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GROUP REF. : SC A3
PREF. SUBJECT : PS2
QUESTION N° : Q7

Q7: The filling pressure of equipment with natural-origin gases is often above 1 MPa. Is there any experience or an estimate on the long-term leakage or other lifetime limiting mechanisms, including mechanical damage, deformation of internal parts, e.g., vacuum interrupters at 0 MPa?

Influence of pressure and temperature on O-ring lifetime in highly pressurized dry air

How to evaluate lifetime of O-ring (gasket) considering its lifetime limiting factors?

Compression set, which is the evaluation indicator of compressed deformation of O-ring, is given by the equation (1). Compression set 80% was defined as the critical value of O-ring lifetime, since gas leakage occurs when the compression set exceeds the value [1]. Gas sealing lifetime is shorten by increasing gas pressure and temperature based on the Arrhenius's law by equation (2):

$$C_S = \frac{t_0 - t_1}{t_0 - t_2} \times 100 \qquad \text{................(1)}$$

(C_S: Compression set[%], t_0:Original thickness[mm], t_1:Thickness after deterioration [mm], t_2:O-ring groove [mm])

$$\frac{1}{\tau} = k = A \times \exp\left(\frac{-E}{RT}\right) \qquad \text{...............(2)}$$

(τ: Lifetime, k: Reaction rate, A: Frequency factor of reaction, E: Activation energy [J/mol], R: Gas constant, T: temperature [K])

Influence of gas pressure on O-ring deteriorations

The O-ring lifetime corresponding to the reaching time to 80% of the compression set was evaluated against the change of gas pressure as a parameter. A trend that the lifetime of O-rings is shorten with the increase of gas pressure was observed. The experimental results are shown in Figure 1. The temperature dependencies of EPDM O-ring lifetime in compressed dry air up to 0.8MPa-abs by using a model flange comparable to the gas tightness structure of GIS [2] were compared with lifetime data in a reference of EPDM O-ring in 0.1 MPa-abs dry air [3]. This figure suggests that highly pressurized dry air would shorten the O-ring lifetime, but it is reported that the EPDM O-ring had enough lifetime in 0.8 MPa-abs dry air over 100 years [2][4].

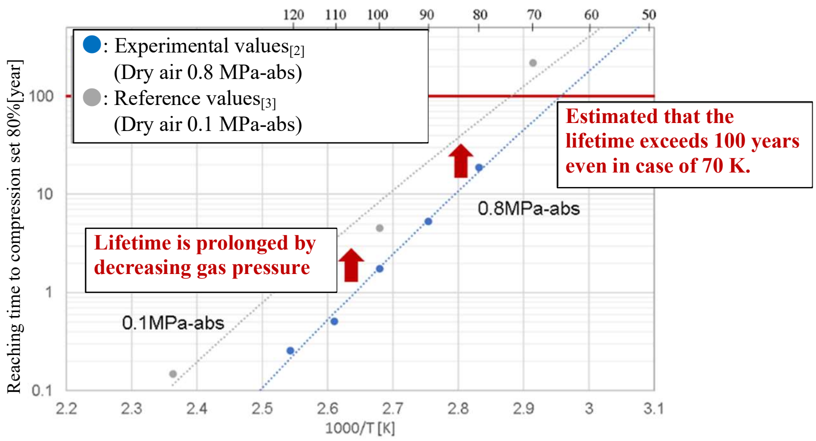

Figure 1. Experimental result of influence of pressure on O-ring lifetime

Influence of temperature on O-ring deteriorations and annual equivalent temperature

Precise deterioration evaluation is not possible if only annual average temperature is given, since oxidation reaction rate increases exponentially with temperature rise based on Arrhenius's law in equation (2). Therefore, annual equivalent temperature [5], which is equivalent constant temperature to the total chemical reaction occurred by the change of temperature of the parts fitted with the O-ring, is applied to improve the precision of the evaluation.

Temperature data on site changing from time to time is converted to reaction rate, and its integral average is converted to temperature again by using equations (3) and (4):

$$T_{(t)} = \theta_{ay} + A\sin\frac{2\pi t}{365\times 24} + B\sin\frac{2\pi t}{24} + T_S\sin\frac{2\pi t}{24} + T_{LC} + T_h \qquad \text{..................(3)}$$

T(t): Temperature in the target area [K], *θay*: Average temperature on the field[K], *A*: Annual variation in average daily temperature [K], *B*: Daily temperature fluctuation range [K] ,*Ts*: Temperature rising due to sunlight [K], *TLC*: Temperature rising during load current flowing[K], *Th*: External heat input [K]

$$T_{EQ} = -\frac{E}{R\times\ln\left[\frac{1}{t_1-t_0}\int_{t_0}^{t_1}\exp\{-\frac{E}{RT(t)}\}dt\right]} \qquad \text{..................(4)}$$

TEQ: annual equivalent temperature [K], *E*: Activation energy [J/mol], *R*: Gas constant, t_0: Measurement starting time [h], t_1: Measurement ending time [h], *T(t)*: Temperature change in the target area [K]

Figure 2 shows an example of calculation results based on the data acquired in a substation in Japan. The calculation result of annual equivalent temperature is 2.6 K higher than that of annual average temperature. This difference of the temperature is converted to the estimated lifetime difference between that calculated by annual equivalent temperature and by annual average temperature based on Arrhenius's law. As the result, the estimated lifetime calculated by annual equivalent temperature is 20% shorter than that by annual average temperature, assuming that the reaction energy is 58 kJ/mol [5]. This result shows the improvement of the lifetime estimation precision.

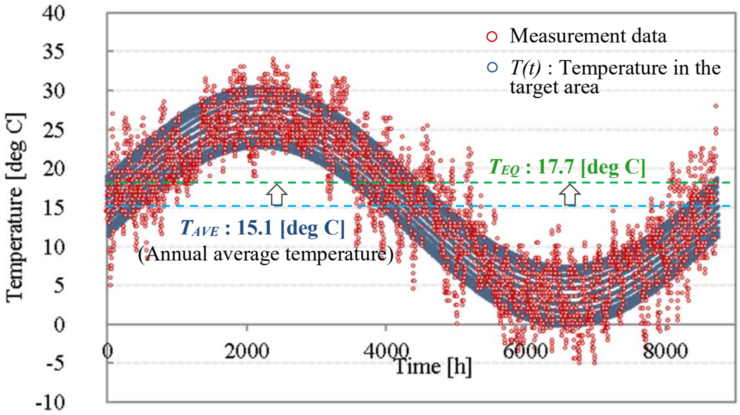

Figure 2. Example of calculation results based on the data acquired in a substation in Japan

Summary

It is well known that oxidation reaction is one of the lifetime limiting mechanisms of O-ring for GIS. Progress of compression set of EPDM O-ring by oxidation reaction was measured in highly pressurized dry air to evaluate the lifetime in terms of pressure and temperature. It was found that application of annual equivalent temperature was effective for the precise lifetime evaluation of O-rings.

References

[1] Sato, et al., "Durability evaluation of O-rings for gas insulated transformers (the 2nd report)", Proceedings of the Annual Conference of Power & Energy Society. IEE of Japan, 404 (2000)

[2] Sato, et al., "Gas tightness properties of the equipment with dry air", Annual Meeting Record, I.E.E. Japan, S0653B (2022)

[3] Sato, et al.," Long-term compression set of various synthetic rubbers", Dai-nippon Densen Jiho, No.58, pp.63-68 (1974)

[4] S. Nakauchi, "High filling pressure trend of potential SF_6 alternative gases and its measures", Contribution (PS2.2) in 2022 CIGRE B3 Paris session

[5] Minagawa, et al., "Degradation Characteristics of O-rings on Highly Aged GIS", IEEJ Transactions on Power and Energy, Volume 125, Issue 3, pp.322-330 (2005)