Household Refrigerator:
Low GWP Blowing Agent Performance Update

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ABSTRACT

Reported to the industry in 2010, the low climate change impact refrigerators built in 2009, utilizing HBA2 blowing agent, exhibited 1.5 – 2.0% energy efficiency improvement, compared to baseline HFC-245fa.. This current study builds on the initial work with an optimized HBA2 formulation that demonstrates energy efficiency improvement exceeding 6% compared to HFC-245fa baseline, exceeds the current DOE Energy Star label by 9.5%., continuing to define the application and performance more broadly across the appliance industry. HBA2, in this commercial household refrigerator/freezer platform exceeded the proposed DOE 2014 energy standard.

As with all new materials, prior to adoption, the industry requires an understanding of factors beyond the initial polyurethane performance characterization. These analyses include quality measures such as dimensional stability and adhesion to liner and exterior case. In all ancillary assessment related to a household refrigerator/freezer, met or exceeded all requirements.

HBA2 regulatory approvals are in process in major markets, encompassing excellent properties of ultra low GWP (GWP = 7), non flammability, and anticipated to be non-VOC Commercial manufacture of HBA2 is estimated by 2013.

DEVELOPMENT SUMMARY

A key raw material in the production of high performance, rigid polyurethane insulation foam is the blowing agent. Although many blowing agent technologies are available to the foam formulation chemist, the use of fluorocarbon blowing agents has historically resulted in foams with the highest insulation performance, best physical properties, safest and simplest processing characteristics, and best value in use. The use of fluorocarbon blowing agents began as early as the mid-1950s with the introduction of trichlorofluoromethane, or 11. This blowing agent became the industry standard until the mid 1990s, when concerns over ozone depletion led to the development of a second generation of high performance foam blowing agents, the HCFCs. For the rigid polyurethane foam industry, the most commonly used HCFC was 1,1-dichloro-1-fluoroethane, or 141b. Although conversion to HCFC-141b reduced the ozone depletion potential of the blowing agent by 90%, subsequent regulation required that these HCFC blowing agents also be phased out and a third generation of high performance blowing agents was developed, the HFCs. The most commonly used HFC blowing agent in rigid polyurethane foam is 1,1,1,3,3-pentafluoropropane, or 245fa. This material satisfied the requirements of ozone depletion regulation while, at the same time, retained the high performance and non-flammability required in many foam applications. In many parts of the world, conversion from HCFC technology to HFC technology is complete while, in certain other regions, this conversion is now occurring.

In recent years, concern over climate change is driving the development of a fourth-generation fluorocarbon, one that meets the requirements of both ozone depletion and climate change regulations, current and anticipated. Honeywell, formerly AlliedSignal, has been the leader in the development of fluorocarbon blowing agents and is now leading the development of this fourth-generation fluorocarbon technology. Honeywell has developed two such fourth generation products: HFO-1234ze(E), a gaseous blowing agent; and a proprietary liquid blowing agent called HBA2. Both products successfully incorporate required environmental properties, while maintaining the non-flammability, non-VOC, and high performance characteristics that have differentiated fluorocarbon blowing agents as the best choice for high performance rigid foam insulation applications. These two fourth-generation blowing agents are also ideal for those applications where a flammable blowing agent is unsafe, too costly to use, or fails to provide the desired foam performance. These new high performance materials, while they contain fluorine, also contain an olefin structure, and are therefore referred to as haloalkenes. Because of the presence of a double bond in the molecule backbone, these haloalkenes are a separate and distinct class of materials from their predecessor HFC materials, resulting in a much shorter atmospheric lifetime than their predecessor fluorocarbons, thereby resulting in a much lower global warming potential, or GWP.

ENVIRONMENTAL and REGULATORY STATUS

Although current activity is limited, the United States government is considering various approaches to address climate change, particularly regulatory-driven changes., which while still too early to predict the final structure and language, will in all probability impact high global warming potential materials to some degree. In anticipation of these regulations, and in response to similar regulatory initiatives globally, industry is preparing solutions to meet current and future climate change regulations. Honeywell counts among this group of industries with its low GWP development program, including, in addition to blowing agents, refrigerant gases and other fluorochemicals.

The European Parliament and the Council of the European Union have committed the Community and its Member States adoption of the Kyoto Protocol in reducing anthropogenic emissions of greenhouse gases listed in Annex A to the Kyoto Protocol by 8% compared to 1990 levels in the period from 2008 to 2012.

To this end, the F-Gas Regulation as outlined in (EC) No 842/2006 (OJEC L161 of 14.06.2006) prohibits the use of fluorinated greenhouse gases with a 100-year GWP of 150 or greater, which include certain HFCs (hydrofluorocarbons), PFCs (perfluorocarbons), and SF_6 (sulfur hexafluoride) as listed in Annex I (EC 842/2006). The EU F-Gas Regulation will be reviewed in 2011, which may result in additional use restrictions for high GWP fluids (Article 10, F-Gas Regulation).

Honeywell's 1234ze(E) and HBA2 are both in full compliance with the EU F-Gas regulation, with respect to two matters: (1) they are not listed in Annex I as a fluorinated greenhouse gas, and therefore not covered by the provisions of the F-Gas regulation, and (2) the GWP of these materials is more than an order of magnitude less than 150. Since the purpose and intent of the EU F-Gas Regulation is to control emissions of high GWP materials, 1234ze(E), with a GWP of 6, and HBA2, with a GWP of 7, are in the same GWP range as many other blowing agents that are considered acceptable, such as hydrocarbons. Therefore, these materials are a solution to global-warming-potential issues facing the industry.

Japan has made voluntary Kyoto Protocol commitments to reduce or limit emissions of greenhouse gases, though has not formally promulgated domestic regulations to enforce these commitments. 1234ze(E) and HBA2 can play an important role in meeting these voluntary commitments.

It is anticipated that, as climate change regulations are developed in other countries, these regulations will contain GWP limits similar to those being promulgated in Europe and, voluntarily, in Japan. 1234ze(E) and HBA2 will, in all likelihood, meet or exceed the requirements of these regulations and will therefore be an integral part of any GWP reduction strategy.

Low GWP materials, because of their very short atmospheric lifetime, often prove to be volatile organic compounds (VOCs), contributing to ground level ozone formation. The measure that characterizes whether a chemical is a VOC is the Maximum Incremental Reactivity (MIR). This measure (MIR) at which chemicals are generally considered to be a VOC, by US regulation, is that of ethane. The MIR of both 1234ze(E)and HBA2 has been measured at less than the value for ethane, hence are expected to be classified as VOC-exempt in the U.S. (Carter, W. P L., 2009). The European Union uses a somewhat different measure to characterize propensity for ground level ozone formation -- photochemical ozone creation potential (POCP) -- which is reported, and compared to ethane, which has a POCP of 12.3 (Nielsen, University of Copenhagen). 1234ze(E) has a measured POCP of 6.4, well below that of ethane. The POCP of HBA2 is also estimated to be in this range.

PRODUCT REGISTRATION STATUS

In the United States, commercialization of new materials requires U. S. Environmental Protection Agency (EPA) compliance with Section 612 of the Clean Air Act (CAA). Toxicology data is submitted to the EPA, together with an application for a Pre Manufacturing Notification (PMN). Approval of the PMN, includes the material's listing on the Toxic Substances Control Act (TSCA) inventory. Further, materials to be used as blowing agents or in certain other applications must have listing as an acceptable substitute for ozone depleting substances under the Significant New Alternatives Program (SNAP). PMN approval and listing on the TSCA inventory is a requirement for all new chemical materials. SNAP listing is a requirement for all materials in applications that have historically used chlorofluorocarbons (CFC). Upon completion of these regulatory requirements, new materials can be commercialized in the United States. Additionally, these materials may be regulated at the federal, state, or local levels to comply with volatile organic compound (VOC) regulations. 1234ze(E) has completed both the PMN and SNAP process and is now approved for commercial sale in the United States. For HBA2, filing for SNAP and PMN has been completed and is currently under U.S. EPA review.

In the European Union, REACH [Registration, Evaluation, Authorization and Restriction of Chemicals, (EC) 1907/2006] regulation has, effective June 1, 2008, replaced the notification provisions of directive 67/548/EEC. Under REACH, each manufacturer or importer of a substance over 1 metric ton per year is obliged to submit a registration file, including a chemical safety assessment for volumes greater than 10 tons. For volumes over 100 and 1000 metric tons, additional data must be submitted. Moreover, for these volume bands, the registrant must submit proposals for animal tests needed to obtain certain (eco) toxicological data points. The goal of the latter provision is to prevent, as much as possible, (duplication of) animal tests. In many cases, waivers for such tests can be proposed. The registration should indicate the intended uses for which the substance is notified. Use outside these registered uses is prohibited, unless a downstream user submits a separate registration file for that use. 1234ze(E) has been notified under REACH at the >1,000 metric ton level.. REACH Registration of HBA2 is in progress.

For Japan, the requirements for commercialization of new chemicals requires submission of toxicological and environmental data to the Japanese Ministry of Health, Labor and Welfare (MHLW), the Ministry of Economy, Trade and Industry (METI), and the Ministry of the Environment (ME) for compliance with the Chemical Substances Control Law. 1234ze(E) and HBA2 registration in Japan is complete, allowing for commercial sales in Japan.

Other regions of the world, individually, have requirements for toxicology assessment and environmental impact assessment prior to commercialization of new materials. Honeywell is committed to obtaining the necessary regulatory clearances for sampling and eventual sales of both 1234ze(E) and HBA2 globally. This registration process is in progress for both 1234ze(E) and HBA2 in several countries, including China, South Korea, Australia, Canada, and others.

TOXICITY ASSESSMENT

At the writing of this paper, Honeywell has made significant progress towards completing risk assessment for use and commercialization of HBA2, as might be anticipated by the U.S EPA SNAP and PMN submissions, as well as the EU notification level discussed earlier.

BLOWING AGENT PROPERTIES

Table 1 lists the properties of low GWP blowing agent compared to 245fa and other commonly used blowing agents. Note that HBA2 blowing agent exhibits certain key physical properties, such as boiling point and flammability, similar to HFC-245fa and superior to those of cyclopentane. Note that the global warming potential (GWP) of HBA2 is 7, and is more than two orders of magnitude lower than that of currently utilized HFCs, and is more than one order of magnitude lower than the present limitations in the EU F-Gas Regulation.

Beyond the excellent insulation performance that 1234ze(E) and HBA2 imparts to polyurethane foam, it is distinctly different from hydrocarbon blowing agents in flammability characterization. 1234ze(E) and HBA2 shipment, storage, handling, and processing does not require flammability risk mitigation, as is the case with flammable blowing agents such as cyclopentane. HBA2 is nonflammable by ASTM E-681 test method and has no limitation on hazards classification. HBA2 is further distinguished from cyclopentane and other hydrocarbon blowing agents by the low potential to contribute to ground level smog formation, and is anticipated to be classified as a non-volatile organic compounds (VOC). Flammability and VOC mitigation may contribute significantly to the OEM's cost of adoption and use and in some cases, such as spray foam, prohibit their use due to safety considerations.

Table 1. Liquid Blowing Agent Comparative Properties

Property	HBA2	245fa	Cyclopentane
Molecular Weight	< 134	134	70
Boiling Point			
ºC	245fa < T_{BP} < 141b	15.3	49.3
ºF	245fa < T_{BP} < 141b	59.5	120.7
Flashpoint			
°C	None	None	- 7
ºF	None	None	19
LFL/UFL (Vol % in air)	None	None	1.5 – 8.7
GWP, 100 yr[1]	7	1030	11[2]
PEL[3]	ND	300	600

1) 2007 Technical Summary. Climate Change 2007. The Physical Science Basis. Contribution of working Group 1 to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. (Except where noted)
2) Generally accepted value
3) Manufacturers' literature, except where noted

LOW CLIMATE CHANGE IMPACT HOUSEHOLD REFRIGERATOR / FREEZER

Honeywell has reported in various papers and proceedings on the commercial development of LGWP blowing agents in the various polyurethane (PUR) applications, including appliance foams. PUR foam properties of thermal conductivity (also known as lambda or k-factor), compressive strength, and dimensional stability derived from characterization of hand mix foams or foam panels prepared by means of a high pressure foam machine have evidenced efficacy in comparison to 245fa foams. This type of effort to develop baseline data is necessary to estimate the performance in the commercial manufacture of refrigerators, refrigerator/freezers, and freezers. However, until commercial refrigerator product has been manufactured under industrial conditions, and assessed for energy performance and ancillary performance, for example, liner compatibility, adhesion to liner and metal cabinet and doors, freeze stability, and other quality aspects, an OEM cannot make a prudent decision that a commercially viable, 'real world' solution is available.

Honeywell reported in the Polyurethanes 2010 Technical Conference the performance of household refrigerators/freezers manufactured utilizing HBA2 blowing agent, compared to baseline 245fa blowing agent in the same refrigerator platform. Further assessment has been performed utilizing an HBA2 appliance polyurethane system optimized for thermal conductivity, for which the resulting assessment will be discussed and contrasted to the prior reported data. To that end, a full scale trial, utilizing Honeywell HBA2 blowing agent, with an optimized polyurethane system, in a commercially available 623 liter (22 ft^3) household refrigerator/freezer [bottom freezer, counter-depth platform] was undertaken. These thirty refrigerator cabinets, with associated door sets, were foamed to investigate:

- Lambda (k-factor) performance in various locations of the refrigerator
- Liner compatibility with High Impact Polystyrene (HIPS)
- Dimensional stability
- Freeze stability at target density
- Compressive strength
- Adhesion to plastic liner material and metal case
- Foam closed cell content
- DOE (Department of Energy) Energy Performance
    - Energy consumption with 134a refrigerant working fluid

- Reverse Heat Leakage (RHL) assessment was additionally performed on this new set of refrigerators

The baseline comparison for these low climate change impact refrigerators is the same commercial household refrigerator/freezer product utilizing 245fa blowing agent and 134a refrigerant (unmodified compressor system). It should be noted that the HBA2 was substituted for 245fa at an equal molar level in the PUR foam formulation.

Polyurethane Foam Formulation

As discussed previously, the polyurethane formulation comprised commercially available materials, and was supplied by a major PUR systems house, with HBA2 equal molar substituted for 245fa. The foaming process conditions including machine temperatures and pressure, were identical to the conditions for the 245fa baseline cabinets and doors. The polyurethane process parameters are illustrated in Table 2. Those familiar with refrigerator factories and scale will observe the scale of foam through-put is consistent to scale found in North American world-scale factories, and is consistent with the size refrigerators manufactured in this trial.

HBA2 processed very similarly to 245fa, and no modifications were made to the PUR foaming equipment or process - effectively, conventional existing PUR equipment, existing in the factory, accommodated HBA2.

Additionally, characterization of the HBA2 versus 245fa foamed cabinets and doors suggest no differences in minimum fill weight or over pack conditions.

Table 2. Appliance Process Parameters

Component	245fa	HBA-2
Door Foam Rate: kg/min (lbs/min)	40.8 (90)	40.8 (90)
Cabinet Foam Rate: kg/min (lbs/min)	95.2 (210)	106.6 (235)
B-Side Temperature °C (°F)	18.3 (65)	18.3 (65)
A-Side Temperature °C (°F)	21.1 (70)	21.1 (70)
Gel Time (sec)	17.0	17.0
Tack Free (sec)	24.0	24.0
Injection Pressure MPa (psi)	10.4 (1500)	10.4 (1500)

Lambda (k-factor) Performance

Foam samples from various locations in the fresh food compartment and freezer compartment were assessed for lambda (k-factor) performance. PUR foam thermal conductivity can and will vary throughout the refrigerator/freezer due to foam flow characteristics and associated density variation. Chart 1 illustrates the average lambda (k-factor) performance measured in varying locations of the refrigerator/freezer. HBA2 lambda performance is approximately 8% improvement to 245fa baseline.

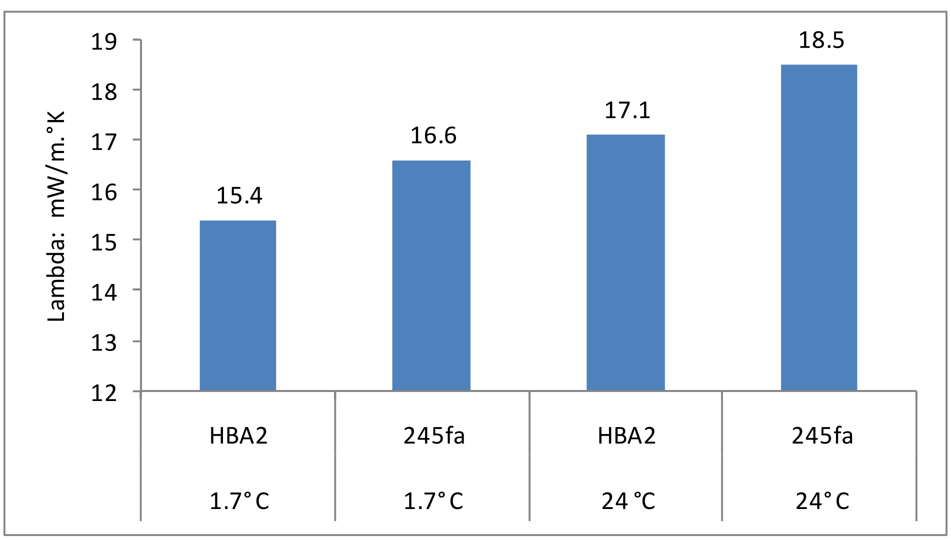

Chart 1. Average lambda measured across various refrigerator/freezer locations

Plastic Liner (HIPS) Compatibility

Plastic liners, either high impact polystyrene (HIPS) or acrylonitrile butadiene styrene (ABS) are currently utilized in household refrigerators/freezers, though, steel liners are used in some specific refrigerator designs and freezers. Differing liner materials (except steel) exhibit varying compatibility to PUR foams. Liner compatibility is dependent upon a wide variety of variables including, but not limited to, plastic thickness, extrusion conditions of the plastic sheet, thermoforming or vacuum forming conditions, and not the least, the blowing agent. Chlorofluorocarbons (11), hydrochlorofluorocarbons (141b, 142b, and 22), and hydrofluorocarbons (245fa and 134a), as well as hydrocarbon blowing agents all exhibited quite varying compatibility with either HIPS or ABS liner material. Liner compatibility to PUR foams containing new blowing agents is a consideration, as correcting liner compatibility, while not an insurmountable problem, can result in added cost to the OEM.

Unfortunately, there is no confident method of assessing refrigerator liner materials without building a refrigerator, subjecting the refrigerator to thermal cycling, and subsequently assessing the liner for blistering and cracking. High impact polystyrene (HIPS) liner material was utilized in this refrigerator trial.

Thermal cycle testing for liner compatibility was conducted using four refrigerator/freezers with doors. The units were placed in and environmental chamber and exposed to 54 ºC (130 °F) for 10 hours, followed by an exposure to -34 °C (-30 ºF) for 10 hours. This cycling was repeated continuously for five consecutive days, after which the liners were observed for blistering or cracking.

Upon completion of the five days thermal cycling protocol, the HIPS liners did not exhibit, and were free of, blisters, cracks, or any visual degradation.

These first trial refrigerators that were reported in 2010, were built in 2009, and continue to exhibit no degradation of the HIPS liner materials after two years.

DOE Energy Assessment

The U.S. Department of Energy (DOE) established, in July 2001, a standard for the maximum energy consumption of household refrigerators. In simplified terms (Federal Register 10CFR 430 for more detail) the standard allows a maximum energy usage by refrigerator internal volume, adjusted for various accessories, such as through-the-door water and ice dispensers. In addition, the DOE provides for the Energy Star label for refrigerators, refrigerator/freezers, and freezers, which, as of March 2008 is DOE Standard minus 20% energy consumption. Further, presently the DOE is in the process of establishing, for promulgation in 2014, a revised and presumably more stringent energy standard for household refrigerators, refrigerator/freezers, and freezers.

Lambda (k-factor) assessments aside, meeting the DOE energy standard is the only criteria that determines whether a refrigerator meets the energy requirements to be sold in the U.S. The refrigerator/freezers manufactured in this trial not only met the DOE Standard, not only met the DOE Energy Star label, but exceeded the Energy Star label requirements. Five refrigerator/freezers utilizing HBA2 blowing agent in an optimized PUR system / 134a refrigerant were assessed by the DOE Energy Star test method. Five refrigerators/freezers utilizing 245fa blowing agent in an optimized system / 134a refrigerant was the baseline comparison. For comparative illustration, the HBA2 refrigerator/freezer ‘drop-in’ and 245fa ‘baseline’ from the 2009 trial is included in Chart 2.

Effectively, the 2011 refrigerators containing HBA2 in an optimized PUR system exceeded the proposed DOE 2014 Energy Standard, without employment of further energy solutions to the platform, such as vacuum insulation panels or compressor modification.

Summary: Household Refrigerator Energy Performance utilizing HBA2 Blowing Agent

Commercially manufactured in 2009 and reported to CPI Conference 2010, 710 liter (25 ft^3) household refrigerator/freezers with HBA2, equal molar substituted for 245fa, in a commercially available 245fa appliance PUR formulation, exceeded the DOE Energy Star performance criteria, and, exceeded the 245fa baseline performance.

Commercially manufactured in 2011, 623 liter (22 ft^3) household refrigerators, utilizing an optimized HBA2 PUR system supplied by Bayer MaterialScience, LLC exhibited an energy efficiency improvement to the baseline 245fa refrigerators exceeding 4%. Further, this 623 liter refrigerator/freezer platform exceeded the ‘proposed’ DOE 2014 Energy Standard for this platform.

HBA2, in all ancillary assessment related to a household refrigerator/freezer, met or exceeded all requirements, including, liner compatibility, compressive strength, dimensional stability, and freeze stability

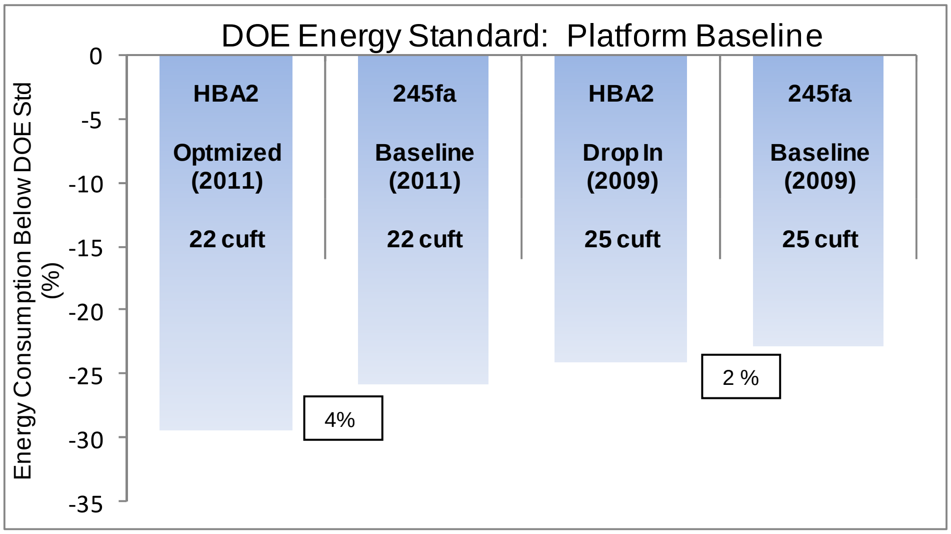

Chart 2. Energy Efficiency Performance.

Reverse Heat Leakage (RHL) Assessment

Assessment of reverse heat leakage for cold storage, such as household refrigerator/freezers, is a methodology to isolate and assess the insulation performance. While RHL is not utilized in the U.S. for energy efficiency standards testing, the method has continued use in other regions of the world, and for those regions with unreliable electricity supply and distribution, provides some indication of the 'time to food spoilage' in the event of extended electrical disruption.

Prototype HBA2 refrigerators from this trial were assessed for RHL, along with baseline 245fa refrigerators. The HBA2 refrigerators exhibited a reduction (in total) RHL exceeding five percent (5%), illustrated in Chart 3. Note that while refrigerator size and wall thickness directly impact heat leakage, these refrigerators were a direct comparison from baseline 245fa refrigerators.

Further, the reverse heat leakage improvement correlates to the separate DOE energy consumption improvement, a validation of the efficacy of HBA2 in an optimized PUR system.

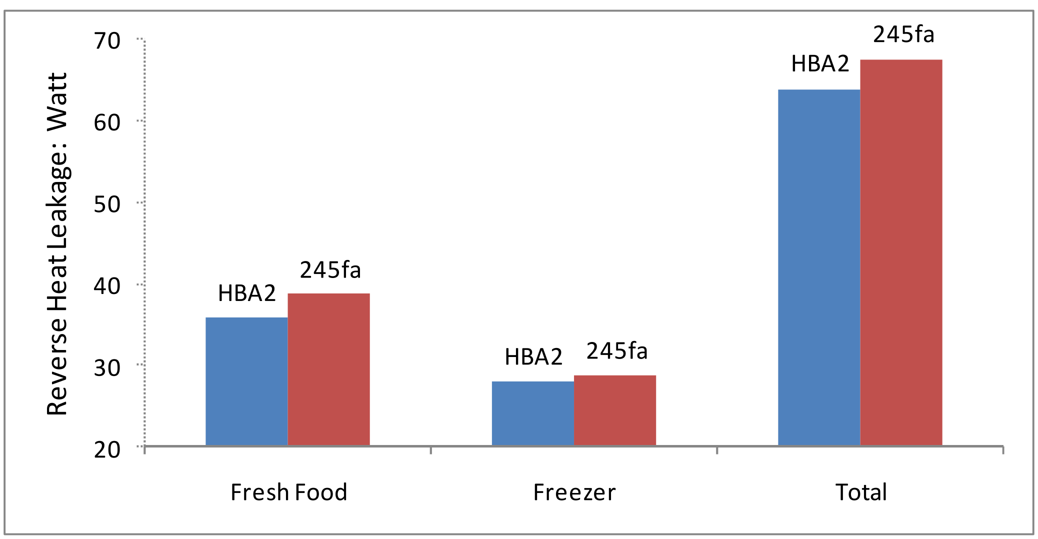

Chart 3. Reverse Heat Leakage Comparison

COMMERCIALIZATION STATUS

Honeywell has successfully commercialized 1234ze(E) in the EU in several foam applications coinciding with the implementation of the EU F-Gas Regulation constraints on the use of high GWP materials. Commercialization of 1234ze(E) in Japan and the U.S. is well underway with several successful major customer trials completed and additional trials planned. Recently, Honeywell announced plans to build a commercial 1234ze(E) commercial manufacturing plant at Baton Rouge, Louisiana, USA – the plant is expect to be in operation in 2013.

With respect to U.S. commercialization of 1234ze(E), the Environmental Protection Agency's SNAP office has added 1234ze(E) to the list of acceptable substitutes for ozone-depleting substances in certain foam, refrigerant, aerosol, and sterilant gas applications. That notice appeared in the Federal Register/Vol. 74/No. 188 on Wednesday, September 30, 2009 (p. 50132) and Federal Register/Vol.75/No.115 on Wednesday, June 16, 2010 (p. 34039 ff). 1234ze(E) PMN (Pre Manufacturing Notification) has been approved by the U.S. EPA.

In the EU, HBA2 is in the REACH Registration process, and has been approved for commercial sales in Japan under the Japan Chemical Substances Control Law. In the U.S., Honeywell has completed HBA2 SNAP and PMN filings and the U.S. EPA is currently reviewing these filings. HBA2 development is significantly underway, with major successful customer trials completed or underway in all major applications.

CONCLUSIONS

An optimized HBA2 formulation has demonstrated a 4% system level energy efficiency improvement in household refrigerator/freezers compared to HFC-245fa baseline, exceeds the current DOE Energy Star label by 9.5%. HBA2, in this commercial household refrigerator/freezer platform exceeded the proposed DOE 2014 energy standard.

As with all new materials, prior to adoption, the industry requires an understanding of factors beyond the initial polyurethane performance characterization. These analyses include quality measures such as dimensional stability and adhesion to liner and exterior case. In all ancillary assessment related to a household refrigerator/freezer, met or exceeded all requirements.

HBA2 regulatory approvals are in process in major markets, encompassing excellent properties of ultra low GWP (GWP = 7), non flammability, and anticipated to be non-VOC Commercial manufacture of HBA2 is estimated by 2013.

With the global attention to climate change, and potential restrictions on the use of high GWP blowing agents and refrigerant gases in the various regions of the world, Honeywell and Whirlpool have validated the energy efficiency of HBA2 low GWP blowing agent in the context of a second North American design platform [623 liter (22 ft^3)]. Further, this work demonstrated improved energy efficiency to the initial design platform [710 liter (25 ft^3)] through the use of Bayer MaterialScience optimized HBA2 PUR system. This highly energy efficient household refrigerator/freezer utilizing an ultra low global warming potential (GWP = 7) blowing agent was demonstrated to meet the requirements of 'proposed' DOE 2014 energy standard without employment of further energy solutions to this refrigerator/freezer platform, such as vacuum insulation panels or compressor modification.

Honeywell's intent is continued commercialization of low environmental impact solutions for the appliance industry, as well as other industries requiring high performance, cost effective energy solutions.

AKNOWLEDGEMTS

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BIOGRAPHIES

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Jim holds a B.S. degree in Chemical Engineering from Iowa State University, Ames, IA, a M.Eng. degree from McNeese State University, Lake Charles, LA, a MBA from Northern Illinois University, DeKalb, IL, and is a registered professional engineer in the State of Louisiana. Jim joined Allied Corporation (AlliedSignal, now Honeywell) in 1984 and has worked in sales, marketing, commercial development, and technical service capacities. He is currently a senior principal engineer in Honeywell's Blowing Agent Technical Service and Development Group with primary responsibility for appliance industry applications of fluorocarbon products.

Yordani Sinaga

Yordani holds a B.S degree in Chemical Engineering from the Indonesia Institute of Technology, Indonesia and a M.S degree in Manufacturing and Industrial Technology from Western Illinois University, Macomb, IL. Yordani joined Maytag, now Whirlpool in 1998, and is currently a Senior Engineer in Materials Technology group for Whirlpool Corporation, where he has been actively involved in product and development of polyurethane insulation for household refrigerators.