Auto AC-1
Development Update

Phoenix Summit
July 2007

INEOS Fluor

Focused on refrigerants

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Summary

- Auto AC-1 Overview
- Properties
- A/C Cycle Performance
- Stability and Materials Compatibility Testing
- Leakage, Servicing and Handling
- Environment and Toxicity

Auto AC-1 overview

Zeotropic refrigerant with no additives

- Designed as a non-flammable near ‘drop-in’
- Similar thermodynamic characteristics to R-134a
- Operating pressures slightly lower than R-134a
- Temperature glide in evaporator 3-4K

Compatible with PAG and POE Oils and with commonly used materials

Equipment optimisation studies through collaboration with industry e.g. SAE CRP150 program

Auto AC-1 properties

Close – not identical – to R-134a

- Effective vapour pressure in cycles slightly lower than R-134a
- Similar critical point
- Lower refrigeration effect for typical A/C cycle (higher mass flow-rate offset somewhat by higher molecular weight)
- Higher heat capacity – lower compressor discharge temperatures and greater benefit of subcooling
- Temperature "glide" effect

….suggests best performance achievable by optimisation of expansion valve, hose sizes and considering benefits of IHX

Thermodynamic comparison

	Auto AC-1	R-134a
Critical point	~102°C/39 bara	101°C/40.6 bara
Evaporator pressure at 4°C mean evaporating temperature	3.3 bara	3.5 bara
Condenser pressure at 55° mean condensing temperature	14.3 bara	15.0 bara

Glide in evaporator +3K with no pressure drop, +1K with pressure drop of 0.25 bar

Glide in condenser 5K with no pressure drop, 6 K with pressure drop of 0.25 bar

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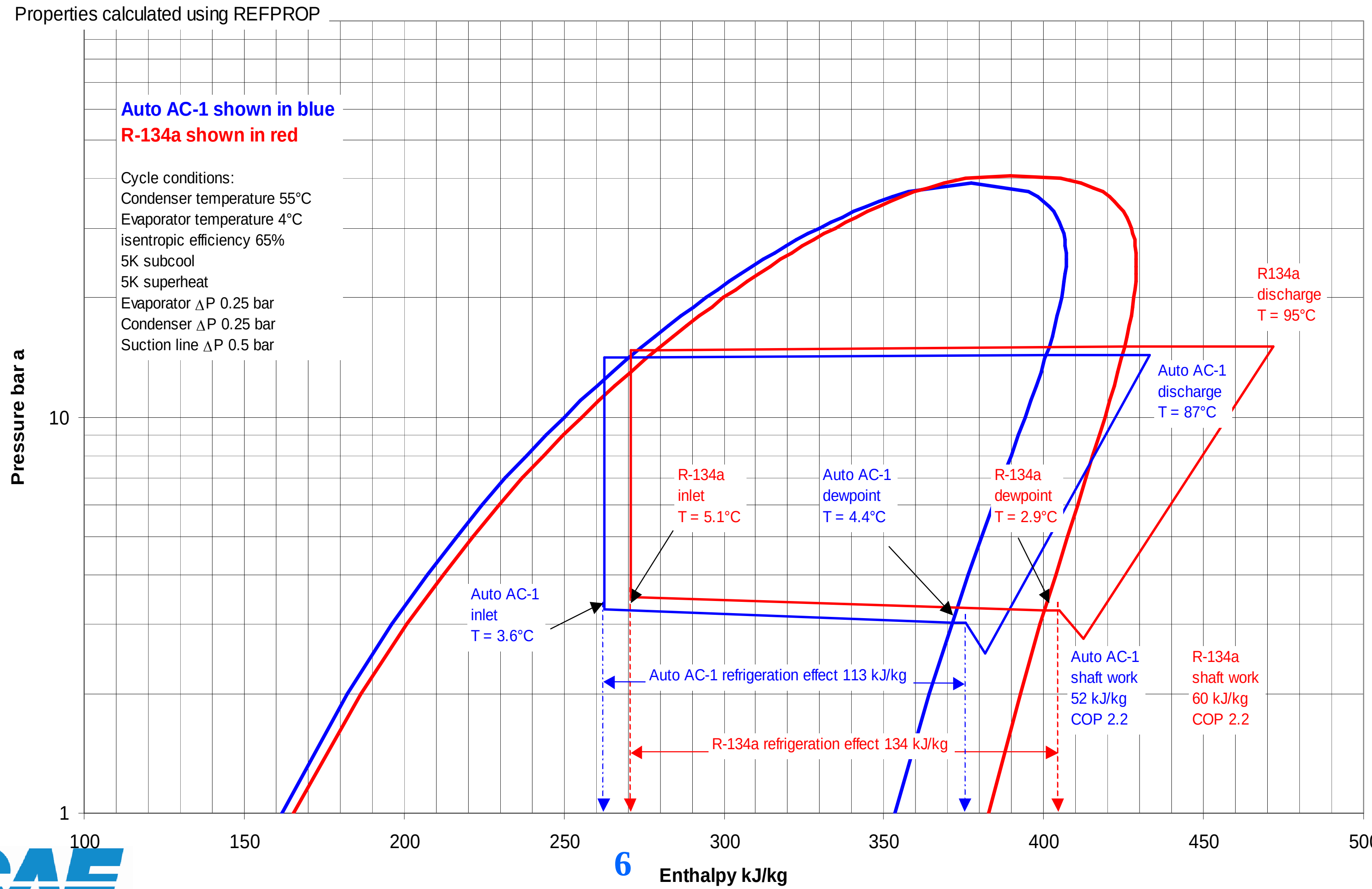
Mollier chart: Auto AC-1 and R-134a



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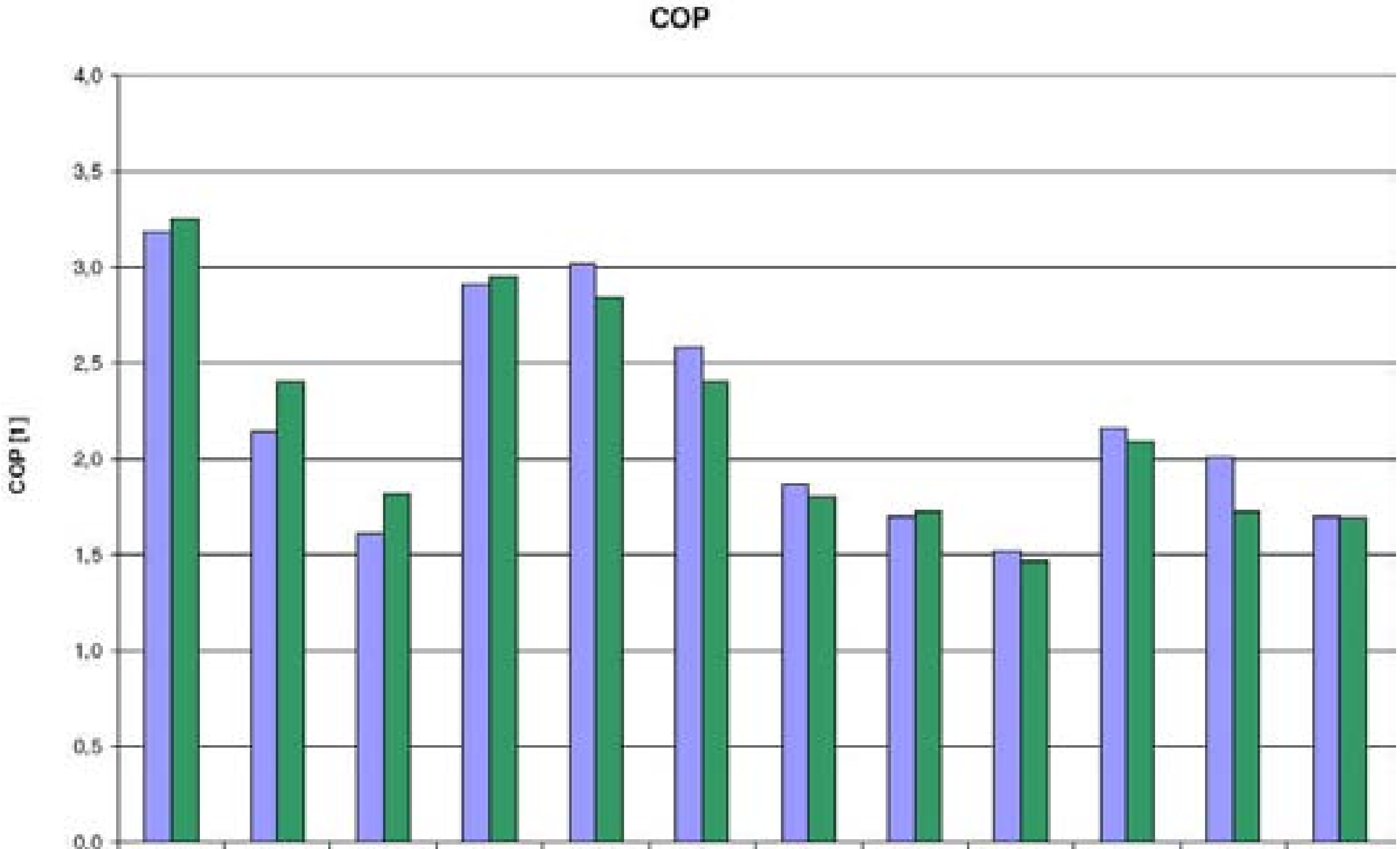
Typical bench test data: R-134a system

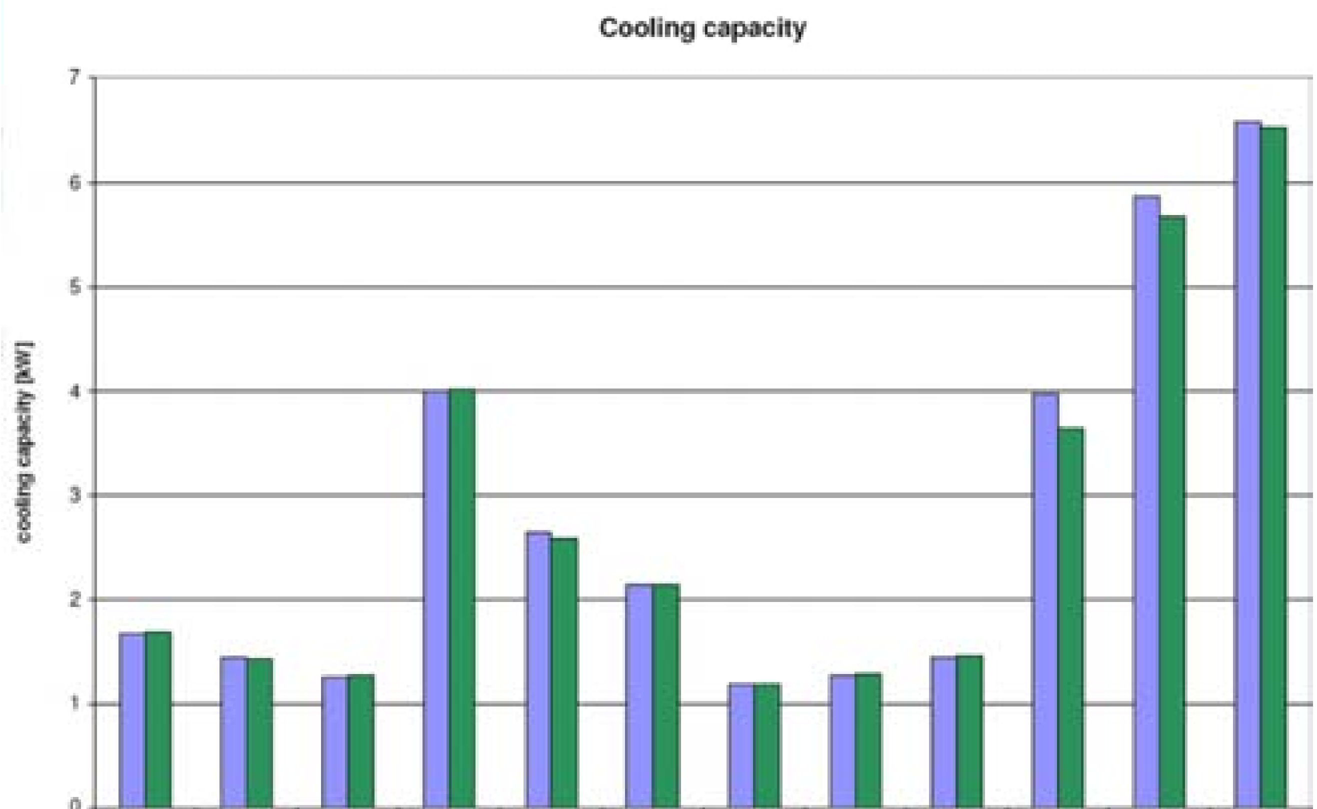
(with TXV and charge adjustment)



	1,1	1,2	1,3	2,1	2,2	2,3	3,1	3,2	3,3	4,1	4,2	4,3
R134a	3,18	2,14	1,61	2,91	3,02	2,58	1,87	1,70	1,52	2,16	2,01	1,70
AC-1	3,25	2,40	1,82	2,95	2,84	2,40	1,80	1,73	1,47	2,09	1,73	1,69

Typical bench test data:R-134a system

(with TXV and charge adjustment)



	1,1	1,2	1,3	2,1	2,2	2,3	3,1	3,2	3,3	4,1	4,2	4,3
R134a	1,67	1,44	1,26	4,00	2,64	2,14	1,18	1,27	1,44	3,97	5,87	6,59
AC-1	1,68	1,43	1,27	4,02	2,58	2,14	1,18	1,28	1,45	3,65	5,68	6,54

Materials compatibility

Thermal stability

- 175°C 14-day typical test
- Good compatibility with metals

Polymer & Lubricant stability

- 130 °C autoclave test for 14 days with refrigerant and lubricant
- Lubricants used: commercial PAG lubricant and a typical commercial POE
- Materials tested to date include: range of artificial polymers and natural rubber
- Thus far that the behaviour of a range of polymers with Auto AC-1 is rather similar to that of R-134a
- Testing continues

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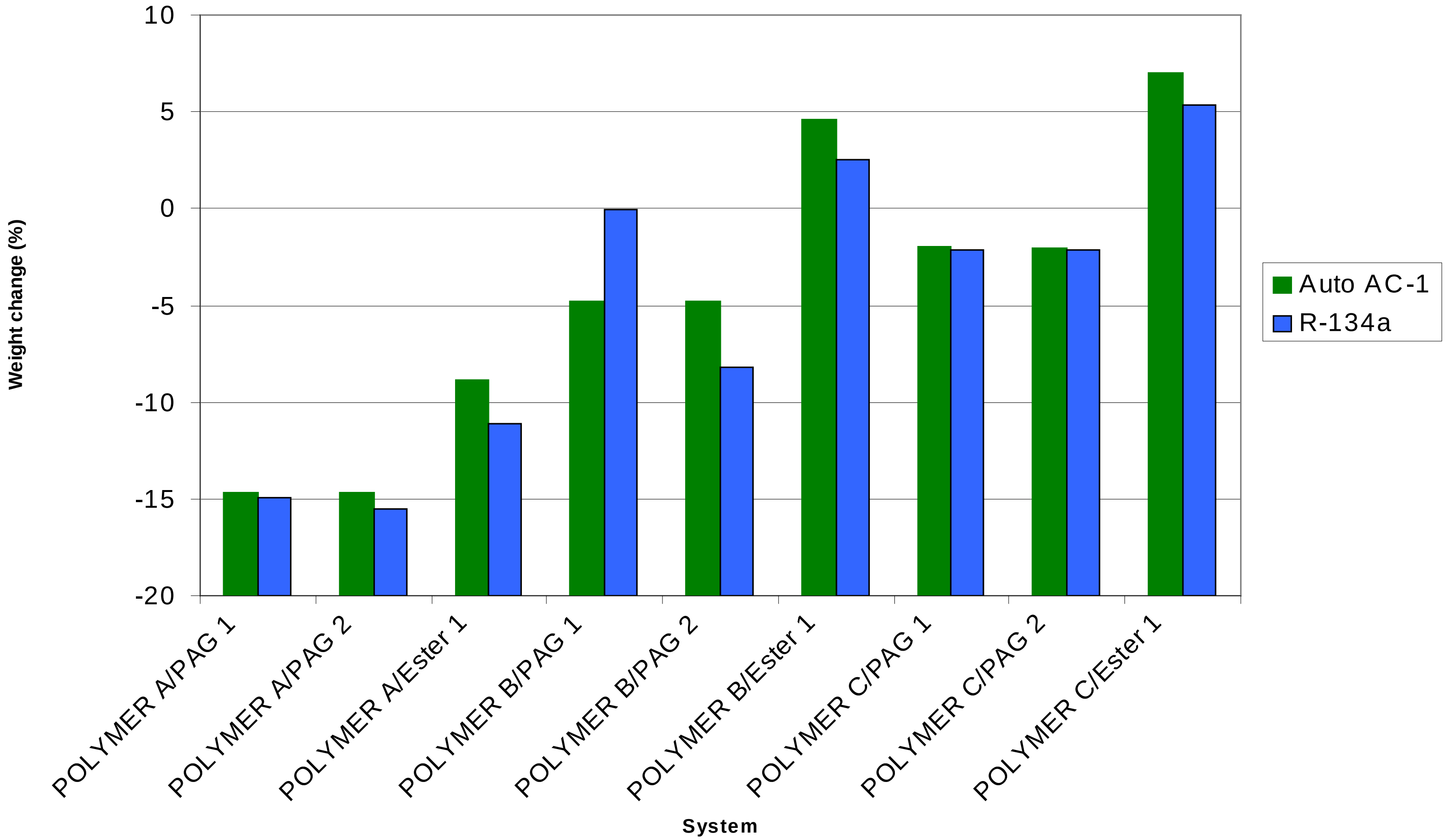
Weight change of elastomers

by autoclave testing 130°C/14 days



Thermal stability with oils

ASHRAE sealed tube method in stainless steel autoclaves

175°C for 2 weeks as typical test condition

Equal mass of refrigerant and lubricant (50 gm) with metal test coupons (Cu/Fe/Al)

Lubricant	Temperature	BEFORE TEST			AFTER TEST				METALS % weight change		
		Moisture (ppm)	T.A.N (mgKOH/g)	Colour (Hazens)	Moisture (ppm)	T.A.N (mgKOH/g)	Colour (Hazens)	Fluoride (ppm)	Copper	Aluminium	Steel
PAG A	175°C	137.9	0.01	10	208.6	0.91	200	131	0.00	0.11	0.01
PAG A	175°C	129.8	0.01	10	147.3	0.80	250	133.60	0.05	0.26	0.06
PAG B	175°C	138.7	0.18	10	134	0.17	50	25.20	0.03	0.17	0.03
PAG C	175°C	144.4	0.01	10	190.9	0.5	100		0.03	0.12	0.03
POE A	175°C	63.8	0.01	10	50.6	0.01	70		0.01	0.03	0.02
POE B	175°C	59.78	0.01	10	46.3	0.08	30		0.07	0.22	0.03

Variations in TAN being investigated

Basestock compatibility with fluid is acceptable

Zeotropic refrigerants

Use of zeotropic refrigerants not wide-spread in the automotive sector.

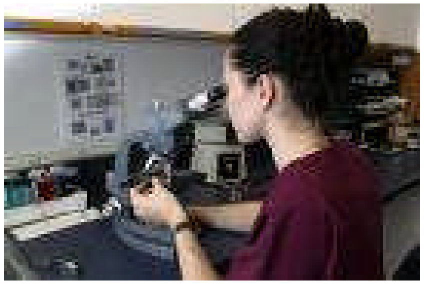
Widespread in the stationary refrigeration and air-conditioning sectors.

- For example R-407C

Aspects

- Temperature glide in evaporator and condenser
- Vapour and Liquid in a container have different compositions
  - Effect of leakages
  - Effect on handling

Aspects are predictable by simulations



Leakages

Theoretical Scenarios

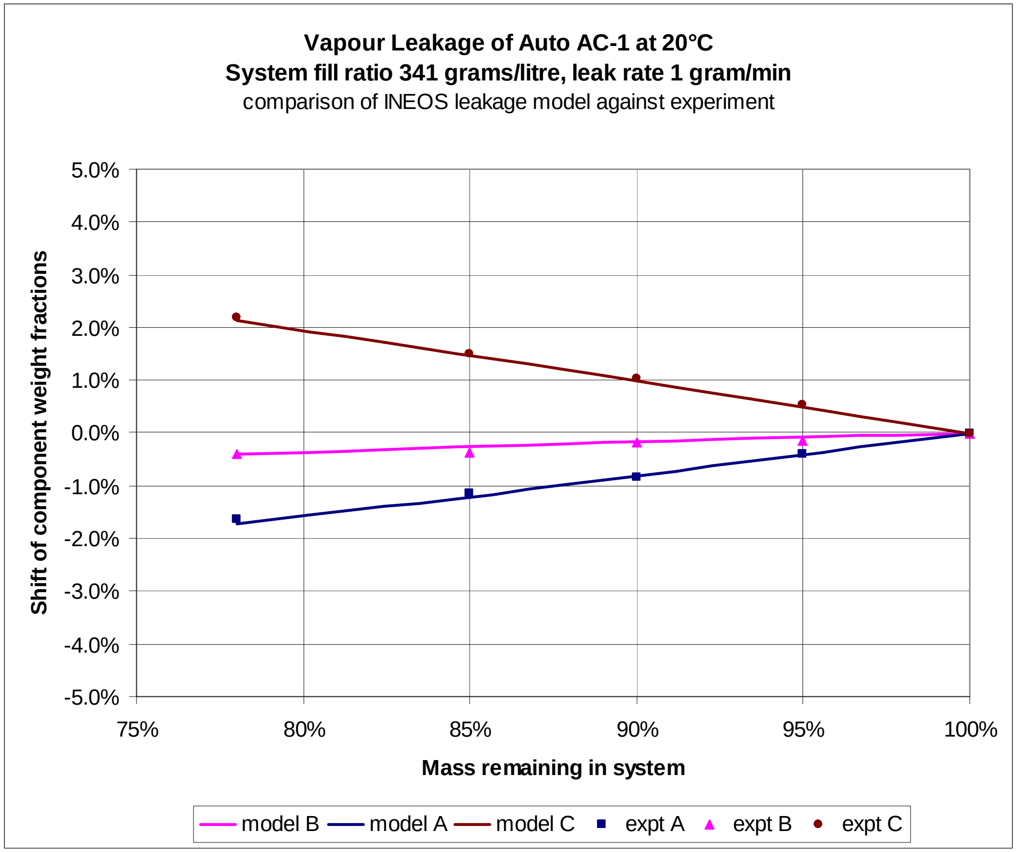
- Selective permeation through hoses
- Vapour leak from a static system (through shaft seal)

Findings:

- Neither composition of liquid nor of vapour will ever be flammable
- At a leak of 10-40 g/a it is practically unlikely that composition shift effects will be an issue before a replacement of the lost fluid is needed.
- About 50% of charge need to be lost before effects are expected
- Performance is largely recovered by top up.

Leakage simulation and test

Composition measured by GC
Leakage model used to predict composition
Excellent agreement
Effects are:
- ✓ Predictable
- ✓ Repeatable
- ✓ Within blending tolerances



Leakage effect on performance

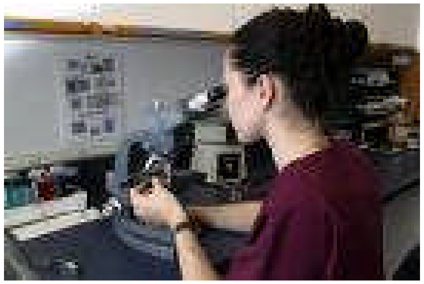
Composition after a slow vapour leak of 30% tested

Performance of the “leaked” composition modelled

- Calculation predicted loss of capacity of 7% and of COP of 0.5%.

Observed capacity loss in test 3-5%; no change in COP

- ✓ Rarely a need to remove or discard the residual charge on the basis of composition shift alone.
- ✓ Recovered refrigerant could be replaced in the system and could be topped up with fresh Auto AC-1.



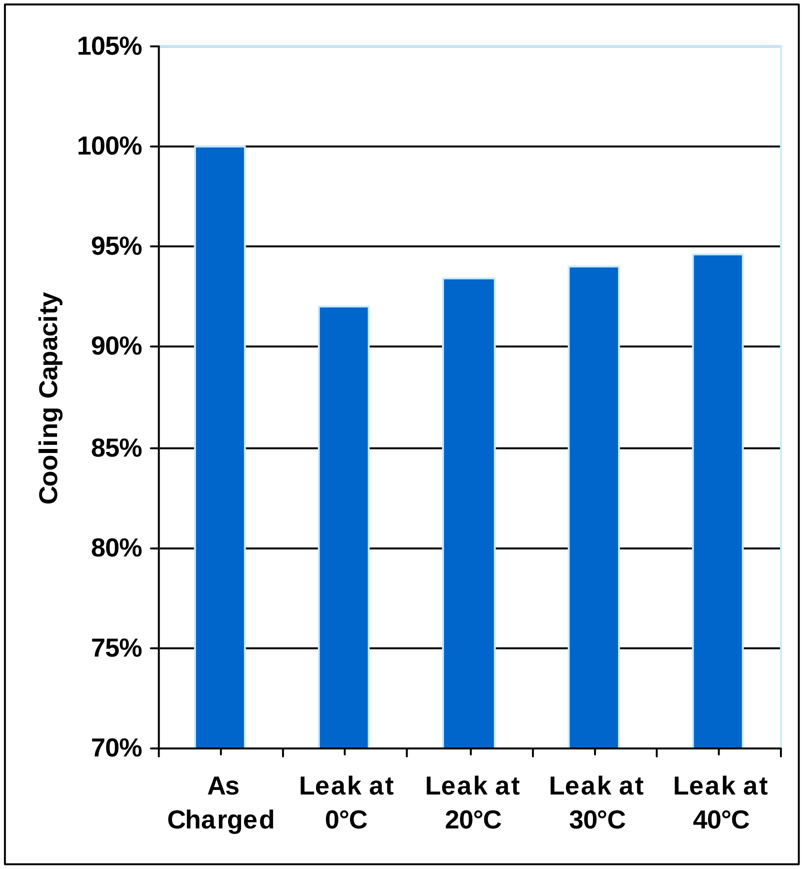
Repeated leakage and top-up (1)

Graph shows the capacities obtained by repeatedly leaking as vapour and topping up 50% of charge with original composition

- A running system would not fractionate so this is pessimistic

If leak is not repaired worst case for system is loss of capacity of 6-8%

- Depending on average temperature during leakage



Repeated leakage and top-up (2)

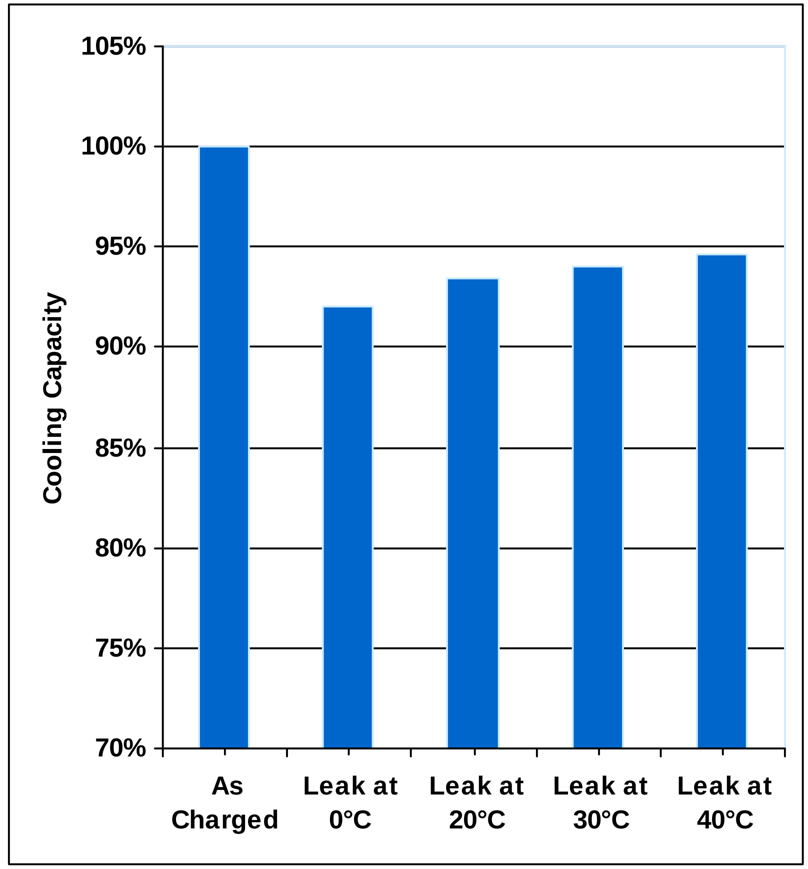
Known from IMAC project work that static cold systems don't leak as rapidly as static hot systems

So expect in practice, with a mixture of running and static leaks, that capacity loss will be less than 6% even if selective leakage occurs

COP is not significantly affected by this leak

- Fuel consumption should stay similar to original composition

In practice for this level of leak, repair necessary in any event irrespective of fluid type



Auto AC-1 - Service & recovery

AC-1 fluid recoverable using R-134a recovery units

Laboratory test

- Cylinder with ca. 400g Auto AC-1 and 10:1 or 5:1 refrigerant/PAG oil
- Recovery as vapour at 20°C and 50°C
- Recovery using a vacuum pump and condensation into a second cylinder
- Even incomplete recovery < 90% results in minor composition shift (within blending tolerance)
- Suggests this mode of transfer results in recovery of liquid/vapour mix...so worst case theoretical composition shift not realised in practice
- Confirmed by experience from analysis of sample returns recovered by 3rd parties (OEMs and Tier 1 engineers)

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Composition checker

- Ultimately it may be possible to provide service technicians with a reclaim protocol that could allow return of the recovered charge to the system.
- This goal would be greatly simplified by an inexpensive, handheld composition checker instrument.
- Testing an infra-red based sensor unit, which can be connected onto the vapour port of a standard cylinder.
    - Instant readout of composition with “pass/fail” recommendation
    - Will warn of presence of other fluids if required

Composition checker

Logistics, storage, reclaim

- Same logistic routes as for R-134a
  - Similar pressures and material compatibility
  - Same containers and handling units
- Reclaim and disposal of non-reusable material via routes established for stationary refrigeration
- Now planning these logistics for implementation

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Toxicity results

Auto AC-1 has low acute toxicity

- ✓ Ames test passed (negative)
- ✓ LC50 data show no effect at 50,000 ppm
- ✓ Cardiac Sensitisation Results better than R-134a (75,000 ppmv NOAEL for Auto AC-1)

Chronic toxicity

- Micronucleus test passed
- 28 day inhalation test completed.
  - New fluid is more active than R-134a.
  - OEL will be lower than for R-134a.
- 90 day inhalation test exposure planned for 2007

Working with SAE and VDA toxicologists to interpret toxicology data and support a full risk assessment

Environmental performance

	Auto AC-1	HFC 134a
ODP Value	0	0
GWP	<130	1300
Atmospheric Lifetime	<20 days for new fluid	14 years
Decomposition products	CO_2, HF, TFA	CO_2, HF, TFA

- GWP of formulation is less than 150: design to maximise technical benefits within the F-Gas cap
  - ✓ Minimise glide, reduce pressure drops, boost capacity
- No real benefit to environment of lower GWP if it results in worse system performance
  - Auto AC-1 COP close to R-134a over ambient temperature range

Direct or indirect GWP?

If I had Auto AC-1 in my typical European car (emission 160 gm/km) and changed it for a fluid with GWP that was 100 lower, then I would reduce the maximum direct effect of the charge by the equivalent of driving my car an extra 30 km/year over its design life…..

- Let's do the LCCP analysis: compare the LCCP in Europe and in the USA with typical end-of-life recoveries
  - over a 12 year life for Auto AC-1 and for a fluid of GWP lower by 100
  - take Auto AC-1 efficiency equal to R-134a
  - Test effect of GWP and COP on the LCCP

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Direct or indirect GWP?

GWP 100 lower → Reduction of 30km/year in drive distance

COP lower by 3% ← Increase of 45km/year in drive distance

If the COP is 2% lower with the lower GWP fluid then the LCCP of the "low-GWP fluid" system would be equivalent to the Auto AC-1 LCCP

Every 1% loss in COP compared to Auto AC-1 would be like adding 50 to the effective GWP of the "low GWP" fluid

At GWP<150 the focus should be on INDIRECT GWP because performance of the A/C cycle is the real issue

Auto AC-1 summary

- ✓Close Match to R-134a...engineering to adapt is straightforward
- ✓Auto AC-1 can be recovered and handled using standard equipment
- ✓Effect of selective vapour leaks on Auto AC-1 composition and performance is small
- ✓Materials compatibility of the refrigerant promising
- ✓Full toxicology assessment underway
- ✓Environmental performance is strong