REALMETER TECHNICAL SERIES

Technical Calculation · RM-CAL-2026-0731-EN

R134a Refrigerant Annual Leakage ↔ N_2/H_2 Tracer-Gas Leak Rate Equivalence Calculation

5%H_2/95%N_2 tracer gas · Gas-/liquid-phase dual-mode derivation (equal pressure 10 bar(g))

7.6×10^{-6} ⟶ 5.22×10^{-6} / 1.75×10^{-6} ⟶ Limit ≈ 1.8×10^{-6} mbar·L/s

Industry-customary value → rigorous two-step values → min-rule guaranteeing limit

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Document No.	RM-CAL-2026-0731-EN
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Purpose	Theoretical basis for limit setting and instrument configuration of N_2/H_2 tracer-gas leak testing (equal pressure 10 bar(g)) for R134a systems

1 Task Statement and Boundary Conditions

Task: Convert the R134a annual leakage **1 g/year @ 10 bar(g)** into the equivalent leak rate (mbar·L/s) for hydrogen-nitrogen tracer gas (5% H_2 + 95% N_2, non-flammable safe concentration), with the **tracer gas charged at the same pressure as the refrigerant duty (10 bar(g))**, computed separately for gas-phase and liquid-phase leak modes.

No.	Boundary condition	Value
BC-1	Pressure reference	Gauge pressure; tracer gas and refrigerant at the same 10 bar(g)
BC-2	Test method	N_2/H_2 sniffer method (ambient atmosphere outside, p_2 = 1 atm) as primary; accumulation/vacuum method differences noted separately
BC-3	Tracer gas	5% H_2 + 95% N_2 mixture (H_2 below the 5.7% lower flammability limit, safe)
BC-4	Leak-point phase	Gas-phase and liquid-phase modes computed separately; limit by the min rule
BC-5	Temperature	23 °C (296.15 K)

2 Physical Properties and Data Sources

Symbol	Parameter	Value (23 °C)	Source
M_134a	R134a molecular weight	102.03 g/mol	SDS/REFPROP[1]
η_v	R134a vapour dynamic viscosity	12.0 µPa·s	Saturated vapour at 25 °C: 12.1–12.2 µPa·s (REFPROP family)[2][3]; literature range 11.77–12.2 µPa·s[4]; 12.0 µPa·s adopted
η_l	R134a saturated liquid viscosity	195 µPa·s	0.195 mPa·s at 25 °C (REFPROP family)[3]; literature table 190.46 µPa·s[4]; 195 µPa·s adopted
ρ_l	R134a saturated liquid density	1207 kg/m³	1207 kg/m³ at 25 °C (REFPROP family)[3]
p_sat	R134a saturation pressure at 23 °C	≈ 6.3 bar(abs)	6.654 bar(abs) at 25 °C[3]; 23 °C ≈ 6.3 bar(abs) via Clausius–Clapeyron
η_N2	Nitrogen dynamic viscosity	17.6 µPa·s	Measured 1.76×10^{-5} Pa·s at 20 °C[5]; Sutherland 20→23 °C correction (+0.5%) negligible
η_H2	Hydrogen dynamic viscosity	8.9 µPa·s	Measured 0.89×10^{-5} Pa·s at 20 °C[5]
M_N2 / M_H2	N_2/H_2 molecular weight	28.014 / 2.016 g/mol	Standard atomic weights (Wilke inputs)
R	Molar gas constant	8.314 J/(mol·K)	CODATA
T	Calculation temperature	296.15 K	BC-5 (23 °C)
η_mix	5%H_2/95%N_2 mixture viscosity	**17.59 µPa·s**	Computed herein by the Wilke mixing rule (§3.2)

Notes on value selection: 1. The 2 K gap between 23 °C and the 25 °C literature data is small: the R134a vapour-viscosity temperature coefficient is about +0.03 µPa·s/K, liquid viscosity about −2%/K — both within the cited literature ranges. Representative values are adopted directly; the residual deviation is already covered by the §7 uncertainty budget (±3–5%). Per-degree interpolation is deliberately avoided to prevent false precision. 2. The 20→23 °C difference for N_2/H_2 viscosities is <1%, below the Wilke rule's own uncertainty (±2%); the 20 °C values are used as-is. 3. **Reliability grading**: REFPROP states R134a viscosity

uncertainty of 3% (liquid) and 3–5% (vapour)[6]; N_2/H_2 viscosities are classical measured values (<1%); the mixture viscosity uses the Wilke semi-empirical mixing rule (well validated on hydrocarbon/hydrogen blends[7]).

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3 Theoretical Model

3.1 Flow-regime criterion (same as the R1234yf calculation book, abbreviated)

The equivalent leak-channel diameter is about 1–2 μm; at 10 bar, Kn ≈ 0.005 ≪ 0.01 — the flow in the channel is **continuum viscous (laminar) flow**, so the compressible laminar formula applies. Misusing the molecular-flow formula would overestimate by about 10×.

3.2 Tracer-gas viscosity: Wilke mixing rule (worked in full)

$$\eta_{mix} = \sum_i \frac{x_i \eta_i}{\sum_j x_j \phi_{ij}}, \qquad \phi_{ij} = \frac{\left[1 + (\eta_i/\eta_j)^{1/2} (M_j/M_i)^{1/4}\right]^2}{\sqrt{8\,(1 + M_i/M_j)}}$$

Inputs: $x_{H_2} = 0.05$, $x_{N_2} = 0.95$, $\eta_{H_2} = 8.9$ μPa·s, $\eta_{N_2} = 17.6$ μPa·s, $M_{H_2} = 2.016$, $M_{N_2} = 28.014$ g/mol.

Step 1: combination parameters φ_ij (φ_ii ≡ 1):

$$\phi_{H_2,N_2} = \frac{\left[1 + (8.9/17.6)^{1/2} (28.014/2.016)^{1/4}\right]^2}{\sqrt{8\,(1 + 2.016/28.014)}} = \frac{[1 + 0.7110 \times 1.9318]^2}{\sqrt{8.576}} = \frac{5.633}{2.928} = 1.9229$$

$$\phi_{N_2,H_2} = \frac{\left[1 + (17.6/8.9)^{1/2} (2.016/28.014)^{1/4}\right]^2}{\sqrt{8\,(1 + 28.014/2.016)}} = \frac{[1 + 1.4063 \times 0.5177]^2}{\sqrt{119.17}} = \frac{2.987}{10.917} = 0.2736$$

Step 2: denominator terms:

$$\sum_j x_j \phi_{H_2,j} = 0.05 \times 1 + 0.95 \times 1.9229 = 1.8768$$

$$\sum_j x_j \phi_{N_2,j} = 0.05 \times 0.2736 + 0.95 \times 1 = 0.9637$$

Step 3: weighted sum:

$$\eta_{mix} = \frac{0.05 \times 8.9}{1.8768} + \frac{0.95 \times 17.6}{0.9637} = 0.2371 + 17.3501 = 17.587 \ \mu\text{Pa s} \approx 17.59 \ \mu\text{Pa s}$$

(Although hydrogen's viscosity is only half that of nitrogen, its molecular weight is 14× lower, and the Wilke weight φ_N_2,H_2 = 0.274 strongly suppresses its contribution — this is the quantitative reason why "5% hydrogen barely changes the viscosity".)

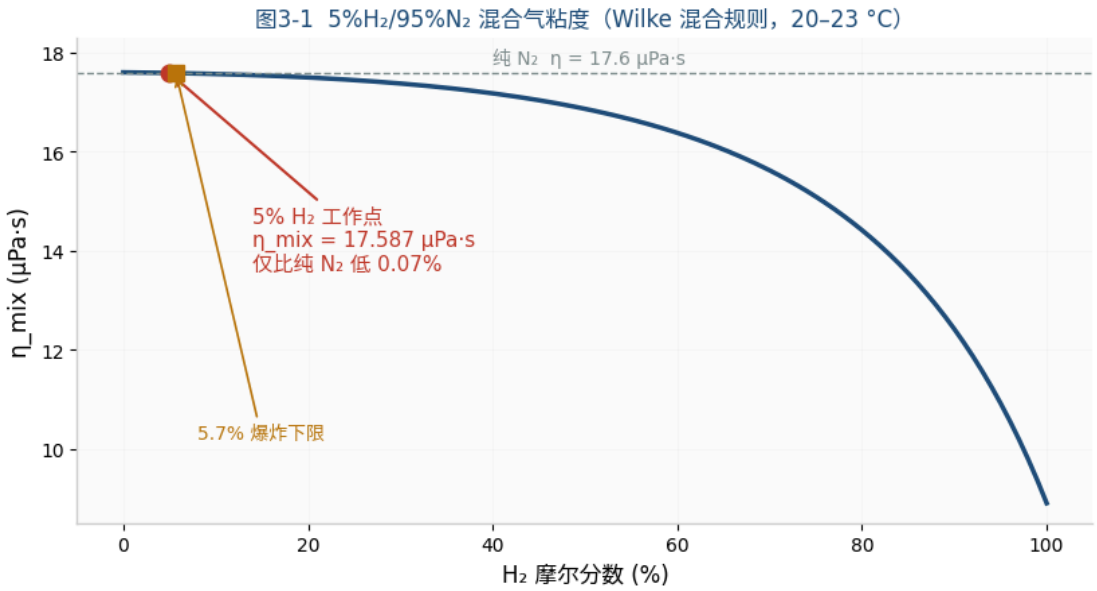

Fig. 3-1 Mixture viscosity vs H_2 mole fraction computed by the Wilke rule. The working point (5%) and the lower flammability limit (5.7%) lie almost on top of each other and next to the pure-N_2 end; viscosity drops significantly only near 100% H_2. The effect of 5% hydrogen (−0.07%) is far below the viscosity-data uncertainty itself (±2–5%).

Key physical conclusion: 5% hydrogen hardly changes the mixture viscosity (only 0.1% below pure N_2) — **the flow behaviour of the N_2/H_2 mixture ≈ pure nitrogen**. Hydrogen only plays the role of a "tracer marker"; all results in this document are expressed as **total mixture leak rates**. Note: hydrogen sensors respond only to the H_2 fraction, so instrument selection must be checked against the manufacturer's actual sensitivity under mixture conditions.

3.3 Gas-phase leak mode (equal pressure, ambient outside)

Compressible laminar flow $Q = \dfrac{\pi r^4}{16\eta L}(p_1^2 - p_2^2)$; for the same channel the geometry factor cancels. Because tracer gas and refrigerant are at the **same pressure**, with atmosphere on both outer sides, the squared-pressure terms are identical and cancel:

$$\boxed{Q_{N_2/H_2} = Q_{134a} \times \frac{\eta_v}{\eta_{mix}} = \frac{\dot{m}\,RT}{M_{134a}} \times \frac{\eta_v}{\eta_{mix}}}$$

This is the minimal form of equal-pressure conversion: in gas-phase mode, tracer-gas leak rate = refrigerant leak rate × viscosity ratio, independent of pressure.

3.4 Liquid-phase leak mode (equal pressure, ambient outside)

Incompressible Hagen–Poiseuille combined with compressible laminar flow, eliminating the geometry:

$$\boxed{Q_{N_2/H_2} = \dot{m} \times \frac{\eta_l}{2\,\rho_l\,\eta_{mix}} \times \frac{p_1^2 - p_2^2}{\Delta p}}$$

Flashing reduces the actual liquid flow below the incompressible model, so this expression is a conservative upper bound.

3.5 Limit-setting rule (min rule)

The leak-point phase cannot be known in advance; the limit must guarantee compliance for any phase:

$$Q_{limit} = \min\left(Q_{gas},\ Q_{liquid}\right)$$

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4 Calculation Procedure

4.1 Step one: refrigerant pV leak rate (= the industry-customary value)

Step 1: annual leakage → mass flow rate. 1 year = 365.25×86400 = 3.15576×10⁷ s:

$$\dot{m} = \frac{1 \times 10^{-3}\ \mathrm{kg}}{3.15576 \times 10^{7}\ \mathrm{s}} = 3.1688 \times 10^{-11}\ \mathrm{kg/s}$$

Step 2: mass flow → molar flow (M_134a = 0.10203 kg/mol):

$$\dot{n} = \frac{3.1688 \times 10^{-11}}{0.10203} = 3.1058 \times 10^{-10}\ \mathrm{mol/s}$$

Step 3: ideal-gas law → pV flow rate (outlet at atmosphere; Q defined as volumetric flow at outlet pressure):

$$Q_{134a} = \dot{n}RT = 3.1058 \times 10^{-10} \times 8.314 \times 296.15 = 7.647 \times 10^{-7}\ \mathrm{Pa\,m^3/s}$$

Step 4: unit conversion. 1 mbar = 100 Pa, 1 L = 10⁻³ m³, hence 1 mbar·L/s = 100×10⁻³ = 0.1 Pa·m³/s:

$$Q_{134a} = 7.647 \times 10^{-7}\ \mathrm{Pa\,m^3/s} \times 10 = 7.65 \times 10^{-6}\ \mathrm{mbar\,L/s}$$

Dimensional check: [ṁRT/M] = (kg/s)×(J/(mol·K))×K/(kg/mol) → Pa·m³/s ✓ (J = Pa·m³).

Cross-check against industry practice: the INFICON automotive leak-testing e-book explicitly states "1 g/a = 7.6·10⁻⁶ mbar·l/s (only for R134a)"[9], consistent with this result. This is the origin of the widely quoted "R134a 1 g/year ≈ 7.7×10⁻⁶ mbar·L/s" — it is the **pV leak rate of the refrigerant medium itself**, before the tracer-medium conversion (step two), and cannot be used directly as the reading or limit of an N_2/H_2 leak detector.

4.2 Step two · gas-phase mode (sniffer, equal pressure 10 bar(g))

Viscosity ratio (dimensionless conversion factor):

$$\frac{\eta_v}{\eta_{mix}} = \frac{12.0}{17.587} = 0.6823$$

$$Q_{N_2/H_2} = 7.647 \times 10^{-6} \times 0.6823 = \mathbf{5.22 \times 10^{-6}}\ \text{mbar L/s}\ (5.2 \times 10^{-7}\ \text{Pa m}^3/\text{s})$$

Physical-direction check: the R134a molecule is heavier and more polar than N_2, and η_v = 12.0 < η_mix = 17.6, so R134a "flows more easily" through the same channel; the N_2/H_2 pV leak rate corresponding to the same mass leakage is therefore only 68% of the refrigerant's own pV rate — direction is reasonable ✓.

4.3 Step two · liquid-phase mode (sniffer, equal pressure 10 bar(g))

Pressures must be absolute (both the ideal-gas law and the laminar-flow formula require absolute pressure): p_1 = 10 + 1.01325 = 11.01325 bar(a), p_2 = 1.01325 bar(a), Δp = $p_1 - p_2$ = 10 bar (gauge equals differential).

Step 1: medium/geometry factor:

$$\frac{\eta_l}{2\rho_l\eta_{mix}} = \frac{195 \times 10^{-6}}{2 \times 1207 \times 17.587 \times 10^{-6}} = 4.593 \times 10^{-3}\ \text{m}^3/\text{kg}$$

Step 2: squared-pressure ratio (with identity check: $(p_1^2-p_2^2)/(p_1-p_2) \equiv p_1+p_2$):

$$\frac{p_1^2 - p_2^2}{\Delta p} = p_1 + p_2 = 11.01325 + 1.01325 = 12.0265\ \text{bar} = 1.20265 \times 10^6\ \text{Pa}$$

Numerical verification: (11.01325² − 1.01325²)/10 = (121.292 − 1.027)/10 = 12.0265 ✓ (consistent with the p_1+p_2 identity).

Step 3: synthesis:

$$Q_{N_2/H_2} = 3.1688 \times 10^{-11} \times 4.593 \times 10^{-3} \times 1.20265 \times 10^6 = 1.750 \times 10^{-7}\ \text{Pa m}^3/\text{s} = \mathbf{1.75 \times 1}$$

Reverse check: from Q = 1.75×10⁻⁶ mbar·L/s back to ṁ = Q/(4.593×10⁻³×1.20265×10⁶)×0.1 = 3.17×10⁻¹¹ kg/s = 1.00 g/year ✓ (closed loop).

4.4 If the vacuum / accumulation method is used (vacuum outside)

The squared-pressure terms no longer cancel; multiply by:

$$\frac{p_1^2}{p_1^2 - p_2^2} = \frac{11.01325^2}{11.01325^2 - 1.01325^2} = \frac{121.292}{120.265} = 1.00854$$

i.e. gas phase 5.22×1.0085 = 5.26×10⁻⁶, liquid phase 1.75×1.0085 = 1.765×10⁻⁶ mbar·L/s; the difference is <1%, negligible in engineering.

4.5 Pressure dependence and crossover pressure

Generalising §4.2/§4.3 to any charge pressure p_g (gauge): in gas-phase mode the squared-pressure terms cancel and the equivalent rate is pressure-independent; in liquid-phase mode the ratio ≡ p_1+p_2 = (p_g+2.0265) bar rises linearly with pressure. Setting the two expressions equal (ṁ and η_mix cancel on both sides): $\frac{\eta_l}{2\rho_l}(p_1 + p_2) = \frac{RT\,\eta_v}{M}$, giving:

$$p_1 + p_2 = \frac{2\rho_l\,\eta_v\,RT}{\eta_l\,M} = \frac{2 \times 1207 \times 12.0 \times 10^{-6} \times 8.314 \times 296.15}{195 \times 10^{-6} \times 0.10203} = 3.585 \times 10^6\ \mathrm{Pa} = 35.85\ \mathrm{ba}$$

$$p_{g,cross} = 35.85 - 2.0265 = \mathbf{33.8}\ \mathrm{bar(g)}$$

(The analytical solution agrees with the numerical scan in Fig. 4-1.)

(Dimensional check: [ρηRT/(ηM)] = (kg/m³)(Pa·s)(J/mol)/(Pa·s)(kg/mol) = (kg/m³)(J/kg) = J/m³ = Pa ✓)

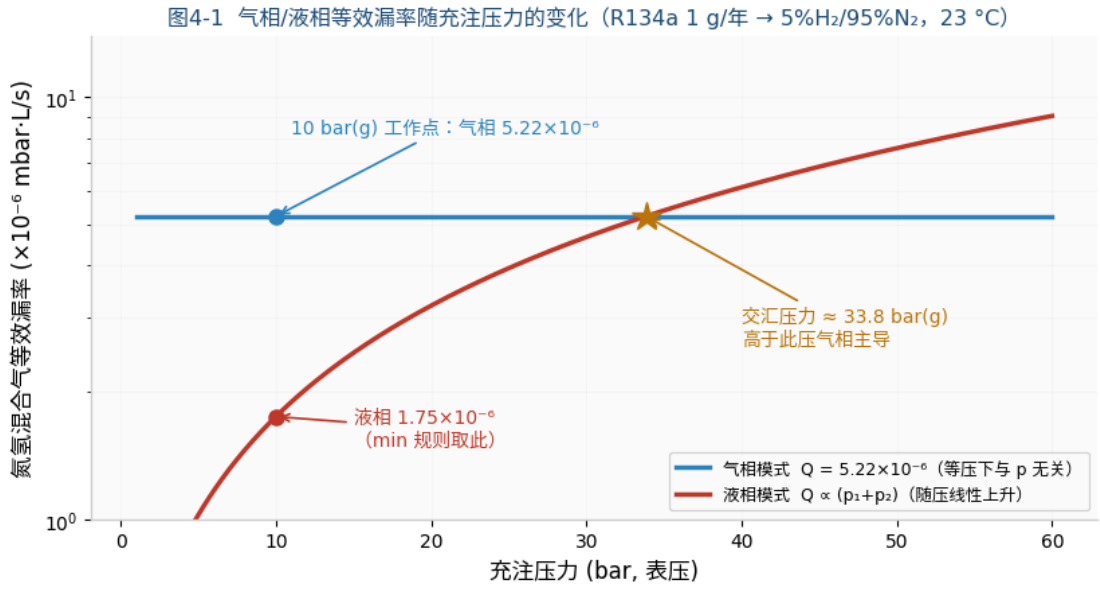

Fig. 4-1 Gas-/liquid-phase equivalent leak rates vs charge pressure. The 10 bar(g) working point lies far below the crossover pressure of 33.8 bar(g); the liquid value (1.75×10^{-6}) is smaller than the gas value (5.22×10^{-6}), so the min rule takes the liquid value — the general rule that "liquid phase dominates low-pressure refrigerant duties". If the test pressure exceeds 33.8 bar(g), the dominant mode reverses to gas phase and the limit should take the gas-phase value instead.

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5 Results Summary and Discussion

Level	Total mixture leak rate (sniffer, 10 bar(g))	Note
Step one: R134a own pV rate (industry-customary value[9])	7.6×10^{-6} mbar·L/s	Mass→pV conversion only, no medium correction; cannot serve directly as the N_2/H_2 limit
Step two · gas-phase leak	**5.2×10^{-6} mbar·L/s**	= refrigerant rate × viscosity ratio 0.6823
Liquid-phase leak	**1.75×10^{-6} mbar·L/s**	Conservative upper bound
Guaranteeing limit (min rule)	**≈ 1.8×10^{-6} mbar·L/s**	False-reject band 2.98×

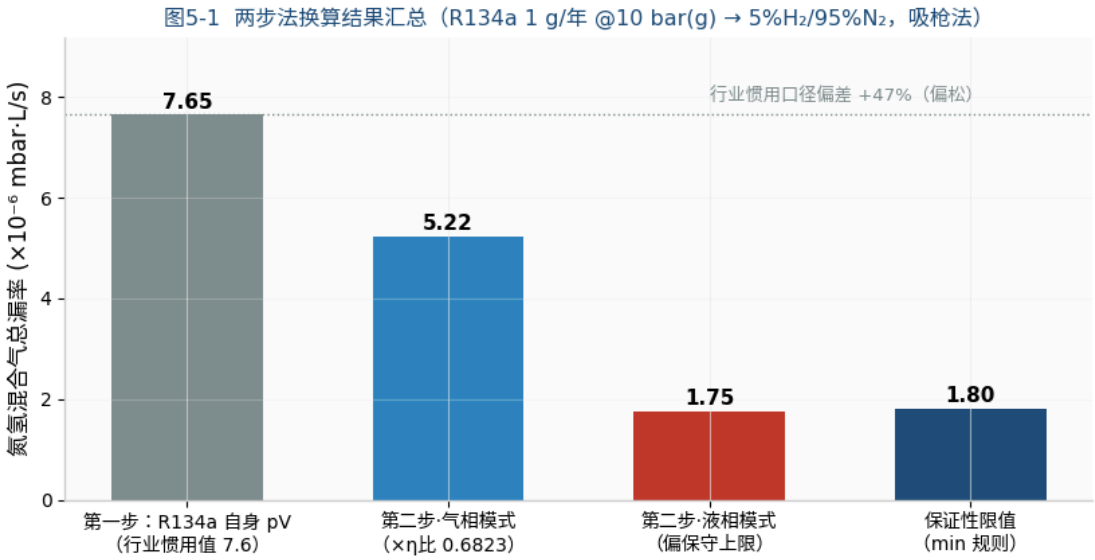

Fig. 5-1 Summary of the two-step results. Grey bar: industry-customary figure (step one only, no medium correction); blue/red bars: rigorous values; dark-blue bar: guaranteeing limit. The customary figure deviates +47% from the rigorous gas-phase value (lenient direction).

Discussion:

1. **Deviation of the customary value**: using 7.6×10^{-6} directly as the N_2/H_2 test limit implicitly assumes $\eta\_R134a = \eta\_N_2/H_2$, a +47% deviation that would pass parts leaking 1.47 g/year in gas phase — lenient, not conservative; suitable only for quick estimation and communication.
2. **Liquid phase dominates the limit**: the gas/liquid ratio is 2.98×, almost identical to the R1234yf @10 bar duty (2.9×) — 10 bar is far below the crossover pressure; liquid dominance is the general rule for low-pressure refrigerant duties.
3. **Quantitative comparison with helium testing**: for the same specification, the R1234yf helium gas-phase conversion is 4.0×10^{-6} (η ratio 11.46/19.6 = 0.585), while R134a N_2/H_2 gives 5.2×10^{-6} (η ratio 12.0/17.59 = 0.682). Same order of magnitude, but the N_2/H_2 method's **sensor-side signal is diluted to 5%**, so the equivalent detection-sensitivity requirement is about 20× more stringent than helium.
4. **Instrument sensitivity check**: by the engineering convention "instrument resolution ≤ 1/10 of the limit", the leak-test system must stably resolve a **total mixture leak rate of 1.8×10^{-7} mbar·L/s**. The sniffer method suffers dilution of the leaking gas by the sniffer flow (typically losing 1–2 orders of magnitude), and the hydrogen sensor responds only to the 5% H_2 fraction — selection must strictly follow the manufacturer's mixture-condition sensitivity specification; switch to the accumulation method for compensation if necessary.

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6 Leak-Test System Design Recommendations

Item	Value
Guaranteeing reject limit (total mixture)	**1.8×10^{-6} mbar·L/s**
(Alternative) known gas-phase-zone limit	5.2×10^{-6} mbar·L/s
Minimum detectable leak rate (limit/10)	1.8×10^{-7} mbar·L/s (total mixture)
Tracer gas charge	5% H_2 + 95% N_2, 10 bar(g)
Calibration reference leak	A 5%H_2/95%N_2 reference leak around 1.8×10^{-6} mbar·L/s (calibrated at 23 °C) is recommended, or convert from a He reference leak (×η_He/η_mix = 1.11)

Additional recommendations:

1. **Method selection**: at this specification the sniffer signal-to-noise ratio is weak (sniffer dilution + hydrogen sensor responding only to the H_2 fraction); the **accumulation method** (closed hood accumulation with hydrogen-sensor concentration-growth reading) is recommended, improving SNR by 1–2 orders of magnitude;
2. **False-reject band management**: same three options as Chapter 6 of the R1234yf calculation book (min-rule default / phase demarcation / zone testing); band width 2.98×;
3. **Temperature correction**: 23 °C reference; ±10 °C drift affects the viscosity ratio by <2%;
4. **Check against R134a saturation pressure**: saturation pressure at 23 °C is 6.3 bar(abs); at 10 bar(g) the subcooling is about 4.7 bar, so the liquid-phase model holds.

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7 Uncertainty Analysis

Source	Magnitude	Impact
η_v (R134a vapour)	±3–5% (REFPROP statement)[6]	Gas phase ±5%
η_l, ρ_l (liquid)	±3% (REFPROP liquid viscosity)	Liquid phase ±4%
η_mix (Wilke rule)	±2%	All modes ±2%
Temperature (23±5 °C)	<2%	Negligible
Flashing effect (liquid)	One-sided, conservative	Liquid value is an upper bound
Phase uncertainty (limit direction)	Systematic, 2.98×	**Dominant factor**, covered by the min rule

Combined expanded uncertainty (k=2): gas phase ≈ ±6%, liquid phase ≈ ±8%. A ≥20% engineering margin on the limit is recommended.

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8 Conclusions: The Theoretical Position of the Industry-Customary Value and Its Usability Boundary

8.1 The numerical lineage (logic of all results in this document)

Level	Value (mbar·L/s)	Physical meaning
① Industry-customary value (INFICON figure[9])	7.6×10^{-6} (= 7.6×10^{-7} Pa·m³/s)	The **refrigerant's own** pV leak rate: only the "mass → pV" step-one conversion
② Rigorous value · gas phase	5.22×10^{-6}	① × viscosity ratio 0.6823 (step-two medium conversion)
③ Rigorous value · liquid phase	1.75×10^{-6}	Conservative upper bound
④ Guaranteeing limit (min rule)	$\approx 1.8\times10^{-6}$	Design limit when the phase is unknowable

8.2 What is wrong with the INFICON figure

"R134a 1 g/year = N_2/H_2 leak test 7.6×10^{-6} mbar·L/s" — the most widely circulated figure in the industry — **is, strictly speaking, not correct: it completes only half of the conversion**. After converting the annual

refrigerant mass loss into the refrigerant's own pV leak rate (step one), it takes that number directly as the N_2/H_2 leak rate, omitting the step-two medium conversion. The implicit assumption is $\eta\_R134a = \eta\_N_2/H_2$, whereas in fact 12.0 ≠ 17.6 μPa·s — a 47% difference. Used directly as the N_2/H_2 test limit, 7.6×10^{-6} would pass parts leaking up to 1.47 g/year in gas phase — **the deviation is lenient, not conservative**.

8.3 Why this "wrong number" has been used for decades without causing problems

Not because the conversion happens to be right, but because **the margin structure of the specification absorbs the conversion error entirely**, with three layers of buffering:

1. **First layer: the specification itself is set very high.** 1 g/year is the customary industry specification, while the functional-failure threshold of a refrigerant system (the cumulative leakage needed for noticeable capacity loss) is of order ~150 g/year — about **two orders of magnitude** of margin. A +47% limit deviation is a rounding error against two orders of magnitude.
2. **Second layer: production leak rates are bimodally distributed.** Sound parts cluster around ~10^{-10} mbar·L/s, defective parts around ~10^{-2} mbar·L/s, with a "no-man's land" of about 8 orders of magnitude in between. Whether the limit sits at 1.8×10^{-6} or 7.6×10^{-6}, it falls inside that gap — **the accept/reject outcome for any real part is identical**.
3. **Third layer: even a false pass is harmless.** The worst-case boundary part released under 7.6×10^{-6} leaks 1.47 g/year — still two orders of magnitude below the functional threshold, with no practical consequence within the warranty period.

In other words: **the customary value is a "wrong but harmless" number** — it uses only half the theory, yet is thoroughly protected by the excess margin of the specification.

8.4 When the rigorous values must be used instead

Margins are not infinitely thick. In the following situations the buffer thins and the +47% deviation of the customary figure can have real consequences; the rigorous values (②③④) of this document should be used:

- **Certification, traceability, and customer audits**: the limit must withstand theoretical review; the step-one figure cannot justify itself;
- **Tightened specifications or new refrigerants**: e.g. low-charge R1234yf systems and A2L mildly flammable refrigerants (where the cabin concentration limit becomes the real bottom line) compress the margin from two orders of magnitude to below one — a ±50% limit-setting error is no longer negligible;
- **Limit setting in liquid-dominated duties**: at 10 bar(g) the rigorous liquid value (1.75×10^{-6}) is 4.3× tighter than the customary figure; when the phase is unknowable, the min rule applies — otherwise there is a 4.3× lenient false-pass risk for liquid-phase leakers.

8.5 One-sentence conclusion

7.6×10^{-7} Pa·m³/s is the communication figure; 1.8×10^{-6} mbar·L/s (min rule) is the design limit: the former comes from a half-completed conversion and has remained harmless only thanks to the specification's margin; the latter is the rigorous value from the complete two-step conversion with phase analysis. Use the former in everyday communication; use the latter for leak-test system design and audit documentation.

Appendix A Symbols

Symbol	Meaning	Unit
Q	Leak rate (pV flow rate)	Pa·m³/s or mbar·L/s
ṁ, ṅ	Mass / molar flow rate	kg/s, mol/s
η_v, η_l, η_mix	Vapour / liquid / mixture viscosity	Pa·s
ρ_l	Liquid density	kg/m³
x_i, M_i	Mole fraction / molecular weight	—, g/mol
p_1, p_2, Δp	Inlet / outlet absolute pressure / differential	Pa

Appendix B References

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