R407C:

Environmentally Friendly Refrigerant

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Air-conditioning systems are widely used within MTR premises. The refrigerants in these air-conditioning systems are either hydro-chloro-fluoro-carbon (HCFC) or chloro-fluoro-carbon (HFC) which might cause certain degree of ozone depletion. Under the Montreal Protocol 1987, ozone depletion substance must be phased out in an orderly manner.

R12 refrigerant was used by the Corporation until 1996 and later replaced by R134a. Recently, R407C, another commercially alternative refrigerant, is available. In response to the concern of its stability, chiller manufacturer had arranged chiller performance tests under different conditions and the results demonstrated the impact of these concerns on cooling capacities is insignificant and R407C is an encouraging alternative to R134a.

Background

Under the Montreal Protocol 1987, halon, the ozone depletion substance, must be phased out in an orderly manner. Depending on their chlorine contents, halon is broadly categorized into two groups, namely the HCFC (hydro-chloro-fluoro-carbon) and CFC (chloro-fluoro-carbon). HCFC, with less ozone depletion potential was decided to be phased out by 2030 whereas, CFC, with higher ozone depletion potential, had been phased out since 1996. MTR's commonly used refrigerant is R12 of CFC type. Countries which signed the Montreal Protocol have stopped manufacturing of CFC as well as importing and exporting. CFC that is still in use is only the left over or recovered from replaced machines.

Current Position

In view of this phasing out and taking into the spare parts obsolescence of R12 chillers, the Corporation decided in 1992 to replace all the chillers using R12 as refrigerant, commencing in 1993. The most suitable and commercially available replacement refrigerant with zero ozone depletion potential identified at the time of replacement was R134a of HFC type. Subsequently, it was specified in all our chiller replacement projects. There were altogether 80 R12 chillers to be replaced. 12 chillers were replaced in two years under a single contract in the initial stage. Replaced chillers and refrigerant extracted from them were stored up as spare parts for supporting maintenance and refrigerant consumption for the remaining chillers.

With more R12 refrigerant extracted from replaced chillers and less remaining chillers using R12 refrigerant, the demand of refrigerant and spare parts for maintenance is becoming less. The current replacement programme has been revised to a maximum of 3 chillers per year with the target completion by 2016.

Refrigerant Development

Although R134a is one of the most popular environmentally friendly refrigerants with zero ozone depletion potential, refrigerant producers are still developing other refrigerants with better properties for different applications. In recent years, a new refrigerant with zero ozone depletion potential, R407C, has been gradually commercialized and more chiller manufacturers are producing chillers using R407C as their refrigerant. The table below compares the properties between R134a and R407C.

Refrigerant	R134a	R407C
Composition in percentage of R32 / R125 / R134a	0 / 0 / 100%	23 / 25 / 52 %
Molecular Weight with reference to R22 at 86.47	102.03	86.2
Ozone Depletion Potential	0	0
Global Warming Index	1300	1600
Atmospheric Life	R134a 13.6 years	R32 5.6 years R125 32.6 years R134a 13.6 years
Cooling Capacity comparing with R22 having the (100%) same refrigerant charge	64%	99%
Coefficient of Performance as compared with R22(100%) under the same outdoor and indoor conditions	10.89 (100%)	10.69 (96%)
Operating Pressure Differential	1.32 Mpa Medium Pressure	2.09 Mpa High Pressure
Temperature Glide (°C)	0 As a true compound, it operates with consistent pressure temperature relationship	4.9 As a zeotropic blend refrigerant, it boils and condenses in a glide range. This is not suitable for flooded chiller application resulting in freezing problem
Initial Cost of same cooling capacity fully charged up with refrigerant	Higher due to larger chiller size	Lower due to smaller chiller size
Refrigerant Cost	Lower	About 2-3 times of R134a, however, the cost is expected to drop in futurewhen demand established

From the above, the smaller molecular size of R407C, its higher cooling capacity for the same refrigerant charge and its relatively lower installation cost due to its smaller chiller size are its merits. However, R407C is a blended HFC with R32, R125 and R134a physically bonded together with composition of 23%, 25% and 52% respectively. It is only suitable for direct expansion shell & tube evaporator or tube-in-tube evaporator and not for flooded chiller applications. Furthermore, because R407C is a mixture, it is relatively less stable than a homogeneous chemical, such as R134a. When R407C leaks, the remaining mixture fractionates and its composition will change. Changes in physical properties and thus cooling capacity after leaking and subsequent refill is a major concern, however, its impact has yet to be determined.

Chiller and Refrigerant Test

In view of these uncertainties of possible change of physical properties of refrigerant R407C, chiller manufacturers are eager to carry out tests to demonstrate that the changes would be insignificant both in the composition and the resulted chiller performance.

Recently, Hitachi, one of the major chiller manufacturers, arranged a series of tests on chiller performance using R407C. The manufacturer carried out the tests in their factory using an air-cooled chiller with single compressor rated at 106kW. Results of the test will also be applicable for chiller with larger capacities using multiple compressors.

These tests were checked and certified by a representative from an independent institution, Japan Electrical Safety & Environment Technology Laboratories (JET), a recognized certification body accepted by the Electrical & Mechanical Service Department of the Hong Kong Special Administration Region (E&MSD of HKSAR) under the Electrical Products (Safety) Regulation (Cap.406 Sub. Leg.). Representatives from the E&MSD of the HKSAR and MTRC were invited to witness these tests.

Test Details and Objectives

Four tests were carried out inside a factory's testing chamber. Details are listed below.

Model	Hitachi RCUP1180A
Serial No	U7739202
Measuring Conditions (Standard Conditions)	❋ Ambient Temperature: 35 ± 0.5∞C ❋ Chilled Water Inlet/Outlet Temperature: 12 ± 0.3ºC / 7 ± 0.3ºC ❋ Power Supply: 200V ± 2% / 50Hz ± 2%

Figure 1 Measuring item and instruments

No.	Name	Model	Specifications	Manufacturer	Measuring Items
1	Clamp-on Wattmeter	3165	Maximum Measurable *Voltage : 600V*	HIOKI	Frequency, Voltage, Power Input, Current : 300A Running Current Accuracy : ± 0.5%
2	Hybrid Recorder	HR1300	Number of Measurable Point : 20 Channels Accuracy : ± 0.5%	YOKOGAWA	Suction & Discharge Gas Temp., Chilled Water Inlet & Outlet Temp., Ambient Temp.
3	Turbine Type WateType Flow Meter	CM31-125	Maximum Flow Rate : 100m3/h Accuracy : ± 0.2%	NAGANO	Water Flow Rate
4	Digital Weighing Scale	HW60KA2	Maximum Measurable Weight : 60kg Minimum Measurable Unit : 10g	A&I	Refrigerant Weight

Test 1 (100% Original Refrigerant Charge: 29.0 kg)

This was the performance test under design conditions with ambient temperature at 35ºC inside the testing chamber and chilled water temperature of 7ºC to 12ºC. The test results were used as a reference for subsequent tests. Sample of refrigerant was taken out after the test for composition analysis.

Test 2 (50% leakage from and re-fill to chiller stopped)

The purpose of this test was to determine the change in refrigerant composition and cooling capacities after refrigerant leak and subsequent refill. Gaseous leak was simulated at discharge side of compressor (at high pressure) by approximately 50% of the total refrigerant charge, 14.47kg, while the chiller stopped. Brand new refrigerant, 15.20kg, was subsequently re-charged in liquid form at low-pressure just after expansion valve. Performance test under the same design conditions as Test 1 was carried out in the testing chamber. Sample of refrigerant was also taken out after the test for composition analysis.

Test 3 (25% leakage from running chiller and refill subsequently)

The purpose of the test was to check the performance change and the impact on chiller operation with total leakage of 25% while the chiller was running and subsequently refilled. Gaseous leak of 25%, 7.62kg, was simulated at low-pressure side just after expansion valve. Brand new refrigerant, 7.63kg, was re-charged in liquid at the same location. Performance test under the same design conditions as Test 1 was carried out. The chiller was proved to be functioning properly during the whole process. Sample of refrigerant was also taken out as usual after test for composition analysis.

Test 4 (60% loading after 2 leakage tests)

The purpose of the test was to determine the part load chiller efficiency. Performance test with 60% load by raising the chilled water entering temperature and lowering the ambient temperature was carried out.

Following these tests in factory testing chamber, sample of refrigerant collected at the end of Test 1, 2 and 3 were sent to an independent laboratory, Gas Technology Service Group, Technical Centre, Mitsui-Dupon Fluroro Chemicals Ltd., Tokyo for composition analysis.

Results of the tests

Below shows the test results, highlighting the changes in cooling capacities and refrigerant composition.

Test	1	2	3	4
Measured Cooling Capacities, kW	107.00	104.80	109.10	64.19
Refrigerant composition in % of R32, R125 and R134a	24.89/24.61/ 50.45	22.77/23.35/ 53.84	23.53/23.71/ 52.72	Not applicable

Insignificant change in capacity, within 3% as compared with the full load conditions was observed though there were variations in refrigerant composition. The chiller was running properly even with 25 % of the refrigerant charge released while in operation. Part load performance was also acceptable after significant refrigerant leak and subsequent refill.

Conclusion

Changes in cooling capacities and refrigerant composition after leaking and subsequent refill were observed. The degree of change and impact on cooling capacities were considered insignificant.

R407C chiller can be considered as an alternative having taken into account its merits and limitations. It is worth broadening our choice of chillers and refrigerants where applicable.

References

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