Refrigerant Leakage Calculation Reasoning

1. Ideal gas equation

$$\boldsymbol{P * V = n * R * T}$$

- P - Pressure (Pa)
- V - Volume (m^3 or L)
- n - Molecule amount (mol)
- R - Gas constant (8.314J/(mol·K))
- T – Temperature (K)

Also Known

$$\boldsymbol{n = \frac{m}{M}}$$

- m - Gas weight (g)
- M - Gas mole constant (g/mol)

Combining the two equations

$$\boldsymbol{P * V = \frac{m}{M} * R * T}$$

Hence, the gas weight is equal as the following:

$$m = \frac{P * M * V}{R * T}$$

Let's Introduce the mass leakage rate formula

$$Q_m = \frac{dm}{dt}$$

- Q_m - Leakage rate of quality
- t - Time

Hence

$$Q_m = \frac{d}{dt}(\frac{P * M * V}{R * T})$$

To simplify the computational effort, only the change in V is considered

$$Q_v = d/dt(V)$$

- Q_v **-** Leakage rate of volume

$$\boldsymbol{Q_m = \frac{P * Q_v * M}{R * T}}$$

To convert the leakage under actual conditions to the leakage under standard conditions, we need to introduce the correction factor for standard conditions. The standard state defines the temperature. $T_0 = 273K$, pressure $P_0 = 1.01 * 10^5 Pa$, Standard molar volume $V_0 = \frac{22.4L}{mol} = 0.224m^3/mol$,

Therefore, Standard state correction factor includes:

- Temperature correction factor $\boldsymbol{\frac{T_0}{t}}$
- Pressure correction factor$\boldsymbol{\frac{p}{p_0}}$
- Standard molar volume correction factor $\boldsymbol{\frac{1}{V_0}}$

After correction, got following formular

$$Q_m = (Q_v * M) * \frac{T_0}{T} * \frac{P}{P_0} * \frac{1}{V_0}$$

The derivation process is as follows

Under standard conditions(p_0, T_0), the molar volume of an ideal gas is defined as

$$P_0 * V_0 = n * R * T$$

Under the standard state $n = 1\ mol$

$$P_0 * V_0 = R * T$$

$$V_0 = R * T_0/P_0$$

$$\frac{1}{V_0} = \frac{P_0}{R * T_0}$$

$$Q_m = \frac{P * Q_v * M}{R * T} = Q_v * M * (\frac{P}{R * T})$$

To introduce $\frac{1}{V_0}$ in equation of Q_m , Q_m will be multiply with $\frac{T_0}{T_0} * \frac{P_0}{P_0} = 1$

Hence

$$Q_m = Q_v * M * \frac{P}{R * T} * \frac{T_0}{T_0} * \frac{P_0}{P_0} = Q_v * M * (\frac{T_0}{T} * \frac{P}{P_0} * \frac{P_0}{R * T_0})$$

$$Q_m = Q_v * M * \frac{T_0}{T} * \frac{P}{P_0} * \frac{1}{V_0}$$

Conclusion

$$\boldsymbol{Q_m = Q_v * M * \frac{T_0}{T} * \frac{P}{P_0} * \frac{1}{V_0}}$$

$$\boldsymbol{Q_v = \frac{Q_m * T * P_0 * V_0}{M * T_0 * P}}$$

In some equation, this Q_V with unit pa* m^3/s

$$Q_V = Q_v * P$$

Hence conclusion

$$\boldsymbol{Q_m = Q_V * M * \frac{T_0}{T} * \frac{1}{P_0} * \frac{1}{V_0}}$$

$$\boldsymbol{Q_V = \frac{Q_m * T * P_0 * V_0}{M * T_0}}$$

Remarks:

This formula uses s as the unit. If the required refrigerant leakage rate is required per year, corresponding change in time is necessary.

Item	Definition
Q_v	*Actual gas volume leakage rate(m³/s or L/s)*
Q_V	*Actual gas volume leakage rate multiply with press (pa*m³/s or pa* L/s)*
M	*Molar mass of a gas*
$\frac{T_0}{T}$	*Temperature correction (temperature increase →volume increase →mass decrease)*
$\frac{P}{P_0}$	*Pressure correction (pressure increase →density increase → mass increase)* ***absolute pressure***
$\frac{1}{V_0}$	*Standard molar volume inverse term*

2. Convert refrigerant leakage rate to helium leakage rate

$$\boldsymbol{Q_{He} = Q_{Refrigerant} * \frac{\eta_{He}}{\eta_{Refrigerant}}}$$

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- $\eta_{Refrigerant}$ - Refrigerant viscosity coefficient (μPa.s)
- η_{He} **-** Helium viscosity coefficient (μPa.s)

For laminar flow according to Poiseuille law.

$$q_v = \frac{1}{8 * \eta * l} * \pi * R^4 * (P_1 - P_2)$$

For q_{test} and q_{work}

$$\frac{q_{test}}{q_{work}} = \frac{({P_{test}}^2 - {P_{vac}}^2)}{({P_{work}}^2 - {P_{env}}^2)}$$

- P_{test} - Helium test pressure
- P_{vac} - Vacuum pressure in helium test
- P_{work} - Work pressure in workstation, e.g. within AC system
- P_{env} - environment pressure in workstation

$$\boldsymbol{Q_{He} = Q_{Refrigerant} * \frac{\eta_{He}}{\eta_{Refrigerant}} * \frac{({P_{work}}^2 - {P_{env}}^2)}{({P_{test}}^2 - {P_{vac}}^2)}}$$

$$\boldsymbol{Q_{Refrigerant} = Q_{He} * \frac{\eta_{Refrigerant}}{\eta_{He}} * \frac{({P_{test}}^2 - {P_{vac}}^2)}{({P_{work}}^2 - {P_{env}}^2)}}$$