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# RISK ASSESSMENT OF HFC-32/HFC-134A (30/70) IN MINI-SPLIT RESIDENTIAL AIR CONDITIONERS

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## ABSTRACT

A risk assessment was conducted for the substitution of HFC-32/134a (30/70), a marginally flammable HFC blend, for HCFC-22 in mini-split air conditioners in Japanese residences. The results suggest that such a change would cause a very small increase in the risk of fires. Predicted incidences of fires are extremely low during operation or idle, and slightly greater during servicing. Risks during servicing can be reduced through proper training and enhanced regulations on venting. Modification of this analysis to consider ducted central air conditioners, commonly used in American homes, should be considered, since typical American systems use a different design concept, contain a substantially larger charge, and are used in a different environment.

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## INTRODUCTION

Concerns about ozone depletion and global warming from chlorine-containing refrigerants such as HCFC-22, which is used in the vast majority of air conditioners in the world, have led to the development of several alternatives, such as HFC-407C, HFC-410A, and HFC-410B. All have drawbacks, including reduced efficiency or a requirement for major compressor and system redesign. One other possibility is HFC-32/134a (30/70 wt %), a blend which offers similar efficiency to HCFC-22, with limited requirements for system redesign. Although substances like HFC-32/134a (30/70) are flammable by currently accepted laboratory testing standards, their actual safety risks in real-world applications may be acceptably low. This paper describes the process and results of a risk assessment of HFC-32/134a (30/70) in residential mini-split air conditioners.

A fault tree analysis was conducted to estimate the frequency of fires or explosions that could result from substituting HFC-32/134a (30/70) for HCFC-22 in a ductless, mini-split air conditioner. This design is the most common type of air conditioner in Japan, where typical annual production is between 6 and 8 million units. It is also widely used elsewhere in Asia and in Europe, and in smaller numbers in the U.S. Ducted central systems are typically used to cool several rooms in American homes, while Japanese homes are usually cooled by several mini-splits. The assessment was based on a typical Japanese home design, and although American homes are quite different, the final results would be expected to be similar.

Full scale room testing of HFC-32/134a in various blend compositions, as well as pure HFC-32, was conducted to validate the fault tree model and provide some of the data. This testing is described in further detail in the accompanying paper from Daikin Industries, Ltd., entitled, "Flammability Evaluation of HFC-32 and HFC-32/134a Under Practical Operating Conditions." Additional small scale testing of various ignition sources was conducted to determine whether these common sources could ignite the blend under optimum conditions for ignition and is also described in that paper.

## FLAMMABILITY CHARACTERISTICS OF HFC-32 AND HFC-32/134a

HFC-32/134a is a zeotropic blend, so the composition of the liquid and vapor vary from the nominal composition depending on operating conditions, temperature, and leak rate. Since HFC-32 has a higher vapor pressure than HFC-134a, the concentration of HFC-32 is higher in the saturated vapor phase than in the saturated liquid phase. The concentration of HFC-32 in the vapor increases as the ambient temperature decreases. Since HFC-32 is flammable and HFC-134a is non-flammable, the blend becomes more hazardous as the temperature decreases.

The critical flammability ratio (CFR) of a blend is defined as the percentage of non-flammable refrigerant required to make a blend non-flammable in air. The CFR of the HFC-32/134a blend has been the subject of considerable debate. The most conservative room temperature values reported for the CFR are in the range of (40/60) [1]. Humidity, ignition source, test temperature, and test vessel size and type all affect the test results. Thus, taking conservative CFR values, it is easily conceivable that a leak from a system charged with HFC-32/134a (30/70) could be flammable, even during warm weather. At room temperature, the gas in equilibrium with the liquid at the nominal composition of HFC-32/134a (30/70) contains nearly 50% HFC-32, well within the flammable range.

Another factor to be considered is blend composition variation in the system during operation. To investigate this phenomenon, tests were conducted in an operating system. The system was charged with HFC-32/134a (30/70). The fluid was sampled and analyzed at various locations in the system, and the receiver was the only place where the blend was more than 4.1% richer in HFC-32 than the nominal composition. [2] However, the receiver is a factory manufactured steel vessel, quite robust and highly unlikely to leak, and it is located outdoors. Furthermore, if the receiver ruptured, we could expect immediate flashing of the liquid in it, making the resulting leaked refrigerant close to nominal composition.

Preferential solubility of the refrigerants in the polyolester (POE) oil could also impact the fluid composition in the system. However, experiments have shown that a larger amount of HFC-32 than HFC-134a dissolves in the POE oil. Thus, presence of POE oil has a beneficial effect on the flammability of this blend, so it has been neglected in our risk assessment. [2] Therefore, composition variation within an operating system was insignificant for our purposes. These test results also indicate that the risk of a leak of flammable refrigerant during operation is negligible.

We can conclude that the worst case scenario from a composition perspective is when the heat pump is stopped or has just started on a cold day and fractionated fluid from the outdoor unit migrates to the indoor unit and leaks into a warm room. Experiments have shown that within about 5-7 minutes of starting operation, the blend becomes sufficiently mixed that it reaches its steady state composition. [2]

## RISK ASSESSMENT

### Study Model

A schematic diagram of the study model, a FTY223C heat pump, is shown in Figure 1. The indoor unit contains the evaporator and a fan for circulating conditioned air to the room. The evaporator consists of about 20 copper tubes 7 mm (0.28 in.) in diameter and approximately 0.64 m (25 in.) long. The outdoor unit consists of a compressor with a suction accumulator, a reversing valve, a condenser, filter dryers, a muffler, an expansion valve, and a receiver. The condenser is made from 8.0 mm (0.31 in.) diameter finned copper tube, approximately 0.67 m (26 in.) long. The design is typical of mini-split heat pumps sold in Japan and elsewhere. Small differences in size or design would be unlikely to change the study results significantly.

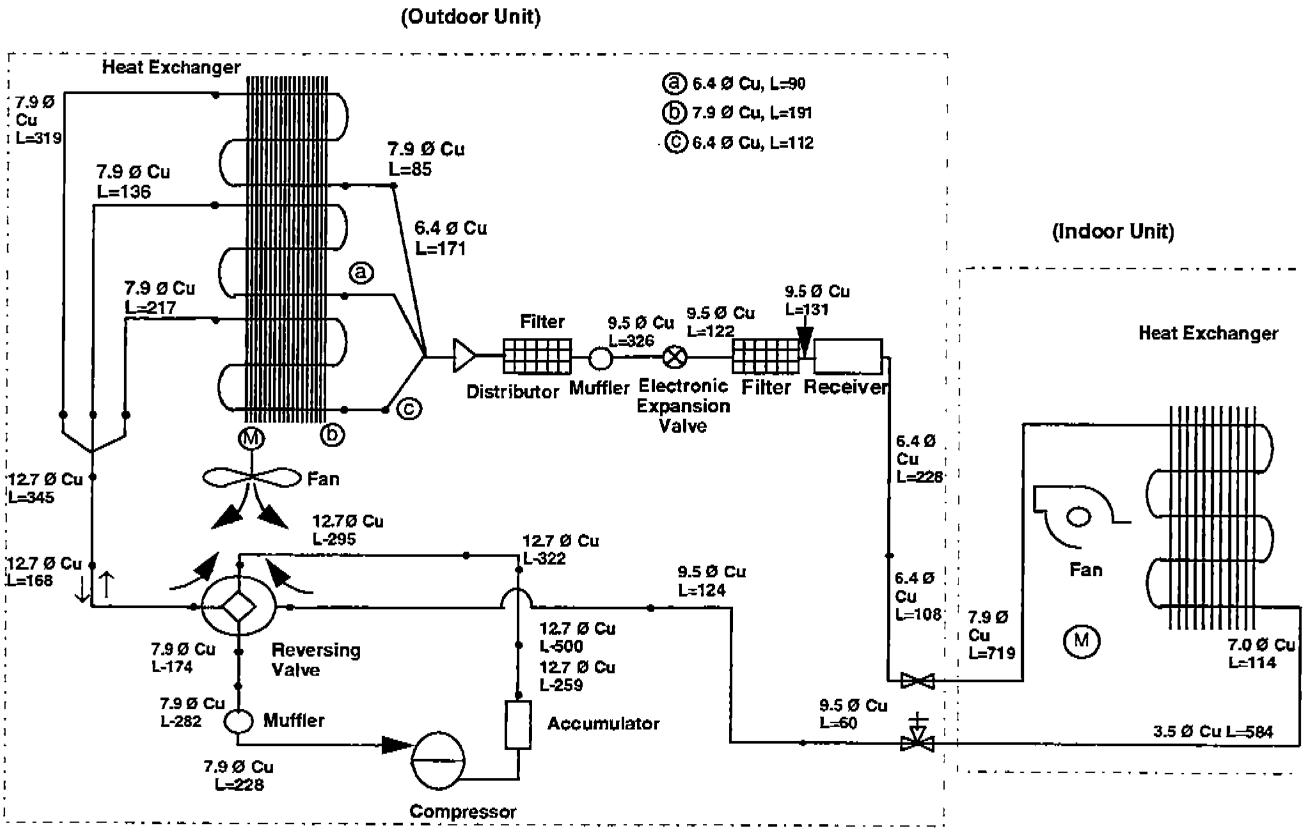
### Methodology

The risk assessment process consists of identifying hazards, estimating consequences and frequencies of occurrence, and using this information to estimate the level of risk. Fault tree analysis was used to estimate the frequency of occurrence of the identified hazard scenarios.

- **Hazard Identification**

In this case, the primary hazard is the potential for fires or explosions as a result of ignition of the flammable refrigerant due to a leak into the conditioned space. It is believed that the potential of a fire or explosion due to a leak to the outdoors is orders of magnitude lower than the risk due to an indoor leak, so while the probability of outdoor leaks was estimated, outdoor leaks were eliminated from further consideration for consequences and risks. Experience shows that an outdoor leak disperses rapidly, and the likelihood of an ignition source being present outdoors is far lower than indoors. However, servicing and installation is a special case where an outdoor leak might be dangerous, due to the presence of people, the high probability of a release, and the potential that an ignition source may be present. It has been generally accepted, and test results have confirmed, that a slow leak will disperse rapidly enough so that no localized area will reach the LFL and present a significant risk of ignition. Therefore, catastrophic leaks, defined as the loss of a substantial amount of refrigerant within a few minutes, are of primary interest.

Figure 1. Schematic Diagram of FTY223C Heat Pump



All fluorocarbons can react with a heat source to produce highly toxic substances such as HF, so toxicity of the products of combustion must also be considered. Combustion of HFCs yields two toxic products, hydrofluoric acid (HF) and carbonyl fluoride ($COF_2$). The threshold limit value (TLV) for HF is 3 ppm (volume/volume), and that of $COF_2$ is 2 ppm. [3] Therefore, combustion of HFC-32/134a, even if it did not result in a fire, could release potentially hazardous concentrations of HF. However, any fluorocarbon can decompose and release HF if it comes into contact with a flame, and HFC-32 is believed to be more stable than many non-flammable refrigerants like HCFC-22. In 1995, a person was seriously injured in Japan, presumably due to inhalation of decomposition products from HCFC-22 released from a room air conditioner. It was believed that the refrigerant came into contact with a kerosene heater, producing HF and HCl.

A series of experiments was undertaken, using a glowing NiCr wire or an open flame as heat sources, to determine the decomposition products of various fluorocarbon refrigerants. [4] The results indicate that decomposition of HFC-32 produces similar or lower concentrations of toxic products than that of other non-flammable refrigerants like HCFC-22 and HFC-134a. Since similar or worse concentrations of toxic by-products can be produced when conventional, non-flammable refrigerants such as HCFC-22 or HFC-134a come into contact with an open flame or hot surface, we believe that the substitution of HFC-32/134a (30/70) for HCFC-22 would not cause a significant increase in risk due to toxicity.

- **Ignition Sources**

Ignition sources can be classified into 3 general categories: hot gases (i.e. flames), electrical sources, and hot surfaces. Hot gases include cigarettes, matches, pilot flames, space heaters, welding torches, fireplaces, and wood or pellet stoves. Electrical sources include arcs from electric motors, switches, or faulty wiring, as well as gas appliance ignitors. Hot surfaces include toasters, room heaters, or clothes dryers. However, most common household hot surfaces, except kitchen range tops, are well below the HFC-32 autoignition temperature of 648 °C(1134 °F), and the autoignition temperature of the blend would be higher. The potential for igniting HFC-32/134a in its worst-case fractionated state was determined by various methods, many of which are described in Daikin's paper. Other small scale testing of other substances with common household ignition sources has been reported in the literature. Any source that has been demonstrated to be unable to ignite substances like HFC-152a, propane, or methane is assumed to be unable to ignite HFC-32 and its blends.

- **Data Collection**

Data was provided by manufacturers on average leak rates per month for ten different regions of Japan. This data shows a range of roughly 0.002-0.007 leaks/unit/year. The highest values occur in the Osaka and Tokyo metropolitan areas, where the service networks and reporting systems are thought to be the best. Using the most conservative value of 0.007, and adding a substantial safety margin to cover possible unreported or misreported leaks, we arrived at a conservative value of 0.01 leaks/unit/year. In fact, it is unlikely that many leaks would go unreported, since the leak data comes from warranty service calls. A customer with a unit under warranty is unlikely to have it repaired by a serviceman other than one from the manufacturer, since a repair would normally be free. Furthermore, these leaks are during the first year warranty period, and the failure rate tends to decrease after that period until many years later, around the end of the unit's useful life. Thus, the initial failure rate is a conservative estimate of the average rate over the life of the unit.

Some data on the distribution of leaks by location and equipment item were also provided. The data by equipment item were so sparse for some items that just the overall average leak rate of 1% per year has been used in the analysis. Because the risks are influenced more by where the leak occurs than by what fails, the base rate is modified by a location factor. Reliable information was available for slightly more than half of the 550 leaks studied. The base data showed that about 12% of leaks were indoors, 34% were outdoors, less than 1% were in the wall, and the location of 54% was unclear. The "unclear" data was initially split 50-50 between indoors and outdoors, which is thought to be conservative given the ratio for known locations. Given the low count for leaks in the wall, which could reflect either a low chance of leaks here or difficulty in pinpointing leak location, it was judged that 5% of leaks might occur here. This figure was subtracted from the revised total for outdoors, as reducing the number of spills outdoors has minimal effect on the risk. These adjustments gave revised totals of 39% for indoors (rounded to 40%), 5% for in the wall, and 56% for outdoors (rounded to 55%).

- **Fault Tree Analysis**

Fault tree analysis displays not only the chance of the initiating event occurring, such as a leak from the unit or a service call, but also explicitly considers the other factors and conditions that must be present for the leak to pose a hazard. These other factors may include ignition, the chance that the leak is not naturally diluted by ventilation in the room, etc.

A set of four fault trees has been developed for this study. One addresses fires which occur indoors as a result of the unit being idle. Another addresses the potential for flammable leaks outdoors for the same state. Ignition is not considered in the outdoor case due to the greatly reduced likelihood of having ignition sources nearby and the higher amount of natural ventilation. The composition of the refrigerant is such that it does not pose a significant risk while the unit is operating. If the blend is altered due to a mischarge, the risk exists, but is negligible by the time the frequency of leak is coupled with the chances of a mischarge and ignition. There is a scenario for fires from releases in the wall, regardless of operating state. There is also a scenario involving releases/venting during service calls that are ignited and lead to a fire.

The three basic fault trees that address leaks by location and operating state all consider:

- the frequency of a catastrophic leak, as small leaks are not a concern
- the location of the leak (indoors, outdoors, in the wall)
- the fraction of the time that the unit is in the operating state of interest
- the chance that the refrigerant is flammable as a result of either ambient conditions or an error in charging

In addition, the indoor and wall leaks also consider several factors regarding ignition:

- the chance that one or more ignition sources are present and on
- the fraction of ignition sources that have sufficient strength to ignite the blend
- the chance that these sources are found within the flammable zone

The fault tree for servicing considers the rate of service calls per unit and whether releases are taking place at the same time ignition sources are present. The primary ignition sources of concern are brazing and smoking by servicemen.

Two representative fault trees are given in Figures 2 and 3. The first addresses indoor fires, while the second covers fires as a result of servicing activities.

## DISCUSSION OF RESULTS

The overall results of our analysis showed, on a per-unit basis, the following frequencies of various events:

Leaks: $1 \times 10^{-2}$/year
Fires indoors: $5 \times 10^{-10}$/year
Catastrophic leaks: $2 \times 10^{-4}$/year
Fires during servicing: $3 \times 10^{-8}$/year

If all of the approximately 50 million Japanese residential air conditioners [5] were replaced with new units containing HFC-32/134a (30/70), we could expect a negligible number of fires per year due to release and ignition of the refrigerant from an operating or idle unit. We might expect an average of 1.5 fires due to servicing. In comparison, approximately 1,500 fires due to kerosene heaters are reported annually in Japan, resulting in 60 deaths. [5] U.S. data for 1993 suggests that the chance of death due to lightning strikes is about $3 \times 10^{-7}$/person-year, resulting in about 75 deaths in the population of 250 million people. The overall chance of death from fires or burns in the U.S. is roughly $1.7 \times 10^{-5}$/person-year. [6]

## RISK MITIGATION

The best method of reducing the incidence of fires due to refrigerant ignition during operation would be to reduce the catastrophic leak frequency. Reducing the number of brazed joints and improving the brazing process are the key areas to address, since the vast majority of leaks occur at joints. Such efforts are already underway in the industry, driven partly by the much higher cost of HFC refrigerants compared to HCFC-22, which has been used until now.

Safety during servicing can be improved by requiring refrigerant recovery and avoiding venting of these refrigerants. Since HFC-32/134a is zeotropic, it is expected that service technicians will need to remove all the remaining refrigerant from a system before servicing and recharging it. In the U.S., recently enacted laws require that all fluorocarbon refrigerants be recovered. However, Japan has just begun to legislate refrigerant recovery, and current Japanese regulations are not comprehensive. Therefore, many service technicians in Japan will probably continue to vent refrigerants during servicing for the next several years, since refrigerant recovery is time-consuming and expensive. Refrigerant recovery would both enhance worker safety and reduce global warming impact.

Service technician training is also critical to prevent mischarging of air conditioners with an excessive percentage of HFC-32. Technicians must charge from the liquid side of the cylinder. Warning labels such as those specified by UL 2182 will be required, and a preferred arrangement would be a valve on the cylinder to prevent vapor charging.

Risks also exist in other parts of the product life cycle. These risks were not examined in detail, but we believe that the risks during operation and servicing demand the most attention as they would occur in homes, as opposed to a more limited and controlled factory setting. Risks during manufacture are much more easily controlled, since many industries work with far more flammable substances with high levels of safety. Risks during shipment should also be controllable by proper packaging and highly reliable factory leak testing. The risk of injury during disposal could be significant, but could be reduced by requiring recovery of refrigerant prior to disposal.

## CONCLUSIONS

Risks due to fires resulting from leaks of HFC-32/134a (30/70) in a mini-split air conditioner in a Japanese residence appear to be extremely low. Risks from servicing are a greater concern but can be more easily controlled through proper training and enhanced regulation. Risks in other areas of the product life cycle should be addressed, but it appears that HFC-32/134a (30/70), would not significantly increase risks to consumers or service personnel, and therefore could be a viable substitute for HCFC-22 in residential mini-split air conditioners.

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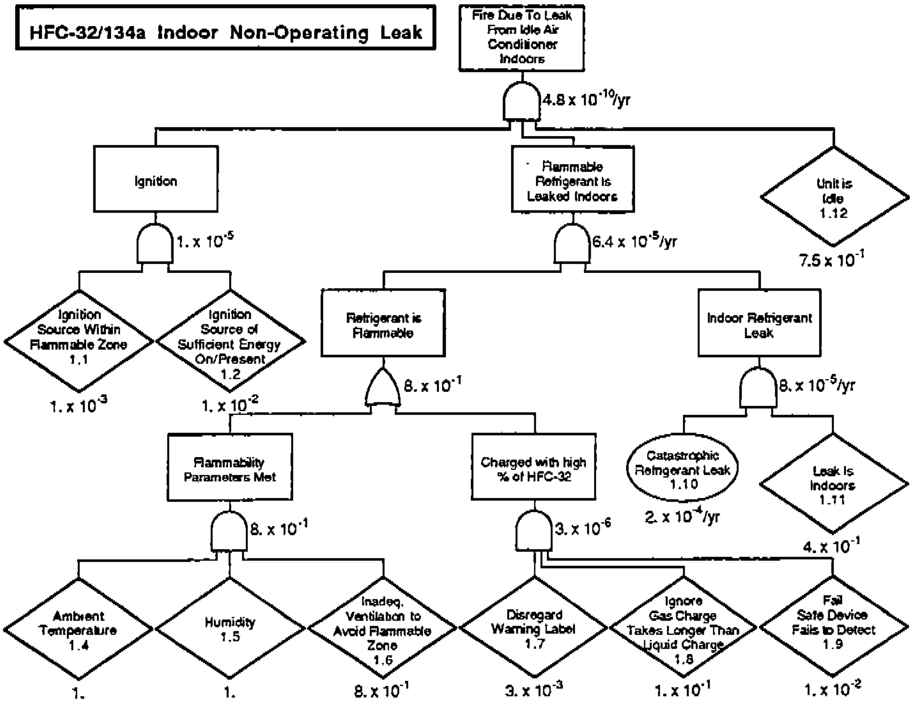
## Figure 2. Fault Tree for Indoor Fire Risk



## Figure 3. Fault Tree for Service Fire Risks