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.

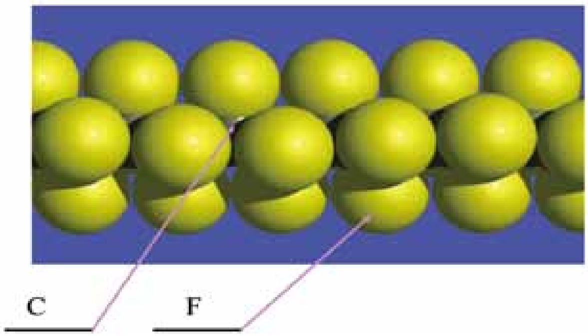

Figure1 Molecular structure of PTFE

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.

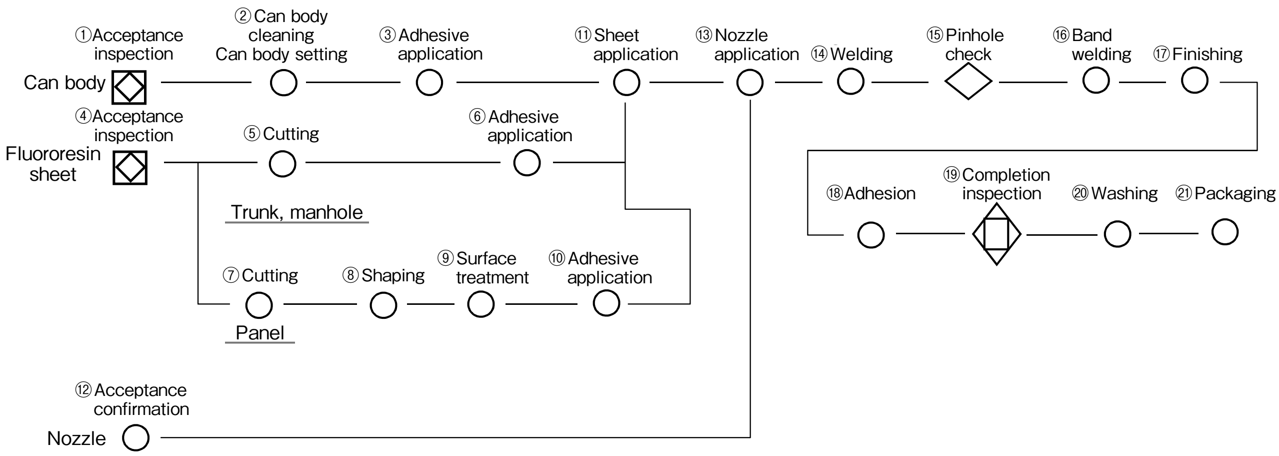

Figure2　Lining process

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

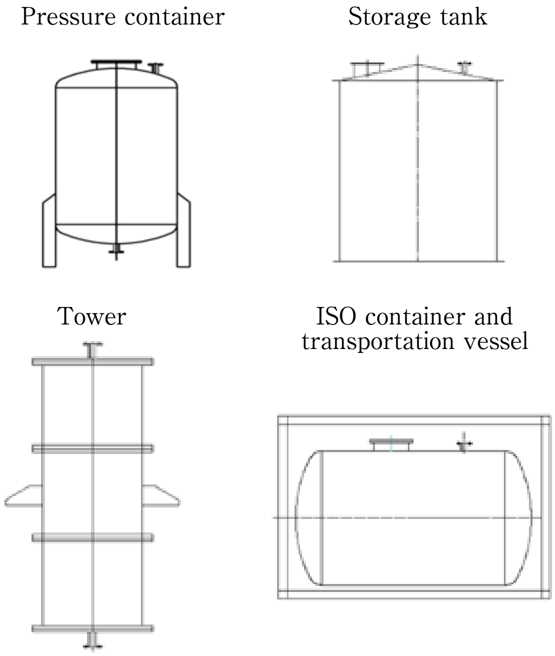

Figure3 Types of tanks

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.

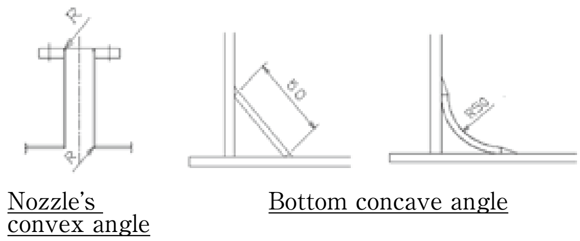

Figure4 Construction of convex and concave parts in corners

・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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