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SEALING THE THERMAL RELIEF VALVE WITH PCTFE IS CRUCIAL FOR PREVENTING SEAT LEAKAGE

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ABSTRACT— Rocket propulsion systems, long-distance transportation, and the long-term preservation of vast quantities of frozen food all rely on cryoliquids. Cryoliquids, which have a boiling point below absolute zero, are notoriously difficult to store and transport. Since the expansion ratios of these low-temperature liquids are as high as 700 times, additional safety measures must be installed in the pipelines or storage facilities that house them. Pipes may rupture if the pressure within them rose over safe levels. Here is when the value of the safety pressure release valve becomes apparent. At a certain pressure, the thermal relief valve will pop up to release pressure from the section, and then it will return to its original position.

Most cryo systems come with thermal relief valves that are designed to release a minimum of 300 standard cubic feet per minute (SCFM) of air and include metal to metal seating to prevent leaks. Surface finish restrictions make it impossible for metal-to-metal seated valves to achieve zero leakage or Class VI leakage rating.

The feasibility of soft-sealing conventional metal-to-metal seated valves has been investigated. The disc and nozzle setup already in place need a soft seal, therefore PCTFE (Poly-chlro-tri-flouro-ethylene) will do the trick. To re-use the valve's original spring. Calculations of force balance and strength for the new disc shape. The leakage pressure was computed using the new geometry. Then, we put it to the test using air and Liquid Nitrogen in the lab. More effective and practical in the long run The development of a cryogenic valve that can resist increased pressure surges is underway.

PCTFE, Seat leaks, and Cryogenic Pressure Relief Valves

I.INTRODUCTION

Over the years there have been a number of advancements in the Cryogenic and Industrial gas industries with the aim of keeping liquefied gases colder longer. At some point even, the best cryogenic storage tanks will experience some heat flux from their surroundings, causing the temperature inside the tank to rise to a point that some of the liquefied gas begins to evaporate and reverts back to its gaseous state. This process is known as Boil-Off Gas (BOG). The use of a safety relief valve specifically designed for cryogenic temperatures is the best choice for handling pressure rise due to BOG. The first of these safety features is typically an ASME certified safety relief valve, which has an operating temperature range of -423°F to +400°F, which also makes them an ideal choice for labs and other facilities where nitrogen and other gases are supplied by boil-off from liquid gas storage tanks.

1.1 Functions of PRV

Every industrial process system is designed to work against a certain maximum pressure and Temperature called its rating or design pressure. The law requires that when everything fails regardless of the built-in redundancies, there is still an independent working device powered only by the medium it protects. This is the function of the PRV, which, when everything else works correctly in the system, should never have to work.

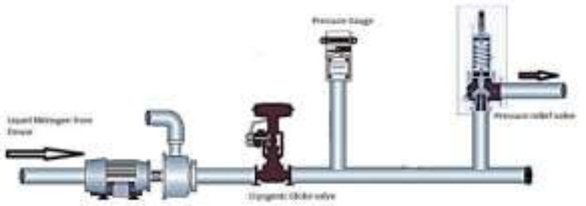

Fig. 1.1 Traditional control loop

1. THERMAL RELIEF VALVES

2.1 Thermal relief valve – Introduction

Thermal relief valve is a self-actuated spring-loaded relief valve is designed to popup for reliving excess pressure from at a predetermined pressure and reseat after reliving the excess pressure from the segment. The basic elements of a thermal relief valve consist of a nozzle connected to the vessel or system to be protected, a movable disc which controls flow through the nozzle, and a spring which controls the position of the disc. Under normal system operating conditions, the pressure at the nozzle inlet is less than the set pressure and the disc is seated on the nozzle by spring force preventing flow of fluid.

The operation of a thermal relief valve is based on a force balance. The spring-load is present to equal the force exerted on the closed disc by the inlet fluid when the system pressure is at the set pressure of the valve. When the inlet pressure is below the set pressure, the disc remains seated on the nozzle in the closed position. When the inlet pressure exceeds set pressure, the pressure force on the disc overcomes the spring force and the valve opens. When the inlet pressure is reduced to a level below the set pressure, the valve re-closes.

Fig. 2.1 Cryogenic PRV in operation at LSSF

2. 2 Thermal relief valves in Cryo systems

In order to meet the requirement of different operating conditions encountered during launch servicing, spring loaded relief valves (Thermal relief valves) are provided in cryo systems for gas/vapor relief and full flow relief valves for the purpose of liquid relief Thermal relief valves provided in cryo systems are installed between two isolation valves to relive excess pressure due to locked up vapors attributing to high volumetric expansion of cryo Liquids.

All the valves are metal to metal seated for ensuring leak tightness and are sized to relieve minimum flow rate of 300 SCFM of air. Following table gives the details of all models of valves provided along with effective orifice areas as per API 520 sizing standard.

S.no	Model.NO	Orifice area (mm^2)
1	951111MD	0.47
2	961111MD	0.71

Table 2.1 Valve- orifice area

2.3 VALVE SEAT LEAK TESTING STANDARDS

Allowable leakage values are specified in respective API codes –API 527 based on orifice diameter, size of the valve, type of sealing adopted. The following table gives the leakage values provided by API527.

The allowable leakage values for metal to metal seated relief valves.

Test medium: Gaseous Nitrogen

Table 2.2 Allowable leakage values

2.4 ACCEPTANCE CRITERIA

The following criteria must be met with, in order to incorporate the modified seat design:

- For metal to metal seated valves tested with GN2/Air, the leakage rate shall

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not exceed the valves specified in the above table.

- For soft seated valves should perform till minimum 20 popups without failurein practical condition.

2.5 Main reasons of Valve Seat Leakage

- Improper alignment of subassemblies after testing.
- Spring buckling resulting in angular misalignment
- Loose tolerances for spindle at its seating area, clearances between disc holder and disc.
- Poor Surface finish/wear at metal to metal seat contact area of valve

2.6 Problems faced with metal to metal seated valves:

Even though specified leak rate is allowed, due to hazardous nature of cryofluids like hydrogen, no leakage of hydrogen vapors/gases is permitted across the valve during normal operation. For metal to metal seated valves, attaining zero leakage or Class VI leakage classification is not possible due to surface finish limitations.

To meet the leakage classification of ANSI – Class VI, the only option is to provide soft seal across valve seat.

3. SELECTION OF SOFTSEAL

3.1 Polychlorotrifluoroethylene (PCTFE or PTFCE)

Polychlorotrifluoroethylene (PCTFE or PTFCE) is a thermoplastic chlorofluoropolymer with the molecular formula (C2F3Cl)n, where n is the number of monomer units in the polymer molecule. It is similar to polytetrafluoroethene (PTFE), except that it is a homopolymer of the monomer chlorotrifluoroethylene (CTFE) instead of tetrafluoroethene. It has the lowest water vapor transmission rate of any plastic

3.2 Properties of PCTFE

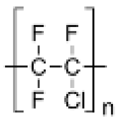
- PCTFE has high tensile strength and good thermal characteristics. It is nonflammable. It has a low coefficient of thermal expansion.
- It has good chemical resistance & exhibits properties like zero moisture absorption and non-wetting.
- PCTFE is resistant to the attack by most chemicals and oxidizing agents.

Sl.No	Description	Valves	
		[illegible]	[illegible]
1.	[illegible]	2.2	1.375
2.	Orifice size (mm)	[illegible]	10
3.	Maximum allowable Bubbles/minute	40	20

3.3 PCTFE is selected for the following reasons:

- Has very high compressive strength, flexural rigidity.
- Better creep resistance, fatigue life

compared to PTFE.



- Can withstand very low temperatures.
- Very good friction and wear characteristics at low temperatures.
- Very low deformation at low temperatures
- Low permeability for gases like N2, O2 and GH2.

4. EXPERIMENTAL SETUPS

4.1 Experimental Setup

Experimental setup consists of Liquid nitrogen storage tank (Dewar), Cryogenic globe valve, Pressure gauge, Cryogenic pressure relief valve. The arrangement of these are shown in the following schematic diagram.

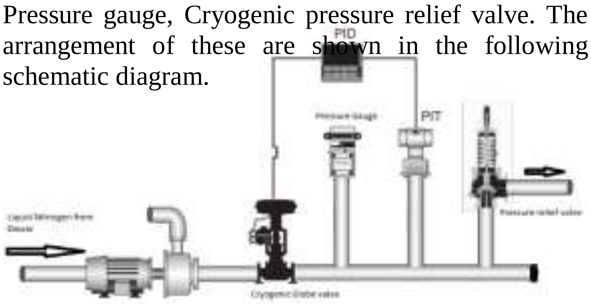


Fig. 4.1 Experimental setup schematic representation

Initially the liquid nitrogen which was stored in Dewar was connected to vacuum sealed pipe line and is made flow through the setup as shown above. This liquid nitrogen initially flown through the cryogenic globe valve which is in open condition. Pressure gauge was connected to the pipe line so that the pressure in the pipe line can be noticed. To observe the performance of the Pressure relief valve it is connected to the pipe line and the flow is restricted after the attachment of Pressure relief valve to the pipe line. As pipe line was closed at the end, pressure will build up inside the pipe line over the time. When the pressure inside the pipe line reaches the set pressure of the cryogenic pressure relief valve, it will relieve the excess pressure inside the pipe line by popping up the excessive liquid inside the pipe line so that the normal predetermined pressure is maintained.

4.2 Dewar

Cryogenic Vessels are designed for storage and transport of liquid gases at sub-zero temperatures.

Fig. 4.2 Liquid nitrogen storage tank at operation

4.3 Cryogenic Globe Valve

Cryogenic globe valve used to regulate the flow direction, flow rate of the fluid flows through the pipe line.

Fig. 4.3 Cryogenic globe valve

4.4 Pressure gauge:

This device used in the setup to know the pressure inside the pipe line and also examine whether the valve pop-up at the set pressure or not.

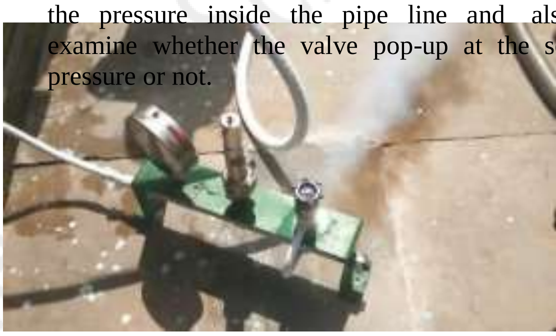


Fig. 4.4 Pressure Gauge – Globe valve setup

4.5 Cryogenic Pressure relief valve

These are used to relieve the excess pressure inside the pipeline.

Fig. 4.5 Cryogenic pressure relief valve

5. MODIFICATIONS CARRIED OUT

5.1 Modification carried out:

To incorporate PCTFE seal in to nozzle disc contact area, the disc is modified and soft seal is assembled in to disc with interference fit so that the seal does not come out in case of valve pop up.

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5.2 Design

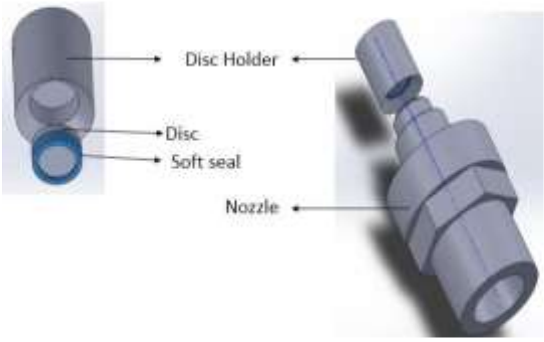

Fig. 5.1 Metal disc with disc holder and nozzle assembly

5.3 Disc

The disc is made of forged bar stock as per ASTM A479 SS316 for low temperature compatibility.

5.4 Soft Seal

The soft seal is made out PCTFE.

Metal disc

S.no	Description	Disc = Metal	
		951111MD	961111MD
1.	Height - h (mm)	5	7.5
2.	Width - w (mm)	11.9	14.5

Fig 5.2: Metal disc

Table-5.1: Metal disc - Dimensions

Disc with Soft seal

S.no	Description	Disc = Metal + Soft seal	
		951111MD	961111MD
1.	Height - h (mm)	5.4	7.8
2.	Width - w (mm)	12	14.5

Fig 5.3: Metal disc with sealing

Table 5.2: Soft seal – Dimensions

5.5 Nozzle

The same nozzle provided for metal to metal seated valves is used for soft seated valves also.

- Model: 951111MD-Orifice Size as per API: 8.33mm
- Model: 961111MD-Orifice Size as per API: 10.12mm

5.6 Spring

The spring selected is same as that used for metal to metal seated safety valve having the same spring range, Spring Index are calculated as given in Table.

Spring Data		Units	951111MD	961111MD
Tag No.			VST - 4700	VST – 720,721
Range		PSIG	248 - 274	195 - 216
		MP$_a$	1.709 - 1.889	1.344 – 1.489
Material			SS316	SS316
Mean Diameter	D_m	mm	24.61	30.3
Wire Diameter	d	mm	4.35	4.8
Spring index	I		5.65	6.31
Modulus of Rigidity	G	N/mm^2	82000	820000
Number of active coils	W_c		6	8
Solid length	L_s	mm	26.1	38.4
Spring constant	k	N/mm	41.03	24.44

Table 5.3 Spring data

6. DESIGN CALCULATIONS

The movement of the disc depends on the force balance between the upward fluid force, F_{up} and the downward spring force and back pressure forces F_B [13]

1. Fluid pressure force.
2. Spring force.
3. Reaction force on the disk contact area.
4. Body force (disc).

6.1 Pressure Distribution on PCTFE Seal in Static condition [2]:

Initially when the disc is in contact with the nozzle seat (static condition) and the displacement of the spring $Y_D=0$.

Then the total downward force acting on the disc is $F_{Dn} = P_B A_D + K\, Y_O$

The total downward force acting on the disc is

$$F_{Up} = PA_D$$

Then the net upward force acting on the disc can be then calculated as:

$$F_{Net} = F_{Up} - F_{Dn}$$

$$= (P - P_B)\, A_D - K\, Y_O$$

P = System fluid pressure
P_B = Backpressure
A_D = Area of the disc
K = Spring constant
Y_O = initial spring compression

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Sn	Description		units	Safety valve model	
a	**Spring Data**			**951111MD**	**961111MD**
1	Mean Diameter	Dm	mm	24.61	30.3
2	Wire Diameter	d	mm	4.35	4.8
3	Modulus of rigidity	G	N/mm²	82000	82000
4	No of active coils	Wc		6	8
5	Free Length	Lf	mm	50	76
6	Solid Length	Ls	mm	26.1	38.4
7	Spring rate	k	N/mm	41.038	24.44
8	Spring Initial Compression required		mm	5.8	9.12
9	Assembled Load	Fa	N	238.02	222.97
10	Assembled length	La	mm	44.2	66.88
b.	**Fluid Pressure Load**	**P**	**N/mm²**	**1.6**	**1.1**
1	Outer Diameter	do	mm	12	14.5
2	Inner Diameter	di	mm	9.3	11.5
3	Seat Land width	ds	mm	1.35	1.5
4	Effective seat diameter (2/3 rd of seat Land diameter)	deff	mm	11.1	13.5
5	Disc effective contact area	Ae	mm²	28.843	39.275
6	Fluid Pressure Load	Fp	N	46.149	43.202
7	Net Sealing Load	Fn	N	191.87	179.78
8	Seal Land width	w	mm	1.35	1.5
9	Seal Sealing Area	As	mm²	50.900	68.338
10	Sealing Stress Induced in PCTFE Seal for provided land width	S	N/mm2	3.7696	2.630

Table 6.1 Seating stress calculationThis Seating stress is sufficient for PCTFE to seal at the above Spring assembled Load for normal operating conditions.

6.2 Study of dynamic Force Balance during valve lift at various flow deflection angles[11]

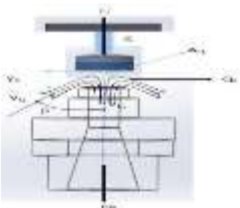

Fig. 6.1 Different forces acting at the opening condition of valve

When the fluid pressure reaches the set value, the disc loses contact with the seat and starts lifting against spring force.

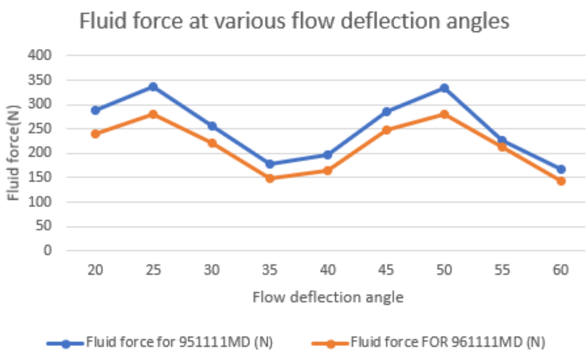

Fig. 6.2 Fluid force at various deflection angles

Sl no	Description	Units	Symbol	Safety valve model					
				951111MD	951111MD	951111MD	[illegible]	[illegible]	[illegible]
1	Mass flow rate through the valve	Kg/sec	m	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	Density of the fluid	Kg/m3	ρ	17.84	17.84	17.84	[illegible]	[illegible]	[illegible]
3	Diameter of the nozzle	m	Dnozzle	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	Actual area of the nozzle	m2	Ae	5.45E-05	5.45E-05	5.45E-05	[illegible]	[illegible]	[illegible]
5	Mean fluid velocity at nozzle exit	m/sec	Vfn	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	Maximum Lift of the valve disc	m	YL	0.0008	0.0008	0.0008	[illegible]	[illegible]	[illegible]
7	Curtain area at maximum disc lift	m2	AYL	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8	Mean fluid velocity in jet	m/sec	VfJ	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9	**Flow deflection angle (Assumption at maximum Lift**	**deg.**	**β**	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
10	System Pressure	N/m2	P	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
11	Pressure Force	N		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
12	Momentum Force due to deflection of fluid jet	N		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
13	Total Fluid Force	N	Ffluid	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
11	Gas's heat capacity ratio		k	1.4	1.4	1.4	1.4	1.4	1.4
12	Discharge coefficient		Kd	0.975	0.975	0.975	[illegible]	[illegible]	[illegible]
13	Constant C	constant	c	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
14	Mass flow rate through the valve m	Kg/sec	m	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
15	Pressure Force	N		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
16	Momentum Force due to deflection of fluid jet	N		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
17	Fluid force = pressure force + momentum force	N	Ffluid	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Table 6.2 Dynamic force calculation

From above the observation is made such that as the Flow deflection angle is increasing the fluid force is decreasing, which is a welcome note because usually the flow deflection angle is greater than 45 degrees which means the momentum force acting on the disc is in the acceptable region.

7. EFFECT OF MISALIGNMENT ON SET PRESSURE

F is the applied load or the spring force at equilibrium condition and φ is the angle in case of misalignment of the applied load. [2]

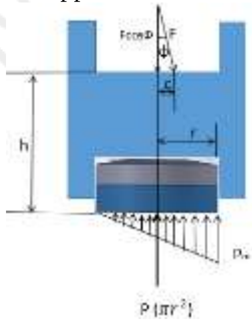

Fig. 7.1 valve leakage analysis

Sn	Description		Units	951111MD	961111MD
1	Distance of disc from Load application point	h	mm	7.76	7.76
2	Applied load (Due to Spring)	F_a	N	238.0251	222.979
3	Safety valve Set pressure	P	N/mm²	2.2	1.375
4	Disc radius	r	mm	6	7.25
5	Distance from centre axis to applied load	c	N	0	0
6	Angle of the applied load	ϕ	Deg	0	0
7	Frictional Forces	F_f	N	0	0
8	Maximum force acting on sealing surface of disc	$F = F_a$	N	238.0251	222.973
9	Pressure at which disc starts Lifting	P_{lift}	N/mm²	2.105672	1.3514

Table 7.1 Leak pressure calculations

From the above table we can conclude that the Lifting pressure calculated matches to the set pressure of the disc. This means the PCTFE Sealing disc works in a desirable way and gives the best results.

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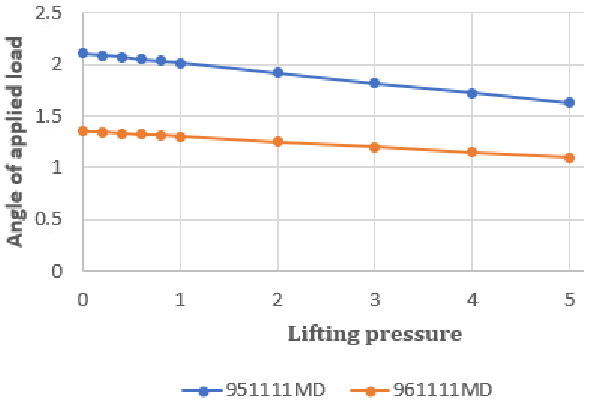

Fig. 7.2 Lifting pressure at various applied loads

the above chart represents considering the misalignment of the application of load which further calculated for the pressure at which valve disc starts lifting.

8 LEAKAGE FLOW CALCULATION BY SURFACE STUDY

8.1 Calculation of Leakage flow by considering surface study: [1]

The seat leakage is a combination of laminar and molecular flow. If valve seat leakage is to be considered from initial contact to the molecular diffusion level, all defects like waviness, scratches, roughness, nodules, Localized pits on the surface are to be taken in to account to a relative degree. The height (h) and wave length (λ), can be assumed to represent various waveforms on the surfaces and exist as waviness or roughness or a combination of both.

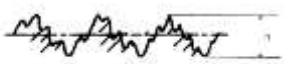

Fig. 8.1 Surface asperities representation

8.2 Stress calculation based on Surface test:

Stress calculation based on Surftest				
Description	Symbol	units	95111MD	961111MD
Wave length of the surface (seal)	λ1	mm	0.25	0.25
Wave length of the surface(metal)	λ2	mm	0.1	0.1
Avg. peak to valley height for Seal surface	h1	mm	0.0017	0.0038
Avg. peak to valley height for metal surface	h2	mm	0.001	0.00085
Avg. asperity slope	φ	rad.	0.0136	0.0304
Elastic modulus for the seal	E1	N/mm2	1400	1400
Elastic modulus for the metal	E2	N/mm2	193000	193000
Outer Diameter	do	mm	12	14.5
Inner Diameter	di	mm	9.3	11.5
Seat Land width	ds	mm	1.35	1.5
Mean seat diameter	D	mm	11.1	13.5
Poissens ratio for the seal	'1		0.4	0.4
Poissens ratio for the metal	'2		0.3	0.3
Elastic constant for surfaces in contact	α	1/(N/mm	0.000595	0.000595
Yield strength	Y	N/mm2	39.3	39.3
Maximum Seat load (Assembled load)	Fm	N	191.87	179.777
Seal land width	W	mm	1.35	1.5
Maximum apparent contact stress	Sm	N/mm2	4.077751	2.827349
Values of the variables			3.676471	1.398026
	A		1.5	0.91
	B		0.4	0.63
	C		1.9	2
Max. apparent stress (to surface yield)	Sm	N/mm2	3.024399	4.249767

Table 8.1 Stress calculation based on surface test

8.3 Total Leakage calculation:

STRESS - LEAKAGE		units	951111MD	961111MD
Inlet pressure	P1	N/mm2	1.6	1.1
Outlet pressure	P2	N/mm2	0	0
Viscosity of the fluid	μ	Nsec/mm2	1.87E-05	1.86E-05
Gravitational acceleration	g	mm/sec2	9810	9810
Stnd.Pressure	P	N/mm2	1.013	1.013
Gas constant	R	J/Kgk	296.8	296.8
Temperature	T	K	313	313
Density	ρ	Kg/m3	17.23705	11.8477
maximum apparent contact stress	Sm	N/mm2	48.84262	9.775289
Apparent seat stress to flatten	Sf	N/mm2	5.871474	13.12447
contact deformation	δ	mm	0.001158	0.001463
Weighted peak to valley height for both surfaces(laminar flow)	HeL	mm	0.000655	0.001669
Weighted peak to valley height for both surfaces(molecular flow)	HeM	mm	0.000588	0.001498
Laminar flow rate	ωL	Kg/sec	4.45E-10	3.83E-09
molecular flow rate	ωM	Kg/sec	4.93E-06	2.41E-05
Leakage due to Laminar flow	QL	mm3/sec	4.09E-09	4.32E-07
Leakage due to molecular flow	QM	mm3/sec	3.37E-05	0.000135
Total Leakage	Q	mm3/sec	3.37E-05	0.000136

Table 8.2 Total leakage calculation

From above table of calculations, note that the apparent stress calculated by using surface study is matching with the seating stress that calculated earlier. Also note that the total leakage is very minute amount which reflects no amount of leakage.

9. EXPERIMENTAL TESTS:

Experimental tests have been carried out for evaluation of safety valve performance by conducting the following tests.

1. Verification of PCTFE Seal performance by leakage test (Bubble test) with Gaseous nitrogen as its medium.
2. Verification of seat leak tightness of PCTFE Seal by checking the number of pop-ups that the valve could sustain without any leakage in practical conditions.

9.1 Leakage Test

In order to check the leakage of the valves, the gaseous nitrogen has to be sent through the pipeline to which these valves are connected. The end of the output of the pressure relief valve kept under the water.

Sl.No	Description	Valves	
		951111MD	961111MD
1.	Set Pressure (N/mm^2)	2.2	1.375
2.	Orifice size (mm)	7.89	10
3.	Maximum allowable Bubbles/minute	40	20

Table 9.1 API standards for Pressure relief valve leakage

To check the API standards of leakage, the pressure has to be maintained for a minimum of 3 minutes duration. In order to achieve this, the pressure inside the pipeline is maintained at constant pressure for a certain duration and count the number of bubbles coming out from the outlet of the pressure relief valve, whose end is under the water.

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Pressure	Number of bubbles/minute for 951111MD valve	
	Without PCTFE seal	After providing PCTFE seal
1.6	12	1
1.7	15	3
1.8	21	4
1.9	28	6
2	37	7
2.1	46	9

Table: 9.2 Leakage test results for 951111MD valve

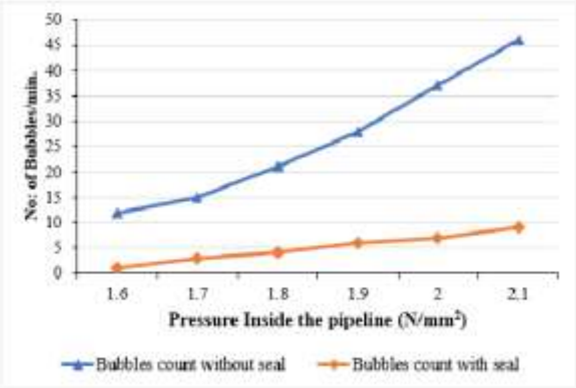
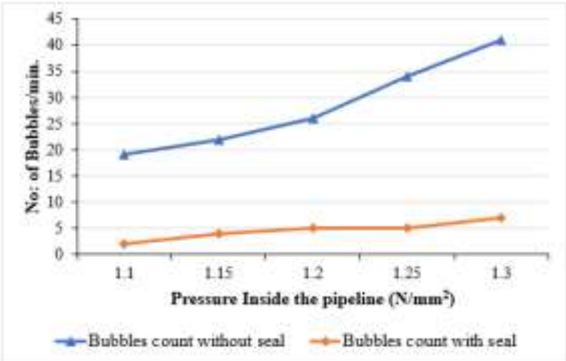


Fig.9.2 Number of Bubbles/minute for 951111MD valve

Pressure N/mm²	Number of bubbles/minute for 961111MD valve	
	Without PCTFE seal	After providing PCTFE seal
1.1	19	2
1.15	22	4
1.2	26	5
1.25	34	5
1.3	41	7

Table: 9.3 Leakage test results for 961111MD valve



From the above test results is evident that the performance of the valve is increased and it is acceptable as per API standards.

9.2 Practical Testing of the Thermal Relief Valves

The practical testing has been made on both the configurations of valves at a set pressure to check performances of the valves. As the valve pops up at set pressure and relieves the excess pressure, the number of popups that the valve gives without causing leakage is noted down.

S.No	Description	951111MD	
		Disc without seal	Disc with PCTFE seal
1	Set pressure	2.2 N/mm²	2.2 N/mm²
2	Number of popups produced without any leakage	8	48

Table: 9.4 Practical testing results of 951111MD valve

S.No	Description	961111MD	
		Disc without seal	Disc with PCTFE seal
1	Set pressure	1.375 N/mm²	1.375 N/mm²
2	Number of popups produced without any leakage	13	65

Table: 9.5 Practical testing results of 961111MD valve

In both kind of experiments (Leakage observation by Bubble test, and Popup test) the results obtained for the PCTFE soft sealed valves are acceptable as per the API standards.

After conducting all experimental tests that are conducted in Nitrogen storage Facilities it is noted that the valve with PCTFE sealing performed well and results are very acceptable in both models of the cryogenic pressure relief valve.

10. CONCLUSIONS

- By With the modifications made in the cryogenic pressure relief valve the following conclusions are made
- Pressure relief valve with PCTFE seal provided on the disc performed well compared to the one without seal on the disc.
- The number of bubbles coming out of pressure relief valve at 90% of set pressure has reduced from 46 bubbles/min to 9 bubbles/min for 951111MD and 41 bubbles/min to 7 bubbles/min for 961111MD
- Performance of the pressure relief valve in the bubble test has increased by providing PCTFE sealing on the disc significantly. This makes the pressure relief valve to be accepted as per American Petroleum Institute (API 527) leakage standards.
- During the practical testing of the 951111MD thermal relief valve with the modifications made, performed until 48 popups continuously without any minute leakage and still can work. Whereas initially, metal to metal contact disc valve fails for every 8 popups that it made. Similarly,

961111MD valve performed until 65 popups from 13 popups initially.

- The modifications in the valve made an increase in performance by 6 times for 951111MD valves and 5 times for 961111MD valves.
- These modifications considered on the PRV has to make proven that these modifications will withstand the conditions that they might undergo. By analytical calculations on the seating stress acting on the disc in operating condition and proved that, it is comparatively can withstand the pressure and seating stress. And by conducting the experimental tests it is proven that providing a soft seal to disc helps in minimizing the leakage from the valves.

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