Assessment of Propane in North American Residential Air Conditioning

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ABSTRACT

Three unitary split systems were evaluated for use with propane as the refrigerant. These three systems were then compared to systems using hydrochlorofluorocarbon (HCFC) R-22 and hydrofluorocarbon (HFC) R-410A for environmental effectiveness. The propane systems included one using safety measures, another using propane with flame suppressant, and one using a secondary heat transfer loop to isolate propane from residences. The performance for all the systems was evaluated through computer simulation. The system environmental effects were assessed using the Total Equivalent Warming Impact (TEWI) concept, by considering the refrigerant leakage and the energy use in North American applications. The system cost was estimated in order to evaluate the TEWI reduction per unit of investment. Other manufacturing issues are discussed also.

Of the three unitary propane split systems, the system with safety features has the best performance and the lowest TEWI. However, adding the safety features raises the initial unit cost about 30 percent. If this cost adder is used to increase the efficiency of an R-410A system, this will result in a significant reduction in TEWI. In other words, a high efficiency R-410A system has the best TEWI reduction per unit of investment in the unitary split system application within North American region. Extensive revision of the manufacturing process is necessary to handle propane safely in the plant.

Besides good environmental properties, propane has good thermodynamic and heat transfer properties. For these reasons, propane should continue to be evaluated for those markets and applications where it provides the best environmental solution. In this study, propane does not provide the optimum environmental solution for unitary split systems in the North American market. Since the system performance was derived from computer modeling, more experimental work is required for further evaluation.

INTRODUCTION

Due to the ozone depletion problem, 39 countries of the world met in 1987 and established the Montreal Protocol. According to this and the subsequent protocols, the production of HCFC is going to be limited and eventually will be phased out in year 2020. EPA is calling for a phase-out of R22 for new equipment application by the year 2010.

Significant effort has been put into the search for R-22 alternatives, including HFCs, Hydrocarbons, CO2, Ammonia, etc.. While different "green" products with new refrigerants have been introduced in many countries, the search for other new refrigerants continues.

Propane (R290), one of the Hydrocarbons, has many advantages as a refrigerant, such as, it is a natural substance, has zero ozone depletion, has negligible Global Warming Potential (GWP), is compatible with mineral lubricant oils, and has good heat transfer characteristics. The major disadvantage of propane is that it is flammable. In Europe, some development is occurring and products are available with propane as the refrigerant. Those products use very little refrigerant.

However, unitary air conditioners or heat pumps use much more refrigerant. It would be beneficial to do a preliminary assessment of the environmental effect, system performance, and manufacturing issues of propane in unitary systems. This paper presents an evaluation of propane in the residential unitary split system application within the North American region.

PROPANE SYSTEM DESIGN

A schematic drawing of a typical air conditioning system is shown in Figure 1. It has mainly four components: a compressor, a condenser, an expansion device, and an evaporator. Due to the amount of the refrigerant in a unitary split system (which typically exceeds the maximum allowable by ANSI/ASHRAE Standard 15-1994 -- Safety Code for Mechanical Refrigeration), the flammability of propane needs to be mitigated in designing a unitary system when using propane as the refrigerant.

There are three ways to potentially solve the flammability problem: leakage and ignition control, adding a flame suppressant, or using a secondary heat transfer loop to isolate propane from residences. They are briefly discussed as follows:

Using Safety Measures -- Leakage and Ignition Control

A refrigerant is flammable only when it leaks out and there is an ignition source. If safety measures are taken to prevent propane leakage from the system and to an ignition source, a propane system could be as safe as a regular system. Underwriters Laboratories (U.L.) has proposed a list of safety considerations necessary to ensure the safety when using flammable refrigerants. Some examples of those are: to braze tubing joints to prevent leakage, to place electrical components in an air-tight box to avoid possible ignition source, to use a pump-down cycle to store the refrigerant in the outdoor unit when idle, to protect coils from puncture, etc..

This system has the same main components as shown in Figure 1. Adding those safety features will not degrade the propane system performance. However, the cost adders would be very high, and were estimated to be 30% of the first cost of a typical residential unit (Treadwell, 1994).

Adding Flame Suppressant

Like other HFC mixtures, some flame suppressant can be added to propane to produce a non-flammable mixture. One way is to add R-227ea to propane. Douglas et al. (1995) performed studies on this. The results indicated that propane requires a large fraction of flame suppressant R-227ea to form a non-flammable mixture. Industry data of the required R-227ea ranges from 70 to 93 by weight percentage. When using this mixture, the system components are still the same as shown in Figure 1. However, R-227ea is an HFC with a GWP of 0.59 over a 100 year time period. Also, adding R-227ea may cause a system performance degradation. The higher the percentage of R-227ea, the larger the performance degradation. A mixture of 30/70 of R290/ R-227ea by weight percentage is used in this analysis.

Using a Secondary Heat Exchanger to Isolate Propane From Residences

Another option is to use a secondary loop of heat transfer so that only the secondary heat transfer fluid will be in the indoor unit. A typical air conditioner design of this system is shown in Figure 2. The conventional evaporator is replaced by a secondary heat transfer loop. The secondary loop is composed of a pump, a refrigerant/ brine heat exchanger, and a brine/air heat exchanger as an indoor unit. The refrigerant/ brine heat exchanger could be a tube-to-tube heat exchanger, or a brazed plate one. The system performance will be degraded some, depending on the size of those heat exchangers. In this study, the brine/air heat exchanger was sized to give the required capacity. The refrigerant/brine heat exchanger was designed to have an 80% temperature effectiveness while keeping the pressure drop reasonable. The cost adder of this system is estimated to be 30% or more of the first system cost. Also, brines can have some environmental effect, and there are risks of spillage, disposal, etc..

PROPANE SYSTEM PERFORMANCE

Including the three propane systems, five unitary split systems have been analyzed in total. An R22 system is used as the base system. An R-410A system is designed as a reference using zero-ozone-depletion refrigerant. Those five systems were designed to have the same capacity by adjusting the compressor size while maintaining the same heat exchangers, except the propane system with the secondary heat transfer loop.

The system performance was estimated using computer simulation. The propane systems are compared with the R22 and R-410A systems to investigate the advantages in performance and environmental impact. The propane system with safety features has to use a slightly larger compressor to match the R22 system capacity. For the R290/R-227ea (30/70, weight percentage) system, the capacity dropped significantly with the addition of R-227ea. The compressor size was increased to compensate for this capacity loss, but the system efficiency dropped as a result.

The capacity and efficiency of all the systems are listed in Table 1. The cyclic degradation factor was assumed to be the same for all systems in the seasonal energy efficiency ratio (SEER) calculation. It can be seen from Table 1 that for a 3 ton air conditioner, an R-410A system would have an SEER 7% better than an R22 system, a propane system with safety features 2% better, a 30/70 (weight percentage) of R290/R-227ea system 8% worse, a propane system with secondary heat exchanger 16% worse. The main contributors to the efficiency drop of the system with secondary heat transfer loop are the pump power and the intermediate temperature difference of the secondary heat transfer loop.

Table 1: The capacity and efficiency for a 3 ton air conditioner using different refrigerants

System Number	Refrigerant	Capacity Tod=95 F, Tid=80 F, Btu/hr	SEER Ratio to R22
1	R22	36,000	1
2	R-410A	36,000	1.07
3	R290 (regular, with safety features)	36,000	1.02
4	R290/R-227ea (30/70, weight %)	36,000	0.92
5	R290 (with secondary heat transfer loop)	36,000	0.84

ENVIRONMENTAL EFFECT ASSESSMENT OF A PROPANE SYSTEM

TEWI Concept and its Application

An air conditioning system contributes to the global warming in two ways. The one is the CO2 equivalent contribution due to the actual release of the refrigerant into the atmosphere, called direct contribution. Another one considers the CO2 released when generating the electrical energy required to operate the unitary product, called indirect contribution. Both components must be considered when evaluating the environmental effect of equipment using alternate refrigerants. The TEWI combines both the direct and indirect equivalent CO2 contributions, and this concept will be used to evaluate the environmental effect of all systems.

The direct effect of a system is a function of the refrigerant used and the refrigerant leakage rate. In this analysis, the leakage rate is assumed to be 4% per year, and the Global Warming Potential (GWP) of a refrigerant is for the 100 year integrated time horizon. The indirect effect is a function of the system efficiency and the power plant CO2 emissions. The power plant CO2 emission is used to measure how much CO2 is emitted from fossil fuels when generating electric power. The actual emissions will depend on the fuel used and the operating efficiency of the power plant. The more the fossil fuels used, the larger the CO2 emission from a power plant. The regional average for North America is 0.672 kg CO2/kW-hr. (Fischer, et al., 1991). For regions where more non-fossil fuels are used in generating electric power, for example Europe, this emission is smaller.

A 3 ton air conditioner operating in DOE region IV with 1000 cooling hours per year is used for this analysis. The product life is assumed to be 15 years.

TEWI Assessment for Different Systems

Table 2 gives the results for those systems using different refrigerants operating in the North American region. For all the three unitary propane split systems, it looks like that the system with safety features has the lowest TEWI, about 3393 kg lower than that of the R22 system. However, this system would require at least a 30% cost increase to add the safety features according to Treadwell's analysis as mentioned earlier in this paper.

Table 2: The TEWI of a 3 ton air conditioner using different refrigerants during the product life operating in North American region

System Number	Refrigerant	Charge	GWP[1]	Direct contribution[2]	Indirect contribution[3]	TEWI	Diff. with R22	
		lb.	to R11	kg	kg	kg	kg	%
1	R22	6	0.49	2,801	30,249	33,049	----	----
2	R-410A	6	0.54	3,086	28,270	31,356	(1,693)	(5.1)
3	R290 (regular, with safety features)	3	0	0	29,656	29,656	(3,393)	(10.3)
4	R290/R-227ea (30/70, weight %)	6	0.41	2,343	32,879	35,223	2,174	6.6
5	R290(with secondary heat exchanger)	3	0	0	36,011	36,011	2,962	9.0

[1] GWP is for 100 year integrated time horizon, and based on R11 of 3500 kg CO2/kg R11.
[2] Leakage rate is assumed to be 4%/year, product life is assumed to be 15 years.
[3] For North America, the CO2 emission from a power plant is 0.672 kg CO2/kW-hr., and cooling hours in DOE region IV is 1000 hr/year.

Since R22 will eventually be phased out, the industry is trying to find out the best alternative. Thus an R22 alternative, such as R-410A, should be used to compare with propane systems in the assessment of the environmental effect. The TEWI of the propane system with safety features is 1700 kg lower than that of the R-410A system. However, the first costs of the two systems are different. Kuijpers (1995) proposed an idea of TEWI reduction per unit of investment. This will determine what is the largest reduction in TEWI for the lowest amount of money compared to a reference system. Using this idea, the R-410A system has been compared with the propane system. The propane system has a cost adder of 30 percent. With this 30% cost adder, the efficiency of an R-410A system can be increased enough to decrease the indirect CO2 contribution by more than 2000 kg for a system under 13 SEER (seasonal energy efficiency ratio) in North American region. Thus, the R-410A system has a bigger TEWI reduction per unit of investment in the unitary split system application. This result also indicates that the system efficiency is a more important factor than the GWP of a refrigerant to reduce the TEWI in the North American region.

THE FLAMMABILITY IN MANUFACTURING PROCESS AND OTHER ISSUES

The above three unitary propane split systems were designed to be non-flammable in the customer end. The flammability in the manufacturing process needs to be considered to ensure the propane is handled safely in the plant (Kulmbacher Klimagerate Werke, 1995). There are mainly three areas that require special measures, including the charge and leak detection procedure, the reclaim process, and the evacuation system. There needs to be a separate room in the plant for the charging and leak detection process. This room needs to be equipped with a propane monitor and very good ventilation system. Also, there must be no ignition source in the room. The leak detection needs to be performed with helium or nitrogen gas prior to the charging of propane. The reclaim and the vacuum processes need to be performed within this room also.

If the systems are to be stored, the storage room needs a good ventilation system and some monitoring device. The transportation and the service of those systems need special caution also. Extensive training is necessary for engineers, service people, operators, etc..

CONCLUSIONS

Three unitary propane split systems were evaluated for their performance and environmental impact within North American region. Of the three propane systems, the system with safety features has the best performance and the lowest TEWI. However, adding the safety features requires about a 30% increase in the first unit cost. If this cost adder is used to increase the efficiency of an R-410A system, this will result an even smaller TEWI. In other words, a high efficiency R-410A system has the best TEWI reduction per unit of investment in the unitary split system application within North American region.

Extensive revision of the manufacturing process is necessary to handle propane safely in the plant, including the charge and leak detection procedure, the reclaim process, and the evacuation system.

Propane needs more attention in the future due to its features and advantages as a refrigerant. In this study, the system performance is derived from computer modeling and the assessment is for unitary split systems in North American applications. More experimental work is required for further evaluation.

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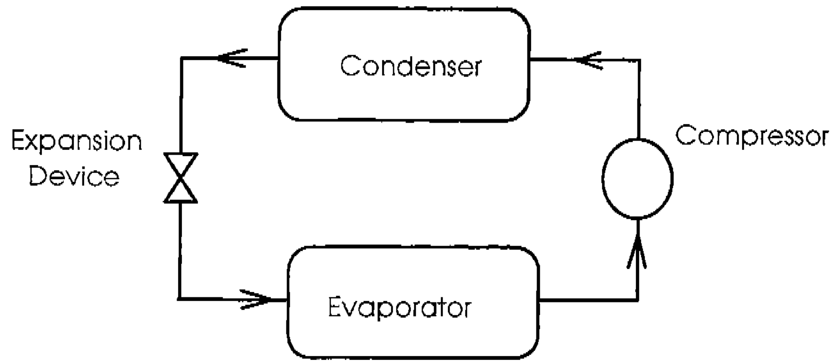

Figure 1. Schematic of a regular air conditioning system

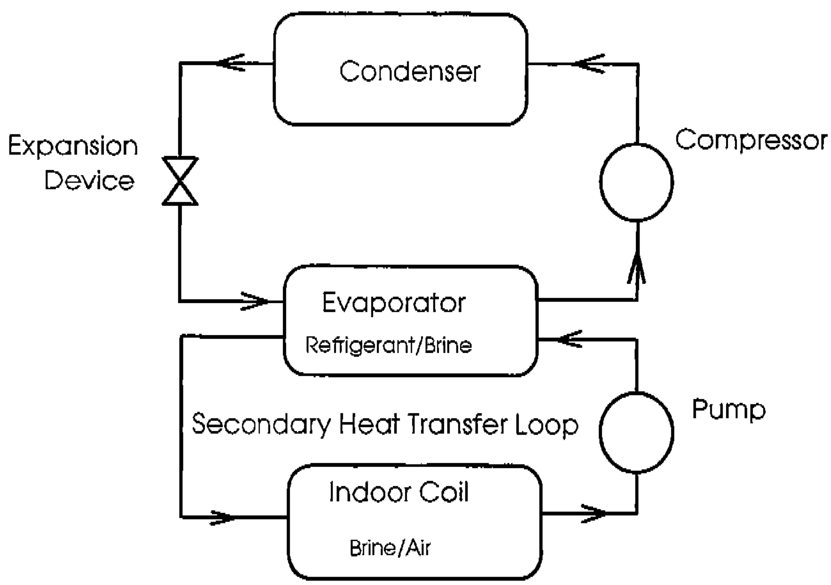

Figure 2. Schematic of an air conditioning system with a secondary heat transfer loop