【Introduction】

・IP codes are used in electrical product catalogs, etc., to indicate waterproofness and so on.
For the purposes of this document, "IP code" refers to the degree of protection (IP code) provided by electrical equipment enclosures, the JISC0920:2003 standard relating to waterproofness and dust resistance. The content is equivalent to IEC60529:2001.

・The dust resistance and waterproofness expressed by IP codes are not quantitative. Moreover, if the water which ingresses is not of an amount which has a harmful effect, in other words, if there is no harmful effect had, the ingress of water is permitted. Therefore, there is no correlation of air leak amount and hole diameter with IP codes that is common to all products. Hence it is necessary to confirm air leak amounts and hole diameters by conducting experiments using actual defective products.

This document provides a simple explanation of water ingress in regards to IPX7 and IPX8 test conditions. This document also contains the results of water and air leak experiments performed for stainless steel sheets and can be used as reference material when performing air leak tests.

【What is an IP code?】

・IP code is the coding of designated degrees of protection and associated additional items.
They are configured from 4 or 6 characters beginning with "IP". For example, in the case of "IP68", the first digit of "6" is referred to as the "first characteristic numeral" and indicates the degree of protection against solid foreign objects, in other words, the "dust resistance". The second digit of "8" is referred to as the "second characteristic numeral" and indicates the degree of protection against water. Furthermore, the letter "X" is used to omit either of the degrees of protection. However, care must be taken as "omission" does not equal "no protection".

・There are 9 levels, IPX0 to IPX8, used to indicate resistance against water. IPX0 indicates a condition of no protection against water. Standards designate the respective testing methods for levels 0 to 7, however in the case of IPX8, the only designation is that it should have "more stringent test conditions than IPX7" and no actual test conditions exist, therefore IPX8 is a manufacturer-independent standard.

・Regarding IPX0 to IPX6, while there is some possibility of internal immersion occurring, it is not necessarily the case that the product will be immersed, and in the reverse, even if IPX7 or IPX8 is allocated, these only indicate the waterproofness in accordance with the standard and do not eliminate the occurrence of sudden failure, degradation or accidents such as erroneous operation.

・High numerals include the performance indicated by numerals lower than them, however care must be taken concerning the second numerals of "7" and "8". This is because, although "7" and "8" indicate the respective degrees of protection during temporary and continuous immersion, they do not mean that there is protective performance against water jets, etc. Therefore, equipment which has degrees of protection against both water spray and immersion are shown as "IP66/IP67".

・The test methods, etc., for each characteristic numeral are shown on page ５.

【About water immersion…What is required for water to pass through a hole】

Wettability, capillary action and viscosity are 3 important elements in order to consider the ability of a liquid to pass through a hole and ingress. In particular, different wettability values determine whether water can or cannot pass through holes of identical diameter. Capillary action relates to tube diameter and length. The viscosity of a liquid is a measure of its resistance when it travels as a fluid. Therefore, the lower the viscosity of a liquid, the greater the leak amount will be, while the higher the viscosity, the smaller the leak amount. The viscosity of water changes slightly depending on temperature, as shown in the table on the right, however there is no problem considering it as practically constant.

Relationship between water temperature and viscosity

Temperature ℃	Viscosity mPa・s
20	1.002
25	0.890
30	0.797
35	0.719

Wettability

Wetting is said to occur when liquid makes contact with a solid at a contact angle of 90°or less.

When liquid drips on a solid surface it will ball up due to its "surface tension", however this condition depends on the type of liquid and solid, as well as the condition (surface tension of a liquid and limit surface tension of a solid). Here, the angle between a liquid and solid is referred to as the "contact angle".

There is no general definition of an angle at which a solid "wets easily".

As an approximate, contact angles of 10° or less are said to make wetting extremely easy.

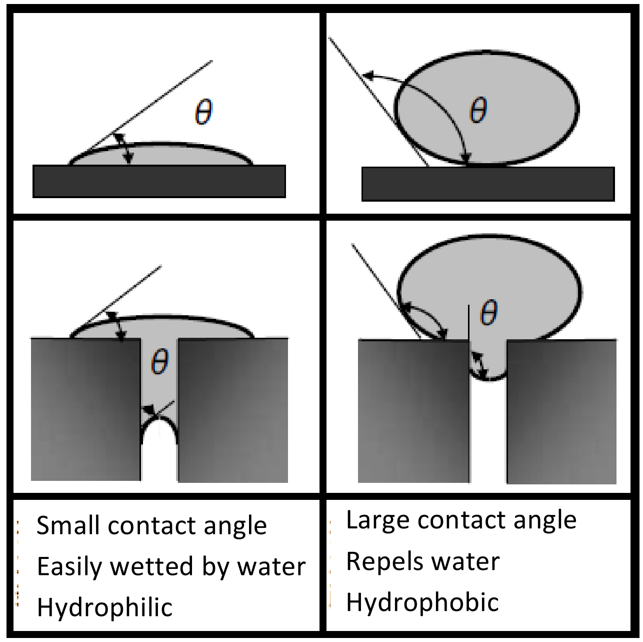
Amount of liquid	Contact angle
1.7 µL	83°

This figure shows the ability of a liquid to ingress a solid depending on the difference in contact angle.

The contact angle is also affected by the amount of liquid.

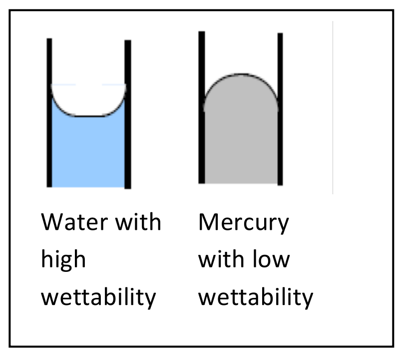
For example, the table on the right shows the results obtained with water and a stainless steel object.

Contact angles of liquid amounts in the minimum range (several dozen pL to several hundred pL) are also greatly affected by vaporization and volatilization, and care must be taken as such contact angles may significantly differ to those when the liquid amount is in the µL order.



Capillary action

Capillary action is a phenomenon where liquid climbs up
(or in some cases, down)
the interior sides of a thin tube. The height to which the liquid climbs up depends on surface tension, wall wettability and liquid density. The main characteristics are described below.

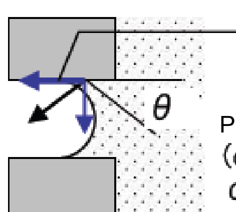


1. The surface of the liquid is tilted, not flat, due to the balance with wall wettability.
For example, if water was poured into a glass tube, the liquid surface of capillaries would rise up, however in the case of mercury (which has low wettability), the liquid surface of capillaries would lower (be repelled by the glass).

2. The liquid surface will rise up until the abovementioned force and weight of the liquid being lifted balance out. The weight of liquid is found by multiplying density by volume (tube cross-sectional area x height), <u>however in the case of thin tubes, this tube cross-sectional area is extremely small. Therefore, the liquid surface rises up extremely high.</u>

3. There is force being applied in the direction that the liquid surface is attempting to contract due to surface tension.

4. The water surface is raised as a result of a liquid surface with a tilt near the wall attempting to contract. In other words, the force that raises the liquid will become equal to the vertical component of surface tension near the wall.



$$P2 = \frac{2\sigma\cos\theta}{R}$$

P2: Force due to surface tension (dyn/cm2)

σ : Surface tension (Water: 72 dyn/cm)

R : Radius of opening

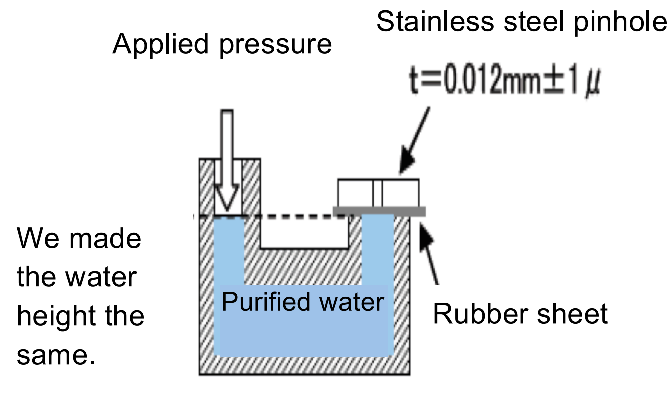
10 dyn/cm2 ＝ 1Pa

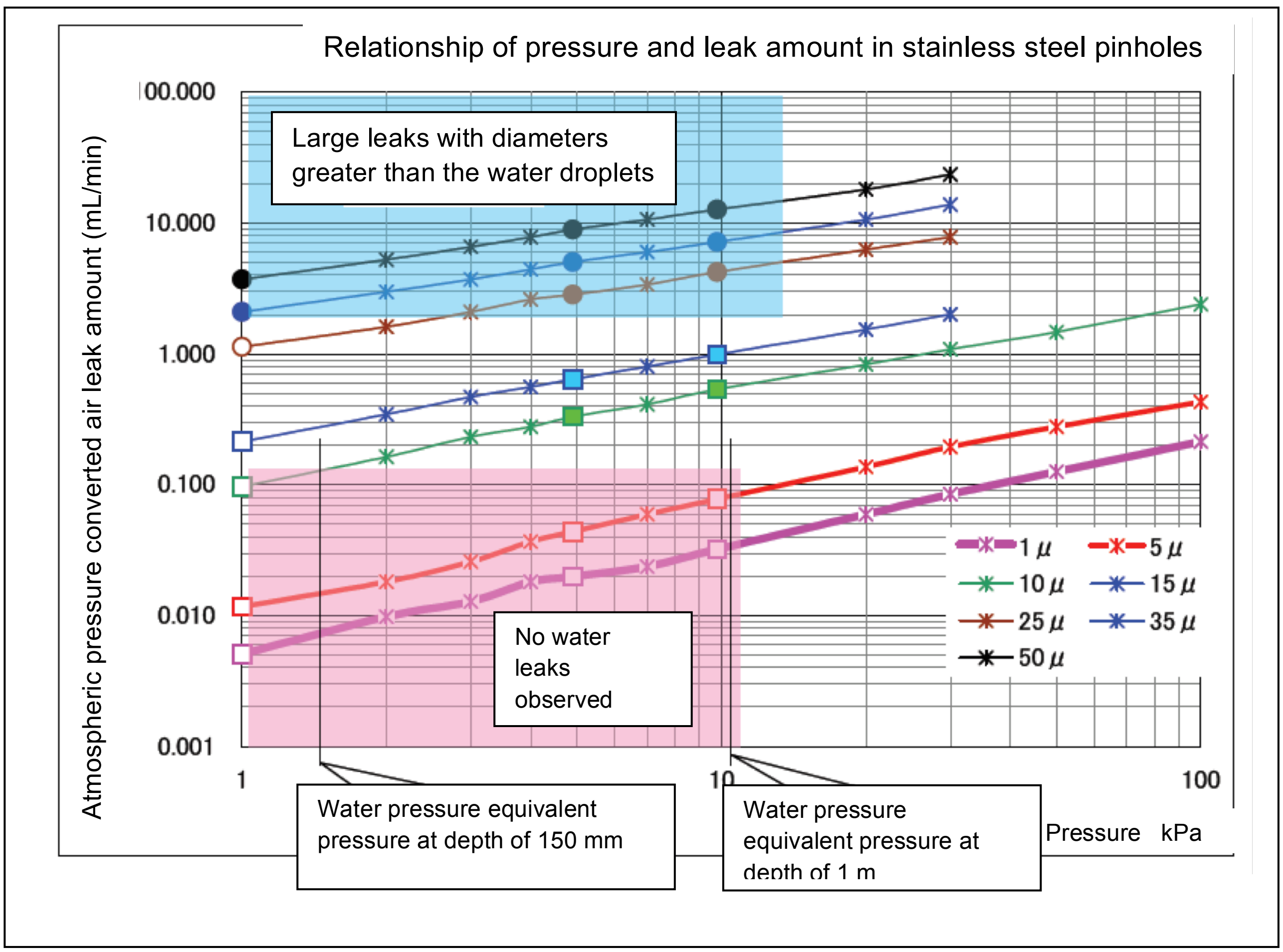
* As shown in the figure on the right, if water ingresses (due to capillary action, etc.) the leak path (radius of opening: R), surface tension (σ) will be applied in the leak direction of the path at a contact angle of θ, for the vector portion only, therefore the force due to surface tension will be as shown in the formula on the right.

【Reference data on the passage of water through holes】

We visually confirmed whether or not water leaked from a stainless steel pinhole when a constant pressure was applied.
We also measured the amount of air which leaked from the same stainless steel pinhole when a constant pressure was applied.
The relationship between pressure and leak amount obtained from these experiment results are shown in the graph below.

We confirmed the water leak status when the pressures of 1 kPa, 4.9 kPa and 9.8 kPa were applied respectively.
The whited out points are those which were observed for 1 hour with no occurrence of water leaks.
Points shown in a light color are those where measurable water leaks (0.01 mL/min or less) were observed.
Points colored over are those where large, immeasurable water leaks were observed.





Here, the tests for IPX7 relating to the ingress of water during immersion are carried out at water depths of 1 meter and 150 mm. The equivalent water pressure is 111.458 kPa abs = 10.1 kPaG at a depth of 1 meter and 102.854 kPa abs = 1.5 kPaG at 150 mm. From the graph, it can be predicted that water ingress will not be observed at a depth of 1 meter for 0.012 mm thick stainless steel material when the hole size is 5 µ or less and the atmospheric pressure converted air leak amount is 0.08 mL/min or less. Likewise, it can be predicted that water ingress will not be observed at a depth of 150 mm for 0.012 mm thick stainless steel material when the hole size is 5 µ to 10 µ and the atmospheric pressure converted air leak amount is 0.1 mL/min or less.

As stainless steel was used in the experiment, the contact angles were very big (between 80 and 90°) and the thickness was small at 0.012 mm, therefore differing from both the material and thickness of actual workpieces.
As mentioned, even in the case of materials with the same contact angle, it is believed that water will not ingress if the material is thick, even if the hole diameter and atmospheric pressure converted air leak amount are the same. However, an object can be wetted very easily if the contact angle is small , therefore it is believed that water will be able to ingress thick material even if the hole diameter and atmospheric pressure converted air leak amount are the same.

The contact angle varies greatly depending on surface roughness more than material. In reality, confirm the difference between stainless steel and the contact angle by dripping a small amount of water onto the subject and use the experiment data as reference material for consideration.

IP

[Overview of IP codes]

First characteristic numeral (Ingress of solid objects)

Numeral	Degree of protection against contact and ingress of solid foreign objects provided by the product enclosure
0	No protection
1	Protected against solid foreign objects with a diameter of 50 mm or more. Protected so that an adult's clenched fist cannot come within close proximity of dangerous areas.
2	Protected against solid foreign objects with a diameter of 12.5 mm or more. Protected so that an adult's finger cannot come within close proximity of dangerous areas.
3	Protected against solid foreign objects with a diameter of 2.5 mm or more. Protected so that tools cannot come within close proximity of dangerous areas.
4	Protected against solid foreign objects with a diameter of 1.0 mm or more. Protected so that wire cannot come within close proximity of dangerous areas.
5	Protected so that even if dust for dust resistance tests (dia. = 75 μm) does ingress, it does not interfere with the designated operations and safety of equipment.
6	Protected against the ingress of dust for dust resistance tests (dia. = 75 μm).

Second characteristic numeral (Waterproof)

Numeral	The degree of protection that the enclosure provides against harmful ingress of water		Test method used by a testing authority
0	No particular protection	No particular protection against water ingress.	No test
1	Protection against dripping water	Vertically falling drops shall have no harmful effects.	Exposure to vertically dripping water in a droplet testing device for 10 minutes.
2	Protection against dripping water	Vertically falling drops shall have no harmful effects when the enclosure is tilted at any angle up to 15°on either side of the vertical.	Drop 3 mm/min droplets of water from a height of 200 mm above the apparatus. Set up the product on an angle of 15° and measure 4 positions for 2.5 minutes each, for a total of 10 minutes over the entire test sample.
3	Protection against spraying water	Water sprayed at an angle up to 60°on either side of the vertical shall have no harmful effects.	Spray with water for 10 minutes at angles up to 60°on either side of the vertical.
4	Protection against splashing water	Water splashed against the enclosure from any direction shall have no harmful effects.	Splash with water for 10 minutes from all directions.
5	Protection against water jets	Water projected in jets directly against the enclosure from any direction shall have no harmful effects.	Subject to water jets of 12.5 l/min from angles up to 60°on either side of the vertical for 1 minute on areas with external surface area of 1m2, for a total time of at least 5 minutes over the entire test sample.
6	Protection against powerful water jets	Water projected in powerful jets directly against the enclosure from any direction shall have no harmful effects.	Subject to powerful water jets of 100 l/min from all directions for 1 minute on areas with external surface area of 1 m^2, for a total time of at least 5 minutes.
7	Protection when temporarily immersed in water	Ingress of water shall not be possible when the enclosure is temporarily immersed in water under standardized conditions of pressure and time.	Immerse test specimens 850 mm or less in height in a tank filled with 1 meter of water for 30 minutes. For test specimens exceeding a height of 850 mm, leave at least a gap of 150 mm from the top of the specimen to the water surface.
8	Protection when fully immersed in water	Ingress of water in quantities causing harmful effects shall not be possible when the enclosure is continuously immersed in water under conditions more stringent than for Grade 7.	To be agreed upon by the manufacturer and user of equipment.