IJFANS INTERNATIONAL JOURNAL OF FOOD AND NUTRITIONAL SCIENCES
ISSN PRINT 2319 1775 Online 2320 7876
 Journal Volume 10, Iss 09, 2021

# UTILIZING PCTFE TO ENSURE EFFECTIVE SEAL OF THERMAL RELIEF VALVE AND PREVENT SEAT LEAKAGE

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**ABSTRACT—**Rocket propulsion systems, long-distance transportation, and the long-term storage of vast quantities of frozen food all depend on cryoliquids. Cryoliquids are notoriously difficult to transport and store since they boil at a temperature below absolute zero. The expansion rates of these low-temperature liquids may reach 700 times, thus additional safety precautions must be included in the pipelines or storage facilities that house them. Pipes may rupture if internal pressure rises over safe thresholds. At this point, the significance of the safety pressure release valve becomes evident. When the thermal relief valve reaches a certain pressure, it will open to release pressure from the section and then shut to return to its starting position.

Most cryogenic systems have minimum air release capacity of 300 standard cubic feet per minute (SCFM) and thermal relief valves with metal to metal seating to prevent leakage. Surface finish limitations prevent metal-to-metal seated valves from achieving zero leakage or a Class VI leakage rating.

The feasibility of soft-sealing conventional metal-to-metal seated valves has been investigated. A soft seal is needed for the current disc and nozzle arrangement, and PCTFE (poly-chloro-tri-flouro-ethylene) may provide this. to use the valve's original spring. computations for strength and force balancing for the new disc shape. The leakage pressure was computed using the updated geometry. Next, we test it in the lab using air and liquid nitrogen. Longer term, more sensible and efficient It is being researched to create a cryogenic valve that can resist larger pressure surges.

Seat leaks, PCTFE, 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.

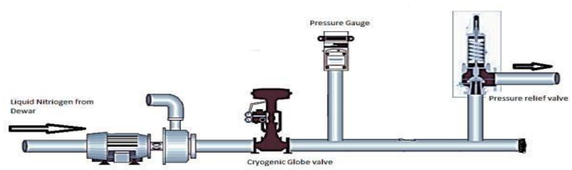


Fig. 1.1 Traditional control loop

## 2. 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



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ISSN PRINT 2319 1775 Online 2320 7876
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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 | Orificeare a($mm^2$) |
|---|---|---|
| 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

| 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 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 not exceed the valves specified in the above table.
- For soft seated valves should perform till minimum 20 popups without failure in practical condition.
- 2.5 Main reasons of Valve Seat Leakage
- Improper alignment of subassemblies after testing.

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- 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:**

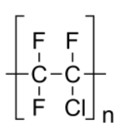
Even though specified leak rate is allowed, due to hazardous nature of cryofluids like hydrogen, no leakage of hydrogen vapors/gases is permitted across the valve during normal operation. For metal to metal seated valves, attaining zero leakage or Class VI leakage classification is not possible due to 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 $(C_2F_3Cl)_n$, 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.

**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.

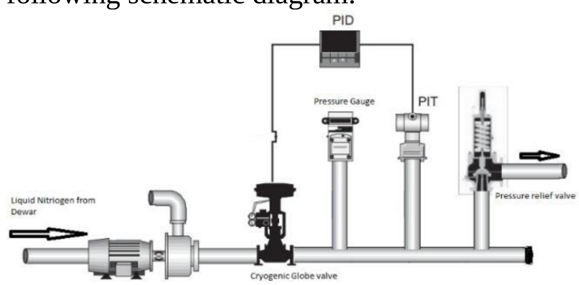



Fig. 4.1 Experimental setup schematic representation Initially the liquid nitrogen which was stored in Dewar was connected to vacuum sealed pipe line and is made flow through the setup as shown above. This liquid nitrogen initially flown through the cryogenic globe valve which is in open condition. Pressure 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

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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**Liquidnitrogenstoragetankatoperation

**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.

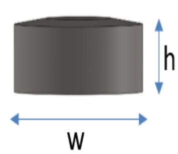
Fig. 4.5 Cryogenic pressure relief valve

**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.

**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

**5.2 Design**

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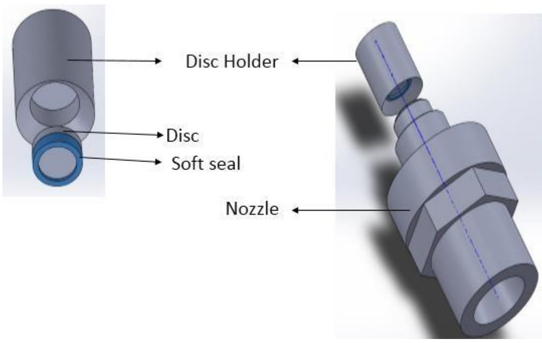



Fig. 5.1 Metal disc with disc holder and nozzle assembly

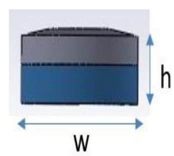
## 5.3 Disc

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

| 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

**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

## 5.4 Soft Seal

The soft seal is made out PCTFE.

## 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.

## 6. DESIGN CALCULATIONS

The movement of the disc depends on the force balance between the upward fluid force, Fup and the downward spring force and back pressure forces FB [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 YD=0.

Then the total downward force acting on the disc is FDn = PBAD + K YO

The total downward force acting on the disc is

$$FUp = PAD$$

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

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

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ISSN PRINT 2319 1775 Online 2320 7876
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P = System fluid pressure
PB = Backpressure
AD = Area of the disc
K = Spring constant
YO = initial spring compression

| 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 calculationThisSeating 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]**

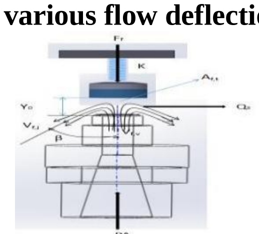

Fig. 6.1 Different forces acting at the opening condition of valve

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

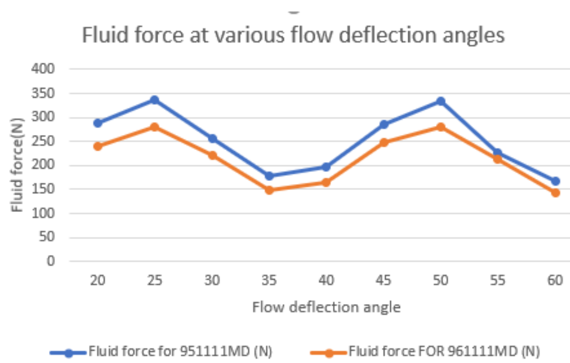


Fig. 6.2 Fluid force at various deflection angles

| Sl.no | Description | Units | Symbol | Safety valve model | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | 951111MD | 951111MD | 951111MD | 961111MD | 961111MD | 961111MD |
| 1 | Mass flow rate through the valve | Kg/sec | ṁ | 0.268312 | 0.268312 | 0.268312 | 0.258036 | 0.258036 | 0.258036 |
| 2 | Density of the fluid | Kg/m3 | ρ | 17.84 | 17.84 | 17.84 | 200 | 11.84 | 11.84 |
| 3 | Diameter of the nozzle | m | Dnozzle | 0.00833 | 0.00833 | 0.00833 | 0.01 | 0.01 | 0.01 |
| 4 | Actual area of the nozzle | m2 | An | 5.45E-05 | 5.45E-05 | 5.45E-05 | 7.86E-05 | 7.86E-05 | 7.86E-05 |
| 5 | Mean fluid velocity at nozzle exit | m/sec | Vf,v | 275.936 | 275.936 | 275.936 | 16.42494 | 277.4483 | 277.4483 |
| 6 | Maximum Lift of the valve disc | m | YD | 0.0036 | 0.0036 | 0.0036 | 0.0036 | 0.0036 | 0.0036 |
| 7 | Curtain area at maximum disc lift | m2 | Af,t | 9.42E-05 | 9.42E-05 | 9.42E-05 | 0.000113 | 0.000113 | 0.000113 |
| 8 | Mean fluid velocity in jet | m/sec | Vf,j | 159.723 | 159.723 | 159.723 | 11.41347 | 192.7952 | 192.7952 |
| **9** | **Flow deflection angle ( Assumption at maximum Lift)** | **deg.** | **β** | **30** | **45** | **60** | **30** | **45** | **60** |
| 10 | System Pressure | N/m2 | P | 2000000 | 2000000 | 2000000 | 1400000 | 1400000 | 1400000 |
| 11 | Pressure Force | N | | 109.01 | 109.01 | 109.01 | 109.97 | 109.97 | 109.97 |
| 12 | Momentum Force due to deflection of fluid jet | N | | 80.64736 | 96.54978 | 33.22067 | 4.692507 | 97.72536 | 24.21091 |
| 13 | Total Fluid Force | N | Ffluid | 189.6573 | 205.5597 | 142.2306 | 114.6625 | 207.6954 | 134.1809 |
| 11 | Gas's heat capacity ratio | | k | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 |
| 12 | Discharge coefficient | | cd | 0.975 | 0.975 | 0.975 | 0.975 | 0.975 | 0.975 |
| 13 | Constant C | constant | c | 0.684731 | 0.684731 | 0.684731 | 0.684731 | 0.684731 | 0.684731 |
| 14 | Mass flow rate through the valve ṁ | Kg/sec | ṁ | 0.375504 | 0.375504 | 0.375504 | 1.262804 | 0.307254 | 0.307254 |
| 15 | Pressure Force | N | | 109.01 | 109.01 | 109.01 | 109.97 | 109.97 | 109.97 |
| 16 | Momentum Force due to deflection of fluid jet | N | | 157.9575 | 189.1043 | 65.06665 | 112.3872 | 138.561 | 34.32772 |
| 17 | Fluid force = pressure force + momentum force | N | Ffluid | 266.9675 | 298.1142 | 174.0766 | 222.3572 | 248.531 | 144.2977 |

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]

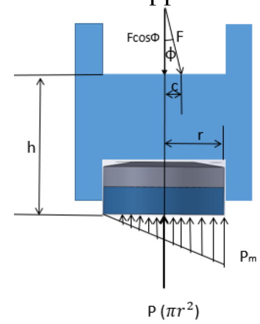


Fig. 7.1 valve leakage analysis



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| 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 | $N/mm^2$ | 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 | $P_{lift}$ | $N/mm^2$ | 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.

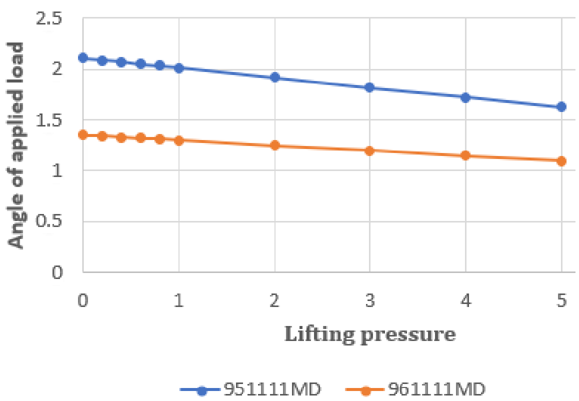


Fig. 7.2 Lifting pressure at various applied loads

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.

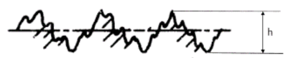


Fig. 8.1 Surface asperities representation

### 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 | ʸ1 | | 0.4 | 0.4 |
| Poissens ratio for the metal | ʸ2 | | 0.3 | 0.3 |
| Elastic constant for surfaces in contact | α | 1/(N/mm2 | 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:

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| 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.

| 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

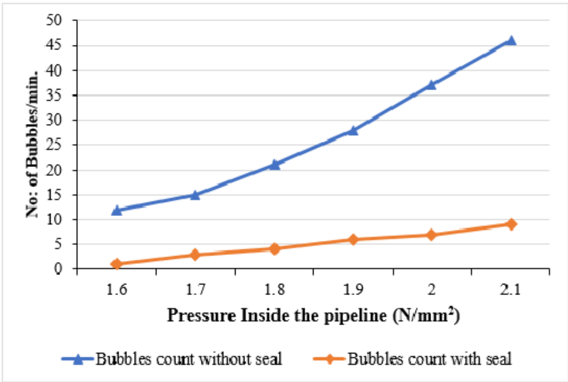
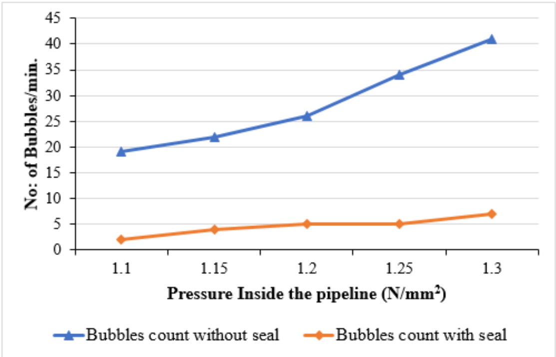



**Fig.9.2** Number of Bubbles/minute for 951111MD valve

| Pressure N/mm$^2$ | 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

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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/mm$^2$ | 2.2 N/mm$^2$ |
| 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/mm$^2$ | 1.375 N/mm$^2$ |
| 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.

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.

## 10. CONCLUSIONS

The following findings are drawn from the changes made to the cryogenic pressure relief valve:

- The pressure relief valve that had a PCTFE seal on the disc worked better than the one that did not.
- t 90% of the specified pressure, the number of bubbles exiting the pressure relief valve decreased from 46 to 9 bubbles/min for 951111MD and from 41 to 7 bubbles/min for 961111MD.
- By using PCTFE sealing on the disc, the pressure relief valve's performance improved dramatically in the bubble test. As a result, the pressure relief valve satisfies the leakage specifications set out by the American Petroleum Institute (API 527).
- The 951111MD thermal relief valve with the changes underwent continuous testing for 48 popups without any minute leaks and was found to be functional. In contrast, the metal-to-metal contact disc valve used to malfunction once per eight popups. Likewise, the 961111MD valve functioned up to 65 popups after originally operating at 13 popups.
- For 951111MD valves, the valve adjustments increased performance by six times, and for 961111MD valves, it increased performance by five times.
- The changes that are taken into consideration for the PRV must demonstrate that they can endure the possible circumstances. It was shown that the disc can sustain pressure and sitting stress in comparison by doing analytical calculations on the seating stress acting on it under operational conditions. Furthermore, it has been

ISSN PRINT 2319 1775 Online 2320 7876
 Journal Volume 10, Iss 09, 2021

shown via practical testing that minimising valve leakage may be achieved by adding a soft seal to the disc.

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