Considerations for Next Generation HVAC Refrigerants

A 2011 *Engineers Newsletter* discussed the need for a balanced approach between environmental impact and efficiency when selecting replacement refrigerants for HVAC equipment.

This article continues the refrigerant discussion by addressing safety, regulations and other considerations associated with the next generation of refrigerants.

Policy Drivers

Over the past few decades, refrigerants in the HVAC industry have been under constant regulatory pressure. Whether the focus is ozone depletion or global warming, our industry strives to discover the right balance of efficiency and safety while minimizing the impact on the environment.

Figure 1 illustrates the policy pressure impacting nearly all commercially available refrigerants today. These pressures have accelerated the development of alternative refrigerants. The next generation of refrigerants are olefin-based and have properties similar to HCFCs and HFCs, but with minimal direct environmental impact. The first commercially available next generation refrigerant on the market (R-1234yf), developed to replace refrigerants by the auto industry, signals the beginning of their acceptance into the HVAC and other industries.

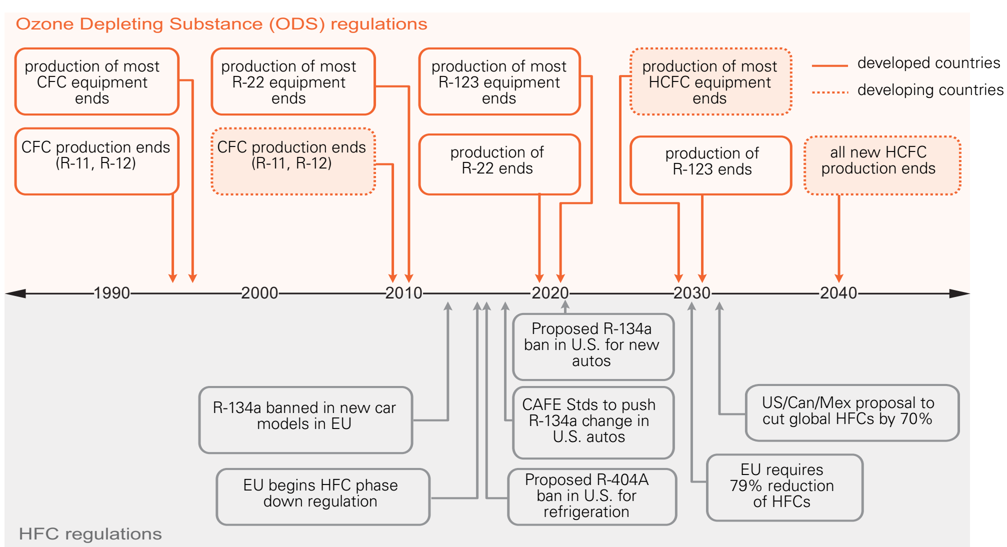
Non-fluoronated refrigerants. When considering next generation refrigerant alternatives it is recommended that policy makers, the public, and manufacturers balance direct environmental concerns (e.g. ODP, GWP, leak rates), indirect environmental concerns (energy efficiency), safety and performance.

As we move beyond HFCs and HCFCs, manufactured chemicals like fluorocarbons, and non-fluoronated refrigerants, such as CO_2, ammonia, or hydrocarbons are being considered.

While non-fluoronated refrigerants (sometimes called "natural" refrigerants) have some desirable characteristics in vapor compression cooling, the majority of the HVAC industry is arguably best served by using fluorocarbon refrigerants because they offer the best balance of efficiency, safety and environmental impact. In fact, many of the new olefin-based refrigerant options have GWP values lower than non-fluoronated refrigerant alternatives.

Non-fluoronated refrigerants will see increased usage in the coming years in applications where their unique characteristics are best suited—such as in low temperature refrigeration.

Figure 1. Legislative actions involving refrigerant



As a reference Table 1 compares many of the characteristics of today's commercial refrigerants and potential future refrigerants.

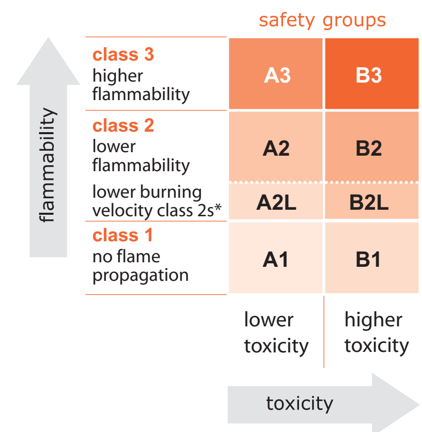
Flammability-the next big industry challenge. With the current generation of fluorocarbons, the HVAC industry has had no problem finding nonflammable refrigerant solutions. However, in the coming years as the industry transitions to olefin-based refrigerants, one of the challenges will be incorporating *slightly* flammable refrigerant solutions. Currently, the American Society of Heating, Refrigerating, & Air-Conditioning Engineers (ASHRAE) has taken the leadership role in developing guidelines for how to safely use refrigerants that are classified as slightly flammable (Figure 2). In 2010, ASHRAE designated a new flammability category—2L—to cover many of the new refrigerants being developed. Some of these 2L refrigerants are difficult or impossible to ignite at room temperature, and may be able to be applied with similar servicing techniques that are used today.

A seemingly simple subject such as flammability is actually quite nuanced. Flammability can be expressed with several metrics. The two most important metrics are the minimum ignition energy, and the burning velocity.

Minimum Ignition Energy (MIE). The minimum ignition energy indicates the amount of energy needed to ignite a refrigerant at room temperature. The higher the number, the more difficult it is to ignite.

Burning Velocity (BV). The burning velocity is the rate at which a refrigerant burns when ignited. The slower the flame rate the lower the risk.

Figure 2. ASHRAE Standard 34-2013 4 safety classifications



* A2L and B2L are lower flammability refrigerants with a maximum burning velocity of ≤ 3.9 in./s (10 cm/s).

Table 1. Refrigerant data

	atmospheric life		environmental		safety				COP (efficiency)	
	years	days	ODP	GWP	toxicity	flammable	burn velocity (BV) (cm/s)	minimum ignition energy (MIE) (mJ)	max theory 2-stage	max theory 1-stage
R-11	45	16,425	1	4750	A	1	0	-	9.467	9.101
R-12	100	36,500	0.82	10,900	A	1	0	-	9.102	8.584
R-22	11.9	4,344	0.034	1760	A	1	0	-	8.965	8.483
R-123	1.3	475	0.012	79	B	1	0	-	9.401	8.949
R-134a	13.4	4,891	0	1300	A	1	0	-	9.055	8.472
R-410A	28.2	10,293	0	1924	A	1	0	-		7.988
R-245fa	7.7	2,811	0	858	A	1	0	-	9.305	8.778
R-32	5.2	1,898	0	677	A	2L	6.7	15		8.215
R-1233zd(E)	0.0712	26	0.0002	1*	A	1	0	-	9.345	8.854
R-1234yf	0.031	11	0	<1*	A	2L	1.5	5000	8.868	8.168
R-1234ze(E)	0.038	14	0	<1*	A	2L	0**	-	9.067	8.452
R-513A	5.9	2,158	0	572	A	1	0	-	8.934	8.280
CO_2	50	18,250	0	1	A	1	0	-		3.533
ammonia	0.01	4	0	0	B	2L	7.2	100		8.774

* Hodnebrog. O. et. al. "Global Warming Potential and Radiative Efficiencies of Halocarbons and Related Compounds: A Comprehensive Review," *Reviews of Geophysics* (June 2013)
** at room temperature

Figure 3 shows the relationship between both MIE and burn velocity. The graph helps illustrate that many 2L refrigerants are both very difficult to ignite (MIE) and, if they do ignite, have a very low flame propagation rate (burn velocity). The olefin-based refrigerant options are either nonflammable or very low 2L refrigerants.

Challenges of high and low pressure for next generation refrigerants.

For years our industry has embraced a variety of refrigerants and operating pressures to address the many different applications and compressor types in the HVAC industry. With next generation refrigerants, the higher the operating pressure, the more challenging it will become to find low GWP, nonflammable refrigerant options. Low pressure replacements for R-123, such as R-1233zd(E) provide low GWP (<1GWP) performance that is efficient, and nonflammable. However, medium pressure alternatives provide more of a challenge (Figure 4).

Nonflammable alternative blends that include olefin-based refrigerants will be available with GWP values below 500; however, slightly flammable levels are difficult to avoid while still maintaining performance. Therefore 2L refrigerants such as R-1234ze are being considered in order to balance safety and performance amongst medium-pressure refrigerants.

For higher pressure R-410A, the current replacement choices offered by refrigerant manufacturers are slightly flammable. Work continues to find non-flammable blends for risk adverse R-410A applications. Highly flammable options such as propane are being considered for some applications, but safety concerns limit consideration to only very low charge applications, such as domestic refrigerators.On the positive side, many of the R-410A alternatives currently considered show improved efficiency and improved high-ambient performance over R-410A.

Figure 3. Burning Velocity (BV) versus Minimum Ignition Energy (MIE) ASHRAE TRP-1584

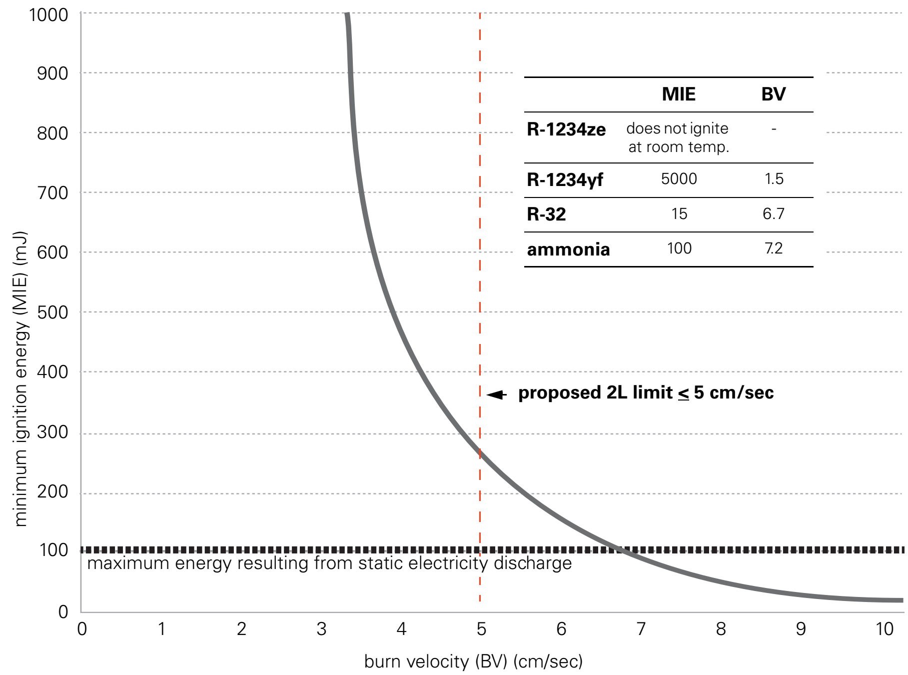
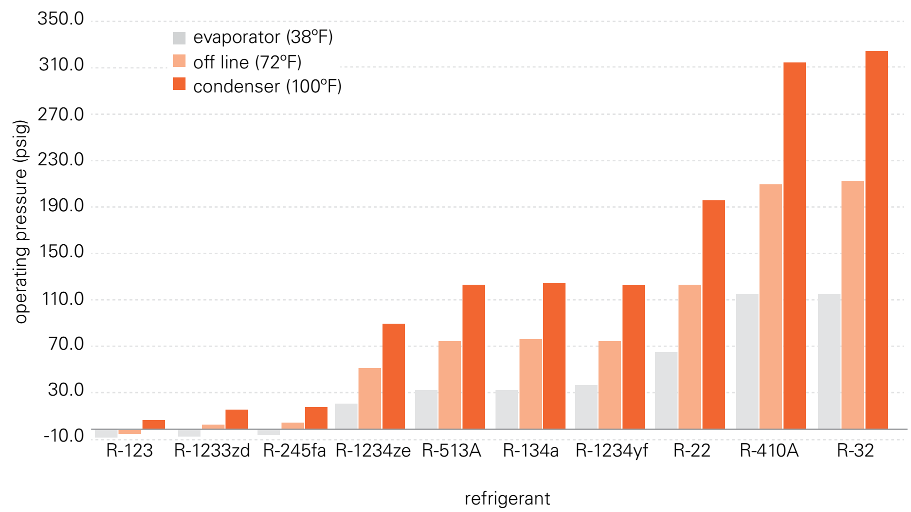


Figure 4. Refrigerant operating pressure



Green buildings and refrigerant selection

Green building rating systems such as USGBC's LEED (Leadership in Energy and Environmental Design) and GBI's Green Globes take refrigerant usage into consideration. The current LEED rating system uses a formula to calculate the impact of ozone depletion, global warming, equipment life, leakage rate, and refrigerant charge. Similarly, the Green Globes rating system accounts for ozone depletion, global warming and leak detection.

By following the criteria in the rating systems, the selected refrigerants can help the project achieve points toward green building status. For example, most centrifugal chillers (both R-123 and R-134a) can achieve the refrigerant points for LEED Energy and Atmosphere credit 4. However, there are HVAC systems, such as many of the split systems, that cannot achieve these credits due to the large volume of refrigerant.

For more information, see www.usgbc.org or www.thegbi.org.

Managing Risk in a Changing Refrigerant Environment

In a constantly changing regulatory environment, a perceived risk surrounds the selection of the right refrigerants. Understanding the risk involved in refrigerant selection is a crucial first step in minimizing that risk.

When you evaluate cost over the operational lifetime of equipment, the magnitude of the risk in selecting the right refrigerant becomes clear. For example, Figure 5 illustrates the major costs associated with operating a centrifugal chiller over a 30 year life span. As you can see, the vast majority of expenditures over its life (over 88%) stems from energy consumption followed by service and first costs.

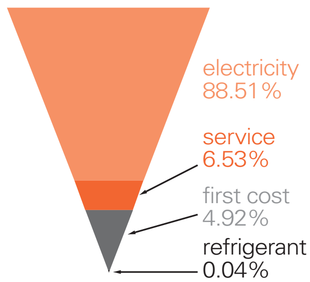
Last on the list, at < 0.04%, is the cost of adding refrigerant over the life of the chiller (assuming a low pressure refrigerant and 0.5% annual leakage rate).

With a better understanding of the major costs over the life of the equipment, how can you minimize risk when buying a chiller?

- Minimize refrigerant charge - Use the least amount of refrigerant (lbs/ton) as possible
- Monitor/Track/Repair any refrigerant leaks in the system - Ensure equipment is well maintained and leak-tight; Annual refrigerant leaks of well below 0.5% are easily achievable in low pressure chillers
- Maintain your equipment at peak performance—proper maintenance of equipment and taking corrective action to repair leaks will minimize life cycle costs

When compared to the overall life cycle cost of a chiller, refrigerant cost is one of the smallest expenditure items. With a little effort, that expenditure can be reduced to practically zero.

Figure 5. Cost over the life of a chiller



Based on a 30-year life, the analysis assumed a low-pressure, direct-drive centrifugal chiller. Service cost estimates were based on maintenance requirements and typically recommended items such as: tube cleaning, refrigerant analysis, leak testing, controls updates, compressor overhaul, electrical checks, bearing inspection, and oil analysis. Additional items may be warranted pending the application of the chiller.

Summary

The HVAC industry is yet again bracing for a new generation of refrigerants. New refrigerants mean new challenges and new opportunities. The last major move away from CFCs resulted in a stronger industry with new options that proved to be reliable and efficient.

Likewise, the current move away from HFCs and HCFCs offers both challenges and opportunities. Balancing performance and emissions while keeping safety at the forefront, there is no doubt the HVAC industry will confidently move into the next generation of refrigerants to find low GWP options that allow for efficient, safe operation.

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