blowing agent remains in the foam, *the major reason for K-factor drift is moisture invasion!*

Table 6. Amount of CFC-11 Blowing Agent in Sampled Refrigerators

Sample	When Produced, Pre-1993	At End of Life, Prior to Shredding, 2004
A-1	15.2 %	15.4 %
A-2	14.1 %	13.0 %
B-1	15.9 %	16.0 %
B-2	16.7 %	15.2 %
C-1	16.0 %*	16.0 %
C-2	13.0 – 14.0 % *	13.8 %
D-1	14.0 – 16.0 % *	15.7 %
D-2	14.0 – 16.0 % *	14.3 %

* - estimate; exact records not available

Many of the products our industry currently builds have foam exposed to the air. That air is laden with moisture. This study demonstrates that moisture will ruin the effectiveness of the foam insulation. If your customers demand the best insulation that money can buy, and yet leave that insulation open to the air – they are deluding themselves [not to mention wasting their money]. If we are truly concerned about thermal conductivity, we must protect PUR and PIR foams from atmospheric gas [especially water vapor] intrusion.

CONCLUSIONS

- Water vapor has horrific effects on thermal conductivity - getting worse with higher water concentration.
- Blowing agent diffusion out of foam is much slower than atmospheric gas [especially water] infusion – at least half as fast according to Graham's Law
- Oven aged foams show worsening thermal properties - because dry air is a worse insulator than any physical blowing agents.
- AHAM studies show that blowing agents DO NOT diffuse out of foamed refrigerators over their lifetime
- Literature examples show the marked difference in thermal drift with only 50% RH moisture.
- Therefore, water vapor seems the predicating factor in k-factor drift.

ⁱ Graves, R.S., McElroy, D.L., Weaver, F.J., and Yarbrough, D.W. January, 1995. "Interlaboratory Comparison on Estimating the Long-Term Thermal Resistance of Unfaced, Rigid, Closed-Cell Polyisocyanurate (PIR) Foam Insulation – a Cooperative Industry/Government Project," ORNL/M-3976.

ⁱⁱ ASTM C1303-07, 2007. "Standard Test Method for Predicting Long-Term Thermal Resistance of Closed-Cell Foam Insulation" West Conshohocken, PA USA

ⁱⁱⁱ CAN/ULC-S770-03. 2003. "Standard Test Method for Determination for Long-Term Thermal Resistance of Closed-Cell Thermal Insulating Foams," *Underwriters Laboratories of Canada*, Ontario, Canada.

^{iv} Baitinger, Dishart, Asgough "Barrier Packaging Technology – A New Approach to the Thermal Aging Problem of Rigid Foam Insulation", 30th Annual Polyurethane Technical /Marketing Conference, pp388-392 (October 15-17, 1986)

^v L. Wentje, AHAM study on regrinding refrigerators, 2006

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.

