Air leak test equivalent to IPX7 and IPX8

In order to perform quantitative tests

Fig. 1 shows the relationship between air leak amount and water leak amount. By performing an air leak test accommodating a water leak allowance equivalent to IPX7 and IPX8, quality control using air leak amount (numerical) is possible, and there is a better chance of preventing waterproof defective products from leaking out to customers.

A water leak amount with “no harmful effect”

IPX7 and IPX8 are designated as “Ingress of water in quantities causing harmful effects shall not be possible.” There is a need to determine the water leak amount (permissible amount which has no harmful effect. If this value is stipulated, waterproof tests within air leak tests will be possible.

Below is an introduction on how air converted amount is found presuming two types of leak hole models (orifice and straight pipe) and assuming a water leak permissible amount of 0.09 mL/30 minutes.

【Straight pipe model】

According to the Hagen–Poiseuille law,
\[
\frac{Q_a}{Q_w} = \frac{(\eta_w/\eta_a)}{(P_1+P_2)/(2\times P_2)}
\]

Viscosity coefficient \(\eta_w = 1.00 \times 10^{-3}\) Pa sec 20°C
\(\eta_a = 1.81 \times 10^{-5}\) Pa sec 20°C
Upward pressure \(P_1 = 1.11 \times 10^5\) Pa abs (absolute pressure reference)
Downward pressure \(P_2 = 1.01 \times 10^5\) Pa abs
Average pressure \(1.06 \times 10^5\) Pa abs
\[
\frac{Q_a}{Q_w} = 58.0
\]

If the permissible limit of water leak amount \(Q_w\) was assumed to be 0.09 mL/30 minutes \(Q_w=5 \times 10^{-11}\) m³/s, the air volume flow rate would be \(Q_a = 2.9 \times 10^{-9}\) m³/s.
The air leak amount would then be found by multiplying the average pressure, therefore \(3.1 \times 10^{-4}\) Pa·m³/s (ΔP=9.8kPa).

【Orifice model】

According to the orifice flow formula (JIS8762-2)
\[
\frac{Q_a}{Q_w} = \varepsilon \times \sqrt{\rho_w/\rho_a}
\]
(\(\varepsilon\) : expansion compensation coefficient)

If the below is the case;
P1 upward pressure \(1.11 \times 10^5\) Pa abs
P2 downward pressure \(1.01 \times 10^5\) Pa abs
Water density \(\rho_w = 997\) kg/m³ at 25°C
Air density \(\rho_a = 1.25\) kg/m³ at 25°C
then \(Q_a/Q_w = \varepsilon \times 28.3 = 28.3\)

(Assuming that P1 and P2 are close then \(\varepsilon = 1\)...JISZ8762-2)
If the permissible limit of water leak amount \(Q_w\) was assumed to be 0.09 mL/30 minutes, from \(Q_w=5 \times 10^{-11}\) m³/s, the air volume flow rate would be \(Q_a = 1.4 \times 10^{-9}\) m³/s.
The air leak amount would then be found by multiplying the average pressure, therefore \(1.5 \times 10^{-4}\) Pa·m³/s (ΔP=9.8kPa).

* Please refer to Page 3~7 "Reference Material" for the theoretical formulas used here.
Measurement value with an air leak tester presuming an IPX7-equivalent test is performed. Compared with the straight pipe model, the orifice model uses conditions whereby air leaks and water leaks could easily occur, therefore the orifice model air leak amount and water leak amount ratio of $Q_a/Q_w = 28$ is applied and the relationship between air/water leak amounts is shown in the below figure.

**Fig. 1** Relationship between air leak amount and water leak amount
Leakage of Gas or Fluid (Viscous Flow)

Leakage is a phenomenon which occurs when a fluid such as air, water, or oil passes through an unintended opening such as a small hole. A resultant leak volume differs according to the difference of pressure across the opening; and relates with the ease of fluid flow through the opening; conductance.

This can be expressed by the following equation.

\[ Q = C \left( P_1 - P_2 \right) \]  

(1.1)

Where \( Q \) is leak volume, \( P_1 - P_2 \) represents the difference between two pressures, and \( C \) is conductance.

When leakage is the subjective problem, the ease of fluid flow (\( C \)) depends on a variety of factors, including the configuration of the opening, length, etc. It is therefore difficult to apply one type of equation to all cases. In this section, an explanation is given using general application equations.

Theoretical Equation of Leak Volume

As a representative theoretical equation to explain the behavior of fluids passing through a very narrow opening, the Hagan-Poiseuille Law is often used. According to this law if the opening is so small that the flow of fluid is within a range of viscous flow (laminar flow), and the ratio of the hole length vs. the hole diameter is large enough, the following equation can be applied;

\[ Q_a = \frac{\pi R^4 (P_1^2 - P_2^2)}{16 \eta_a / P_2} \]  

(1.2)

Where \( Q_a \) is the volumetric flow of outlet side pressure (atmospheric pressure) converted from compressible fluid such as air.

However, if \( P_1 \) is negative, the leak volume is expressed in terms of the state of atmospheric pressure. The \( P_2 \) in the denominator in equation 1.2 is replaced with \( P_1 \).

With a volumetric flow rate \( Q_w \) representing non-compressive fluid such as water, oil, etc. the following equation is applied;

\[ Q_w = \frac{\pi R^4 (P_1 - P_2)}{8 \eta_w \ell} \]  

(1.3)

\( Q_a \) : Volumetric flow rate of compressive fluid (air) under pressure \( P_2 \) (mL/s)

\( Q_w \) : Volumetric flow rate of non-compressive fluid (mL/s)

\( P_1 \) : Primary (test) pressure

(when negative pressure, atmospheric pressure) (Pa)

\( P_2 \) : Secondary (test) pressure

(when negative pressure, test pressure) (Pa)

\( R \) : Radius of the opening (cm)

\( \ell \) : Length of the opening (cm)

\( \eta_a \) : Viscosity of compressive fluid (Pa \cdot s)

\( \eta_w \) : Viscosity of non-compressive fluid (Pa \cdot s)

The relationship of volumetric flow rate influenced by the difference between gaseous fluid and liquid, and between two pressures with the same test piece is shown in Table 1.3. Refer to equations 1.1 and 1.2.
<table>
<thead>
<tr>
<th>Condition</th>
<th>Relative Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gas</strong></td>
<td></td>
</tr>
<tr>
<td>The ratio of leak volume to the different test pressures towards the same gas.</td>
<td>[ \frac{Q_{ax}}{Q_{ay}} = \frac{P_1^2 x - P_2^2 x}{P_1^2 y - P_2^2 y} ]</td>
</tr>
<tr>
<td>The ratio of leak volume to the fixed test pressures towards different gases.</td>
<td>[ \frac{Q_{ax}}{Q_{ay}} = \frac{\eta_{ay}}{\eta_{ax}} ]</td>
</tr>
<tr>
<td>The ratio of leak volume to the different test pressures towards different gases.</td>
<td>[ \frac{Q_{ax}}{Q_{ay}} = \frac{\eta_{ay} \times P_1^2 x - P_2^2 x}{\eta_{ax} \times P_1^2 y - P_2^2 y} ]</td>
</tr>
<tr>
<td><strong>Fluid</strong></td>
<td></td>
</tr>
<tr>
<td>The ratio of leak volume to the different test pressures towards the same liquid.</td>
<td>[ \frac{Q_{wx}}{Q_{wy}} = \frac{P_1 x - P_2 x}{P_1 y - P_2 y} ]</td>
</tr>
<tr>
<td>The ratio of leak volume to the fixed test pressure towards different liquids.</td>
<td>[ \frac{Q_{wx}}{Q_{wy}} = \frac{\eta_{wy}}{\eta_{wx}} ]</td>
</tr>
<tr>
<td>The ratio of leak volume to the different test pressures towards different liquids.</td>
<td>[ \frac{Q_{wx}}{Q_{wy}} = \frac{\eta_{wy} \times P_1 x - P_2 x}{\eta_{wx} \times P_1 y - P_2 y} ]</td>
</tr>
<tr>
<td><strong>Gas/ Liquid</strong></td>
<td></td>
</tr>
<tr>
<td>The ratio of leak volume to the different test pressures towards different gases and liquids.</td>
<td>[ \frac{Q_{ax}}{Q_{wy}} = \frac{\eta_{wy} \times (P_1^2 x - P_2^2 x)}{2\eta_{ax} \times P_2 x (P_1 y - P_2 y)} ]</td>
</tr>
<tr>
<td>The ratio of leak volume to the fixed test pressure towards different gases and liquids.</td>
<td>[ \frac{Q_{ax}}{Q_{wy}} = \frac{\eta_{wy} \times (P_1 + P_2)}{2\eta_{ax} \times P_2} ]</td>
</tr>
</tbody>
</table>
Viscosity (Viscosity Coefficient) \( \eta \)

Viscosity is one of the important factors when handling fluid. Different units are used in different fields. Here are some examples:

\[1 \text{Pa} \cdot \text{s} = 1 \text{N} \cdot \text{s} \cdot \text{m}^{-2} = 1.02 \cdot 10^{-5} \text{kgf} \cdot \text{s} \cdot \text{cm}^{-2} = 10 \text{P} \]

P: Poise
N: Newton
kgf \cdot \text{s} \cdot \text{cm}^{-2}: Engineering Unit
Pa: Pascal

Also, to represent kinematic viscosity of the fluid, use the equation:

\[\nu = \frac{\eta}{\rho}\]

But \( \rho \) is the density of the fluid.

Some examples of the viscosity coefficients for air, water, brake oil and gasoline are shown in Table 1.4.

Leak Rate Calculation Using a Variety of Units of the Viscosity Coefficient (Pressure: Absolute Pressure)

(1) Calculation of Leak Rate in Compressive Fluid

Using equation 1.2, volumetric flow rates of compressive fluid based on a variety of calculations units are summarized in Table 1.5.

<table>
<thead>
<tr>
<th>Fluid</th>
<th>Temperature</th>
<th>Viscosity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air</td>
<td>0°C</td>
<td>1.71x10^{-5} Pa\cdot s</td>
</tr>
<tr>
<td></td>
<td>20°C</td>
<td>1.81x10^{-5} Pa\cdot s</td>
</tr>
<tr>
<td>Water</td>
<td>0°C</td>
<td>1.79x10^{-3} Pa\cdot s</td>
</tr>
<tr>
<td></td>
<td>20°C</td>
<td>1.00x10^{-3} Pa\cdot s</td>
</tr>
<tr>
<td>Brake Oil</td>
<td>50°C</td>
<td>0.55x10^{-3} Pa\cdot s</td>
</tr>
<tr>
<td></td>
<td>70°C</td>
<td>0.7x10^{-3} Pa\cdot s</td>
</tr>
<tr>
<td>Gasoline</td>
<td>20°C</td>
<td>6.0x10^{-4} Pa\cdot s</td>
</tr>
</tbody>
</table>

Table 1.5 Leak Rate of Compressive Fluid

<table>
<thead>
<tr>
<th>Case</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>[Q (\text{m}^3/\text{s}) = 3.927 \times 10^{-1} \frac{R^4}{\ell \eta_a} \frac{P_1 + P_2}{2} \times \frac{P_1 - P_2}{P_2}]</td>
</tr>
<tr>
<td>b</td>
<td>[Q (\text{ml/s}) = 3.927 \times 10^{-1} \frac{R^4}{\ell \eta_a} \frac{P_1 + P_2}{2} \times \frac{P_1 - P_2}{P_2}]</td>
</tr>
<tr>
<td>c</td>
<td>[Q (\text{ml/s}) = 3.927 \times 10^{-1} \frac{R^4}{\ell \eta_a} \frac{P_1 + P_2}{2} \times \frac{P_1 - P_2}{P_2}]</td>
</tr>
<tr>
<td>d</td>
<td>[Q (\text{ml/s}) = 3.851 \times 10^{5} \frac{R^4}{\ell \eta_a} \frac{P_1 + P_2}{2} \times \frac{P_1 - P_2}{P_2}]</td>
</tr>
</tbody>
</table>

Note: \( R \): Radius of Pipe, \( \ell \): Length of Pipe, \( \eta_a \): Viscosity of Fluid, \( P_1 \): Primary Absolute Pressure, \( P_2 \): Secondary Absolute Pressure
(2) Calculation of Leak Rate in Non-Compressive Fluid

Using equation 1.3, volumetric flow rates of non-compressive fluid based on a variety of calculation units are summarized in Table 1.6

<table>
<thead>
<tr>
<th>Table 1.6 Leak Rate of Non-compressive Fluid</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>b</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>c</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>d</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

R: Radius of Pipe, ℓ: Length of Pipe, η_w: Viscosity of Fluid, P_1: Primary Absolute Pressure, P_2: Secondary Absolute Pressure

**Leak Rate Conversion from Air to Liquid**

Using Table 1.2 and Table 1.3 the leak rates of water, gasoline, and brake oil in reference to air are calculated, provided that the same test piece is used. The temperature of fluid is kept fixed at 20°C, and the test pressure is kept at the same level. The results are as shown Fig. 1.3.
Calculation of Orifice model

\[ Q = \varepsilon \alpha A \left( 2 \times (P_1 - P_2)/\rho \right)^{1/2} \]

- \( Q \): Air volume flow rate
- \( \varepsilon \): Expansion compensation coefficient
- \( \alpha \): Flow coefficient
- \( A \): Area of the hole
- \( P_1 \): Upward pressure abs
- \( P_2 \): Downward pressure abs
- \( \rho \): Air density