International Refrigeration and Air Conditioning Conference

School of Mechanical Engineering

2002

An Overview Of The Properties And Applications of HFC-245fa

G. J. Zyhowski
Honeywell International Inc. USA

M. M. Spatz
Honeywell International Inc. USA

S. Y. Motta
Honeywell International Inc. USA

Zyhowski, G. J.; Spatz, M. M.; and Motta, S. Y., "An Overview Of The Properties And Applications of HFC-245fa" (2002). *International Refrigeration and Air Conditioning Conference.* Paper 559.
http://docs.lib.purdue.edu/iracc/559

AN OVERVIEW OF THE PROPERTIES AND APPLICATIONS OF HFC-245fa

*Gary J. Zyhowski, Sr. Technical Service Engineer, Honeywell, 20 Peabody St., Buffalo, NY 14210, USA;
Tel: 716-827-6331; Fax: 716-827-6275; E-mail: Gary.Zyhowski@Honeywell.com
Mark W. Spatz, Technical Service and Applications Manager, Honeywell, 20 Peabody St., Buffalo, NY 14210, USA; Tel: 716-827-6238; Fax: 716-827-6275; E-mail: Mark.Spatz@Honeywell.com
Samuel Yana Motta, Applications Engineer, Honeywell, 20 Peabody St., Buffalo, NY 14210, USA;
Tel: 716-827-1485; Fax: 716-827-6275; E-mail: Samuel.YanaMotta@Honeywell.com

ABSTRACT

HFC-245fa is a newly developed hydrofluorocarbon with a broad range of potential uses including foam blowing agent, solvent and aerosol, and working fluids. The drivers for the commercialization of HFC-245fa are enumerated as part of the introduction to this new hydrofluorocarbon. The status of EPA approval for the various applications is reviewed. HFC-245fa lends itself to a number of heat transfer and working fluid applications based on its thermophysical properties. The thermophysical properties of HFC-245fa (pentafluoropropane) will be reviewed. The resultant fit in various applications such as centrifugal chillers, Organic Rankine Cycle for energy recovery, sensible heat transfer in low-temperature refrigeration and passive cooling devices will be discussed with reference to several illustrations. Additionally, the thermal and chemical stability and compatibility with materials of construction will be discussed. A description of the thermal and chemical stability testing conducted to date and the results of testing will be presented. The acceptability of a number of common materials of construction including metals, engineered plastics, and elastomers is included in the discussion. Aspects related to health, safety, and the environment such as toxicity, recommended exposure limits, flammability characteristics, ozone depletion, global warming potential, and safe product handling are also covered in this overview of HFC-245fa.

NOMENCLATURE

ACGIH-American Council of Governmental and Industrial Hygienists
AIHA-American Industrial Hygiene Association
DOT-Department of Transportation
OSHA-Occupation Safety and Health Administration
RCRA-Resource Conservation and Recovery Act
SNAP- Significant New Alternatives Program
TSCA-Toxic Substances Control Act
VOC-Volatile Organic Compound
WEEL-Workplace Environmental Exposure Limit

Efficiency- kW/Ton, COP (coefficient of performance)
Energy- kW (kilowatt)
H, ΔH- Enthalpy, Enthalpy change, respectively
Pressure- psia (pounds per square inch absolute), psig (pounds per square inch gauge), kPa (kilo Pascal)
Refrigeration Capacity- Ton, kW
S-Entropy
T, ΔT -Temperature, Temperature change, respectively; ºF (Fahrenheit), ºC (Celsius)
Volume- M^3 (cubic meters)
Volumetric Flow Rate- CFM (cubic feet per minute), M^3/min. (cubic meters per minute)
≈, approximately equal to

INTRODUCTION

Replacements for chlorofluorocarbon (CFC) and CFC-containing refrigerants such as CFC-12 and R-502 were developed using HCFCs (hydrochlorofluorocarbons) and HFCs (hydrofluorocarbons). In addition to use of pure fluids such as the HFC 1,1,1,2-tetrafluoroethane, numerous blends and azeotropes based on HFCs and HCFCs were developed. Today these refrigerants, among them R-507, R-404A, R-408A, R-402A, R-401A, R-409A are familiar to most everyone in the HVAC&R industry. In most cases, HCFCs are viewed as interim replacements for CFCs since the HCFCs still contain chlorine and have an associated ozone-depletion potential. HCFCs have been phased out is some countries and will be phased out in the near future in others. In response, the industry has developed replacements for HCFC-22 that utilize, for example, HFCs. Residential and light commercial air-conditioning and commercial refrigeration applications may be viewed as having well-defined replacements.

Identification of replacements for some ozone-depleting refrigerants, for example, CFC-113 has proven more difficult. CFC-113 is a low-pressure refrigerant typically used in centrifugal chillers. CFC-11 is also used in centrifugal chillers and has been successfully replaced with HCFC-123. With the eminent commercialization of HFC-245fa, there is the opportunity to utilize HFC-245fa in chiller applications. Other applications exist for HFC-245fa as well. Its primary application on a volume basis is as a blowing agent for rigid insulating foams. HFC-245fa physical properties and environmental characteristics make it suitable for a number of heat transfer applications. This paper discusses some of the properties and applications of HFC-245fa.

RESULTS AND DISCUSSION

Environmental Characteristics and Regulatory Information

HCFCs are subject to phase-out in many countries that have agreed to the Montreal Protocol or in the United States via the Clean Air Act requirements. The availability of HCFCs such as HCFC-123 for equipment servicing following the phase-out may not allow for predictable economical use. Further, the EPA has publicly stated its intent to place a cap on the consumption of HCFC-123 and HCFC-141b in the U.S. beginning some time in 2002[1]. Similarly, Canada EPA established a cap on HCFCs[2].

Table 1 contains pertinent regulatory and environmental information for HFC-245fa. The environmental properties of Genetron 245fa include a zero Ozone Depletion Potential (ODP) and a low Global Warming Potential (GWP). In addition, it is not considered a Volatile Organic Compound (VOC) in the US. ACGIH and OSHA have not published recommended exposure limits to date. The Workplace Environmental Exposure Level (WEEL) time-weighted average 8-hour value published by AIHA is 300ppm[3]. HFC-245fa is approved by the US EPA as a substitute for CFC-11 in new centrifugal chillers [4].

Table 1- Regulatory and Environmental Information

CAS Number	460-73-1
Ozone Depletion Potential	0
Global Warming Potential (100-yr time horizon)	950
US VOC status	Exempt
Exposure guidelines	
ACGIH TLV	None
OSHA PEL	None
WEEL (AIHA) TWA - 8 hrs	300ppm
US DOT Hazard Class	Not regulated
US RCRA	Unused Material Not RCRA Waste
US TSCA Inventory Status	Listed
US SNAP Approval	Approved for use in new Centrifugal Chillers

Working Fluid Applications

For applications currently using HCFCs such as HCFC-123 or HCFC-141b, Genetron 245fa may be preferable due to its favorable heat transfer characteristics, lower toxicity, and its lack of chlorine that make it non-ozone-depleting and more stable in certain environments.

Sensible and phase-change working fluid applications for 245fa include:

- Brines (e.g., commercial secondary loop systems)
- Organic Rankine Cycle (e.g., power generation)
- Heat Pipes and Thermosiphons
- Centrifugal Chillers (comfort cooling)

Centrifugal Chillers

Currently, most centrifugal chillers intended for comfort cooling applications are designed to operate with either HCFC-123 or HFC-134a. Despite the fact that HCFC-123 has a very low ozone depletion potential (0.016 relative to R-11), it is scheduled to be phased out in new equipment by 2020 and for all uses by 2030 per the Montreal Protocol. In some regions the phase-out will occur earlier. Since HFC-134a is an HFC with zero ozone depletion potential, there is no scheduled phase-out date for this refrigerant. The question at hand is what should be used to replace HCFC-123 in chiller applications? One answer would be to design all chillers to utilize the higher-pressure refrigerant HFC-134a. The issue with the exclusive use of HFC-134a is that there is a thermodynamic efficiency penalty associated with this refrigerant relative to HCFC-123 and other lower pressure refrigerants. There are also changes necessary for manufacturers of lower pressure refrigerant chillers to adapt their product lines and manufacturing operations for HFC-134a.

Another option is to use HFC-245fa. This refrigerant would be considered a lower pressure refrigerant but not as low as HCFC-123. Its normal boiling point is 59°F, so evaporation would take place below atmospheric pressure like HCFC-123 but condensing pressure would likely exceed 15 psig so a coded pressure vessel would be required. Table 2 shows the results of the thermodynamic analysis of both single-stage and multi-stage chiller applications. Although there is slightly lower thermodynamic efficiency than HCFC-123 for single-stage machines, this difference decreases with multiple stages. Superior transport properties can also reduce any thermodynamic differences. In addition, this refrigerant can be used to increase the capacity of an existing HCFC-123 product line.

Table 2- Centrifugal Chiller Theoretical Performance[5]

40 °F (4.4 °C) Evaporating 2 °F (1.1°C) Superheat 0 °F (0 °C) Sub-cooling 80% Compressor Efficiency

	HCFC-123	**HFC-245fa**	**HFC-134a**
Single Stage			
Evaporating Pressure, Inches Hg vacuum (kPa)	18.2 (40)	10.6 (65)	35.0* (343) * psig
Condensing Pressure, psig (kPa)			
T = 90 °F (32°C)	2.5 (119)	13.4 (194)	104.3 (821)
T = 110 °F (43°C)	10.3 (172)	26.0 (281)	146.4 (1111)
Suction Flow Rate CFM/Ton (M^3/min-kW)			
T = 90 °F (32°C)	18.2 (0.1465)	11.5 (0.0926)	2.84 (.0229)
T = 110 °F (43°C)	19.7 (0.1586)	12.7 (0.1023)	3.176(.0256)
kW/Ton (COP)			
T = 90 °F (32°C)	0.484 (7.27)	0.494 (7.12)	.511 (6.89)
T = 110 °F (43°C)	0.710 (4.95)	0.736 (4.78)	0.769 (4.57)
Multi-Stage 90/40°F 32/4.4 °C			
CFM/Ton (M^3/min-kW)			
1 stage	18.2 (0.1465)	11.5 (0.0926)	2.84 (.0229)
2 stages	16.7 (0.1345)	10.3 (0.0829)	2.52 (.0203)
3 stages	16.2 (0.1304)	9.9 (0.0797)	2.43 (.0196)
kW/Ton (COP)			
1 stage	0.484 (7.27)	0.494 (7.12)	.511 (6.89)
2 stages	0.464 (7.58)	0.469 (7.50)	.482 (7.30)
3 stages	0.458 (7.68)	0.461 (7.62)	.473 (7.43)

To understand the economic impacts of the choice between HFC-134a and HFC-245fa, an evaluation of the present value of the operating cost differences was conducted. The results are shown in Table 3. The analysis was based on comparing the thermodynamic efficiency at conditions that would be seen when running tests to establish the Integrated Part Load Value for efficiency. This analysis does not include the impact of any work recovered by an expander turbine. The analysis is done for a 750-ton chiller. The economic analysis was based on the performance of a single-stage HFC-134a machine and compared against single and two-stage HFC-245fa machines (multi-staging is only used for low-pressure chillers). It assumes a 15% annual rate-of-return with a 15-year life and a cost of electricity of 10¢ per kW-hr. The present value of the operating cost savings for a single-stage HFC-245fa is in excess of $20,000. The savings associated with a two-stage HFC-245fa machine would have a present value in excess of $45,000.

Table 3 - Chiller Economic Analysis

Comparison of R-134a and R-245fa

	R-134a Single-Stage	**R-245fa Single-Stage**	**R-245fa Two-Stage**
IPLV KW/ton	0.370	0.361	0.350
IPLV COP	9.49	9.73	10.06
Chiller Capacity (tons)	750	750	750
Chiller Capacity (kW)	2638	2638	2638
Power Consumption of Chiller (kW)	278	271	262
Cooling Hours (per ARI Std 550-590-98[6])	5010	5010	5010
Annual Power Consumption (kW-hr)	1392015	1357584	1313575
Cost of Electricity (US$/kW-hr)	$ 0.10	$ 0.10	$ 0.10
Operating Cost (US$)	$ 139,202	$ 135,758	$ 131,357
Savings Relative to R-134a Single-Stage	$ -	$ 3,443	$ 7,844
Present Value Analysis:			
Annual Rate of Return(%)	15%		
Number of Years	15		
Present Value of Savings:		$20,133	$45,867

Assumptions:

1. Evaporating temperature of 40°F (4.4°C) based on a 4°F (2.2°C) temperature difference between entering water and saturation temperature
2. Condensing temperature dependent on load and based on a 5°F (2.8°C) temperature difference between leaving water and saturation temperature
3. Compressor isentropic efficiency of 80%
4. Superheat and subcooling of 2°F (1.1°C)
5. Entering water temperature for evaporator and condenser per ARI Std 550-590-98
6. Condenser leaving water temperature based on water flow rate per above standard.

Organic Rankine Cycle

HFC-245fa is well suited for use as a working fluid, particularly in Organic Rankine Cycle systems. The benefit of such systems is that they recover useful energy, often as electrical output, from low-energy sources such as the low-pressure steam associated with steam-driven turbines for electricity generation. Essentially, a waste heat source can be converted to a useful energy source such as electricity by utilizing

HFC-245fa as the working fluid. Previous use of this technology has been limited. With HFC-245fa, the match between the working fluid and the energy source being recovered, for example, in the case of low-pressure steam is favorable. Within a homologous series, as chain length and molecular weight increase, the molar heat capacity and entropy increase. More specifically, with comparable latent heats, as the slope of the entropy lines decrease, the cycle efficiency will increase. Given the proportionality between the natural log of pressure and the inverse of temperature, the slope of the entropy line will be approximately the change in enthalpy with change in temperature (for small changes in temperature), that is, the heat capacity. Even though CFC-11, HCFC-123 and HFC-245fa are not in the same homologous series, the longer molecular chain length of HFC-245fa means that the vibrational component of heat capacity will increase as will the entropy due to the increased degree of freedom[7]. The way in which entropy and enthalpy, affected by the increased heat capacity, translates into improved efficiency is illustrated in Figure 1.

Until recently, most halogenated working fluids have been based on one- or two-carbon molecules. In general, the demand for Organic Rankine cycle fluids was small; manufacture of fluids solely for this purpose was not practiced. Most often, a fluid had other primary applications and was employed for energy recovery if the fluid happened to fit the application. For example, CFC-113 was used as a cleaning agent (solvent), carrier fluid, reaction media, centrifugal chiller fluid, dielectric, working fluid, and a heat transfer fluid. Its manufacture would not have been justified if it were for use as a working fluid for energy recovery alone.

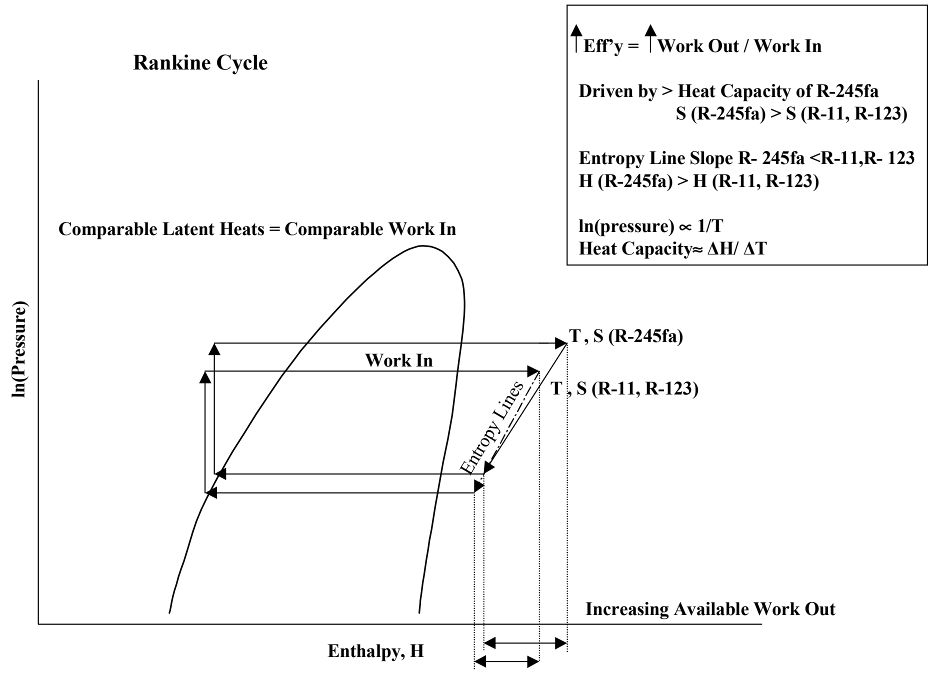


Figure 1- Influence of Heat Capacity on Efficiency

The favorable performance of HFC-245fa in the Rankine cycle provides an opportunity to realize greater electrical energy output from power generation facilities that rely on steam-driven turbines.

Likewise, large industrial enterprises can now consider recovery of waste heat with the option to convert the energy to useful electricity. With the employment of HFC-245fa for conversion of waste heat to useful energy in fossil fuel-fired power generation facilities, the amount of available electrical energy per unit weight of fossil fuel burned would increase thus helping to satisfy demand without increasing facility emissions. The favorable performance of HFC-245fa in energy recovery, if adopted by industrial facilities, would ease demand for electricity, concomitantly decrease the burning of fossil fuels, and increase the consumer's overall energy efficiency. Solar-driven energy conversion systems could also be developed around HFC-245fa. In the same way, this would lead to lower pollution levels by curbing fossil fuel burning. In Table 3, boiler pressure, condenser pressure and thermodynamic efficiency are compared for R-11, R-123 and R-245fa. It can be seen in Table 3 that as molecular chain length increases, so does the thermodynamic efficiency.

Table 4- Organic Rankine Cycle Comparison[8]

Boiler temperature 300ºF (149 ºC)
Condenser temperature 100 ºF (38 °C)

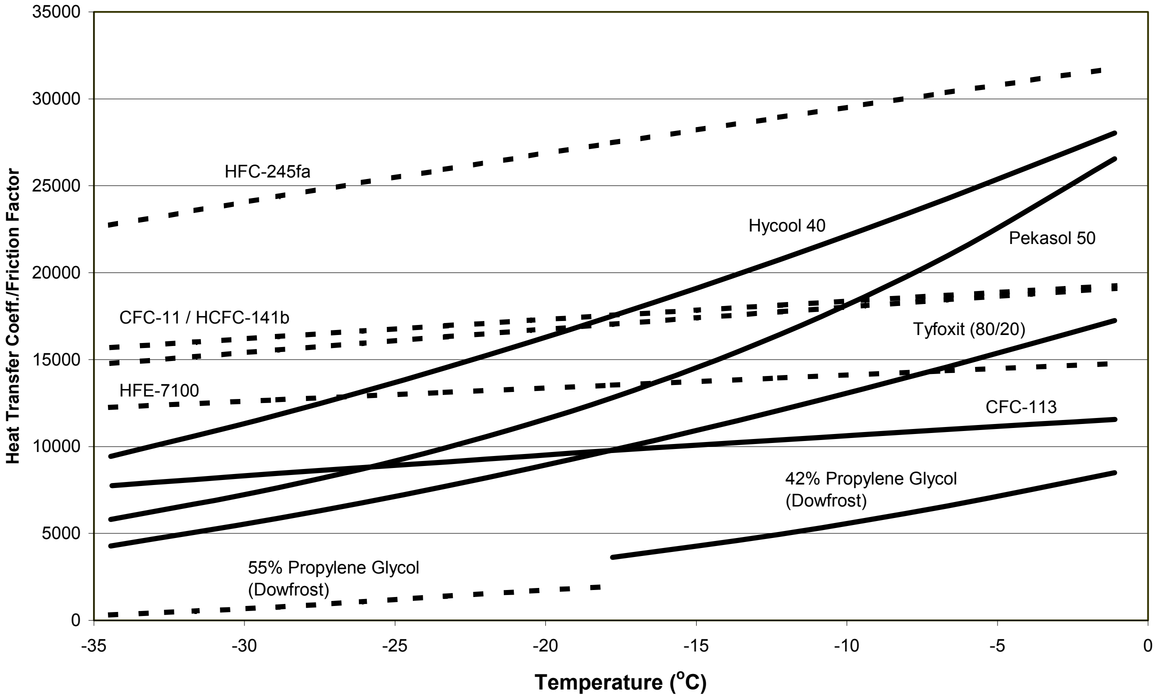
	HFC-245fa	HCFC-123	CFC-11
boiler pressure, psia (kPa)	466 (3213)	284 (1958)	286 (1972)
condenser pressure, psia (kPa)	19.2 (132.4)	6.1 (42.1)	8.9 (61.4)
Thermodynamic Efficiency (%)	59.9	56.6	51.8
Molecular Chain Length	3-carbon	2-carbon	1-carbon

Sensible Heat Transfer

Sensible heat transfer describes the heat exchange process in which the heat transfer fluid does not change phase. Typically, the heat transfer fluid is in the liquid state for such a heat exchange process. In the past, fluids such as CFC-11, CFC-113 and HCFC-141b would have been among the various fluorocarbon fluids used in such applications. The use of HFC-245fa would provide a halogenated hydrocarbon with no ozone-depletion potential, no atmospheric flame limits, and favorable heat transfer and transport properties (high heat exchanger efficiency and low pump power requirements). Sensible heat transfer applications include a number of industrial and commercial applications including use as a secondary loop fluid for commercial refrigeration applications, for example, in supermarkets.

The ratio of heat transfer coefficient to friction factor signifies the heat transfer performance efficiency (one wants to maximize heat transfer and minimize fluid friction or pumping power). Figure 2 below illustrates that HFC-245fa has a higher heat transfer coefficient to friction factor ratio than many other commercially available heat transfer fluids.

Figure 2- Performance of Heat Transfer Fluids



Pekasol is a registered trademark of proKűhlsole
Hycool is a registered trademark of Norsk Hydro
HFE-7100 (3M™)
Dowfrost is a registered trademark of The Dow Chemical Company
Tyfoxit (Environmental Process Systems Ltd)

CONCLUSIONS

HFC-245fa is a new addition to the growing number of hydrofluorocarbons developed to replace CFCs and HCFCs. The preceding overview highlights some of the properties and characteristics of HFC-245fa and compares the performance of HFC-245fa to commercial fluids typically used. From the illustrations above, it should be evident that HFC-245fa provides comparable and, in some cases, improved performance in heat transfer applications including centrifugal chillers for comfort cooling, energy conversion, secondary loop systems, and a variety of other phase-change and sensible heat transfer applications.

-Endnotes-

1. Federal Register/Vol. 66, No. 140 Friday, July 20, 2001/Proposed Rules.
2. Canada Gazette, Part 1, August 29, 1998 "Ozone-depleting Substances Regulations, 1998.
3. Honeywell Material Safety Data Sheet, Genetron® 245fa, Section 8, Exposure Guidelines.
4. http://www.epa.gov/ozone/title6/snap/lists/11cent.html.
5. Output based on National Institute of Standards and Technology, Refprop v.6.01.
6. Air Conditioning and Refrigeration Institute, "Water Chilling Packages Using the Vapor Compression Cycle", Standard 550-590. Arlington, VA. 1998.
7. Donald A. McQuarrie, Statistical Mechanics, Harper and Row, New York, 1976, p. 137.
8. Output based on National Institute of Standards and Technology, Refprop v.6.01.