

**Experimental study of Zeotropic refrigerant mixture  
HFC-407C as a replacement for HCFC-22 in  
Refrigeration and air conditioning systems**

By

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# DECLARATION

This thesis contains no material which has been accepted for the award of any other degree or diploma, except where due reference is made in the text of the thesis. To the best of my knowledge, this thesis contains no material previously published or written by another person except where due reference is made in the text of the thesis.

Signed .....

# ABSTRACT

HCFC-22 is the world's most widely used refrigerant. It serves in both residential and commercial applications, from small window units to large water chillers, and everything in between. Its particular combination of efficiency, capacity and pressure has made it a popular choice for equipment designers. Nevertheless, it does have some ODP, so international law set forth in the Montreal Protocol and its Copenhagen and Vienna amendments have put HCFC-22 on a phase out schedule. In developed countries, production of HCFC-22 will end no later than the year 2030.

Zeotropic blend HFC-407C has been established as a drop-in alternative for HCFC-22 in the industry due to their zero Ozone Depletion Potential (ODP) and similarities in thermodynamic properties and performance. However, when a system is charged with a zeotropic mixture, it raises concerns about temperature glide at two-phase state, differential oil solubility and internal composition shift.

Not enough research has been done to cover all aspects of alternative refrigerants applications in the systems. This research intended to explore behavior of this alternative refrigerants compare to HCFC-22 and challenges facing the industry in design, operation service and maintenance of these equipments.

The purpose of this research is to investigate behavior of R407C refrigerant in chiller systems. This includes performance and efficiency variations when it replaces R22 in an existing system as well as challenges involved maintaining the system charged with R407C. It is a common practice in the industry these days to evacuate and completely recharge when part of the new refrigerant blend was leaked from the system. This has proved to be extremely costly exercise with grave environmental ramifications.

This research is intended to address challenges faced in the real world and practical terms.

Theoretical and experimental approaches used as a methodology in this work. The system mathematically modeled to predict detailed system performance and effect of the leak at various conditions. To make this feasible and accurate enough, two separate approaches made, first system performance for pure R22 and R407C, and second

system subjected to range of leak fractions. The earlier model was relatively straight forward when compared to the latter. Modeling a system charged with R407C ternary mixture and subjected to range of leaks posed enormous challenges.

A sophisticated experimental test apparatus was also designed and built. Comprehensive and detailed tests at various conditions were conducted with special attention on instrumental accuracy and correct methodology.

The first part has been successfully modeled and predicted all the factors and performance with excellent accuracy when compared to the test results. In these approaches pure refrigerants R22 and R407C were used and simulated the system behavior at range of conditions.

However, the second part was the most challenging ever. Comprehensive leak process simulations produced trends of R32/R125/R134a composition change as function of rate of leak. Starting from this point, equations have been created to represent the composition change as function of percentage of the leak. The system thermodynamic cycle was also modeled to calculate capacity, power input and COP at the range of the conditions. Despite many affecting parameters and complexity of the model, the mathematical model successfully predicted the test outcome with a very reasonable accuracy, averaging around 3% with some times reaching to 5 to 6%.

On the experimental stage the system charged with the new HFC-407C was deliberately subjected to refrigerant leak at various leak stages. The aim was to objectively determine to what extent the gas leak can be still acceptable without going through the expensive complete gas charge. The effect of leak was tested and verified at 10% steps, from 10% up to 50% mass fraction for the total charge.

It has been observed that at the leaks beyond 30%, the adverse effect on the capacity becomes more significant, from 8 to about 15% decrease. While the power input decreased at slower pace, from 3% up to about 8% depending on the test conditions. This translated to COP decrease ranging from 4 to about 7%. This capacity loss and efficiency decrease are significant figures which suggests that the system, here chiller, can not be allowed to degrade the performance to that extent and still continue operating.

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# NOMENCLATURE

|         |  |
|---------|--|
| Avg EP  | Average Evaporating Pressure                             |
| $c$     | Compressor clearance fraction                            |
| CFC     | Chloro Floro Carbon                                      |
| Const   | Constant value   |
| $COP$   | Coefficient of Performance                               |
| $C_p$   | Specific heat at constant pressure                       |
| $C_v$   | Specific heat at constant volume                         |
| CP      | Condensing Pressure                                      |
| CT      | Condensing Temperature                                   |
| DX      | Direct Expansion   |
| EP      | Evaporating Pressure                                     |
| ET      | Evaporating Temperature                                  |
| GWP     | Global Warming Potential                                 |
| GTD     | Gliding Temperature Difference                           |
| $h$     | Enthalpy   |
| HCFC    | Hydro Chloro Floro Carbon                                |
| HFC     | Hydro Floro Carbon                                       |
| HVACR   | Heating, Ventilation, Air Conditioning and Refrigeration |
| ID      | Internal Diameter  |
| IGV     | Inlet Guide Vanes  |
| LCHWT   | Leaving Chilled Water Temperature                        |
| LLSL-HX | Liquid Line Suction Line Heat Exchanger                  |
| $N$     | Number of cylinders                                      |
| $n$     | Polytropic Exponent                                      |
| ODP     | Ozone Depletion Potential                                |
| $P$     | Pressure   |
| $P_a$   | Pressure component a                                     |
| $P_b$   | Pressure component b                                     |
| $P_c$   | Critical pressure  |
| $PD$    | Piston displacement                                      |
| $P_t$   | Total pressure   |

|               |  |
|---------------|--|
| $Q$           | Heat transfer rate   |
| RPM           | Compressor speed (rev/min)   |
| $S$           | Entropy  |
| SP            | Suction Pressure   |
| $T$           | Temperature  |
| $T_c$         | Critical temperature   |
| TEWI          | Total Environment Warming Impact                                   |
| UV            | Ultra Violet   |
| $v$           | Specific volume  |
| $W$           | Compressor power   |
| $X$           | Mole fraction of liquid in mixture                                 |
| $X_{iR134a}$  | Mass fraction of R134a in liquid after the leak                    |
| $X_{iR125}$   | Mass fraction of R125 in liquid after the leak                     |
| $X_{iR32}$    | Mass fraction of R32 in liquid after the leak                      |
| $XN_{iR134a}$ | New mass fraction of R134a in the liquid after leak and topping up |
| $XN_{iR125}$  | New mass fraction of R125 in the liquid after leak and topping up  |
| $XN_{iR32}$   | New mass fraction of R32 in the liquid after leak and topping up   |
| $LR_i$        | Leak mass fraction   |
| $Y$           | Mole fraction of vapor in mixture                                  |
| $Z$           | Compressibility factor   |