foam supplies, inc.

ABSTRACT

TITLE:
Ecomate: Recent Developments of a Proven Thermally Efficient Substitute

AUTHOR(S):
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Ecomate® technology (based on methyl formate) has commercially proven itself, i.e. passed commercial tests and is currently sold in diverse market applications; especially applications which permit no compromise in thermal efficiency and energy consuming properties. Thermal performance is directly related to ecomate's inherent gas lambda value as well as resistance to condensation within the foam matrix. Field and lab trials over the past 5 years have shown thermal efficiency synergies with blends of hydrocarbons and ecomate. These synergies negate the need for costly substitutes to achieve thermal performance.

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Environmental legislation is ever-changing, and will continue to be for the foreseeable future. Current regulations from Montreal and Kyoto Protocols are recently having significant impact on a worldwide basis, causing supply, pricing, and transitional challenges; challenges for which the industry will have to face as phase out deadlines for Article 5 countries come due. Generally speaking, the historical trend has been that each transition has shown thermal efficiency (i.e. insulating capability) inferior to the preceding generation.

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Introduction:
Polyurethanes (PU) have progressed significantly since their inception in the late 1930s. Their versatility in various applications have revolutionized the industry as a whole in so many ways. One of the major PU sectors today is rigid polyurethane foams; these materials are not only economically viable but provide excellent physical properties and, most importantly, excellent insulating capabilities. As advancements were made through the years, various generations of PU foam blowing agents [BAs] have come and gone. The mandates set forth by the Montreal and Kyoto protocols have driven change to protect the environment from harmful substances. As the world moves forward, environmental effects of foam blowing agents are becoming more deeply scrutinized with each succeeding generation.

First Generation [CFCs]
In the beginning, water was the sole blowing agent used for polyurethane foams; the reaction of water and isocyanate generates CO_2, which drove foam expansion. Albeit the use of water to generate CO_2 worked, it wasn't until the inception of trichlorofluoromethane (CFC-11 or R-11), that polyurethane foams became a key player in insulation, especially in refrigeration. This liquid boiled at room temperature [75°F] and was non-toxic, non-corrosive, and non-flammable. And most importantly, this foam blowing agent was more thermally efficient [with a gas Lambda of 8.4 mW/m°K versus 14.7 mW/m°K for CO_2]. It allowed formulators to produce polyurethane foams that were approximately twice as efficient per inch of thickness as any other insulation. For comparison purposes, water blown foams typically had a K-factor of 0.24 BTU-in/hr-°F-ft^2 [or lambda of 34.5 mW/m°K] while those made from CFC-11 were 0.11 BTU-in/hr-°F-ft^2 [or lambda of 15.8 mW/m°K]. This significant energy savings bolstered CFC-11 as the supreme blowing agent for over three decades.

Second Generation [HCFCs]
In the mid-Eighties, **Global Warming** became an issue of concern. It was deemed that R-11 was a contributor to global warming and should be eliminated from use. Two candidates: HCFC-141b and HCFC-123, were offered as potential replacements by the fluorochemical industry. R-123 was subsequently eliminated because it was found to be toxic. R-141b [1,1-dichloro-1-fluoroethane] was the next best alternative. R-141b has a gas lambda of 10 mW/m °K [poorer than CFC-11], and presented a stronger solvency than R-11, which necessitated co-blowing 141b with water; both factors resulted in poorer insulation [lambda] values. The industry subsequently optimized formulas around R141b, and used it in the US for over a decade. Although most of HCFCs have been nearly phased out, Article 5 countries are still permitted to use HCFCs with imposed limits. At the time of writing, the current imposed phase-out deadlines for HCFCs are as follows:

Table 1A: Schedule for non-Article 5 countries phase-out for production and consumption of HCFCs

Schedule	Year
Baseline	1989 HCFC consumption + 2.8% of 1989 consumption
Freeze	1996
35% Reduction (65% of Baseline)	2004
75% Reduction (25% of Baseline)	2010
90% Reduction (10% of Baseline)	2015
Total phase-out	2020
0.5% of baseline restricted to servicing of refrigeration & air-conditioning equipment until 2030	2020-2030

Table 1B: Schedule for Article 5 countries phase-out for production and consumption of HCFCs

Schedule	Year
Baseline	Average of 2009 and 2010
Freeze	2013
10% Reduction (90% of Baseline)	2015
35% Reduction (65% of Baseline)	2020
67.5% Reduction (32.5% of Baseline)	2025
Total phase-out	2030

2.5% of baseline averaged over 10 years (2030-2040) allowed, if necessary, for servicing of refrigeration & air-conditioning equipment until 2040	2030-2040

Third Generation [HFCs]
Ozone Depletion became the cry that marked the fall of the HCFC foam blowing agents, and marked the introduction of the HFCs [134a, 245fa, and 365mfc] into the market in the US. These new HFCs have poorer solubility, and poorer lambda values than did R-141b. HFC-134a [1,1,1,2-tetrafluoroethane] and 245fa [1,1,1,3,3-pentafluoropropane] are gases at room temperature [RT=75°F or 23.9° C].

A patent situation restricted the US to use ONLY 245fa, and the EU to use ONLY 365mfc. [A 93%/7% blend of 365mfc and 227ea was created because 365mfc by itself was flammable]. And when 365mfc supplies became *force majeure* because of production issues, Europe was allowed—for nearly a decade—the use of 245fa. The US was denied 365mfc usage until 2014.

Both these **HFCs have poorer gas lambda values** [lambda 245fa = 12.7mW/m°K; Lambda 365mfc = 10.5 mW/m°K] than 141b [lambda = 10mW/m°K]. In fact, each transition up to this point has shown thermal efficiency [i.e. insulating capability] inferior to the proceeding generation of BAs. Recently, US EPA has recently proposed transitioning out of HFCs by the end of 2016 [1 Jan 2017], while still demanding improved efficiencies and lower energy consumption in each refrigerator or freezer unit produced! Spray foams applications must comply with the transition by 2025. Which HFCs are affected? **HFC -134a, 143a, 245fa, and 365mfc, and blends thereof**, in addition **to Formacels B, TI, Z6** in products manufactured or imported into the US after that date—Further information may be found under Federal Register Vol. 79, No. 151.

Fourth Generation – Blends?
The only thing certain in this world is change! A new challenge for foam blowing agents is its **GWP** [or Global Warming Potential] status. This means that certain BAs [including most all of the HFCs] may contribute to CO_2 concentrations in the atmosphere, thus increasing global warming.

The Montreal and Kyoto Protocols were established to drive efforts to promote the use and production of "cleaner" blowing agents. Their implementation led to setting phase-out schedules [with use-limitations and deadline dates] for chlorine-containing BAs [ozone depleting products, ODPs] and HFCs [global warming products, GWPs]. As a result, these regulations are having an impact on a worldwide basis; triggering supply, pricing, and transitional challenges as phase out deadlines for Article 5 countries are imminent.

Enter a new class of foam blowing agents – the HFOs [or Hydro-Fluoro Olefins]. These are compounds that have unsaturation [carbon to carbon double bonds, or C=C] so that they readily decompose in a matter of days rather than hundreds of years and thus not cause damage to the environment. Though their environmental profile is promising, this ease of decomposition may lead to long-term resin system instability, particularly in spray foams. Table 2 describes these HFOs, in addition to two other existing blowing agents that meet current environmental requirements, all of which are current 4th Generation BA choices.

Table 2: 4th Generation Foam Blowing Agents						
	cC5	ecomate	AFA-L1	Solstice LBA	FEA1100	
Name:	*Cyclopentane*	*Methyl Formate*	*HFO 1233zd[E]*	*HFO 1233zd[E]*	*HFO 1336mzz[Z]*	UNITS
MW:	70	60	130.5	130.5	164	g/mol
Boiling Pt:	49.3	32	19	19	33	°C
Flash Point:	-37	-19	None	None	None	°C
LFL:	1.5	5	None	None	None	Vol%
GWP:	11	< 1.5	< 7	< 7	5	100 yr
MIR:	2.39	0.06	0.04	0.04	0.04	Ethane = 0.28 g O VOC
PEL:	600	100	300	300	500	ppm
Gas Lambda:	11	10.7	10	10	10.7	mW/m°K
sp. gravity:	0.75	0.982	1.27	1.27	1.356	g/l

There is no "perfect" blowing agent. There never has been, nor will there ever be one! Each has its merits and its shortcomings. Each has allowed the polyurethane industry to grow, by **optimization** of formulation for the BA then being used. The advantages / disadvantages of each follow:

Ecomate:

- **ADVANTAGES**:
  1. Liquid at room temperature;
  2. Lowest MW [so less needed to produce equivalent densities]
  3. Low toxicity;
  4. NO ODP, GWP, SMOG
  5. No flammability load to urethane systems;
  6. Excellent thermal properties
  7. Shows thermal synergy with all other BAs, especially HFOs;
- **DISADVANTAGES**:
  1. Is Flammable in NEAT form, but not in blends with PU raw materials;
  2. Is a strong solvent

HFO 1233zd(E):

- **ADVANTAGES:**
  1. Non-flammable;
  2. Low GWP:
  3. No Smog issues with Atmospheric life of 26 days;
  4. Good Thermal properties exhibited;
  5. Moderate solubility so can use with a broad range of plastics.
  6. Two manufacturers
- **POTENTIAL DISADVANTAGES**:
  1. Marginal Liquid at RT [BP 19°C];
  2. Double the MW of ecomate, and
  3. Has 3 Fluorine atoms, so moderate economics;
  4. Unsaturation may be a stability issue.
  5. Need for specialty catalysts, as conventional catalysts [e.g. PMDETA] are reported to be unstable in resin system.

HFO 1336mzz(Z):

- **ADVANTAGES:**
  1. Good thermal properties;
  2. True liquid [BP = 33°C];
  3. Not Flammable;
  4. No smog issues [MIR 0.04],
  5. Moderate solubility so it may be used with wide range of plastics;
  6. Azeotropic thermal advantages with blends shown
- **POTENTIAL DISADVANTAGES:**
  1. With the highest MW [=164 g/mol] and 6 Fluorine atoms, may be economically challenged;
  2. Unsaturation may be a stability issue.

Cyclopentane:

- **ADVANTAGES**:
  1. Liquid at room temperature;
  2. low MW;
  3. low toxicity;
  4. shows thermal synergy with HFOs;
- **DISADVANTAGES:**
  1. IS VERY FLAMMABLE;
  2. Flammability load transfers to foams made with it;
  3. SMOG producer;
  4. Worst GWP on list;
  5. poorest insulation potential [worst gas lambda].

Formulators will have access to all of the BAs mentioned above. With their attributes [both high MW and high F content], neat HFOs may be cost prohibitive. We believe that blends will be the future. Why? Because blend optimization will allow the opportunity for improved economics, improved physical properties, and most importantly [because of recently seen thermal synergies], improved thermal properties over neat HFOs.

Ecomate® is a blowing agent technology based on methyl formate which allows this otherwise strong solvent to be successfully used in foaming processes. It has been commercially proven [i.e. passed commercial tests] and is currently sold in diverse market applications; especially applications which permit no compromise in thermal efficiency and energy consuming properties. Among other things, a foam’s thermal properties are based upon the blowing agent's **gas lambda value**, its **resistance to diffusion** from the foam, and its **resistance to condensation** in the foam at low temperatures.

Ecomate's thermal performance is directly related to its inherent low gas lambda value [**10.7 mW/m°K]**, as well as its resistance to condensation within the foam matrix. This resistance is critical, because if ecomate were to condense at low temperatures, the insulation capabilities would be seriously diminished [i.e., there would be a flattening in the slope of the k-factor curve with a lowering in temperature].

The data shown in **Table 3A** was generated from an ecomate blown foam [eco4-90-1.7-SP] whose thermal properties [the data above -4°F] were measured initially on a Netzsch HFM436 Lambda machine. The samples were then carefully wrapped and sent to obtain the lower temperature data values on a LaserComp FOX 200LT instrument. The data obtained [Tables 3A & 3B] is graphed in Figures 1 & 2. Note that the break in the data at -4°F is a result of an overnight shipment. The linearity of the data proves that there is **no condensation of the blowing agent** [ecomate] in the foam as the temperature is lowered.

Table 3A: INITIAL DATA on NETZSCH THERMAL CONDUCTIVITY UNIT

Temperature (°F)	Netzsch K-factor (BTU-in/hr-ft
75	0.1708
65	0.1667
55	0.1632
45	0.1598
35	0.1569
25	0.1522
15	0.1473
5	0.1439
-4	0.1405

Table 3B: ONE DAY OLD DATA from LaserComp FOX 200LT THERMAL CONDUCTIVITY UNIT

Temperature (°F)	K-factor [LaserComp Fox200LT] (BTU-in/hr-ft
-4	0.1455
-40	0.1335
-76	0.1213
-121	0.1064

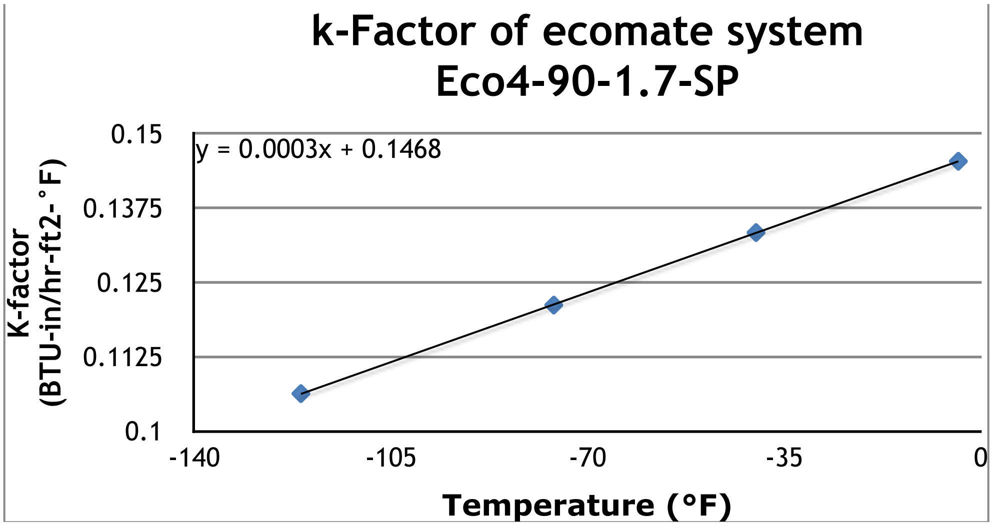

Figure 1: LaserComp FOX 200LT data on eco4-90-1.7-SP at temperatures below -4˚F.

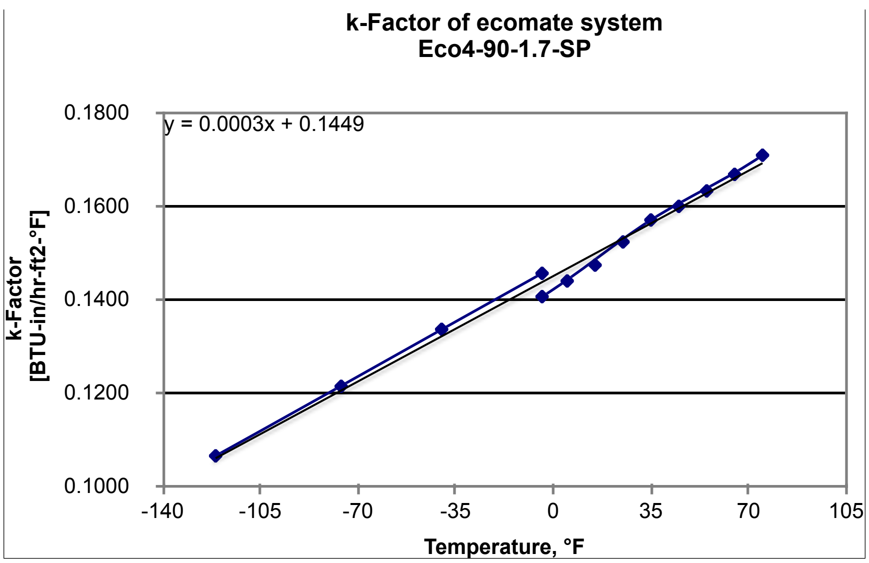

Figure 2: Combined Data - LaserComp FOX 200LT data at lower temperatures & Initial Netzsch data at higher temps - Both showing similar slopes, indicating NO condensation.

Ecomate, despite its low MW, does **not** evaporate out of the foam more rapidly than other BAs over time. The following case study documents its retention in the foam:

Case Study: Aged Soft Drink Dispensers with exposed foam
Soft drink dispensers *with exposed foam skins* were tested using an Ice Melt Method according to industry standards.

The method: one gallon plastic jugs were filled with equal amounts of tap water and then frozen. Lids for the dispensers were constructed from identical pieces of extruded polystyrene to make the test consistent between units. A jug of ice was placed in each unit and the lid placed on top. At 24 hour intervals any water was poured off each jug and the jug was reweighed to calculate the melt. All units were tested at 75°F ambient to simulate a convenience store atmosphere.

Test: identical units were constructed and tested using foam systems blown with different blowing agents. The test units were foamed using an ecomate system against a control - the manufacturer's current HFC-134a system. The test was designed to measure both the difference in insulation value when made and after multiple years in the field.

Results: **after 5+ years in storage**, the unit foamed with ecomate showed a negligible 0.5% more loss of insulation value over time than the 134a control. Neither unit exhibited a change in physical dimensions greater than 1%. Thus **the results are identical**.

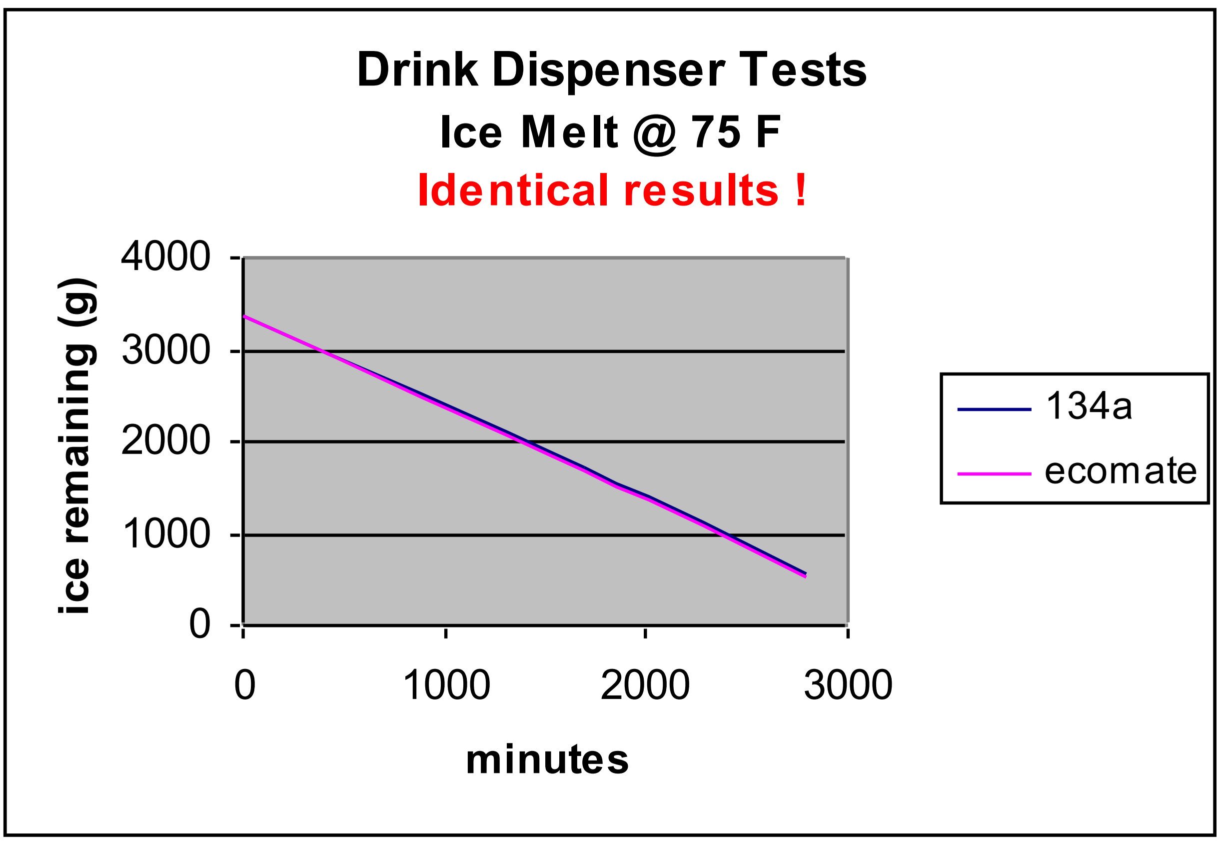

Figure 3: Drink dispenser Tests - showing identical ability of ecomate & HFC-134a to keep ice frozen over a two day period after the similar dispensers being stored for 5+ years at Room Tempeerature.

OUTLOOK FOR THE FUTURE

Synergy of BA Blends with ecomate

Laboratory and field trials run over the past 5 years with blends of hydrocarbons and ecomate have shown synergies of thermal efficiency over the respective BAs run alone. Compared to hydrocarbon blends, those containing ecomate should improve solubility, have less flammability risk, and provide no smog issues. Why? Ecomate has very good solubility for all raw materials used to make foams. Ecomate is less flammable because it has a higher flash point than the pentane materials, a higher LFL, and a lower heat of combustion. Ecomate has a negligible GWP [Global Warming Potential] and is non-smog producing [having an extremely low MIR].

Work completed by Foam Supplies with ecomate blends suggest that thermal values superior to those above can be obtained without the need of an HFO. These data have been obtained from actual laminate board production [on three individual industrial laminator lines]. Using an ecomate/HC blend, we were able to obtain **19.3 mW/m°K at 23.9^{0}C** and **16.9 mW/m°K at -6.7^{0}C**. This blend is flammable, but laminator or refrigeration lines already geared for pentanes are prepared to address flammability. We have burned these panels in our Mini-Tunnel and have obtained estimated ASTM E-84 values of 25 Flame Spread and low smoke index values [<200].

Recent studies **with ecomate and HFOs**, run by Foam Supplies and others, have demonstrated that **thermal synergies exist here** as well. For instance: In a recent paper, DuPont [HFO-1336mzz-Z, or FEA-1100] described work with an ecomate / FEA-1100 blend demonstrating improved flammability and thermal conductivity. The ecomate blend developed the best thermal properties [**19.7 mW/m°K at 23.9^{0}C**]. These great values should become even better with formulation optimization.

Ecomate / HFO <u>blends</u> provide a lower average molecular weight; and since blowing agents are generally used on a molar basis, fewer quantities of HFO is required to achieve comparable densities, thus directly improving formulation economics**. Ecomate carries no environmental footprint** [It has zero ODP, very low GWP, and it is not a smog producer as are the pentanes]. **Ecomate improves solubility of the blend**. In addition, previous studies have proven that **ecomate adds no fire burden** [does not require extra fire retardant to achieve desired flammability]. These new HFO / ecomate blends are expected to become commercial in the future.

CONCLUSIONS:

Blends have long been used to improve foam properties: because there is no perfect Blowing Agent, and each subsequent generation BA has shown poorer gas lambda values.

Blends may be necessary to improve HFO economics.

Ecomate seems well suited to be used in these blends, demonstrating: Excellent thermal synergies, no condensation as low as -121 °F [-85 °C], low gas diffusion rates over a 5+ year period, little environmental impact, improved solubility in all PU raw materials, favorable economics, with no flammability load.

Blends of HFOs / ecomate show **synergetic** thermal improvements, help **improve economics,** and are **environmentally friendly.** <u>Blowing agent blends</u> have truly become the new norm.

Ecomate®: Recent Developments

Foam Supplies, Inc.

Raul Dacomba, John Murphy

Outline

- **Introduction**
- **Brief History of BAs**
  - 1st, 2nd, 3rd Generations
  - Current phase-out schedules
- **4th Generation Candidates**
  - Advantages / Disadvantages
- **The Future** – Blends
- **Conclusions**

Brief History

- **1st Generation** - CFCs
  - CFC-11
    - Excellent insulation – **Gas Lambda 8.4 mW/mK**
    - Banned after 3 decades - High ODP
- **2nd Generation** – HCFCs
  - HCFC-141b
    - Stronger solvent – initially harder to use
    - Poorer insulation – **Gas Lambda 10 mW/mK**
    - Phase out schedules – Still contain Chlorine, ODP concerns

Brief History

- **3rd Generation - HFCs & ecomate**
  - HFC-134a – Gas, poorer Lambda [**13.7 mW/mK**]
  - HFC-245fa – Gas, Poorer Lambda [**12.7 mW/mK**]
  - HFC-365mfc – Liquid, Good Lambda [**10.5 mW/mK**] – Restricted in US 'til 2014
  - **Phase out imminent** – GWP issues
    - US EPA proposed complete phase out by Jan 1st, 2017
    - Pending approval
  - **Ecomate**– Liquid, Good Lambda [**10.7 mW/mK**]
    - Commercially available since 2003

4^{th} Generation BAs

	cC5	ecomate	AFA-L1	Solstice LBA	FEA1100	
Name:	Cyclopentane	Methyl Formate	HFO 1233zd[E]	HFO 1233zd[E]	HFO 1336mzz[Z]	UNITS
MW:	70	60	130.5	130.5	164	g/mol
Boiling Pt:	49.3	32	19	19	33	˚C
Flash Point:	-37	-19	None	None	None	˚C
LFL:	1.5	5	None	None	None	Vol%
GWP:	11	< 1.5	< 7	< 7	5	100 yr
MIR:	2.39	0.06	0.04	0.04	0.04	Ethane = 0.28 g O
PEL:	600	100	300	300	500	ppm
Gas Lambda:	11	10.7	10	10	10.7	mW/m˚K
sp. gravity:	0.75	0.982	1.27	1.27	1.356	g/l

4th Generation BAs

	cC5	ecomate	AFA-L1	Solstice LBA	FEA1100	
Name:	Cyclopentane	Methyl Formate	HFO 1233zd[E]	HFO 1233zd[E]	HFO 1336mzz[Z]	UNITS
MW:	70	60	130.5	130.5	164	g/mol
Boiling Pt:	49.3	32	19	19	33	°C
Flash Point:	-37	-19	None	None	None	°C
LFL:	1.5	5	None	None	None	Vol%
GWP:	11	< 1.5	< 7	< 7	5	100 yr
MIR:	2.39	0.06	0.04	0.04	0.04	Ethane = 0.28 g O
PEL:	600	100	300	300	500	ppm
Gas Lambda:	11	10.7	10	10	10.7	mW/m°K
sp. gravity:	0.75	0.982	1.27	1.27	1.356	g/l

4th Generation BAs

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LFL:	1.5	5	None	None	None	Vol%
GWP:	11	< 1.5	< 7	< 7	5	100 yr
MIR:	2.39	0.06	0.04	0.04	0.04	Ethane = 0.28 g O
PEL:	600	100	300	300	500	ppm
Gas Lambda:	11	10.7	10	10	10.7	mW/m˚K
sp. gravity:	0.75	0.982	1.27	1.27	1.356	g/l

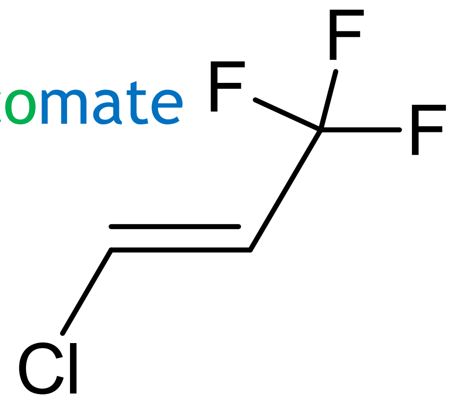
4th Generation BAs

	cC5	ecomate	AFA-L1	Solstice LBA	FEA1100	
Name:	Cyclopentane	Methyl Formate	HFO 1233zd[E]	HFO 1233zd[E]	HFO 1336mzz[Z]	UNITS
MW:	70	60	130.5	130.5	164	g/mol
Boiling Pt:	49.3	32	19	19	33	˚C
Flash Point:	-37	-19	None	None	None	˚C
LFL:	1.5	5	None	None	None	Vol%
GWP:	11	< 1.5	< 7	< 7	5	100 yr
MIR:	2.39	0.06	0.04	0.04	0.04	Ethane = 0.28 g O
PEL:	600	100	300	300	500	ppm
Gas Lambda:	11	10.7	10	10	10.7	mW/m˚K
sp. gravity:	0.75	0.982	1.27	1.27	1.356	g/l

HFO 1233zd[E] – AFA-11 & Solstice LBA

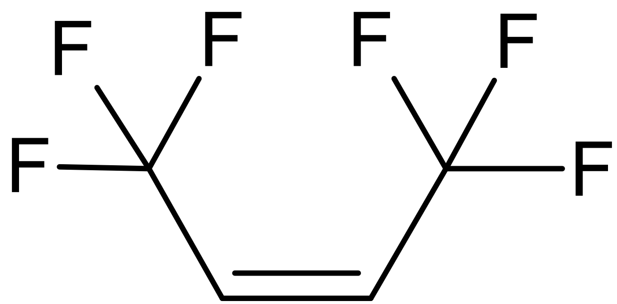
- **ADVANTAGES**
  - Non-flammable
  - Low GWP: <7
  - No Smog Issues
  - Good Thermal Props
  - Moderate Solubility
  - 2 Manufacturers
  - Thermal synergy with ecomate

- **DISADVANTAGES**
  - Marginal Liquid: BP 19°C
  - 2x MW of ecomate
  - 3Fs – compromised economics
  - Reported stability issues
  - Specialty/new catalysts required



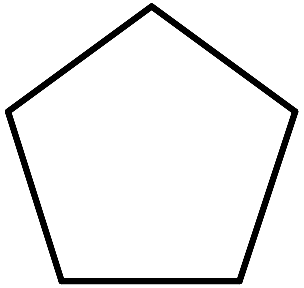
HFO-1336mzz[Z] – FEA1100

- **ADVANTAGES**
  - True Liquid: BP 33°C
  - Good Thermal Props
  - Non-Flammable
  - No Smog issues [MIR=0.04]
  - Moderate Solubility
  - Azeotropic Advantages
- **DISADVANTAGES**
  - Highest MW [164 g/mol]
  - 6Fs – higher costs
  - Formulation challenges



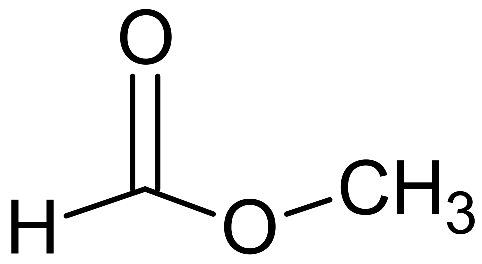
Hydrocarbons

- **ADVANTAGES**
  - Liquid: BP 49.3°C
  - Lower MWs [70-72 g/mol]
  - Low Toxicity
  - Established technology
  - Thermal Synergy with ecomate
- **DISADVANTAGES**
  - VERY Flammable / Explosive
  - Flammability transfers to foams
  - SMOG producer: MIR=2.39
  - Worst GWP on List
  - Poorest Lambda [11-13 mW/mK]



ecomate

- **ADVANTAGES**
  - Liquid: BP 32°C
  - Lowest MW [60 g/mol]
  - No Toxic Concerns
  - Good Lambda 10.7mW/mK
  - Thermal Synergy w/ HFOs
  - Commercially sold since 2003
- **DISADVANTAGES**
  - A Strong Solvent
  - Flammable Neat; Not in Blends

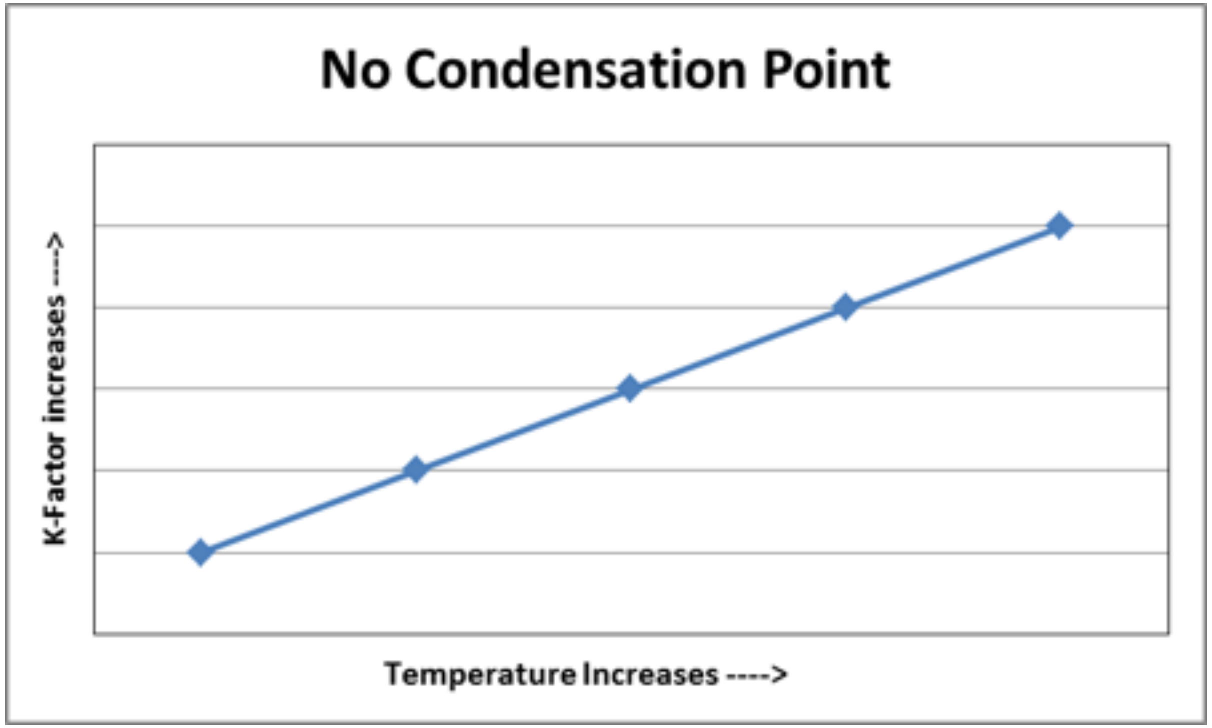


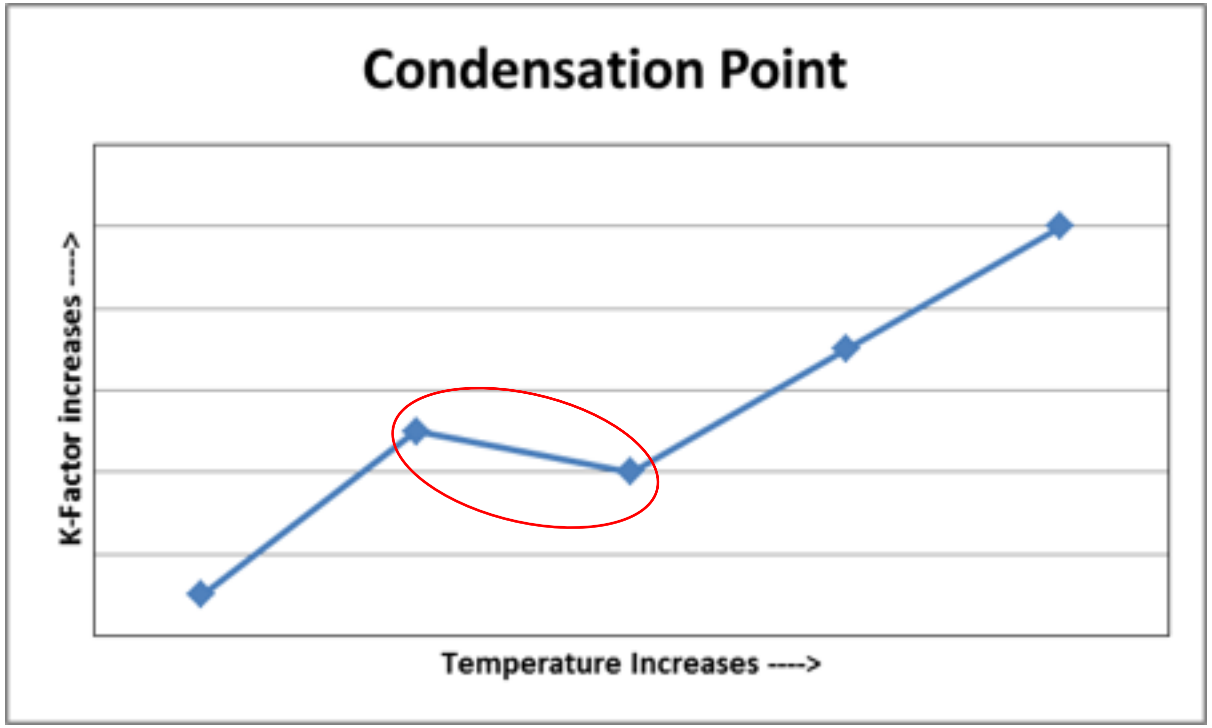
Foam Thermal Properties
required of any foam BA

- BASED UPON (among other things):
  - **LOW LAMBDA BA**
    - Necessary for superior thermal properties
  - **RESISTANCE TO CONDENSATION**
    - Necessary for Low temperature use
  - **RESISTANCE TO DIFFUSION**
    - Necessary for long term performance

- **All candidates have low LAMBDA** [between 10 – 11 mW/mK]

Determining Blowing Agent Condensation Point





Resistance to Condensation

- Measured on an ecomate **blown foam**
    - **eco4-90-1.7SP** – a 90-second gel pour foam with 1.7 pcf (27.2 kg/m^3) density
- Used 2 Heat Flow meters:
    - Netzsch HFM436 Lambda [to -20°C]
    - LaserComp Fox 200LT [to -85°C]

Resistance to Condensation

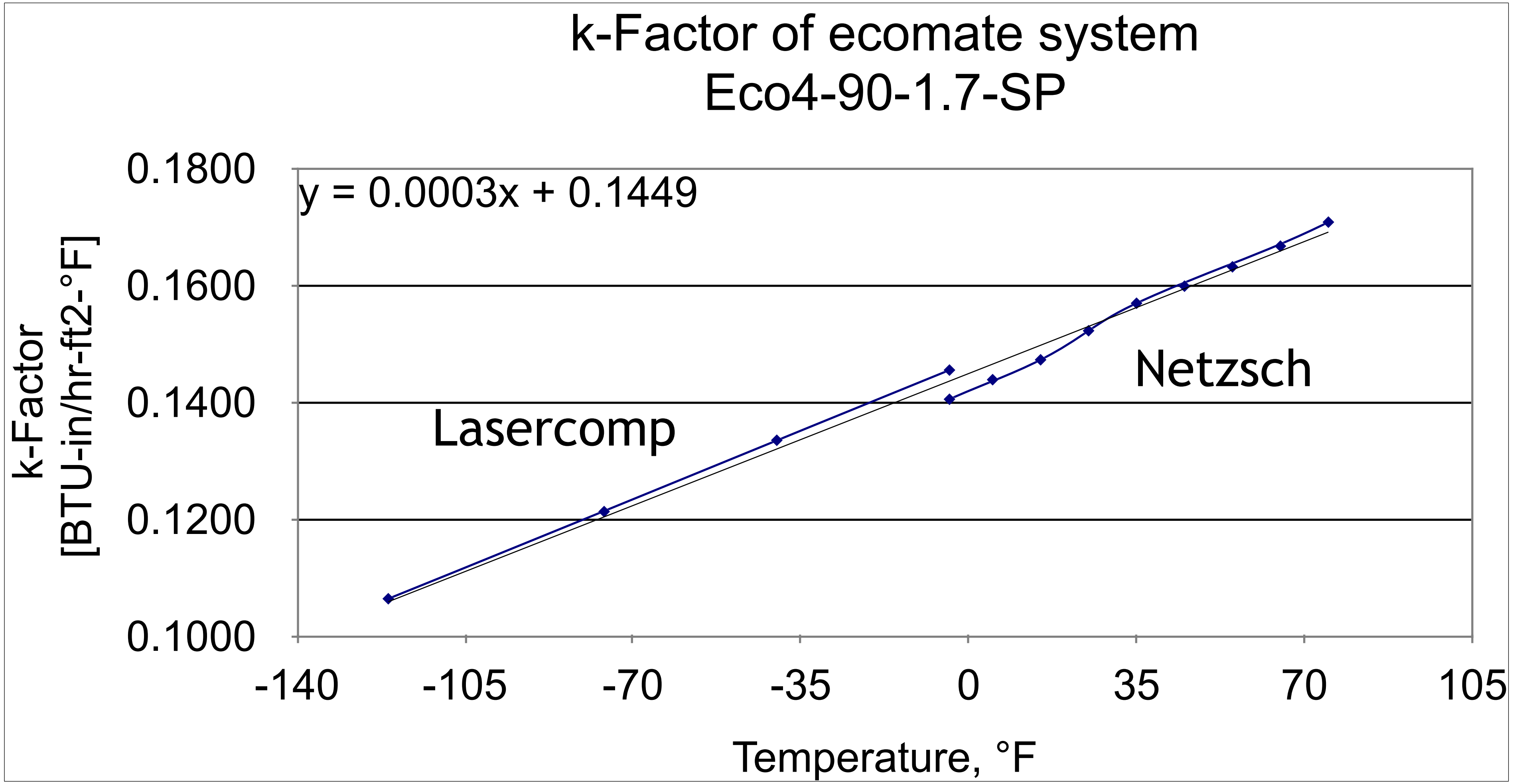
NETZSCH HFM436 Data:

TEMP °C	Temp °F	K-FACTOR
23.9	75	0.1708
18.3	65	0.1667
12.8	55	0.1632
7.2	45	0.1598
1.7	35	0.1569
3.9	25	0.1522
-9.4	15	0.1473
-15.0	5	0.1439
-20.0	-4	0.1405

LASERCOMP FOX200LT

TEMP °C	Temp °F	K-FACTOR
-20.0	-4	0.1455
-40.0	-40	0.1335
-60.0	-76	0.1213
-85.0	-121	0.1064

Resistance to Condensation



FOAM THERMAL PROPERTIES

required of any foam BA

- BASED UPON (among other things):
  - **LOW LAMBDA BA**
    - Necessary for superior thermal properties
  - **RESISTANCE TO CONDENSATION**
    - Necessary for Low temperature use
  - **RESISTANCE TO DIFFUSION**
    - Necessary for long term performance

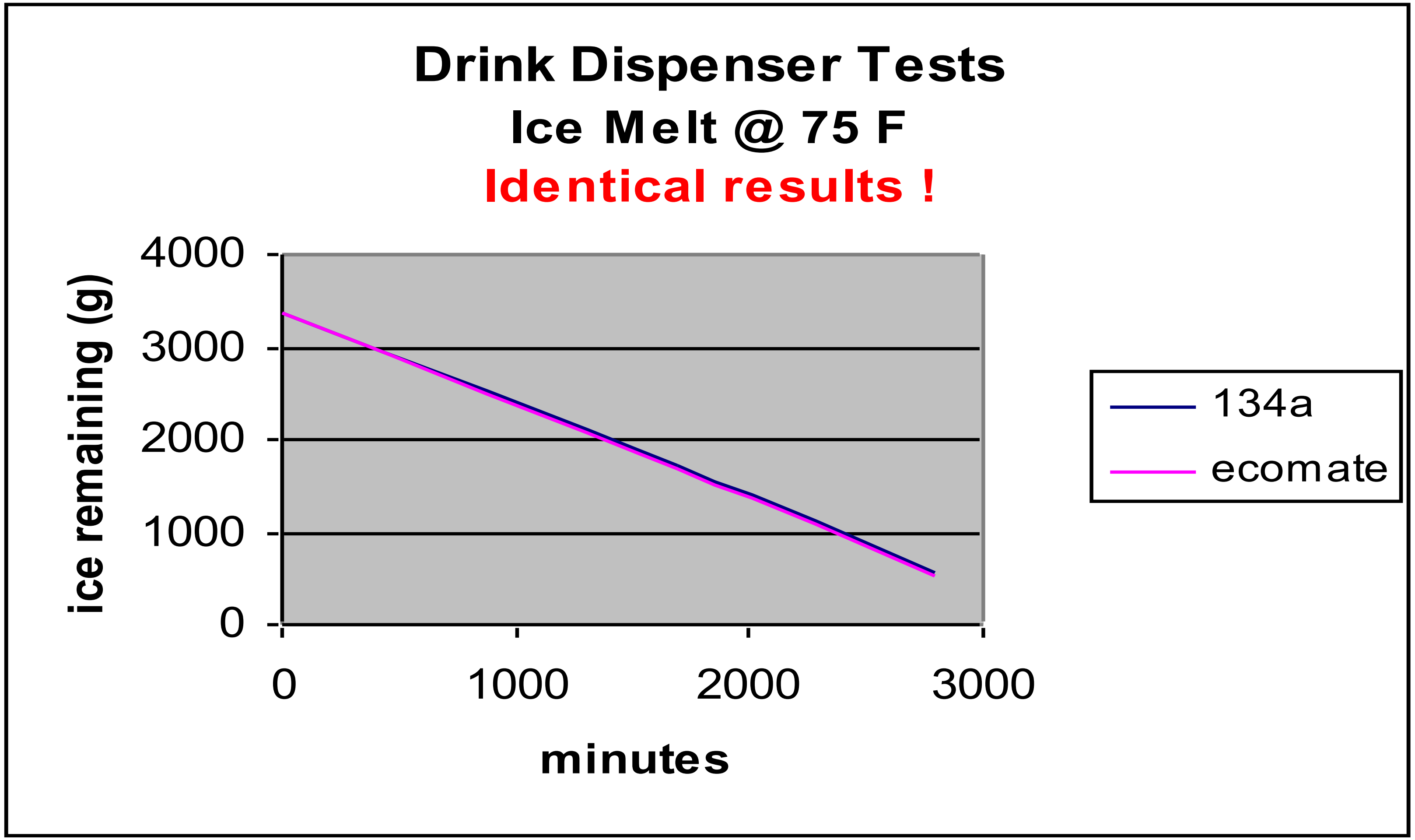
- **All candidates have low LAMBDA** [between 10 – 11 mW/mK]

- **No Condensation with ecomate to temperatures as low as -85°C**

Resistance to Diffusion

- Does ecomate evaporate out of foam faster than other BAs over time?
- Identical Drink Dispensers
  - **HFC-134a vs ecomate blown**
  - Exposed foam skins
  - Aged 5+ years in warehouse
  - Measured Ice Melt with time @ 75˚F Ambient

Resistance to Diffusion



FOAM THERMAL PROPERTIES
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- **All candidates have low LAMBDA** [between 10 - 11 mW/mK]
- **No Condensation with ecomate to temperatures as low as -85°C**
- **Ecomate diffusion rate identical to 134a**

OUTLOOK FOR THE FUTURE:

Continued proliferation of ecomate systems in EU and worldwide; commercially available since 2003.

High Performance Applications

- Thermal Synergy thru Blowing Agent blends.
  - Cost mitigation using ecomate
  - Improved Foam Lambdas

CONCLUSIONS:

Ecomate is the best choice for use in blends, because it has demonstrated:

- Excellent **thermal synergies**
- **No condensation** as low as -85 °C
- **Low gas diffusion** rates over a 5+ year period
- **No environmental footprint**
- **Improved solubility** in all PU raws
- **Favorable economics**
- **No flammability load** transferred to foams

IN CLOSING:

Blends of HFOs / ecomate

- Show synergetic thermal improvements
- Improve economics
- Are environmentally friendly

Thank you for your time.

www.foamsupplies.com

www.ecomatesystems.com