Circular economy ecosystem to Recover, Recycle and Re-use F-gases contributing to the depletion of greenhouse gases - LIFE Retradeables

Deliverable: Evaluation of current solutions for R134a

Action C2

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Abstract

This deliverable is a brief review of current solutions for the identification and recovery/recycling of R134a refrigerant, which is widely used in various cooling and air conditioning applications, such as commercial and domestic refrigeration and chillers. Since R134a was originally developed to replace R12 in car air conditioning (AC) systems, it was also the refrigerant of choice for the automotive industry until recently. The next generation refrigerant for automotive AC is now considered to be R1234yf due to its low Global Warming Potential (GWP), that is below the limit set by the EU's Mobile Air-Conditioning (MAC) Directive. In fact, R1234yf must be used in every single new car manufactured for the EU market from 2017 onwards. Especially for the automotive sector, there are tools that allow both the identification and the recovery, recycling and recharging of either R134a or R1234yf. However, it is not possible to analyse the composition of the refrigerant. On the other hand, diagnostic refrigerant analysers are available for HVAC-R sector, but they cannot perform oil and moisture removal. A different device must be used for this purpose, thus making the whole process more time-consuming, adding complexity and also increasing the service's capital cost. Consequently, the background of the existing situation is directly linked to one of the top priorities of LIFE Retradeables project: the development of a prototype unit that will be fully applicable to both pure HFCs (R32, R134a) and HFC blends (R410A, R407C and R404A), combining a portable refrigerant composition analyser with the Daikin-branded recovery and recycling machine (R-Cycle unit).

Contents

1 R134a properties and applications

1.1 Guaranteed commercial specifications

Table 1: Guaranteed commercial specifications of R134a refrigerant.*

Standard Specifications	Limit Value
Purity	≥ 99.5% weight
Water Content	≤ 10 ppm weight
Non-condensable content (gas phase)	≤ 1,5% volume
High boiling residues	≤ 0.01% volume
Acidity (HCl)	≤ 1 ppm weight

** Source: AHRI Standard 700-2019*

1.2 Main applications

R134a is a hydrofluorocarbon (HFC) commonly used in various refrigeration applications of the residential, commercial and industrial sector, as well as for air conditioning, liquid refrigeration and heat pump applications. R134a was until recently the fluid of choice for automotive air conditioning system manufacturers, replacing R12 refrigerant. R134a also serves as an alternative working substance in domestic refrigerators and other vapour compression systems that previously operated with R12.

R134a is suitable for:

- ✓ medium and high temperature cooling;
- ✓ air conditioning in residential buildings;
- ✓ light air conditioning;
- ✓ vehicle air conditioning and industrial applications, such as centrifugal coolers.

R134a is also a common element in many HFC refrigerant mixtures, and it is also used in applications that require a propellant.

R134a applications and use:

- In water and liquid cooling solutions and heat pumps, the refrigerants can be used in accordance with the F-gas Regulation (EU 517/2014) until 1 January 2030.
- In commercial and professional refrigeration equipment, use is permitted on the primary side of cascade systems – Power exceeding 40 kW as of 2022.
- Refrigerated/frozen transport, use permitted in accordance with the F-gas Regulation until 1 January 2030.

1.3 Physical properties

Table 2: Physical properties of R134a refrigerant.

Physical properties	Units	R134a
Molecular weight	g/mol	102
Boiling point (at 1,013 bar)	°C	-26,1
Melting point/Freezing point	°C	-103
Critical temperature	°C	101,1
Critical pressure	bar	40,67
Critical density	kg/m^3	508
Liquid density (25°C)	kg/m^3	1.206
Liquid density (0°C)	kg/m^3	1.293
Saturated vapour density (at boiling point)	kg/m^3	5,28
Vapour pressure (25°C)	bar	6,657
Vapour pressure (0°C)	bar	2,92
Heat of vaporization at boiling point	KJ/kg	217,2
Specific heat of liquid at 25°C (1,013 bar)	KJ/(kg.K)	1,44
Specific heat of vapour at 25°C (1,013 bar)	KJ/(Kg.K)	0,85
Viscosity of liquid (25°C)	cP	0,202
Surface pressure (25°C)	mN/m	8,09
R134a Solubility in water (25°C at 1,013 bar)	% weight (wt%)	0,15
Volumetric cooling capacity (-25°C)	Kg/m^3	1.192,11
Flammability		No
Ozone Depletion Potential (ODP)	(R11=1)	0
Global Warming Pollution (GWP)	(CO_2=1)	1.430

1.4 Replacement refrigerants for R134a

- Substitutive/alternative refrigerants: R1234yf, R1234ze, R450, R513A.

R1234yf is an HFO refrigerant developed in order to replace R134a in new car air conditioning systems. R1234yf fully meets the requirement of the EU MAC Directive for the use of a refrigerant in the automotive industry with a GWP value below 150. In addition, R1234yf can also be used in chillers designed for its use. All the **key characteristics of R1234yf** are summarized below:

- ✓ Application: Automotive air conditioning and chillers (designed for its use).
- ✓ GWP: 1 (GWP value based on IPCC 5th Assessment).
- ✓ Its use was introduced in 2011 and rolled out across all new cars from January 2017.
- ✓ R1234yf has a GWP of less than 1 – that's 99.9% lower GWP than R134a.

- ✓ R1234yf has an atmospheric life of 11 days compared to a 13-year lifespan for R134a.
- ✓ R1234yf compares in efficiency to R134a and has the same cooling capacity.
- ✓ Vehicles using R1234yf are expected to use less fuel and produce 20-30% less CO_2 which means a significantly reduced carbon footprint.
- ✓ R1234yf is safe to use. It has undergone rigorous testing by third parties and car manufacturers, and is verified as safe to use.

2 Automotive products

2.1 Recovery/Recycle/Recharge (RRR) machines

Recovery/Recycle/Recharge (RRR) machines are used to remove either R134a or the newer R1234yf from car AC systems (**Figures 1 & 2**). There is currently a wide range of models commercially available for each of the two types of refrigerants above. These can be classified into two main categories: i. **fully automatic RRR machines** incorporating various automatic features and ii. **semi-automatic RRR machines**, where only manual A/C service procedures are applied.

Figure 1: Recovery/Recycle/Recharge (RRR) machines for the removal of R134a/R1234yf refrigerant from automotive air conditioning (AC) systems.

Figure 2: Features available via the built-in touch screen of the RRR machines.

An overview of the key features of Recovery/Recycle/Recharge (RRR) machines is presented in **Table 3** below:

Table 3: Key features of Recovery/Recycling/Recharge (RRR) machines.*

Features	R134a Semi – Automatic	R134a Fully Automatic	R134a & Hybrid	R1234yf & Hybrid
Display - Touch Screen	x	x	x	x
Automatic and Manual Procedures	Manual procedures only	x	x	x
Refrigerant Database	Optional	x	x	x
Automatic Vacuum Leak Test: Programmable	x	x	x	x
Auto Oil Discharge	x	x	x	x
Auto and Manual Air Purge	x	x	x	x
Auto Filter and Full Tank Alarm	x	x	x	x
Low Refrigerant Alarm	x	x	x	x
Auto Oil Injection	N/A	x	N/A	N/A
Thermal Printer	Optional	Optional	x	x
Hose Flushing	N/A	N/A	x	x
Vehicle A/C System Flushing	N/A	N/A	x	x
Tank Heater	x	x	x	x
Vacuum Pump**	x	x	x	x
Refrigerant Identifier	N/A	N/A	N/A	x
On-board Instruction Manual	x	x	x	x
Multiple Languages	x	x	x	x
On-board Unit Conversion Calculator	x	x	x	x
New Cabinet Design for Increased Air Flow	x	x	x	x
Large Analog Gauges	x	x	x	x
Hard Wired Power Cord	x	x	x	x
Hose Coupler Storage	x	x	x	x
Solid Durable Wheels with Locking Casters	x	x	x	x
Multi-coloured LED Status Bar	N/A	x	x	x
Self-Diagnostic Check	x	x	x	x
Wi-Fi Capable	x	x	x	x
Dust Cover	x	x	x	x
Dimensions (mm): 1150 (h) x 600 (w) x 770 (d)	x	x	x	x

* The features listed in the table may vary to some extent from model to model and from manufacturer to manufacturer.

** The CFM (cubic feet per minute) of the vacuum pump depends on the manufacturer and model. 3 CFM, 6 CFM, 1.5 CFM dual stage are some of the values reported in product brochures available online (e.g.: Mastercool and Robinair).

In the case of automotive R1234yf recovery, <u>an internal or an external refrigerant identifier is required</u> (**Figure 3**). The identifier ensures that the refrigerant is at least 98% pure R1234yf before the machine allows the recovery process to start. Refrigerant analysers are also recommended prior to servicing automotive R-134a systems.

Figure 3: Portable composition analysers/identifiers for automotive A/C systems.

3 HVAC-R products

3.1 Portable Composition Analysers

Portable composition analysers provide a quick, easy and accurate means of measuring vapour or liquid refrigerants to confirm purity while detecting the presence of other harmful refrigerants or air (**Figure 4**). Diagnostic tools of this type utilize non-dispersive infrared (NDIR) technology to determine the weight concentration of many common refrigerants prior to service or use, including R134a. Refrigerant analysers promote a cleaner recovery process as well as reducing the amount of mixed gas recovered and therefore the amount of refrigerant that must ultimately be destroyed (improving the industries' ecological footprint).

Figure 4: Portable composition analyser for multiple HVAC-R applications.
(Product link: https://www.mastercool.com/product/69legend-hfc/)

An overview of the key features of portable composition analysers is presented in **Table 4** below:

Table 4: Key features of portable composition analysers.

Portable Composition Analysers: Key Features
Quick and accurate determination of refrigerant purity
Advanced ergonomic design
Percentage purity analysis
Analysed Refrigerants: R22, R32, R134a, R404A, R407C, R410A, Hydrocarbons (HC) and Air
Identified Refrigerants: R12, R1234yf, R408A, R409A, R417A, R421A, R421B, R422A, R422B, R422C, R427A, Hydrocarbons
Display of the air percentage (%) independent of the refrigerant sampled
Multiple Languages
Vapour or Liquid Sampling
Internal thermal printer
Improved oil resistance with user replaceable hose assembly
User Interface: Graphic LCD display, soft buttons
Ultra-fast test time
USB port for test data storage and software updates
All accessories stored in hard shell carry/storage case

It is noted that Daikin has also produced a relevant video on how to use a portable composition analyser (YouTube link: https://youtu.be/fok1xr7Lo7c).

3.2 Recovery pumps

The recovery systems currently applied in the HVAC-R sector can be classified into 2 main categories: i. **single-cylinder recovery pumps** and ii. **twin-cylinder recovery pumps**. Furthermore, **Figures 5 & 6** are representative of the operating outline of the 2 available refrigerant recovery methods: direct vapour or liquid recovery and push - pull liquid recovery method, respectively. The former is considered as the standard or "common" recovery procedure. The latter permits recovery of large volumes of liquid refrigerant from HVAC-R systems. Nevertheless, some systems may not have liquid service port, thus preventing the push-pull technique from being used.

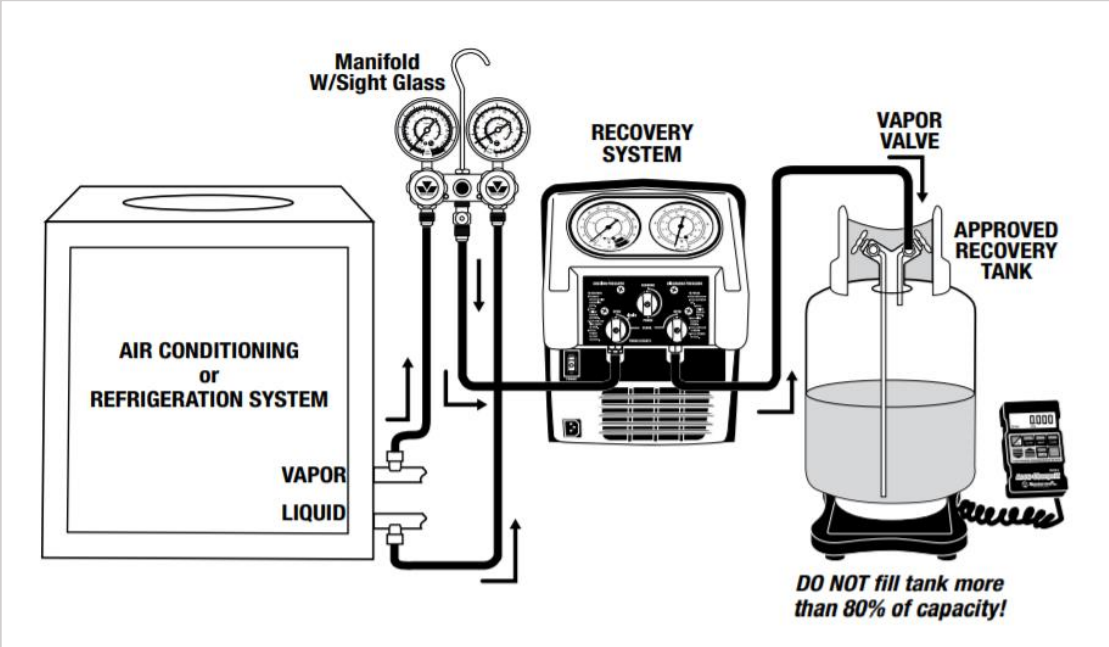

Figure 5: Direct vapour or liquid recovery procedure in the HVAC-R sector (standard method).

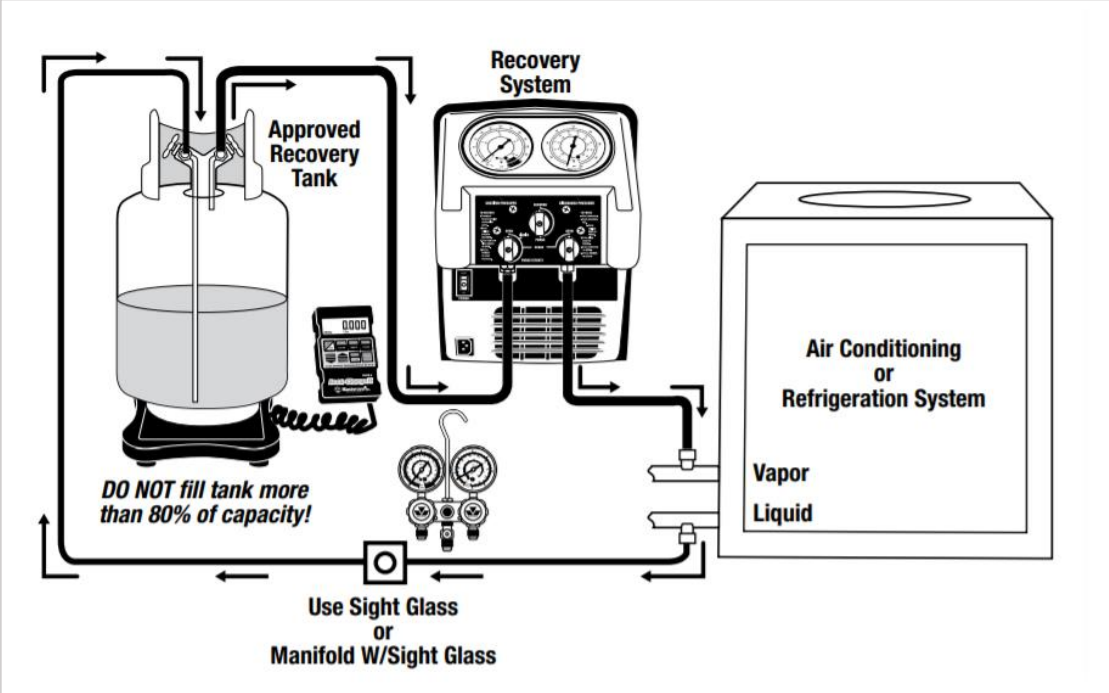

Figure 6: Push - Pull liquid recovery procedure in the HVAC-R sector (method only used on large systems where the liquid is readily accessible).

It is noted that Daikin has also produced a relevant video on how to use a recovery pump (YouTube link: https://youtu.be/p4tS_TcrY0c).

3.2.1 Single-cylinder recovery pumps

Single-cylinder recovery pumps are compact, lightweight and work with all refrigerants, including R134a (**Figure 7**). They are ideal for commercial, residential or industrial appliance applications. Moreover, these recovery systems offer a state-of-the-art oil-less compressor [(1)] with a built-in high volume cooling fan. It is precisely the above innovative design that offers maximum cooling efficiency, thus keeping the compressor working at high capacities even at the hottest temperatures. The compressor is also protected by an automatic low pressure cut-off switch that shuts off the unit once the recovery is complete. This AUTO SHUT-OFF feature eliminates the risk of compressor failure and reduces the user's need to monitor the entire recovery system.

(1). Oil-less Compressor horsepower (HP) is a manufacturing characteristic that varies. Some common values are: 1/2, 1/3, 3/4 & 1.

Figure 7: Single-cylinder refrigerant recovery pumps available on the market (HVAC-R sector).

In addition, recovery systems of this type offer color-coded gauges with pressure readings in PSI, BAR and MPa. The stainless-steel ball valve designed manifold controls the flow smoothly and quickly with only a 1/4 turn. With all of this protected by a reinforced hard plastic case, single-cylinder recovery pumps are considered to meet all the recovery needs of F-gas technicians. An oil separator may also be included in some kits, so along with the filter drier and sight glass, to allow field users to actually clean the recovered refrigerant and potentially reuse it. However, if there is a need to recover multiple, different refrigerants using this unit, a separate filter dryer must be labelled and used for each individual refrigerant type.

An overview of the key features of single-cylinder recovery pumps is presented in **Table 5** below:

Table 5: Key features of single-cylinder recovery pumps.

Single-cylinder recovery pumps: Key Features
Compact and Lightweight: up to 40% smaller footprint, easy to carry.
Oil-less Compressor: Capable of handling both liquid and vapour recovery.
Handles Almost All Refrigerants: Works with all common CFC, HFC, HCFC refrigerants including R-410A.
High Efficiency Cross Flow Design: Layout of fan and condenser is maximized for shorter cycle times.
High Pressure Safety Shut-off Switch: Eliminates potential for cross-contamination and saves time.
Easy to Operate, Rugged Case: Easy to read gauges, comfortable handle and simple 2 valve controls.
IEC connector and power cord

3.2.2 Twin-cylinder recovery pumps

Twin-cylinder recovery pumps offer the same levels of reliability as single-cylinder ones, while incorporating certain additional features that allow both maximum recovery capacity and a reduction in size and weight (**Figure 8**). The new double piston compressor design and oversized fan and condenser cooling make these new recovery systems the most complete solution to the recovery needs of F-gas technicians (**see Figure 9**).

Figure 8: Twin-cylinder refrigerant recovery pumps available on the market (HVAC-R sector).

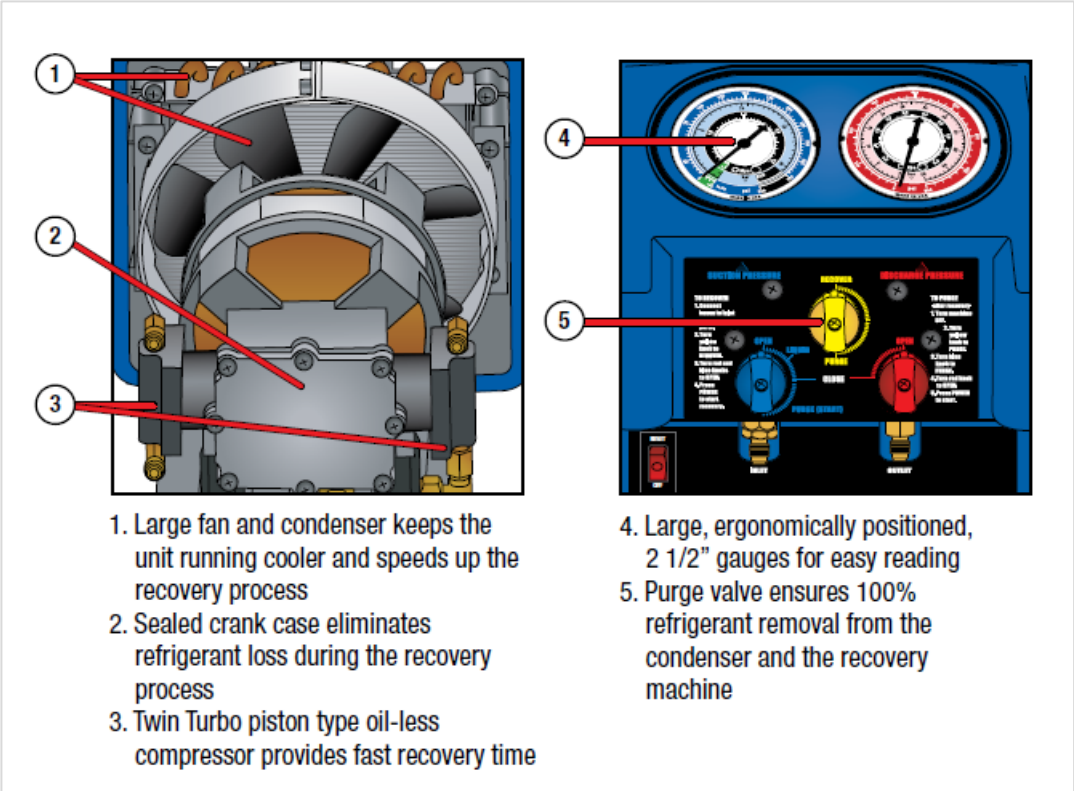

Figure 9: Extra features of twin-cylinder recovery pumps compared to single-cylinder pumps [(2)].

An overview of the key features of twin-cylinder recovery pumps is presented in **Table 6** below:

Table 6: Key features of twin-cylinder recovery pumps.

Twin-cylinder recovery pumps: Key Features
Twin-Cylinder Design: Provides faster recovery time (Better recovery performance).
Oil-less Compressor: Capable of handling both liquid and vapour recovery.
Oversized Condensers and Fan: Larger condenser area and larger fan allow for maximum cooling and shorter cycle times.
High Pressure Safety Shut-off Switch: Automatically shuts off machine if pressure rises above 550 psi
Self-Purge Feature: Eliminates potential for cross-contamination and saves time.
Easy to Operate, Rugged Case: Oversized pressure gauges, comfortable handle and simple controls.
Handles Almost All Refrigerants: Works with all common CFC, HFC, HCFC Refrigerants including R-410A.
IEC connector and power cord

(2). The considered dimensioning of the gauges is indicative.

Conclusions

A significant number of HVAC-R and automotive products related to the overall R134a refrigerant recovery process are currently available on the market. However, none of them is regarded as a total solution. Therefore, the development of a **prototype unit** is one of the key objectives of the project in order to enable real-time and on-site composition analysis, recovery and recycling of the refrigerant contained in HVAC-R equipment. For this purpose, the project partners (DENV/DACE, MAT4NRG, NTUA) are working on a completely innovative concept involving the **combination of a portable composition analyser and Daikin's refrigerant Recovery and Recycling unit** (**see Figure 10**).

The design and basic operating principles of the R-Cycle unit are quite similar to those of RRR engines now used in the automotive industry. However, the R-Cycle unit will be strongly differentiated by the fact that it will be applicable to both pure HFCs (e.g., R32 or R134a) and HFC blends (e.g., R410A, R407C and R404A). Especially in the case of mixed refrigerants, such as R-410A, it is possible to maintain them with minimum changes in composition, because the unit will directly absorb the refrigerant in liquid form and fill it into a cylinder.

Moreover, **3 steps of recycling** will take place to remove the maximum of impurities, such as oil and moisture:

- Oil separation and electrostatic filtering
- Filter drier to remove moisture
- Liquid separation via evaporation

Figure 10: Daikin's Portable Unit for Recovery and Recycling of Refrigerant (R-Cycle unit).

The ultimate goal is the **official launch of the prototypes in the European market** in a short time after the end of the demos (June 2023). Once the final validation of the measurements by MAT4NRG and the addition of IOT capabilities by DACE, with the support of NTUA, is completed, the prototype units with the standard features of F-gas composition analysis, identification, recovery and recycling, are planned to come into production line with the perspective to be later transferred to other sectors such as electronic equipment, air conditioning for the automotive industry and commercial refrigeration.