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Greetings

Thank you for your continuing interest in our magazine.

In 2018, VALQUA initiated the 8th medium-term management plan NVS8. As with NVS7, this new plan will continue to focus on activities to offer total solutions in the Seal Engineering Services.. Through such activities, as an H & S company we will maximize customer value, and through the new plan we will use innovations based on H & S. This will help us create new solutions that drive solid and sustainable growth in global markets. To reflect this intention, we removed the two words "Japan" and "Industry" from our company name "Nippon Valqua Industries, Ltd." and renamed the company "VALQUA, LTD.".

VALQUA is striving to be innovative in global markets which continue to evolve rapidly. To achieve this goal, we are expanding our technical development. We also strive to deliver the results of our technological development as early as possible to respond to demands from all customers. We aim to create new solutions which are valuable for customers through actively introducing methods such as open innovation, and combining accumulated technological know-how with leading technologies, thus satisfying our customers' needs as a true H & S company. This is our overall technical development goal, and we will pursue ingenuity to achieve it.

From this issue, *Valqua Technology News* consists of three parts: 1) Customer solutions, 2) Technical papers, and 3) Product introductions. The VALQUA group will develop new products based on sophisticated technologies, evolve these new products through H & S, and offer customer solutions. With this new magazine structure, this issue introduces several cases of what kinds of achievements can actually be made. We hope it will clearly show the process of creating H & S solutions, through which the VALQUA Group contributes to customers' security and safety. We would also be pleased if readers find the issue to be a useful technological reference.

We hope that you will continue to enjoy *Valqua Technology News* along with VALQUA products and services.

Senior Executive Officer Director of Corporate Research and Development Group Mutsuo Aoki

Seal Training for Maritime Technique Training in Compliance with an International Convention (STCW Convention)

1. Introduction

Sealing engineering is a core technology of VALQUA which has been developing solutions for the issues faced by customers amid the changing times. Recently, we aim to provide customers with essential sealing engineering services. To achieve this goal, we have been actively developing and providing our original services.

We have been expanding seal training as a skill training service, which we aim to introduce in various industries and areas, and completed the development of a maritime technique training in October 2017, as described in this article.

This training has now obtained Certification of Maritime Education & Training (Figure1) from Nippon Kaiji Kyokai (hereafter called "ClassNK"). This training complies with the STCW Convention, an international convention. Currently, two training bases are certified, one in Machida, Tokyo and the other in Gojyo, Nara.

This article explains ClassNK, from which we obtained certification, and the background which led to the enactment of an international convention on seamen's skills. Based on these, as well as the efficacy of Certification of Maritime Education & Training, we explain the seal training.

Figure1 ClassNK's Certification of Maritime Education & Training

2. Nippon Kaiji Kyokai

The Japanese classification society Nippon Kaiji Kyokai is internationally known as ClassNK. ClassNK aims to secure safety regarding human life and property in the marine environment and to prevent marine pollution. With these missions, ClassNK's business includes the following: 1) Registration and inspection of ships' classification, for which classification societies are responsible, 2) Certification of management systems based on international standards including ISO, and 3) Certification of Maritime Education & Training in compliance with international conventions. ClassNK has a history of more than 110 years, has the largest number of ship classifications (approximately 20% of overall ship classifications among more than 50 classification societies worldwide by March 2018), and an international reputation.

3. The STCW Convention, an international convention

To prevent maritime accidents resulting from seamen's lack of skills regarding ship operation, an international convention called the STCW Convention (The International Convention on Standards of Training, Certification and Watchkeeping for Seafarers, 1978), which sets standards for skills and knowledge, was

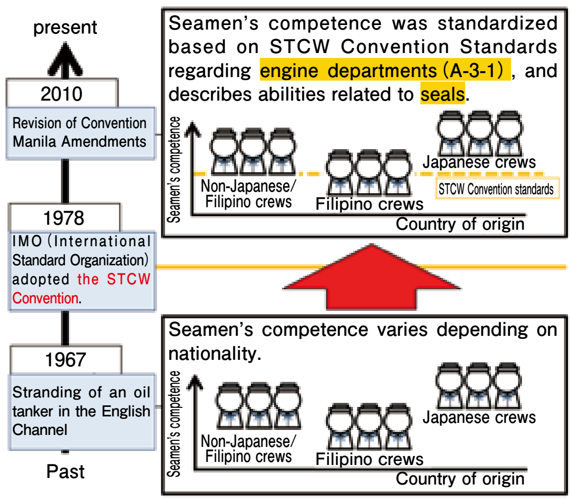

Figure2 Background resulting in establishment of the STCW Convention

adopted, thus standardizing seamen's skills. In the past, qualification systems regarding seamen's skills and competence varied among countries, and so seamen's abilities also varied. However, after an accident in 1967, seamen's technical standards were revised mainly by the International Maritime Organization (IMO). Then, in July 1978, the STCW Convention was adopted and international standards regarding seamen's training and qualifications were set[1] (Figure2).

The STCW Convention's Code A shows seamen's obligation and abilities. A-3-1 of Code A describes skills and knowledge regarding sealing.[2] In addition, based on this convention, the IMO started the IMO Model Course as a basic training program to encourage effective training, which includes more detailed training methods. Sealing skills are indispensable for the safe operation of ships.[3]

4. Seal training for maritime technique training

To become a seaman, a seaman's competency certificate is needed, for which special education at institutions including universities is needed. Such institutions issue the certificate. However, the knowledge and skills required differ depending on the type of seaman, and so the time allocated to sealing is limited.

Therefore, after hiring seamen, each marine transportation company provides its own education on the handling and knowledge of seals as on-the-job training during voyages. Inexperienced seamen, including new employees, depend on the information on sealing skills and knowledge handed down by older workers.

Over many decades, VALQUA has accumulated much knowledge on sealing materials at VALQUA and customers' sites, which it uses to provide sealing engineering. Seal training was developed based on sealing engineering, and is intended to ensure that participants acquire optimal techniques for selecting and constructing sealing materials. The training is practical: participants learn knowledge and acquire techniques through practice. Also, unique characteristics of the training not found in other types of training include visualizing individual skills through an original system, and hands-on construction education in which various on-site techniques are simulated. This training has received positive feedback as being effective for seamen (navigation officers, engineers, and crews) from marine transportation companies as off-the-job training, and is superior to on-the-job training.

As mentioned above, this training targets seamen mainly related to the STCW Convention (navigation officers, engineers, and crews). However, ClassNK recognized the need to ensure security and safety for not only marine transportation companies but also for all those involved in ships and vessels. Therefore, the training is also provided for those engaged in ship-related works (shipbuilding, ship maintenance, public organizations including maritime training institutions), and those handling ship devices and equipment.

The curriculum of the two-day course covers both classroom education and practical training on gaskets, rotary seals including gland packing, and mechanical seals. After participants complete this training, their understanding is then tested, and each successful participant is issued a ClassNK-certified certificate of completion (Figure3).

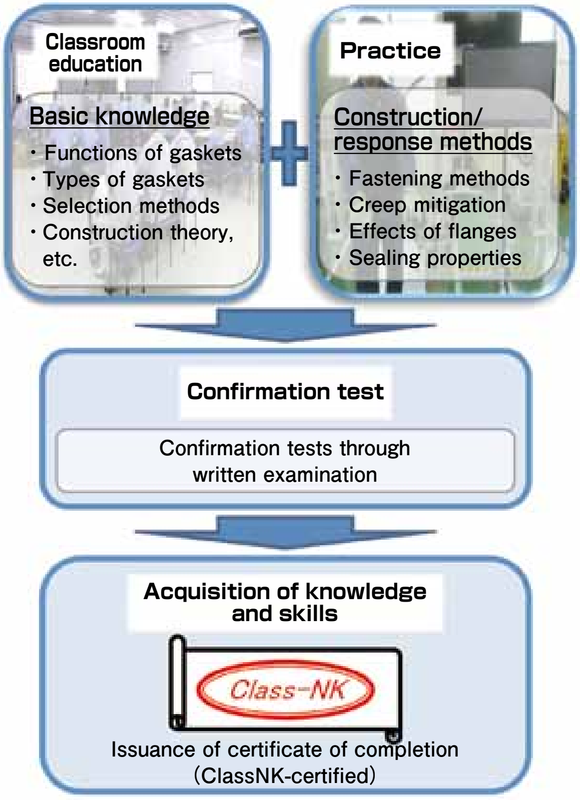

Figure3 Curriculum summary

5. Conclusion

Currently, VALQUA has two training bases, one in Machida, Tokyo and the other in Gojyo, Nara, which offer ClassNK-certified training. We encourage Japanese marine transportation companies to participate in the training. We also have similar training bases in China, Taiwan, Vietnam, Thailand, and South Korea, where we will arrange a training system to offer certified training.

We also offer sealing engineering services including seal training as a skill training service. Based on these services, we will contribute to the development of world marine transportation markets and to the security and safety of the industry.

6. References

1) Seamen's qualification based on STCW Convention, etc., Ministry of Land, Infrastructure, Transport and Tourism, http://www.mlit.go.jp/sogoseisaku/kotsu/bunya/kaiji/stcw.html

2) 2010 STCW Convention (Manila Amendments) in English and Japanese (official translation), supervised by the Maritime Bureau, Ministry of Land, Infrastructure, Transport and Tourism, published by Seizando-Shoten Publishing Co., Ltd.

3) (Model course 7.04) Officer in charge of an Engineering Watch, 2014 Edition

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Cleaning Plant Facilities Using a Low-Pressure Composite Water Flow Cleaner (Cavitation Cleaning)

1. Introduction

A low-pressure composite water flow cleaner physically removes sludge that has adhered to the inside surface of water pipes by using water and air. The cleaning process does not use any high-pressure water, chemicals, or chemical reactions. Previously, such removal required dismantling, liquid-chemical management, and liquid disposal, all of which are costly. Thanks to the cleaner's system, the sludge removal does not involve any dismantling or chemicals, thus achieving low-cost, eco-friendly cleaning.

2. Cleaning method

A hose with a pressure resistance of at least 0.8 MPa is connected to the "IN" and "OUT" ports of the equipment to be cleaned. Water is fed at 0.4 MPa into the hose, while being mixed with fine air bubbles which serve as centers for cavitation. In addition, the direction of water flow is rapidly reversed to create shock waves, which make the fine air bubbles swell and contract, causing cavitation. Also, the air bubbles act as dampers, thus helping to control the cavitation force. Therefore, cleaning can be executed without damaging the equipment to be cleaned.

3. Cleaning effects of resin molding-die water pipes

This section introduces the case of a customer. The customer uses an 850T-class molding machine to mold panel parts, and the mold which we cleaned had been manufactured 7 years ago and then used for production. Cleaning had been performed on-site simply by blowing air into water pipes. Due to clogging since the machine was installed, the product molding cycle of the mold had increased from the initial 113 seconds to 123 seconds or longer. For the analysis, pre-cleaning and post-cleaning conditions were compared as follows:(1) Parts were produced at the mold's passing water flow rate and at the initial condition of 113 seconds. (2) After the mold's temperature stabilized, the temperature was measured using a thermograph. (3) The mold's temperature distribution and defects of molded products before cleaning were compared with those after cleaning.

【Discussion】

The overall flow rate was improved as shown in Table1. Before cleaning, two surface sink marks developed as shown by circles in Figure1. When manufacturing parts, a molding cycle of 123 seconds was required. However, after cleaning, the temperature distribution of the mold improved, the surface sink marks disappeared, and the defects were resolved. Also, the overall temperature was lower. However, the temperature of some areas increased due to changes in the resin flux. Therefore, the molding cycle should be made longer than the initial cycle. Through the extension, the temperature of such areas was lowered. As a result, we showed that parts could be produced without problems at a molding cycle of 115 seconds, which is just 2 seconds longer than the initial condition.

【Results】

The molding cycle was shortened by 8 seconds. We found that regular cleaning of the mold eliminated perforation troubles and achieved stable production. Also, unlike chemicals, the cleaning process is not associated with melting, and thus frequent cleaning does not damage the mold.

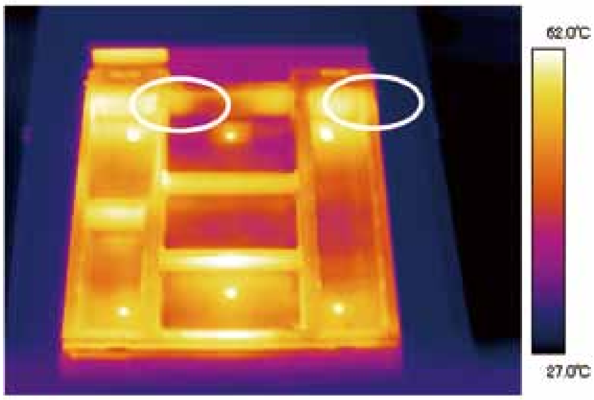

Figure1 Pre-cleaning temperature distribution of the mold and defective areas

Table1 Numerical comparison of pre-cleaning and post-cleaning conditions

Endpoint	Pre-cleaning	Post-cleaning
Overall flow rate (0.2MPa)	59.6L/min	74.6L/min
Circuit 1	1.1L/min	4.2L/min
Circuit 2	8.1L/min	10.3L/min
Circuit 3	3.2L/min	5.3L/min
Circuit 4	5.4L/min	7.0L/min
Circuit 5	10.8L/min	12.5L/min
Sub-circuit 1	16.9L/min	19.5L/min
Sub-circuit 2	14.1L/min	15.8L/min
Molding cycle	123seconds	115seconds
Defective molding (At initial condition)	Surface sink marks developed.	No defect

4. Sales of the cleaning machine

Although we have limited results regarding sales for plants, we have a number of successful sales for the resin-molding industry, and particularly with automobile parts manufacturers. The cleaning machine is applicable to water pipes, not only cast pipes but also those under the molding machine's hopper and in the chiller's heat exchanger. Therefore, the machine can be used for various purposes. Recently, the cleaning machine reduced the cleaning time from approximately 3 days to 24 hours at a PET bottle factory, where previously it was necessary to dismantle pre-form molding dies and the take-out devices' water pipes in order to clean facilities.

In addition, we found that the cleaning machine can be used for cleaning the water pipes of sintering machines for pre-formed screw parts in manufacturing equipment, and rotatory blowing machinery. With these findings, the machine is expected to be used also in the PET bottle industry. Regarding other uses, the machine is used for cleaning the water pipes of castings including aluminum die castings. Although utilization in plants is limited, we have received positive customer feedback. Relative to the effects of chemical cleaning at 100%, the cleaning effect of the machine is 80%. Sometimes, chemical cleaning causes problems for production lines such as chemicals remaining in the lines when production restarts. However, with our cleaning machine, no troubles have been reported. In addition, when cleaning shell- and tube-type heat exchangers (on the side of the shell), only the surface can be cleaned even though a hyperbaric cleaning method is used. However, our cleaning machine can also clean the space between tubes. Such characteristics have been positively evaluated. Since this machine enables plate-type heat exchangers to be cleaned without dismantling, we have received positive feedback such as about the lower cost of exchanging packings.

5. Effects of plant facility cleaning

5-1) Effects for a shell- and tube-type heat exchanger (horizontal-type)

We cleaned a horizontal-type shell- and tube-type heat exchanger shown in Figure2. Before cleaning, a reddish-brown deposit covered the side of the shell as shown in Figure3. The deposit was such that the red deposit could be removed by scratching with a finger. The cleaning machine's "IN" and "OUT" were connected to the handholes and cleaning was conducted without removing the "IN" and "OUT." During cleaning, a large amount of deposit precipitated in the tank as shown in Figure4. This precipitate rapidly clogged the filters as shown in Figure5. A considerable amount of deposit could be removed. In addition, when we confirmed the post-cleaning conditions of the connection outlets, we found that deposit had been thoroughly removed as shown in Figure6, since these areas were exposed to powerful flows.

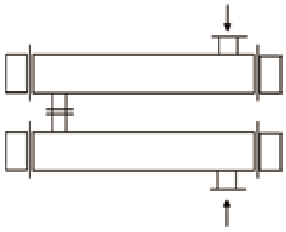

Figure2　Shape of heat exchanger

Figure3　Pre-cleaning condition

Figure4　During-cleaning condition

Figure5　Filter condition

Figure6　Post-cleaning condition

5-2) Effects for a large shell- and tube-type heat exchanger

Before cleaning, as shown in Figure7, the spaces between tubes were clogged with oxide. However, after cleaning, as shown in Figure8, the clogging was removed. The oxide covering the tube surface was not completely removed. However, when the heat exchange conditions during operation were measured, we found that the cleaning was effective.

Figure7　Pre-cleaning condition

Figure8　Post-cleaning condition

5-3) Effects for a large plate-type heat exchanger

As Figure9 shows, the cleaning machine was connected to a large plate-type heat exchanger with a plate number of 410 and a heat transfer area of 391.7m^2 without dismantling. Then, we conducted cleaning for 50 hours on the cooling-water side and for 70 hours on the circulating-water side.

The results are shown in Table2. The flow rate of circulating water was sped up by approximately 45% and the heat exchange amount was increased by approximately 75%. Since the plates were not dismantled, the packing did not need to be exchanged. Customers appreciate such benefits.

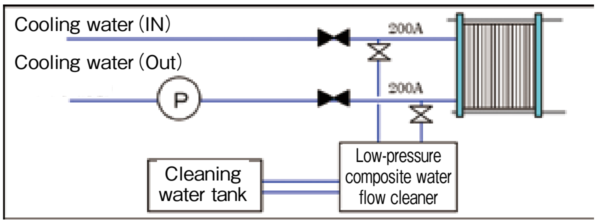

Figure9　Schematic drawing of the connection

Table2　Numerical comparison of pre- and post-cleaning conditions for a large plate-type heat exchanger

	Cooling water temperature (℃)			Circulating water temperature (℃)			Circulating water amount	Heat exchange amount	Heat transmission rate
	IN	OUT	Disparity	IN	OUT	Disparity	m^3/hr	Kcal/hr	Kcal/m^2·h·℃
Pre-cleaning	28.7	35.3	6.6	47.0	42.3	4.7	150	705000	143
Post-cleaning	27.5	36.0	8.5	45.5	39.8	5.7	216	1231200	290

5-4) In-line cleaning of a small plate-type heat exchanger for spa facilities

Although the conditions are different from those of plants, plate-type heat exchangers are also used at spa facilities, which sometimes suffer clogged water pipes. When this happens, they have to dismantle and clean the heat exchangers. Accordingly, we used an in-line cleaning machine (which is less effective than an off-line machine) to clean a small plate-type heat exchanger. During the cleaning, we opened the plates and confirmed the conditions. The cleaning machine was connected to the heat exchanger and the plates were washed for 2 hours as shown in Figure10.

Before cleaning, the entire plates were covered with deposit as shown in Figure11. However, after the cleaning, approximately 80% of the plate surface could be seen, as shown in Figure12. Thus, the cleaning restored the heat-exchange amount and resolved the pressure loss, returning the equipment to normal operation.

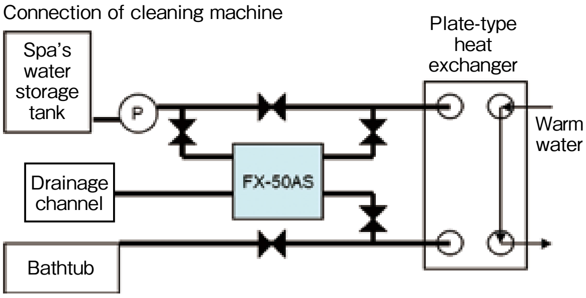

Figure10　Connection of cleaning machine

Figure11　Pre-cleaning condition

Figure12　Post-cleaning condition

6. Conclusion（Expansion to plants）

Until now, plate-type heat exchangers and shell- and tube-type heat exchangers (on the side of the shell) have been cleaned with chemicals or high-pressure water or had to be replaced since such areas could not be dismantled. We have started developing a large cleaning machine (NR-2000) together with VALQUA LTD., which we expect will overcome such problems. Also, when cleaning plant facilities, the channel areas are expected to be large. Therefore, the effects of bubbling through a two-layer fluid and turbulence effects, which develop from switching the flow direction, can exert powerful cleaning rather than with cavitation, which occurs during cast cleaning. Therefore, we need to continue studying physical phenomena regarding cleaning effects.

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Design Guidelines and Troubles for DYNAMICBELLOWS™ and Countermeasures

1. Introduction

The functions of welded metal DYNAMICBELLOWS™ (hereafter "Bellows") are to absorb displacement parallel with the axis, perpendicular to the axis, and in a bending direction as shown in Figure1. The Bellows absorb displacement while maintaining airtightness. When selecting Bellows that absorb displacement parallel with the axis, it is easy to select from the catalog, but for Bellows that absorb displacement perpendicular to the axis and in a bending direction, selection is often difficult.

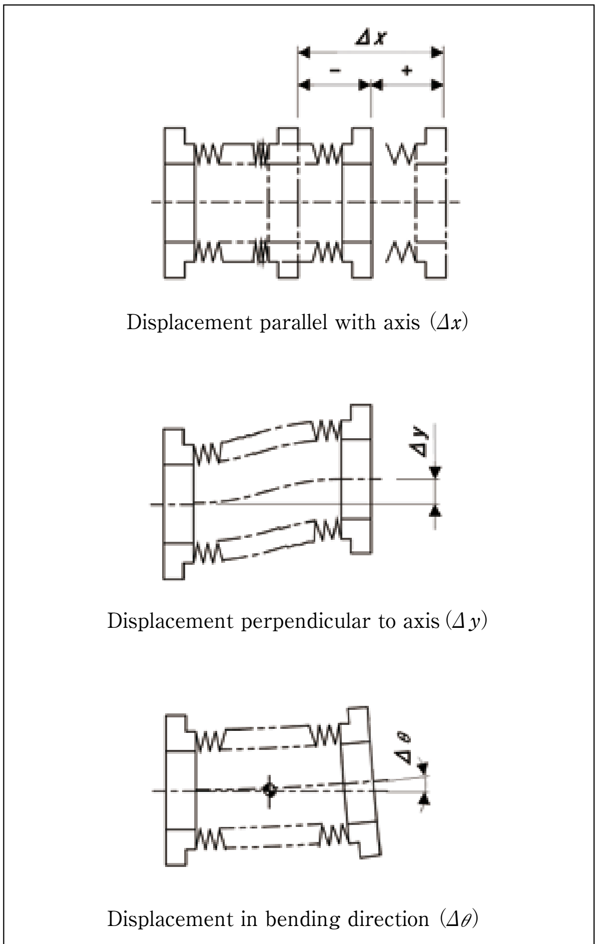

Figure1 Types of displacement

Also, when the Bellows' inner pressure is greater than the outside pressure to maintain airtightness, buckling sometimes develops as shown in Figure2, resulting in the risk of deformation and breakage. Therefore, care is required when designing.

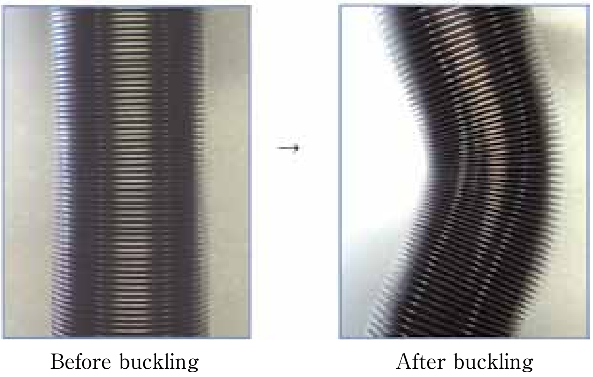

Figure2 Bellows' buckling

In addition, when Bellows are attached in a horizontal direction, the Bellows' own weight causes horizontal deflection as shown in Figure3. Therefore, care is required like the case of buckling.

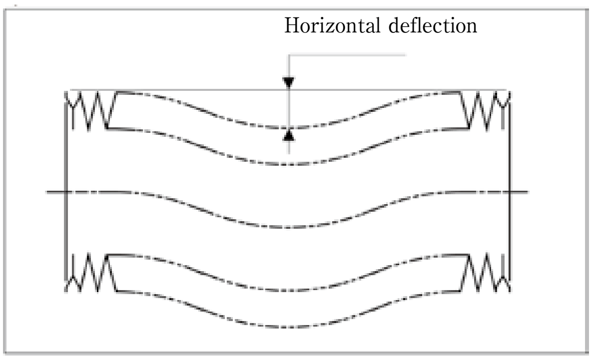

Figure3 Bellows' horizontal deflection

This article examines the case of our standard product V series (catalog No. PC08), and describes the selection method for Bellows that absorb displacement perpendicular to the axis, and design considerations for buckling and horizontal deflection.

2. Design guidelines for Bellows

2-1) Concept of displacement perpendicular to the axis

When investigating the Bellows' displacement perpendicular to the axis, first the displacement perpendicular to the axis is converted into the displacement parallel with the axis, using the equation:

$$\Delta x(y) = \frac{3 \times D \times \Delta y}{L} \quad \cdots\cdots\cdots\cdots \ (1)$$

where, Δx (y) : value converted into displacement parallel with axis (mm)

D : Bellows' outside diameter (mm)

Δy : displacement perpendicular to axis (mm)

L : Bellows' length (mm)

When the converted allowable displacement parallel with the axis is known, the allowable displacement perpendicular to the axis can then be calculated by the equation:

$$\Delta y(\max) = \frac{\Delta x(y) \times L}{(3 \times D)} \quad \cdots\cdots\cdots\cdots \ (2)$$

where, Δy (max) : allowable displacement perpendicular to axis (mm).

2-2) Combination of displacement parallel with axis and displacement perpendicular to axis

In Section 2-1), only displacement perpendicular to the axis was given. However, generally, Bellows are often used with both displacement perpendicular to the axis and displacement parallel with the axis. According to Equation (1), the smaller L is, the larger the converted displacement parallel with the axis Δx (y). Therefore, the calculation should be made to minimize L under the influence of displacement parallel with the axis.

In this case, Equation (1) becomes:

$$\Delta x(y) = \frac{3 \times D \times \Delta y}{(L - \Delta x)} \quad \cdots\cdots\cdots\cdots \ (3)$$

Equation (2) becomes:

$$\Delta y(\max) = \frac{\Delta x(y) \times (L - \Delta x)}{(3 \times D)} \quad \cdots\cdots\cdots\cdots \ (4)$$

However, Δx is displacement parallel with the axis on the contraction side (mm).

Regarding Sections 2-1) and 2-2), the shape of Bellows with displacement perpendicular to the axis is such that expanded parts and contracted parts are combined as shown in Figure4. Therefore, regarding the

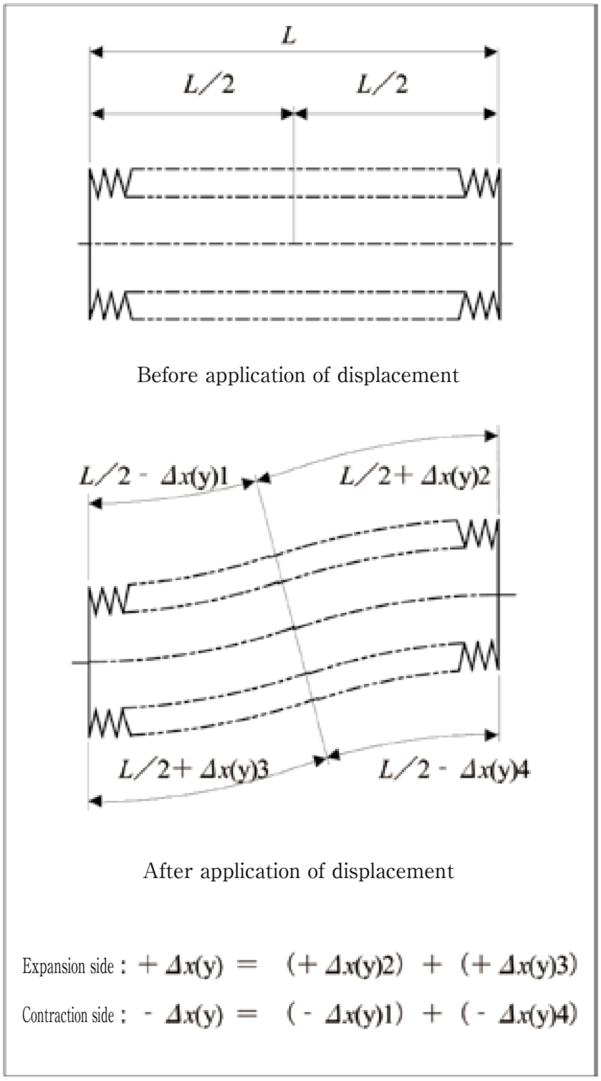

Figure4 Shape of displacement perpendicular to axis

converted displacement parallel with the axis Δx (y), allowance ranges should be prepared for both the expansion side and the contraction side.
Therefore, a Bellows with a length of L is given the value of "+Δx (y) and -Δx (y) ."

3. Selection procedure for V series

3-1) When only displacement perpendicular to the axis is present

Based on the design guidelines described above, we consider the selection of V series (Catalog No. PC08). Refer to the catalog and follow the steps.
Figure5 shows the selection flow. Each step is described below.

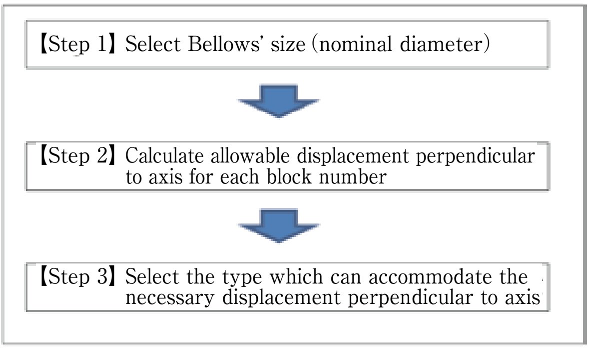

Figure5 Selection procedure for V Series

【Step 1】Select the Bellows size (nominal diameter)

Based on the space in which the Bellows is attached, the Bellows size (nominal diameter) is selected. Here, we selected V20.

Catalog value of V20 (1-block specification)

Internal diameter = 20mm,
Outside diameter = 40mm
Expansion and contraction length = 10mm,
Expansion length = 15mm,
Contraction length = 5mm

【Step 2】Calculate the allowable displacement perpendicular to the axis for each block number

For the selected size (nominal diameter), the allowable displacement perpendicular to the axis is calculated for each block number.

In the case of 1 block:

Expansion and contraction length = 10mm, Expansion length = 15mm, Contraction length = 5mm
In this case, the Bellows length L = 10mm, Δx = ±5mm.
According to Equation (2) ,

$$\Delta y\,(\max) = \frac{5 \times 10}{(3 \times 40)} \fallingdotseq 0.4\text{mm}$$

In the case of 2 blocks:

Expansion and contraction length = 20mm, Expansion length = 30mm, Contraction length = 10mm
In this case, the Bellows length L=20mm, Δx = ±10 mm.
According to Equation (2) ,

$$\Delta y(\max) = \frac{10 \times 20}{(3 \times 40)} = 1.6\text{mm}$$

In the same manner, increase the block number and calculate for each block number. Table1 shows the results.

Table1 V20's block number and displacement amount

Block number	1	2	3	4	5
L (mm)	10	20	30	40	50
Δx (mm)±	5	10	15	20	25
Δy (max) (mm)	0.4	1.6	3.7	6.6	10.4

【Step 3】 Determine the type which can accommodate the necessary displacement perpendicular to the axis

Select the block number which can accommodate the necessary displacement perpendicular to the axis and select the Bellows type.
For example, if the necessary displacement perpendicular to the axis is 5mm, the block number is 4 according to Table 1. So, the required type is V20-111-4.
Regarding the Bellows length L, note that the length excludes the length of fittings on both ends. In the case of V20-111-4, this length on both ends is 3mm, so the overall length is 46mm.

3-2) Displacement perpendicular to the axis and displacement parallel with the axis

In the case where there is both displacement perpendicular to and parallel with the axis, as shown in Section 2-2) , the calculation should be made with the length which becomes minimum under the effects of displacement parallel with the axis. The selection flow is the same as in Figure5.

【Step 1】Select the Bellows size (nominal diameter)

Based on the space in which the Bellows is attached, the Bellows size (nominal diameter) is selected. Here, we selected V30.

Catalog value of V30 (1-block specification)

Internal diameter =30mm, Outside diameter =50mm

Expansion and contraction length = 10mm, Expansion length = 15mm, Contraction length = 5mm

【Step 2】Calculate the allowable displacement perpendicular to the axis for each block number

For the selected size (nominal diameter), the allowable displacement perpendicular to the axis against displacement parallel with the axis is calculated for each block number. When the necessary displacement parallel with the axis is 10mm and the block number is 1, the converted displacement parallel with the axis Δx (y) is 0. Therefore, at least 2 blocks are needed.

In the case of 2 blocks:

Expansion and contraction length = 20mm, Expansion length = 30 mm, Contraction length = 10mm

Bellows length L = 20mm; when there is only displacement parallel with the axis, then Δx of up to ±10mm is acceptable.

When the necessary displacement parallel with the axis of 10 mm is Δx = ±5mm, Δx (y), the converted value of allowable displacement parallel with the axis when displacement perpendicular to the axis is applied, is 5mm (10mm – 5mm = 5mm).

According to Equation (4),

$$\Delta y(\max) = \frac{5 \times (20-5)}{(3 \times 50)} = 0.5\ \text{mm}$$

In the case of 3 blocks:

Expansion and contraction length = 30mm, Expansion length = 45mm, Contraction length = 15mm

Bellows length L = 30mm; when there is only displacement parallel with the axis, Δx of up to ±15mm is acceptable.

When the necessary displacement parallel with the axis of 10mm is Δx = ±5mm, Δx (y), the converted value of allowable displacement parallel with the axis when displacement perpendicular to the axis is applied, is 10 mm (15mm – 5mm = 10mm).

According to Equation (4),

$$\Delta y(\max) = \frac{10 \times (30-5)}{(3 \times 50)} = 1.6\ \text{mm}$$

In the same manner, increase the block number and calculate for each block number. Table2 shows the results.

Table2 V30's block number, displacement parallel with the axis, displacement perpendicular to the axis

Block number	2	3	4	5	6
L (mm)	20	30	40	50	60
Δx (mm) ±	5	5	5	5	5
Δx (y) (mm) ±	5	10	15	20	25
Δy (max) (mm)	0.5	1.6	3.5	6.0	9.1

【Step3】Determine the type which can accommodate the necessary displacement perpendicular to the axis

Select the block number which can accommodate the necessary displacement perpendicular to the axis and select the Bellows type.

For example, if the necessary displacement perpendicular to the axis is 5mm, the block number is 5 according to Table2. So, the required type is V30-111-5. The Bellows length including the fitting length on both ends is 56mm.

4. Design troubles and countermeasures

4-1) Investigation of Bellows' buckling

One of the design problems of Bellows is buckling. Bellows, like columns and springs, suffer buckling due to compressive forces and lose straightness. Refer to Figure2.

This buckling threshold value can be approximated by using the widely-used Euler's formula:

$$Fcr = \frac{4 \times \pi^2 \times EI}{L^2} \quad \cdots\cdots\cdots\cdots (5)$$

where, Fcr : buckling load limit (N)

EI: Bellows' bending stiffness (N・mm²)

L : Bellows' length (mm)

Note : Regarding EI, refer to *Valqua Review* Vol. 40, 1st issue.[1)]

4-2) Bellows' buckling pressure

When Bellows are subjected to internal pressure, the limit pressure which triggers buckling, or buckling pressure, can be calculated assuming that thrust develops in response to the pressure applied to the effective area of the Bellows, and that the buckling load is equivalent to the thrust.

$$Pcr = \frac{4 \times \pi^2 \times EI}{(A \times L^2)} \quad \cdots\cdots\cdots\cdots (6)$$

$$A = \left(\frac{(d+D)}{2}\right)^2 \cdot \frac{\pi}{4} \quad \cdots\cdots\cdots\cdots (7)$$

where, Pcr : Bellows' buckling pressure (MPa)
A : Bellows' effective area (mm^2)
d : Bellows' inner diameter (mm)
D : Bellows' outside diameter (mm)

In this case, the longer the Bellows length L becomes, the smaller the buckling pressure becomes, reducing the strength against buckling. Therefore, when calculating, the maximum service length (expansion length) should be used.

When the pressure significantly exceeds this limit pressure, the Bellows will buckle and not expand or contract, which may result in deformation, a shorter lifespan or early breakage.

Figure6 shows a case of breakage due to buckling.

Figure6 Breakage due to buckling of Bellows

4-3) Investigation of V Series' buckling

Next, we examine the buckling of our standard product V Series (Catalog No. PC08). Refer to the catalog and follow the steps.

In the catalog, one column shows the block number limitation. This shows the case in which the V Series' allowable pressure of 0.1 MPa is outside pressure and the case in which the allowable pressure is the internal pressure. Among these block numbers, when the allowable pressure is internal pressure, the block number limitation is determined based on the buckling pressure explained in Section 4-2).

An example of calculating the buckling pressure is shown below.

Example 1. According to Equation (6) when the block number is 4 which is V20's block number limit,

$$Pcr = \frac{4 \times \pi^2 \times 15477}{(706.86 \times 60^2)} = 0.24 \quad \text{MPa}$$

In this case, the Bellows length L is calculated using the expansion length.

The details of EI are omitted here.

When the block number is 4, L is 60mm (expansion length 15mm × 4 blocks = 60mm) .

Regarding the Bellows' effective area A, according to Equation (7),

$$A = \left(\frac{(20+40)}{2}\right)^2 \times \frac{\pi}{4} = 706.86 \quad mm^2$$

Example 2. According to Equation (6), when the block number is 6 which is V100's block number limit,

$$Pcr = \frac{4 \times \pi^2 \times 485068}{(10386.89 \times 90^2)} = 0.22 \quad \text{MPa}$$

In this case, when the block number is 6, the Bellows length L is 90mm (15mm × 6 blocks = 90mm) .

Regarding the Bellows' effective area A, according to Equation (7),

$$A = \left(\frac{(100+130)}{2}\right)^2 \times \frac{\pi}{4} = 10386.89 \quad mm^2$$

Based on the results of the above calculation, the inner pressure of 0.1 MPa is not greater than the buckling pressure, so buckling does not develop.
When the block number which can be used for the necessary displacement parallel with the axis is selected and the selected block number is greater than the block number limitation, the guide shown in the catalog should be attached. This guide is shown in Section 4-4) below.

4-4) Countermeasures to prevent buckling

When the block number exceeds the block number limitation, a guide should be attached. An example of the structure is as follows.

【Example 1】When a shaft is present on the inside of the Bellows

Figure7 is a frequently used structure.

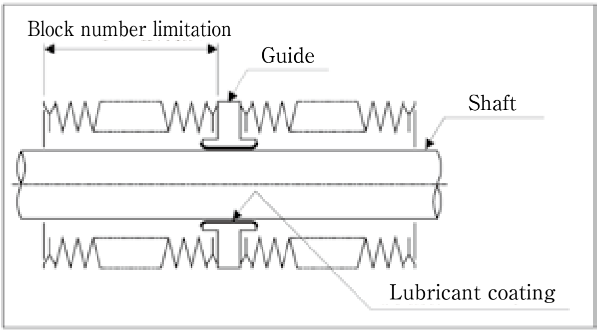

Figure7 A guide inner surface is coated with lubricant

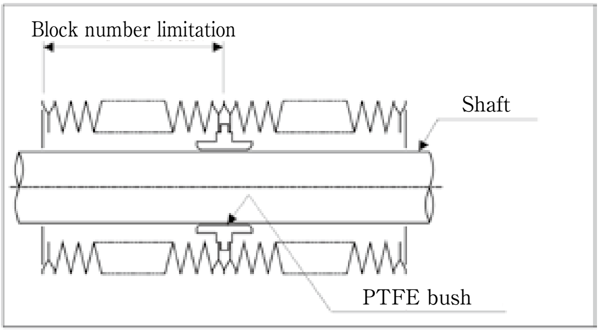

Figure8 A PTFE bush is attached to the guide inner surface

【Example 2】When a shaft is absent on the inside of the Bellows

The structure becomes more complex and accurate positioning of the guide rod is needed.

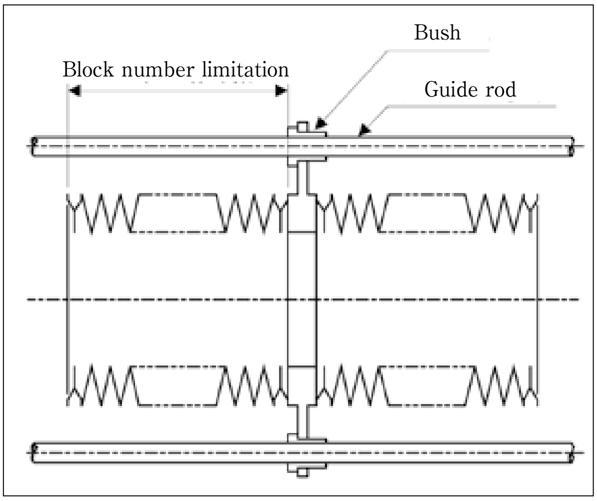

Figure9 Guide rods are placed on the surroundings

As shown above, guides should be placed at every location where the block number is equal to or less than the block number limitation.
When displacement perpendicular to the axis is present, guides cannot be placed. Therefore, displacement perpendicular to the axis which is greater than the block number limitation is not acceptable.

4-5) Block number limitation using outside pressure

The V Series' block number limitation is shown when the outside pressure is 0.1 MPa. In this case, we do not calculate the buckling pressure; we calculate the Bellows' horizontal deflection (refer to Figure3) to prevent the horizontal deflection from exceeding 1mm, using the equation:

$$y(\max) = \frac{9.8 \times W \times L^3}{(384 \times EI)} \quad \cdots (8)$$

where, y (max) : Bellows' horizontal deflection (mm)
W : Bellows' weight (kg)
L : Bellows' length (mm)
EI : Bellows' bending stiffness ($N \cdot mm^2$)

In this equation, the effects of outside pressure are ignored. When outside pressure is applied, the

Bellows' deflection is considered to decrease. Therefore, in this equation, we calculate values when the Bellows inside/outside pressure is atmospheric pressure.

Example 1) According to Equation (8), when the block number is 9 which is V20's block number limit,

$$y(\max) = \frac{9.8 \times 0.13 \times 135^3}{(384 \times 15477)} = 0.53 \quad \text{mm}$$

In this case, the Bellows length L is calculated using the expansion length.
The details of *EI* are omitted here.
When the block number is 9, *L* is 135mm (15mm × 9 blocks = 135mm). Also, the Bellows' weight *W* is 0.13kg.

Example 2) According to Equation (8), when the block number is 20 which is V210's block number limit,

$$y(\max) = \frac{9.8 \times 5.32 \times 300^3}{(384 \times 5653926)} = 0.65 \quad \text{mm}$$

In this case, when the block number is 20, *L* is 300 mm (expansion length 15mm × 20 blocks = 300mm) and the Bellows' weight *W* is 5.32kg.

4-6) Countermeasures to prevent horizontal deflection

When the block number exceeds the block number limitation, a guide should be attached. An example of the structure is similar to the example shown in Section 4-4).

5. Conclusion

This article described the case of our standard DYNAMICBELLOWS™ V series (catalog No. PC08) and examined the selection method when Bellows absorb displacement perpendicular to the axis, and design considerations regarding the block number limitation.
As noted already, when Bellows with a length longer than the block number limitation are used, there are risks of deformation, a shorter lifespan, and breakage, so care is required.
We hope that this article will help prevent design problems when selecting the V Series.

6. References

1) *Valqua Review* Vol.39, 4th issue, Lecture on seals (23)
Vol.39, 5th issue, Lecture on seals (24)
Vol.39, 6th issue, Lecture on seals (25)
Vol.39, 7th issue, Lecture on seals (26)
Vol.40, 1st issue, Lecture on seals (27)
Vol.40, 9th issue, Lecture on seals (28)

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Lining Tank (Basics)

1. Introduction

Fluororesin has excellent non-viscosity, chemical resistance, slip characteristics, electrical characteristics, and antistaining properties, and so is widely used in various fields.

VALQUA started manufacturing and selling fluororesin lining tanks in Japan in 1972, more than 45 years ago, and is now expanding into Taiwan (1997), China (2017), and the U.S. (2017). We have accumulated a wealth of lining technology, and would like to introduce our technologies to customers not only in Japan but also overseas. Therefore, we are publishing these three feature articles: the basics, applications, and future directions.

2. Types of lining materials

There is a wide range of commercially-available lining materials including rubber, phenol resin, polyethylene, epoxy resin, vinyl chloride, glass, and FRP. For comparison with fluororesin, this article focuses on vinyl chloride, glass, and fluororesin. Table1 outlines the characteristics of these three materials.

Regarding the scope of application in terms of temperature and pressure, glass linings have the widest, and vinyl chloride linings have the narrowest. Generally, glass linings are used at high temperatures above 120°C, which is the heatproof temperature of adhesives. Glass linings also tend to be used for negative-pressure areas. Although glass linings have weaknesses such as fragility and vulnerability to temperature impacts, manufacturers market materials that address such problems.

When selecting the optimal lining material, we should consider corrosion resistance, antistaining properties, washability, formability, and cost.

Table1 Characteristics of fluororesin, vinyl chloride, and glass linings

	Fluororesin	Vinyl chloride	Glass
Allowable temperature	120℃ (150℃)	60～70℃	230℃
Allowable pressure (positive-pressure side)	Depends on strength of can body	Depends on strength of can body	Depends on strength of can body
(negative-pressure side)	Balance type	–	FV
Fluid	Inactive against most chemicals	–	Applicable to any chemicals except alkaline chemicals
Main market	Semiconductor	Water and sewage	Pharmaceuticals
	Chemical	Chemical	Chemicals
Cost	Moderate	Reasonable	Expensive
Others	–	–	Shock - resistant materials are available.
			Alkali-proof materials are available.
			Heat - resistant materials are available.

The maximum service temperature of fluororesin and balance types shown in Table1 are explained later.

3. Types and characteristics of fluororesin linings

Five types of fluororesin are currently used for linings as shown in Table2. However, PTFE (polytetrafluoroethylene), PFA (tetrafluoroethylene-perfluoroalkyl vinyl ether copolymer), and ETFE (ethylene tetrafluoroethylene copolymer) account for the majority thanks to their characteristics, which are summarized as follows:

① Excellent chemical resistance
② Outstanding heat resistance
③ Non-viscosity
④ Excellent electrical characteristics

⑤ Low-friction characteristics
⑥ Incombustibility
⑦ Strong weather resistance
⑧ Purity

Fluororesin is an excellent material because it has not just one, but all, of the above characteristics, and so is used in many fields. These characteristics stem from fluororesin's molecular structure. As shown in Figure1, PTFE consists of carbon（C）and fluorine（F）atoms. The two atoms form C-F bonds, which are one of the strongest types of chemical bond. In PTFE, F atoms densely surround the C-C bonds, creating a structure that is resistant to attacks on the C-C bond. Therefore, fluororesin has chemical resistance and low permeability.

In addition, due to weak intermolecular attractive force between dissimilar atoms, fluororesin has non-viscous and antistaining properties. In addition, fluororesin has low-friction characteristics thanks to the following properties: 1）The atomic arrangement of fluororesin is

Table 2　Characteristics of fluororesins used for lining purpose

△：applicable　○：good　◎：excellent　◉：outstanding

	Characteristics	Unit	ASTM test method	PTFE	PFA	FEP	ETFE	PVDF
	Structural formula			$-(CF_2-CF_2)-_n$	$-(CF_2-CF_2)-_m$ $-(CF_2-CF)-_n$ (ORf)	$-(CF_2-CF_2)-_m$ $-(CF_2-CF)-_n$ (CF_3)	$-(CF_2-CF_2)-_m$ $-(CH_2-CH_2)-_n$	$-(CF_2-CH_2)-_n$
Physical characteristics	Melting point	℃	—	327	310	260	270	156−170
	Specific gravity	—	D792	2.14−2.20	2.12−2.17	2.12−2.17	1.70	1.75−1.78
Mechanical characteristics	Tensile strength	MPa	D638	27.4−34.3	24.5−34.3	21.6−31.4	45.1	34.3−43.1
	Extension	%	D638	200−400	300	250−330	100−400	80−300
	Compressive strength	MPa	D695	11.8	16.7	15.2	49	66.6−96
	Impact strength（Izod）	J/m	D256A	160	Non-destructive	Non-destructive	Non-destructive	160−374
	Hardness（Rockwell hardness）	—	D785	—	—	—	R50	R77−83
	Hardness（Shore hardness）	—	D2240	D50−55	D60	D55	D75	D75−77
	Bend elastic constant	MPa	D790	550	660−690	650	1400	2000−2480
	Tensile elasticity	MPa	D638	400−550	—	340	820	1310−1500
	Dynamic friction coefficient	—	0.69MPa 3m/min	0.10	0.2	0.3	0.4	0.39
Thermal characteristics	Thermal conductivity	W/(m･K)	C177	0.25	0.25	0.25	0.24	0.10 ～ 0.13
	Specific heat	J/(g･K)	—	1.0	1.0	1.2	1.9−2.0	1.4
	Coefficient of linear expansion	10^{-5}/℃	D696	10	12	8.3−10.5	5.9	7−14
	Ball pressure temperature	℃	—	180	230	170	185	—
	Heat distortion temperature 1.81MPa	℃		55	50	50	74	87−115
	Heat distortion temperature 0.45MPa	℃		121	74	72	104	149
	Maximum service temperature	℃	(No load))	260	260	200	150−180	150
Electrical characteristics	Volume resistivity	Ω−cm	D257（50% RH.23℃）	>10^{18}	>10^{18}	>10^{18}	>10^{16}	2×10^{14}
	Dielectric breakdown strength（Short time）	kV/mm (Thickness of 3.2 mm)	D149	19	20	20−24	16	10
	Inductivity 60Hz	—	D150	<2.1	<2.1	2.1	2.6	8.4
	Inductivity 10^3Hz	—	D150	<2.1	<2.1	2.1	2.6	8.4
	Inductivity 10^6Hz	—	D150	<2.1	<2.1	2.1	2.6	6.43
	Dissipation factor 60Hz	—	D150	<0.0002	<0.0002	<0.0002	0.0006	0.049
	Dissipation factor 10^3Hz	—	D150	<0.0002	<0.0002	<0.0002	0.0008	0.018
	Dissipation factor 10^6Hz	—	D150	<0.0002	0.0003	<0.0005	0.005	<0.015
	Arc resistance	s	D495	>300	>300	>300	75	50−70
Durability and other characteristics	24h water absorption rate	%	D570	<0.01	<0.03	<0.01	0.029	0.04−0.06
	Flammability Thickness of 3.2mm	—	(UL−94)	V−0	V−0	V−0	V−0	V−0
	Limiting oxygen index	—	D2863	>95	>95	>95	30	44
	Effects of direct sunlight	—	—	None	None	None	None	None
	Acid			◉	◉	◉	◎	○
	Alkaline			◉	◉	◉	◎	○
	Solvent			◉	◉	◉	◎	△

an inflexible, dense, straight-chain structure. 2) The surface of fluororesin is smooth. 3) Fluororesin forms a unique crystal structure in which external forces tend to easily cause sliding within a crystal or between crystals. In addition, the molecules are arranged symmetrically, resulting in nonpolarity. Therefore, fluororesin has exceptionally low dielectric constant and strong insulation resistance.

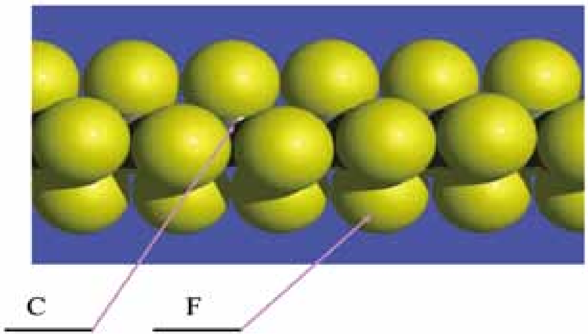

Figure1　Molecular structure of PTFE

PFA is a thermofusion resin with improved workability, which is a shortcoming of PTFE. Although PFA has some differences under extreme conditions, it can be categorized as a fluororesin similar to PTFE.

4. Differences among fluororesin sheet lining, coating, and Roto lining (rotational molding)

Lining, as the name suggests, is a construction method which lines the inside of vessels and pipings, both of which are prepared separately in advance.

Fluororesin sheet lining, coating, and Roto lining (rotational molding) differ depending on the manufacturing method; Table3 shows the differences.

Regarding fluororesin sheet linings, the details are explained later.

Coatings can be categorized into two major types depending on the baking temperature. When coatings are used for non-viscous purposes (such as rice cookers and frying pans), the baking temperature is not raised to the melting point, and so pinholes form on the resin surface.

When coatings are used for corrosion-resistance purposes, the coating materials are baked at a temperature above their melting points to create a resin film on the liquid contact surface. Therefore, there are no pinholes on the resin surface. This report considers only corrosion-resistance coatings. There are limitations on increasing the film thickness of a coating. Under the same conditions, coatings are inferior to fluororesin lining and Roto lining (rotational molding) in terms of longevity.

To increase the film thickness of coatings, spraying and baking processes are repeated several times. However, the membrane sprayed first can be easily peeled when subjected to cycles of repeated heating. Therefore, the limit of coating application is considered to be approximately three times.

In Roto lining (rotational molding), after can bodies are defatted and baked, a given amount (calculated based on the film thickness and surface area) of resin is poured into the inner-diameter space of the can body, which becomes the product. After pouring the resin, the can body is rotated on a two-axis lining machine and heated at a temperature above its melting point from the outside. Through rotation in the melting condition, the resin covers the inside surface of the can body. The can body is rotated and heated thoroughly until a uniform resin film forms. Then, the can body is cooled while it is rotated. Among fluororesins, this manufacturing method can be only applied to PFA, FEP, and ETFE, which are melting-type resins.

It is suitable for manufacturing complex shapes including vapor pipes. Also, the film thickness can be adjusted.

As mentioned above, regarding coatings and Roto linings, resin is cooled while adhered to the metal surface of the can body. As a result, the resin cannot thoroughly contact, causing distortion (residual stress) within the resin. This distortion causes troubles under severe specified conditions.

In addition, the resin film used for coating and Roto lining has a lower resin density than that in sheet lining, to which independently formed sheets are applied. This low density reduces the product lifespan.

Table3　Characteristics of Roto lining, coating, and sheet lining

	Roto lining (rotational molding)	Coating	Sheet lining
Manufacturing method	A can body is set on a two-axis lining machine.	Spraying → drying → baking → cooling	Fixing using adhesives
Metal selection in consideration of heat effects	Approx. 380°C	Approx. 380°C	200°C or lower
Characteristics	Film thickness can be adjusted. Sealing condition can be created. Complex shapes can be formed.	Base finishing requires care. When the film thickness is thin, the base conditions directly affect the painted surface.	Film thickness is uniform. Unsuitable for complex shapes.
Size	Limited depending on electric furnace's size	Limited depending on electric furnace's size	Up to sizes that allow road transportation in each country.
Film thickness	Thickest	Approx. 30μm—1mm	2T—4T
Lifespan	Medium	Short	Long

5. Heat resistance and chemical resistance of fluororesin sheet lining

Heat resistance

Regarding heatproof temperatures of fluororesin sheet lining, there are two standards specified by VALQUA:

120°C : adhesive lining (depending on the heatproof temperature of adhesives)

150°C : loose lining (depending on the heatproof temperature of PFA welding)

Unlike lining piping, loose lining is a construction method in which a liner is not attached to a can. Therefore, loose lining is used under limited conditions. In addition, the balanced type of loose lining was developed to withstand negative pressure by using a loose lining. With the balanced type, vacuuming of the liner's indentations from vent holes is prevented; it is frequently used under negative-pressure conditions at high temperature between 120 and 150°C.

Chemical resistance

Table4 shows the effects of acids, alkalis, and solvents on the weight increase of PTFE. PTFEs do not react with most industrial chemicals and solvents and have very strong chemical resistance. However, PTFEs react with the following chemicals:

① Alkali metals in the molten condition (including sodium, potassium, and lithium) remove F atoms from polymers.

② PTFEs react with fluorine gas, chlorotrifluorine, and other chemicals under high temperature.

③ PTFE can be eroded in high temperature 80% metal hydrogen compounds including 80% NaOH, KOH, B_2H_6, aluminum chloride, and ammonia.

④ PTFE is gradually damaged by nitric acid at 250°C under pressure.

The usable temperature range of PTFEs can be designed depending on the fluid used and your conclusion as to the conditions under which PTFE cannot be used. However, a general understanding of the usable temperature is as follows.

ETFE may crack under stress from chemicals other than those listed above. In addition, PVDF has overall inferior chemical resistance, and is eroded by solvents with strong polarity in particular.

Table4　Chemical properties

a) Effects of acids and alkalis

Effects of acids and alkalis on weight increase of Teflon® PTFE

Reagent		Exposure temperature℃	Dipping time	Weight increase%
Hydrochloric acid	10%	25	12 months	0
		50	12 months	0
		70	12 months	0
	20%	100	8 hours	0
		200	8 hours	0
Nitric acid	10%	25	12 months	0
		70	12 months	0.1
Sulfuric acid	30%	25	12 months	0
		70	12 months	0
		100	8 hours	0
		200	8 hours	0.1
Sodium hydroxide	10%	25	12 months	0
		70	12 months	0.1
	50%	100	8 hours	0
		200	8 hours	0
Ammonium hydroxide	10%	25	12 months	0
		70	12 months	0.1

・These values are obtained when virtually achieving equilibrium. The values are assumed not to significantly increase even if the exposure time is increased.
・Weight changes of 0.2% or smaller are within study error values.
・Regarding studies conducted at temperatures over reagents' boiling points, these studies were conducted within sealed vessels, so the pressure is obtained at its vapor pressure at the temperature.

b) Effects of solvents

Effects of solvents on weight increase of Teflon® PTFE

Solvent	Exposure temperature℃	Dipping time	Weight increase%
Acetone	25	12 months	0.3
	50	12 months	0.4
	70	2 weeks	0
Benzene	78	96 hours	0.5
	100	8 hours	0.6
	200	8 hours	1.0
Carbon tetrachloride	25	12 months	0.6
	50	12 months	1.6
	70	2 weeks	1.9
	100	8 hours	2.5
	200	8 hours	3.7
Ethyl alcohol (95%)	25	12 months	0
	50	12 months	0
	70	2 weeks	0
	100	8 hours	0.1
	200	8 hours	0.3
Ethyl acetate	25	12 months	0.5
	50	12 months	0.7
	70	2 weeks	0.7
Toluene	25	12 months	0.3
	50	12 months	0.6
	70	2 weeks	0.6

・These values are obtained when virtually achieving equilibrium. The values are assumed not to significantly increase even if the exposure time is increased.
・Weight changes of 0.2% or smaller are within study error values.
・Regarding studies conducted at temperatures over reagents' boiling points, these studies were conducted within sealed vessels, so the pressure is obtained at its vapor pressure at the temperature.

Note : Teflon® Properties Handbook, Du Pont-Mitsui Fluorochemicals Company, Ltd. [1)]

The order of chemical resistance of resins is as follows:

PTFE=PFA>FEP※>ETFE>PVDF

※ There are few FEP linings.

Regarding construction methods of linings, the order is as follows:

Sheet lining>Rotational molding>Coating

When corrosion resistance is taken into account, the maximum service temperatures are as follows.

Coating products：80–100°C

ETFE rotational molding：100℃

PFA rotational molding ：120℃

PTFE/PFA-lining products

Adhesive lining：120℃ (adhesive's limitation)

Loose lining：150℃ (welding-joint products)

Note：These results do not apply to special liquid-chemical specifications. Also, the lifespan will differ under long-term use.

6. Process of fluororesin sheet lining

In most cases of fluororesin sheet lining, an adhesive-lining method is used.

Fluororesins are non-adhesive. Therefore, the surface of the fluororesin repels adhesives when applied to the surface. This non-adhesive property prevents fluororesin sheets from sticking to a can body, so surface modification of the adhesive surface in advance is required. Surface-modification methods include: chemical treatment (hereafter called "surface treatment"), glass-backing sheet, and plasma etching. However, lining sheets mainly use the first two methods.

In surface treatment, metallic sodium is melted in ammonia solution or naphthalene solution, then the resulting solution is used to etch the surface. Sodium ions are made to react with fluorine molecules to form NaF. A carbon layer is precipitated on the surface. The adhesive surface after surface treatment turns dark brown and loses non-viscosity. The adhesive structure is "carbon layer – (adhesive) – metal."

Glass-backing sheets are manufactured through a lamination method, which proceeds as follows: 1) A PFA sheet is heated above its melting point. 2) A glass cloth sheet is pressed into the PFA sheet. 3) The resulting sheet is cooled for integration. In the case of a PTFE sheet, its melt viscosity is too strong for this press-in approach, and so a lamination process is conducted via a PFA film.

Figure2 shows the processes of fluororesin sheet lining.

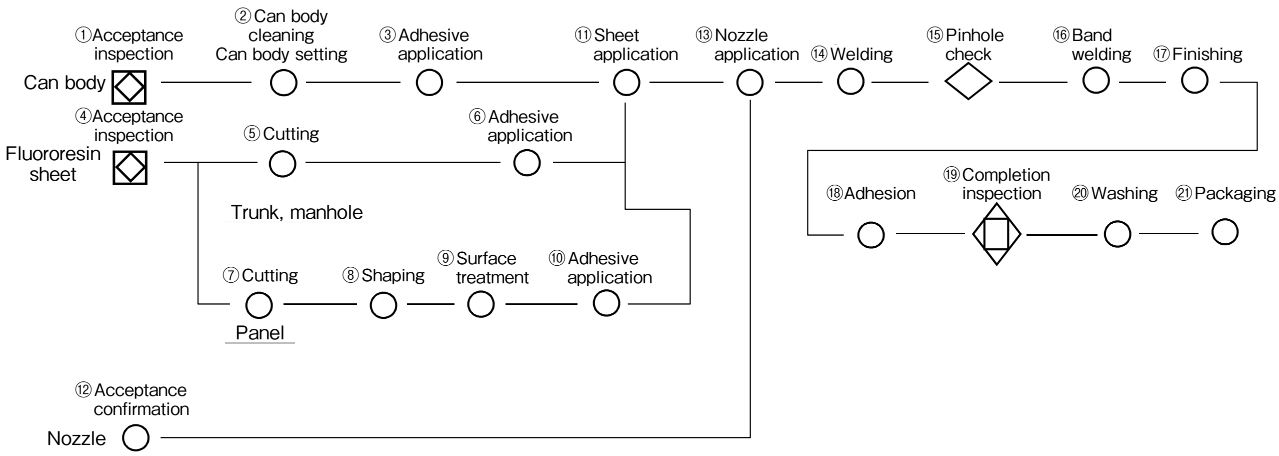

Figure2 Lining process

① Acceptance inspection of a can body :
Inspection after manufacturing of the can body is completed. In particular, it is important to confirm the tie-in position and direction of nozzles, etc. The inside is blasted after the inspection is completed.

② Can body cleaning :
Cleaning of the surface to which an adhesive is applied is important, as it affects adhesion.

③ Adhesive application :
An adhesive is applied to the can body.

④ Acceptance inspection of fluororesin sheet :
Documents are checked.

⑤ Cutting of fluororesin sheet : Cut to the given size.

⑥ Adhesive application to fluororesin sheet.

⑦ Cutting of panels : Ends of the panel are cut.

⑧ Shaping of panels :
Panels are shaped in a unique pattern through vacuum molding.
Details are explained in "Application."

⑨ Surface treatment of panels

⑩ Adhesive application

⑪ A lining sheet is attached to the can body.

⑫ Acceptance inspection of nozzle:
Whether the nozzle is manufactured to the given size is checked.

⑬ Nozzle application :
The nozzle is applied to the can body.

⑭ Welding : The nozzle is connected to the can body by welding (manual).

⑮ Pinhole check :
The can body is checked for welding flaws.

⑯ Belt welding :
(Robot welding; details are explained in "Application.")

⑰ Finishing :
The sealing surface is finished with a central focus on the welded area of the flange parts.

⑱ Adhesion :
A lining sheet is attached to the can body.

⑲ Finished-product inspection :
Inspection is made according to in-house standards.

⑳ Washing, packing, shipping

Among these processes, the welding process is the most important regarding quality. The number of welding processes is proportional to the length of the can body. Therefore, for these processes, adequate time is allocated in the construction schedule.

7. Considerations when designing fluororesin lining tanks

The considerations when designing fluororesin lining tanks are explained below.
The major differences in constructing fluororesin lining tanks compared with metal tanks are that metal burrs and welding do not damage fluororesin liners, and the method of setting angle R to maintain adhesion.

7-1) Types of tanks

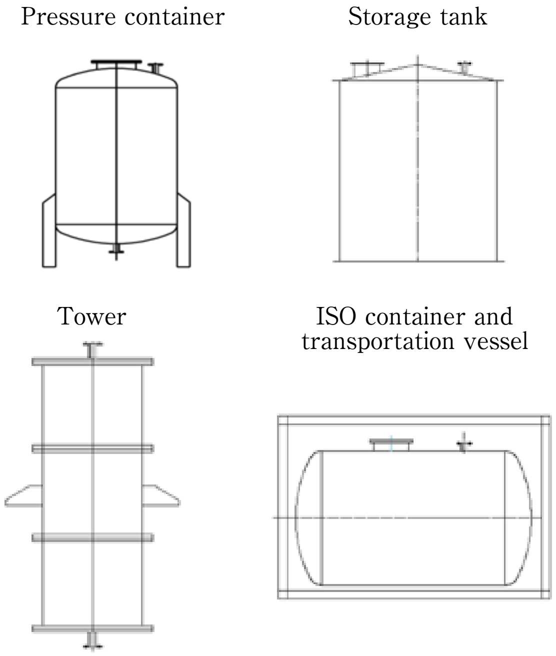

Figure3 Types of tanks

7-2) Applicable manufacturing range

Manufacturing involves coordinating the design and manufacturing of the metal can bodies, and applying the fluororesin sheet lining on the inside surface of the tank. When a can body is classified as a type 1 or 2 pressure container, or is subject to the Fire Service Act, tests by government agencies should be conducted before lining.

7-3) Summary of lining design

- In principle, when a can body is divided into a trunk (torso) and upper lid, or into a trunk and trunk, a flange connection should be used.
- Unlike general metal tanks, the lined surface of a tank should be smooth without convex or concave parts. Metal weld beads within the tank should be smooth.
- The convex angle of the treated surface should be R-shaped; the concave angle should have a slope and large R. In addition, regarding the nozzle angle R, each size has standards ranging from R3 to R5.

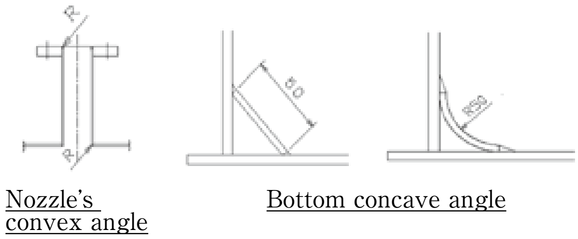

Figure4 Construction of convex and concave parts in corners

- Uent holes on a can body should be perforated. Vent holes have the following functions: 1) To allow the escape of gas which accumulates behind the lining material and through which liquid chemical in the tank may permeate and be discharged from the outlet, and 2) To serve as leakage detection holes in the case of lining breakage. Consultation is required regarding the mounting positions and number.
- Regarding panels, 10% plate panels are generally used for sizes between ϕ500 and ϕ2000. For can bodies of other shapes and sizes, independent consultation is needed.
- Since workers must enter the tank during construction, the can body should have an opening on the main-body flange or a manhole of ϕ500 or greater should be placed. In addition, for tanks of $10m^3$ or greater, two manholes are placed as standard.
- Structures within the tank should be simple. When baffles or supports are mounted, consultation is required.
- If the metal pipes of nozzles protrude into the can body, a sheet lining cannot be used. Therefore, the shape should be as previously described as an example of the convex angle of a nozzle. In addition, as standard, the height of a nozzle is 100 mm from the outer surface of the can body.
- The lining of the flange surface of a nozzle is not flat-face lining due to construction convenience; basically, seal-face shapes are used on the inside of a bolt.
- In principle, lining construction is conducted on a turning roller. If nozzles or attachments interfere, relocation is sometimes required.

8. Considerations when designing fluororesin sheet lining vessels

1. The service temperatures include reaction heat and dilution heat, and so vessels should be used at 120°C or lower.(If the temperature is over 120°C, independent consultation is required.)
2. In principle, vessels cannot be used under negative pressure. If they are, countermeasures against negative pressure should be applied to the vessels. Therefore, when draining a liquid which is contained within a vessel, operation which prevents negative-pressure conditions within the vessel is required, such as pressurization draining or vent opening.
   In addition, when vessels are used under heating conditions, the pressurized condition or vent opening is required until the temperature returns to room temperature.
3. Never weld towers and tanks after lining.
   In addition, when welding is conducted near a vessel, take countermeasures to prevent sparks striking the lining surface, such as covering the vessel with a flame repellent or relocating the welding area.
4. ①For joining-flange areas of lining equipment, Valflon jacketed gaskets(No. N7030-T5N, No. N7035-T5N, and No. N7031-T5N) are recommended.
   ②A vessel should be managed within the tightening contact pressure of the gasket (recommendation) ranging from 14.7 to 19.6 MPa; bolts are fastened uniformly on several occasions. During fastening, if the contact pressure exceeds 29.4 MPa, gasket parts and flare parts may be damaged.
   ③The gasket factor for Valflon jacketed gaskets (No. N7030-T5N and No. N7035-T5N) is m = 3.5 ; the minimal fastening pressure is y = 14.7 N/mm^2.
   ④Regarding the initial fastening contact pressure of gaskets, stress relief develops in areas including flare parts. Therefore, additional tightening should be conducted without fail at the following times:
   ・Three to four hours after initial tightening
   ・Before operation
   ・In particular, when restarting operation under a thermal gradient
   ⑤Spring washers should be used with bolts.

9. Conclusion

Some of our lining tanks have been used for more than 20 years, and so are not expensive in view of functionality and lifespan.
In the next article, “Applications,” we will focus on the characteristics of our lining construction, the mechanism of liquid chemical permeation, and effective countermeasures against liquid chemical permeation.

10. References

1) Teflon® Properties Handbook, DuPont-Mitsui Fluorochemicals Company, Ltd., 2001 version.

Note : “Teflon®” is a registered trademark of The Chemours Company (U.S.).

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Substitute Sealants for Refractory Ceramic Fiber

1. Introduction

Various artificial mineral fibers have been developed and used as substitutes for asbestos. However, there is concern that some of them may be carcinogenic, and so regulations have been introduced in each country. In Japan, in November 2015, refractory ceramic fiber (RCF) was categorized as a Group-2 substance and specified chemical substance to be controlled under the Ordinance on the Prevention of Hazards due to Specified Chemical Substances (hereafter "Ordinance"). The major regulatory items and management tasks required in manufacturing are as follows.[1)]

＜Major management tasks＞

① Placement of local ventilation
② Nomination of an operational chief
③ Creation and preservation of notifications and operation records
④ Measurement of operational environment
⑤ Medical examinations

Although molded products in which binder is used to solidify RCF, and products in which RCF is sealed, are not subject to the regulation, when such products are cut or polished, RCF dust can be dispersed. Therefore, the Ordinance is applied to these products.

RCF is widely used as a refractory material and heat insulator, which can be used at high temperatures of 1,000°C or higher, at various plants including steel, oil and chemical plants. Meanwhile, sealants have been widely used in various products including gaskets and gland packings because of their excellent heat resistance. In line with legal regulations, VALQUA has adopted inorganic fibers to replace RCF, as they are soluble in living organisms, and has developed products which are both safe and functional. Since these fibers readily dissolve within the body when inhaled via the respiratory system, they are considered to pose low risks to health and so are not subject to legal regulations.

Table1 shows products subject to RCF substitution. This article introduces substitute products in terms of spiral wound gaskets, metal jacketed gaskets, rubber-coated woven fabric gaskets, and gland packings.

Table1 Products subject to RCF substitution

Applicable product group	VALQUA part number
Spiral wound gasket	No.8590 series
Metal jacketed gasket	No. N510, N520, N530, N570, N580, N6520, N6580
Rubber-coated woven fabric gasket	No.P-N314
Textile product	No. P-101S, P-102SF, P-102S, P-105S P-105SN, P-112S, P-112S-N
Gland packing	No. N340G-F, N340M-F

2. Spiral wound gaskets

Spiral wound gaskets are semi-metal gaskets designed for use under high temperature and high pressure, and also have excellent sealing properties and heat resistance. Therefore, they are used in a wide range of applications including general piping and devices, as seals for steam and heat media. In a spiral wound gasket, a V-shaped metal belt (hoop) and a soft sealing belt (filler) are wound together. Generally, spiral wound gaskets, to which inner and outer metal rings are attached, are used for various purposes depending on the conditions.

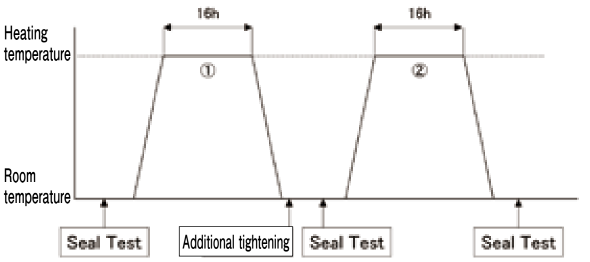
Inorganic paper is one of the fillers used in spiral wound gaskets. In the paper-making process, organic/inorganic fibers, fillers, and rubber binders are mixed and then the mixture is made into paper. The maximum service temperature is 500°C. For inorganic-paper fillers, RCF used to be used as a substitute inorganic fiber for asbestos.

VALQUA developed inorganic-paper filler spiral wound gaskets (No. 8590 series) containing biosoluble rock wool as a substitute fiber for RCF (Figure1). Biosoluble rock wool is a fiber which is not regulated by the Ordinance; it is excluded from the carcinogenic category by Note Q of Commission Directive 97/69/EC "Carcinogenicity categorization and package display regarding artificial amorphous fiber."

The performance of RCF-substitute products (hereafter "RCF-substitute (product)") containing biosoluble rock wool is shown below. The sealing

Figure1 No. 8590 series (RCF-substitute products)

Table2 Comparison of high-temperature characteristics between No. 8596V and No. 8596VL



	Leakage amount (Pa・m³/s)			
Cycle number	Specimen	No.8596V (RCF-substitute)		No.8596VL (RCF-substitute lined products)
	Heating temperature	400°C	500°C	600°C
0		No leakage	No leakage	No leakage
1		No leakage	No leakage	No leakage
2		No leakage	No leakage	No leakage

Note: Test conditions
Internal pressure : 4 MPa (400°C and 500℃), 1 MPa (600℃)
Tightening force : Bolt-fastening under a contact pressure equivalent to 70 MPa

properties of No. 8596V and No. 8596VL were evaluated under the condition of heating the two gaskets while connected to a flange, then cooling them to room temperature. Table2 shows the results. "Lined products" is a foamed-carbon filler in which inorganic-paper filler is placed at both ends of the filler to prevent oxidation loss of the filler. No leakage occurs in RCF-substitutes; they were confirmed to have adequate high-temperature sealing properties.

Table3 shows the results of evaluating steam resistance. Generally, loss of fiber strength of biosoluble fibers is a concern when the fiber comes in contact with steam or water. To evaluate steam resistance, we evaluated the sealing properties of the RCF-substitutes using nitrogen gas after steam exposure, and deterioration was confirmed. The result shows that no leakage developed with the RCF-substitutes, and RCF-substitutes have similar sealing properties to those of RCF-containing products.

Regarding design data including m/y values, there were no changes following the change in fiber; the RCF-substitutes can be used in a similar manner as conventional products containing RCF.

Table3 Comparison of steam resistance regarding No. 8596V

Steam exposure time	Sealing-property evaluation, Inner pressure (MPa)			
	No. 8596V (RCF-containing product)		No. 8596V (RCF-substitute)	
	2.0	4.0	2.0	4.0
Pre-exposure	No leakage	No leakage	No leakage	No leakage
1 week	No leakage	No leakage	No leakage	No leakage
3 weeks	No leakage	No leakage	No leakage	No leakage

Note: Test conditions
Exposure fluid : 30 K steam (230°C, 3 MPa)
Tightening force : Bolt-fastening under a contact pressure equivalent to 70 MPa

3. Metal jacketed gaskets

Metal jacketed gaskets are semi-metal jacketed gaskets in which the outer side of felt (thick plate made from inorganic materials) is covered with a thin metal plate. Since complex shapes and narrow sizes can be manufactured using metal jacketed gaskets, they are used in towers and tanks as well as heat exchangers.

Metal jacketed gaskets are often used at temperatures of 500°C or higher. Since RCF has excellent heat resistance, it is used as a core material for felt. Since the felt of a metal jacketed gasket is completely covered with metal, there is minimal exposure risk, and so the legal regulations do not apply to such gaskets. However, for even safer use, we developed metal jacketed gaskets (No. N510 and N520) which instead use inorganic fiber, which is not subject to the Ordinance (Figure2) .

We compared the sealing properties between RCF-containing products and RCF-substitute products at a heat cycle of 600°C. In the comparison, gaskets were connected to a flange, several thermal cycles were applied, and the room-temperature sealing properties were compared. Figure3 shows the results. According to the figure, even after the heating cycles, the RCF-substitute products appear to have equivalent or superior sealing properties to those of RCF-containing products.

Regarding various design data, the same as in spiral wound gaskets, there were no changes in the metal jacketed gaskets. Therefore, RCF-substitutes can be used in a similar manner as RCF-containing products.

Figure2 No. N510, N520, and others (RCF-substitute products)

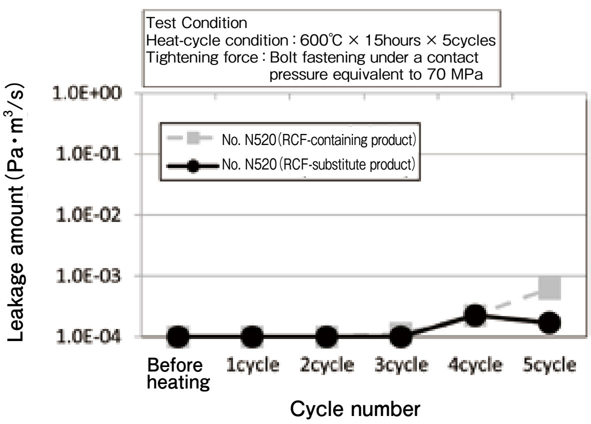


Figure3 Comparison of high-temperature characteristics regarding No. N520

4. Woven fabric gaskets

Woven fabric gaskets are gaskets using fabric, ribbon, or yarn. In these gaskets, RCF materials are used at temperatures of 500°C or higher. In some woven fabric gaskets, special treatments are applied using rubber-soaked cloth. They are used at places where leaking is relatively acceptable, such as in devices' manholes and the flanges of exhaust-gas ducts.

VALQUA started supplying gaskets that use biosoluble fiber (BSF) instead of RCF. BSF remains in the body for a shorter time than RCF and is not subject to the Ordinance.

When making RCF-substitute products, the woven fabric, which the main material of BSF, is added with a small amount of organic fiber and is soaked with rubber. Through this process, RCF-substitute has improved sealing properties.

The sealing properties of RCF-containing products are compared with those of RCF-substitute products at a thermal cycle of 800°C. Figure4 shows the results. According to the figure, RCF-substitute products appear to have equivalent or superior sealing properties to those of RCF-containing products.

Regarding the design data of rubber-soaked woven fabric gaskets, there were no changes. Therefore, rubber-soaked woven fabric gaskets can be used in a similar manner as RCF-containing products. However, when only cloth and ribbon are used as textiles that are not soaked with rubber, care should be taken

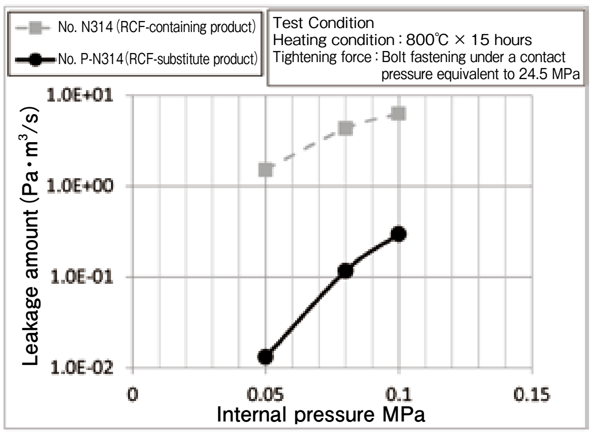


Figure4 Comparison of high-temperature characteristics between No. N314 and P-N314

regarding the maximum service temperature: that of woven fabric using the conventional RCF is 1,260°C, whereas that of woven fabric using BSF is 1,000°C. The temperature difference is due to BSF's inferior heat resistance to RCF. One inorganic fiber that can be used above 1,000°C is alumina fiber, but it is very expensive. Thus, challenges remain in this field.

5. Gland packings

Gland packings are widely used as sealed packings for valves, rotary pumps, and various other devices. In a gland packing, fibers are braided into a rope-like shape. The cross section of a gland packing is square, and so the packing is highly versatile as a sealant and is used for parts where some leakage is acceptable but heat resistance is required. Examples include the coupling of exhaust-heat ducts of boilers and turbines and the fixing parts of manholes.

Gland packings for these purposes are often used at temperatures above 400°C, and so heat-resistant RCF has been used for gland packings. However, RCF became subject to the Ordinance. Therefore, we used BSF, which is not subject to the regulation, instead of RCF, and started supplying the RCF-substitute gland packing (Figures5 and 6).

We compared the high-temperature characteristics of No. N340M (RCF-containing product) with those of N340M-F (RCF-substitute product) at 500°C. Figure7 shows the results. According to the figure, No. N340M-F (RCF-substitute product) appears to have equivalent or superior sealing properties to those of No. N340M (RCF-containing product).

Figure5 No. N340G-F (RCF-substitute product)

Figure6 No. N340M-F (RCF-substitute product)

On the other hand, BSF, which is used as an RCF-substitute, is biosoluble. Therefore, under high temperature and dry conditions (dry heat) involving blast furnace gas or exhaust gas, BSF shows similar performance as the conventional RCF-containing products. However, durability in the presence of steam or hot water (wet heat) is unknown; care is required.

Although BSF will not break down immediately in the case of slight wetting, usage after adequate drying is recommended.

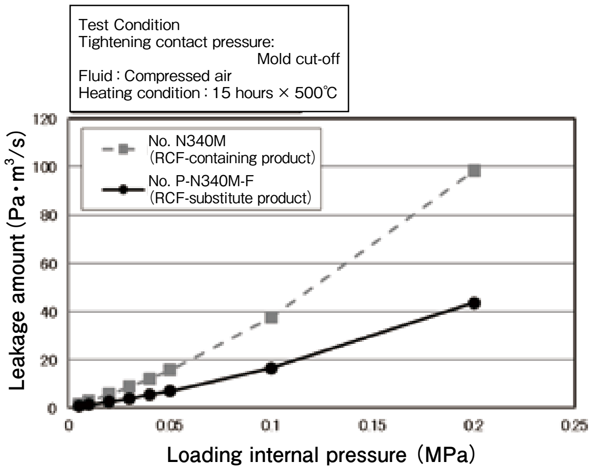


Figure7 Comparison of sealing properties at high temperatures

6. Conclusion

Sealants consist of combined materials with varying characteristics including heat resistance, chemical resistance, and high intensity to withstand various challenging conditions. However, international regulations have been tightened to reduce the environmental burden and negative impacts on the human body, placing increasing restrictions on usable materials.

As a seal manufacturer, VALQUA will continue to reduce the environmental burden and develop products that do not negatively affect the human body, thus contributing to customers' safety.

7. Reference

1) Japan High Temperature Insulation Wool Association, Handling of ceramic-fiber products, revised edition (January 2016) .

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Sheet Gaskets for High-Temperature Use VALQUA HEAT RESIST SHEET™ No. HRS

1. Introduction

Under high-temperature conditions in petroleum refining and petrochemistry industries, spiral wound gaskets, metal jacketed gaskets, ring joint gaskets, and rubber-coated woven fabric gaskets are used. Appropriate gaskets are selected depending on the pressure classes.

Among such gaskets, rubber-coated woven fabric gaskets are used under low-pressure conditions and are not dense, so they cannot provide adequate sealing properties. Furthermore, due to material deterioration, they carry risks regarding medium- to long-term sealing properties. In addition, refractory ceramic fiber (RCF), which is a constituent material of the rubber-coated woven fabric gasket, was categorized as a Group-2 substance and specified chemical substance to be controlled under the Ordinance on the Prevention of Hazards Due to Specified Chemical Substances in November 2015, and so we could not source RCF from the material manufacturers. Although RCF was replaced with biosoluble fiber (BSF), the heat resistance of BSF is inferior to that of RCF, and it is difficult to use BSF above 1,000℃.

To solve these challenges, VALQUA significantly improved the sealing properties compared with those of the conventional rubber-coated woven fabric gasket to develop VALQUA HEAT RESIST SHEET™ No. HRS, a sheet gasket which can be used at temperatures up to 1,200℃. No. HRS solves the problems of gaskets used at high temperature and low pressure. This article introduces the characteristics of VALQUA HEAT RESIST SHEET™.

2. Composition and characteristics

2-1) Composition

No. HRS is a white sheet consisting of inorganic materials. Like foamed carbon sheet No. VF-35E, No. HRS is made by fixing a sheet material on both surfaces of a stainless-steel thin plate (thickness: 0.05 mm).

Figure1 is a photograph of the exterior and Figure2 shows the composition.

2-2) Characteristics

①Compared with the conventional rubber-coated woven fabric gasket, No. HRS offers significantly improved sealing properties, effectively reducing the discharge of environmental contaminants including NOx and SOx in combustion gas.

②No. HRS minimizes the content of organic constituents including rubber binder. In addition, No. HRS contains inorganic fiber which has excellent heat resistance, and so can be used at temperatures of up to 1,200℃.

③No. HRS has less sticking to flanges than rubber-coated woven fabric gaskets, so cleaning is easier.

Figure1 Exterior of VALQUA HEAT RESIST SHEET™ No. HRS

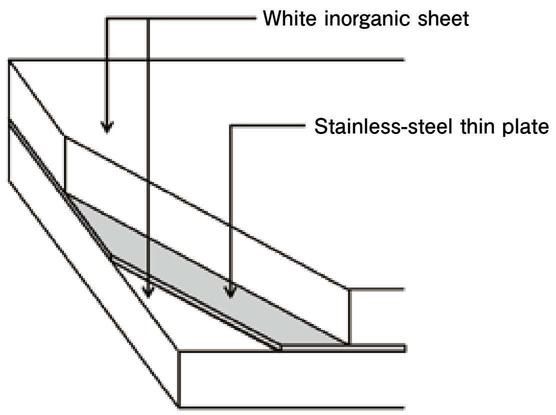

Figure2 Product composition

3. Intended use

No. HRS is suitable as a sealant for places such as devices' manholes and exhaust ducts having the following characteristics：1) Although the inside fluid is at low pressure, the flange's strength is weak, and 2) Although the inside fluid is at low pressure, a large tightening force cannot be applied. Also, No. HRS can be used as a sealant for oil burners, high-temperature wafters, and the access doors of heat-recovery lines.

Although No. HRS has much better sealing properties than the conventional rubber-coated woven fabric gasket, it suffers greater leakage volume than sheet gaskets including joint sheets, so care is required.

4. Product specifications

4-1) Standard size

Table1 shows the standard sizes of No. HRS. Two sizes, 1.5 mm and 3.0 mm in thickness, are available; the maximum outer diameter is 900 mm. Since No. HRS is a sheet gasket, it can be processed into various shapes.

Table1 Standard size (Unit：mm)

Thickness	Maximum outer diameter
1.5 3.0	900

4-2) Service temperature range

The service temperature ranges from −200 to 1,200°C. No. HRS is designed for use under low-pressure conditions including exhaust ducts. Therefore, metal gaskets and semi-metal gaskets are recommended for use under high-pressure conditions of 1 MPa or higher.

4-3) Recommended tightening contact pressure and maximum allowable tightening contact pressure

Table2 shows recommended tightening contact pressures.

Table2 Recommended tightening contact pressures

Fluid	Recommended tightening contact pressure (MPa)
Liquid	20
Gas	20

Note：The recommended tightening contact pressure is that which is necessary under general conditions. It is set without taking the fluid pressure into account. It is the contact pressure regarding the gasket's contact area.

5. Evaluation of characteristics

5-1) Sealing properties at room temperature

Figure3 shows the results of evaluating the sealing properties at room temperature. The leakage volume is 1/100 or less compared with that of the conventional rubber-coated woven fabric gasket, showing that No. HRS has significantly improved sealing properties. In addition, its leakage volume is small even at tightening contact pressures between 10 and 20 MPa. Therefore, No. HRS provides good sealing even at locations where a large tightening force cannot be applied due to the flange's strength.

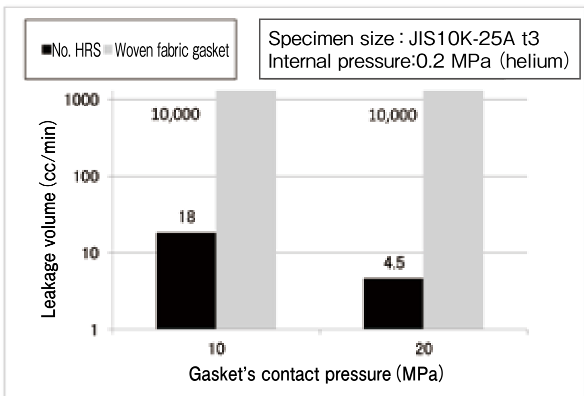

Figure3 Sealing properties at room temperature

5-2) Heat-cycle sealing properties

The sealing properties of No. HRS were evaluated as follows: 1) No. HRS was heated while connected to a flange. 2) The heating/cooling process was repeatedly applied to No. HRS. 3) After cooling, the sealing properties at room temperature were evaluated. Figure4 shows the results. No. HRS has a smaller leakage volume than the conventional rubber-coated woven fabric gasket even after heating, and maintains strong sealing properties even after repeated cycles.

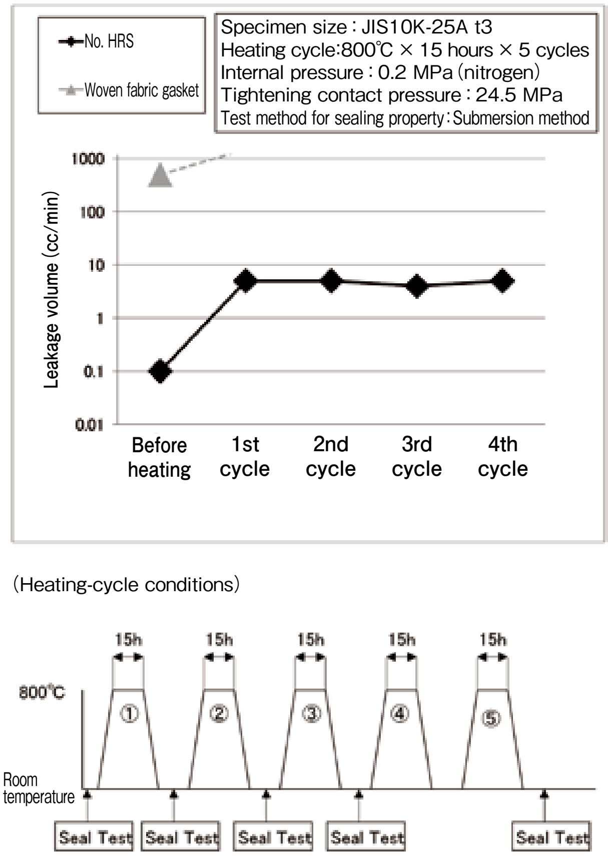

Figure4　Heat-cycle sealing properties

5-3) Sealing properties of joining products at room temperature

The maximum outer diameter of No. HRS is 900 mm. However, joining through dovetail-groove processing (Figure5) enables No. HRS to handle products with larger diameters. In that case, joining is only conducted at the construction site.

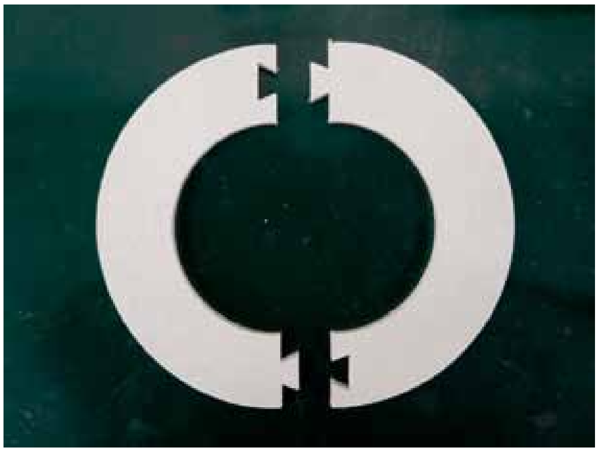

Figure5　Dovetail-groove processing

We evaluated the sealing properties of gaskets with or without dovetail grooves. Figure6 shows the results. Joining ① is without paste application. In Joining ②, gasket paste No. 6M is applied to the surfaces of the joining ends. The difference in leakage volume between no joining and joining ① is insignificant; the two conditions have similar sealing properties. For safer usage, we recommend applying paste No. 6M to the surfaces of joining ends when joining products are used.

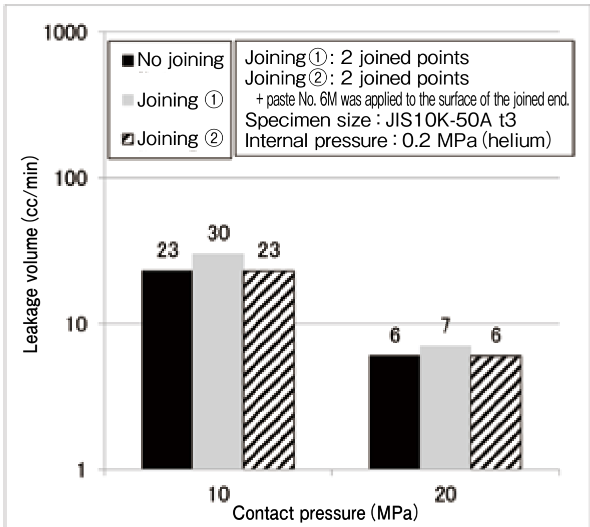

Figure6　Sealing properties of joining products at room temperature

5-4) Heat resistance

To evaluate heat resistance, we evaluated the shape-retention characteristics after heating. Figure7 shows the gaskets' appearance after heating in air at 1,000°C and 1,200°C. Even after heating, No. HRS had no deformation or powdering; it kept its original shape.

Therefore, there is little risk in high-temperature usage of, for example, gasket breakage due to internal pressure.

Heating time：24 hours
Atmosphere：Air
Test-use dimensions：45 mm×15 mm×t3.0

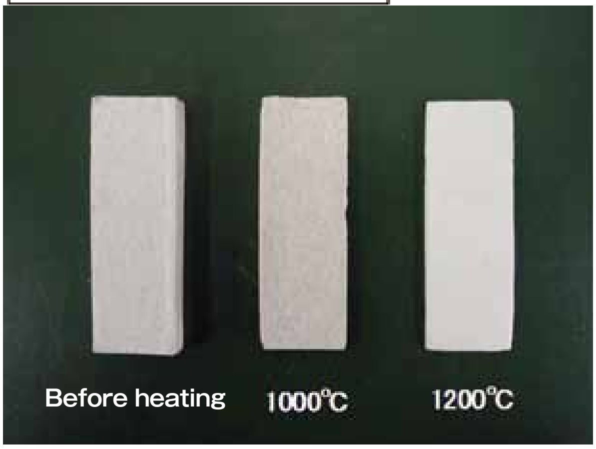

Figure7　Results of evaluating shape retention after heating

5-5) Sticking tendency

In high-temperature environments, gaskets strongly stick to flanges, and so time and labor are required for removal. Figure8 shows the sticking tendency to flanges after repeated heating cycles. In No. HRS, the amount of rubber binder is reduced to the minimum, and very smooth inorganic filler is used. Therefore, No. HRS sticks to flanges much less than the conventional rubber-coated woven fabric gasket, which facilitates flange cleaning and reduces man-hours in construction.

Heating cycle：800℃ × 15 hours × 5 cycles
Flange material：SUS316L

Figure8　Sticking to flanges

5-6) Resistance to crushing

When an excessive tightening force is applied to gaskets, they can break. In an experiment, No. HRS was subjected to a contact pressure of 100 MPa, as shown in Figure9. Even after this tightening contact pressure was applied, the gaskets did not suffer compression fracture.

Test-use dimensions：ϕ100 × ϕ64
Loaded contact pressure：100 MPa
Crushing condition：Cracks developed

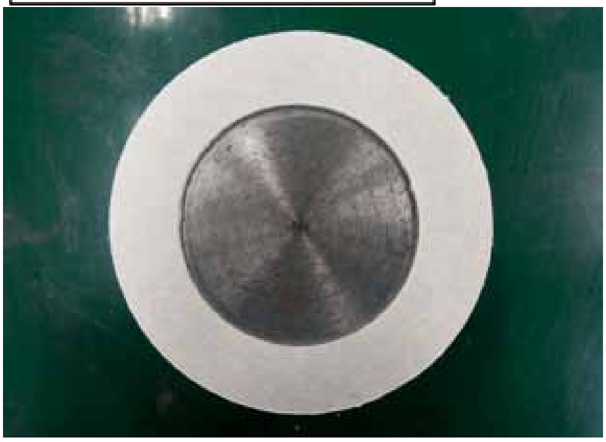

Figure9　Appearance of gasket after application of contact pressure of 100 MPa

6. Conclusion

This article introduced VALQUA HEAT RESIST SHEET™ No. HRS. No. HRS has significantly better sealing properties and heat resistance than conventional rubber-coated woven fabric gaskets, which have been used for high-temperature and low-pressure applications. This product ensures long-term safety. Some customers have already conducted actual evaluations, and some have already introduced No. HRS. Environmental regulations will get stricter in future. We hope you will use No. HRS gaskets which comply with environmental regulations.

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From Nippon Valqua Industries, Ltd. to "VALQUA, LTD."

We will continue to globalize by engaging not only in manufacturing but also in value creation in products, events and human relationships. We will transform into "a value-creation company through products, events and humans".
To reflect this determination, we will change our company name from Nippon Valqua Industries, Ltd. to the new company name "VALQUA, LTD." as of October 1, 2018.

Earth-friendly, Human-friendly Manufacturing

New Gaskets and Gasketing Technology

Recent environmental regulations have led to a major transformation in the different types of gaskets and their materials. Likewise, we are also seeing major changes in the design standards for bolted flange connections.
In response to this technical situation, JISB0116 “Glossary of Terms for Packings and Gaskets” was completely revised for the first time in 37 years.
The recently published “New Gaskets and Gasketing Technology” is the first handbook that both covers the technical background leading up to this JIS terminology standards revision and explains the technical basics of gaskets and bolted flange connections in an easy to understand manner. As such, we feel it will serve as a reference for many of those involved in gaskets.

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