EXECUTIVE SUMMARY

FINAL REPORT ARTI-21CR/610-50025-01
ASSESSMENT OF THE COMMERCIAL IMPLICATIONS OF ASHRAE A3 FLAMMABLE REFRIGERANTS IN AIR CONDITIONING AND REFRIGERATION SYSTEMS

Concerns about the global warming impact of fluorocarbon refrigerants have led to pressure on manufacturers of air conditioning and refrigeration equipment to consider using flammable refrigerants such as propane (R-290), isobutane (R-600a) or hydrocarbon blends as working fluids in their equipment. These substances are classified as highly flammable A3 refrigerants by ASHRAE Standard 34.

Although a substantial amount of information exists on the risks and benefits of flammable refrigerants, it is highly fragmented. For this reason, the Air Conditioning and Refrigeration Technology Institute (ARTI) requested a comprehensive review of the current body of knowledge on the issue of flammable refrigerants in order to assess gaps in existing information and help guide the industry in developing a strategy to address this very complex issue. The objective of the program described in the following report was to synthesize the current body of knowledge regarding the risks, benefits and regulatory issues associated with the use of flammable refrigerants in air conditioning and commercial refrigeration systems. It was not the intent of this project to perform original research on the topic but rather to gather and synthesize existing information.

The first phase of this project consisted of a review of regulatory issues associated with the use of A3 refrigerants in the U.S., Canada, and Mexico. At present, as a practical matter, A3 refrigerants cannot be used in non-industrial settings in the U.S. due to two regulatory barriers. These barriers might be surmountable for certain equipment, if industry mounted a substantial effort to change the applicable regulations.

The first barrier is that the U.S. Environmental Protection Agency (EPA) Significant New Alternative Policy (SNAP) program rule currently prohibits the use of A3 refrigerants except in industrial refrigeration. The EPA has rejected applications to approve flammable refrigerants for non-industrial applications under SNAP due to "a lack of an adequate risk assessment that characterizes incremental flammability risk." If such a risk assessment were performed, they would consider listing A3 refrigerants as acceptable in other end-uses.

The second barrier is U.S. state and local building codes, which require that air conditioning and refrigeration systems be in accordance with appropriate mechanical codes. The mechanical codes in turn are consistent with ASHRAE Standard 15, which prohibits the use of A3 refrigerants except in industrial occupancies or laboratories, unless specifically approved. The provision allows for an exception for charges not exceeding 3.0 kg if "the equipment is installed in accordance with its listing and manufacturer's installation requirements." This means that a product listed by Underwriters Laboratories (UL) or a similar agency and installed correctly could be approved in accordance with ASHRAE Standard 15. However, neither UL nor any similar agency has yet listed any air conditioning or non-residential refrigeration equipment using A3 refrigerants. UL is drafting a standard for air conditioners and heat pumps, and one for small commercial refrigeration equipment (e.g. vending machines, beverage coolers) which will permit usage of flammable refrigerants and therefore satisfy this requirement of the mechanical codes. For large direct expansion air conditioning systems such as large unitary equipment, the required refrigerant charge would often exceed 3.0 kg, so ASHRAE Standard 15 would prohibit the use of A3 refrigerants in such systems without exception. Requirements for indirect systems such as chillers are less restrictive and allow the use of larger quantities of A3 refrigerants in certain laboratory or industrial settings.

In Canada, the major regulatory barrier impeding the use of flammable refrigerants is similar to that of the US, in that building codes reference ASHRAE standards and practices, which by extension, prohibit the use of flammable refrigerants in non-industrial settings, unless approved by UL or a similar organization. In Mexico, as in Canada and the U.S., activities involving flammable substances would be subject to applicable use, storage, and transportation requirements to ensure safety to human health and the environment. However, there appear to be no explicit requirements prohibiting or sanctioning the use of flammable substances as refrigerants in Mexico.

The second phase of our study involved an evaluation of A3 refrigerant performance, benefits, risks, and costs. An extensive literature review revealed a number of documents that suggested that A3 refrigerants such as propane offer similar or slightly superior efficiency to R-22 in air conditioning systems. Unfortunately, few rigorous "apples to apples" comparisons of fluorocarbon and hydrocarbon systems have been reported publicly. However, the available data suggests that efficiency increases of about 2-5% were common in drop-in or "soft-optimized" system tests. In a system specifically optimized for hydrocarbons, one might be able to achieve efficiency increases somewhat greater than 5% by using propane rather than R-22, assuming no other fire safety measures need to be taken which reduce efficiency. For example, if a secondary loop is required in order to keep all the refrigerant outdoors for safety reasons, the hydrocarbon system would suffer a very large reduction in efficiency and increase in cost compared to the R-22 system. Modest efficiency increases can also be achieved without much difficulty, using HFC refrigerants. For example, tests with HFC-410a also show efficiency increases of up to 5% relative to R-22. Therefore, the real dilemma faced by industry is to determine how the costs of safety improvements required for hydrocarbon systems compare with those necessary to raise efficiency of fluorocarbon systems.

In commercial refrigeration, publicly available literature includes tests indicating that the use of hydrocarbons could offer efficiency increases of 0 - 10% compared to certain fluorocarbons, or up to 15% in some specialized applications. Unfortunately, most reports provide limited detail on the equipment used, test conditions, and methodologies, so comparing fluorocarbon and hydrocarbon performance on an equal basis is difficult. The available data is insufficient to provide a basis for a precise judgement on the level of efficiency improvement that could be obtained with hydrocarbon refrigerants in commercial refrigeration. The efficiency improvements should also be analyzed in the context of cost-efficiency tradeoffs accounting for safety improvements needed in hydrocarbon systems.

The most important benefit of hydrocarbon refrigerants is their near zero direct global warming impact. However, to understand the total global warming effect of refrigerants, both direct and indirect effects should be considered, using concepts such as Total Equivalent Warming Impact (TEWI) or Life Cycle Climate Performance (LCCP). Using such metrics, hydrocarbons offer a modest improvement over fluorocarbons in most air conditioning systems, assuming that leak rates were maintained at low levels using the best available technology. Even with leak rates 3-5 times the best practice, the direct warming impact of fluorocarbons would be less than 15% of the total warming impact.

In typical direct expansion supermarket systems where large charge losses are typical, the direct warming impact of the refrigerant is large, so use of hydrocarbons could, in theory, decrease total warming impact substantially. However, the safety issues associated with distributing hundreds of kilograms of flammable refrigerant throughout the store would likely require that a secondary loop be used, in which case the direct warming impact of the refrigerant would be minimal regardless of which refrigerant was used.

The major barrier to adoption of A3 refrigerants is the risk of fires or explosions during any part of the product life cycle of an air conditioner or refrigerator. Testing indicates that ignition of an amount of hydrocarbon refrigerant constituting a portion of a typical air conditioner charge (<240 grams or 0.54 lb) could cause a major fire or overpressure, risking serious injury, fatalities and/or property damage. Many commercial refrigeration systems would also contain hydrocarbon refrigerant charges in excess of these amounts. Such a scenario would be possible if a catastrophic leak occurred. Such leaks are rare, but certainly can occur at some unknown frequency.

Several risk assessments have been conducted to attempt to quantify the risks of fires and explosions. These risk assessments are very application-specific and can not be generalized to the use of hydrocarbon refrigerants in other applications. There is also no consensus on what constitutes an acceptable risk. Progress on standards could eliminate the regulatory barriers, but overcoming the perception of undue commercial risk -- product liability exposure and end user acceptance -- by manufacturers and of undue fire risk by end-users could still be a large barrier to overcome.

Very little information has been published that attempts to estimate the cost savings that can be obtained from the potentially lower cost hydrocarbons, compatibility with low cost mineral oil, and superior transport properties. Hydrocarbons with the high purity levels generally expected of refrigerants are cheaper than fluorochemical refrigerants in some, though not all, cases, but the charge size is significantly lower for hydrocarbons in similar capacity systems, so the total refrigerant cost is lower. Refrigerant cost, however, is a very small component of total system cost. For equivalent performance, aside from the costs associated with fire safety design requirements, the cost of a hydrocarbon system would likely be similar or slightly lower than that of a fluorocarbon system. The critical unknown is the cost of design changes needed to ensure an acceptable safety level, which could drive costs up substantially.

Although domestic refrigerators using hydrocarbon refrigerants have been sold throughout Europe for several years and are now widespread, there appear to be few other commercially available products using hydrocarbon refrigerants. Some commercial refrigerators, small direct expansion air conditioners and chillers which use hydrocarbons are sold in Europe, but sales volumes are very low. Outside of Europe, almost no hydrocarbon-based systems are commercially available.

Because the publicly available information about hydrocarbon-based air conditioning and commercial refrigeration systems is so fragmented, further research could help enhance the understanding of the benefits and drawbacks of such systems. One critical area for further work is a rigorous analysis of the cost impact of achieving acceptable safety levels when hydrocarbon refrigerants are used. Since there is no consensus on what safety level is acceptable, it might be appropriate to use the requirements of the draft IEC standard 60335-2-40 as the basis for such a cost study. Another area for further work would be rigorous “apples to apples” comparative testing of fluorocarbons and hydrocarbons in a variety of real world equipment. This might help resolve the differences in performance reported by various researchers who tested fluorocarbon and hydrocarbon systems. Finally, the key driver for considering hydrocarbon refrigerants is their potential for reducing the global warming impact of air conditioning and refrigeration systems. The key area of uncertainty in evaluating the global warming impact of such systems is the actual field leakage rate. Therefore, a large-scale field survey of actual current practices and refrigerant losses would help provide a sound basis for making accurate judgements about the true global warming impact of various refrigerant options.