Determining the Effectiveness of Oleophobic Gaskets

Update Presentation

Sponsor: Cummins Inc.

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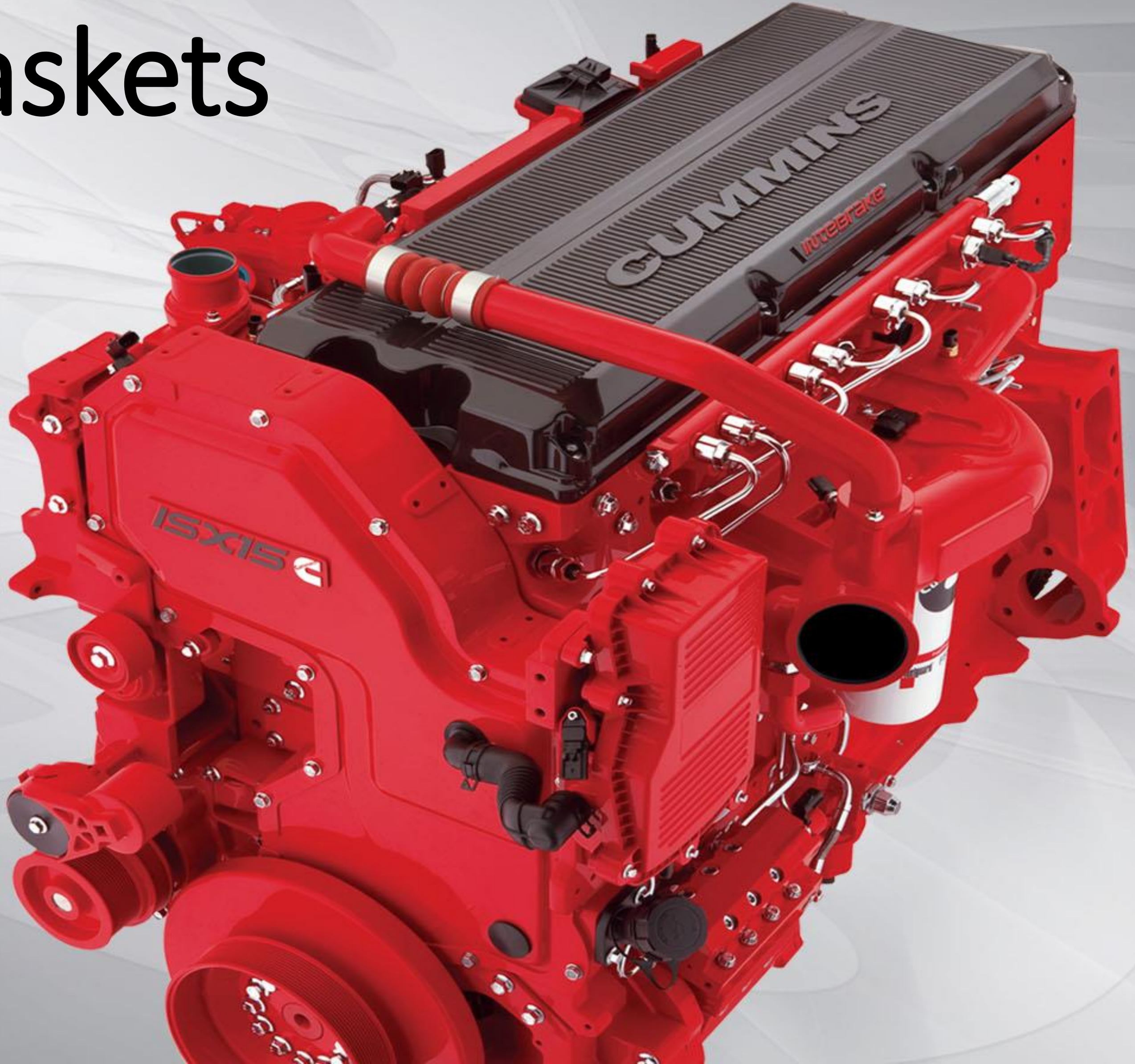

Agenda

- Project Background Recap
- Test Rig Update
- Gasket Testing Update
- Procurement and Budget Update
- On Going Work
- Summary

Presenter: Heather Davidson

Background Information

- Oleophobicity
  - Physical property of a molecule that causes it to repel oil
  - Must have lower surface energy than oil
- Gaskets
  - Mechanical seal created using a variety of materials and shapes
  - Placed in a space between two surfaces and will create a seal while under compression
- Four common gaskets types:
  - Paper
  - Rubber Coated Metal (RCM)
  - Molded Elastomeric (O-rings)
  - Formed in Place Gasket

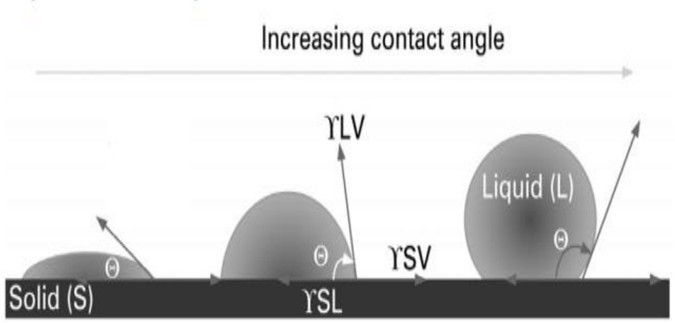

Figure 1. Substance beads up with a high contact angle[1]

Figure 2. Paper and a rubber coated metal gasket[2]

Project Needs and Goals

- Needs Statement:
  - Gaskets used at large joints where the oil is at low pressure leak more oil than desired.

- Goal Statement:
  - Determine the effectiveness of oleophobic gaskets through the use of a test rig designed by the team.

Objectives and Scope

Objective Number	Objective
1	Research what causes items to become oleophobic
2	Create oleophobic gaskets using current market products
3	Create oleophobic gaskets using non conventional gasket materials
4	Design and build the test rig to determine leak rate at different temperatures and clamping pressures at a stipulated pressure (2.5 psi)
5	Test new oleophobic gaskets and currently used gaskets for leak rate and compare results

Test Rig Product Specifications

- Design Specifications:

Design Specifications	**Value**
Test Rig Dimensions	Inner Diameter: ≤ 55 mm
Test Rig Stress Capacity	Minimum of bottom flange: 4.94 mm Vessel thickness not critical as pressure difference nearly negligible.
Flange Dimensions	Inner Diameter: ≤ 55 mm Outer Diameter: > 140 mm
Clamping Pressure	Minimum: 0.5 MPa Maximum: 10 MPa

- Performance Specifications:
  - Measure temperature: 22-120°C ± 2°C
  - Measure internal pressure: 0-5 psi ± 0.01 psi
  - Simulate actual seal

How to Measure Leak Rate

- Ideal Gas Law
    - PV = nRT
        - nRT will remain constant throughout test
        - Therefore $P_1V_1 = P_2V_2$
        - Solve for final volume V_2
        - Change in volume/time = leak rate
- Compressed air used to increase initial pressure
- Hot plate used to vary oil temperature

Figure 3. Pressure transducer[3]

Selected Sensors

- Omega Resistance Temperature Detector (RTD) Sensor
  - Required range: 22 – 120°C
  - Accuracy: ± 2°C
  - Length probe restriction (<55 mm)
  - Compression fitting
- Kulite Pressure Transducer
  - Required range : 0 – 5 psi
  - Accuracy: 0.005 psi
    - Used in further leak measurement calculations

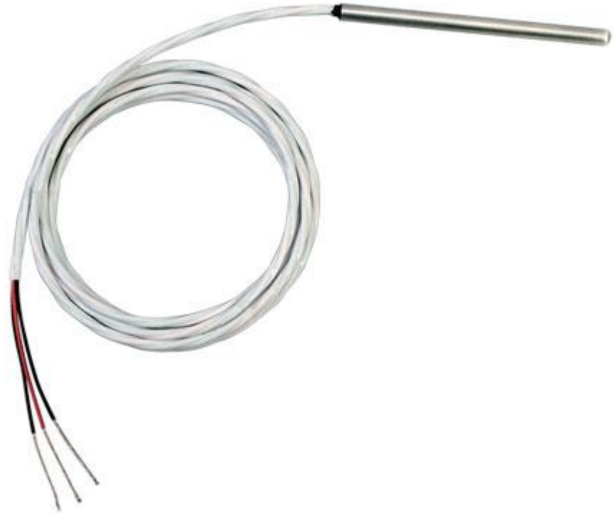

Figure 4. Short RTD probe (PR-20-2-100-3/16-2-E-T)[4]

Figure 5. Pressure Transducer (XT-123B-190-5G)[5]

Previous CAD Model of Test Rig

- Oil inlet valve on top surface, offset from the center of the test rig
- RTD temperature sensor, pressure transducer, and air valve are mounted to the side face
- Bottom flange (red) will be interchanged
- Four M8 bolts used to create a clamping load on the gasket

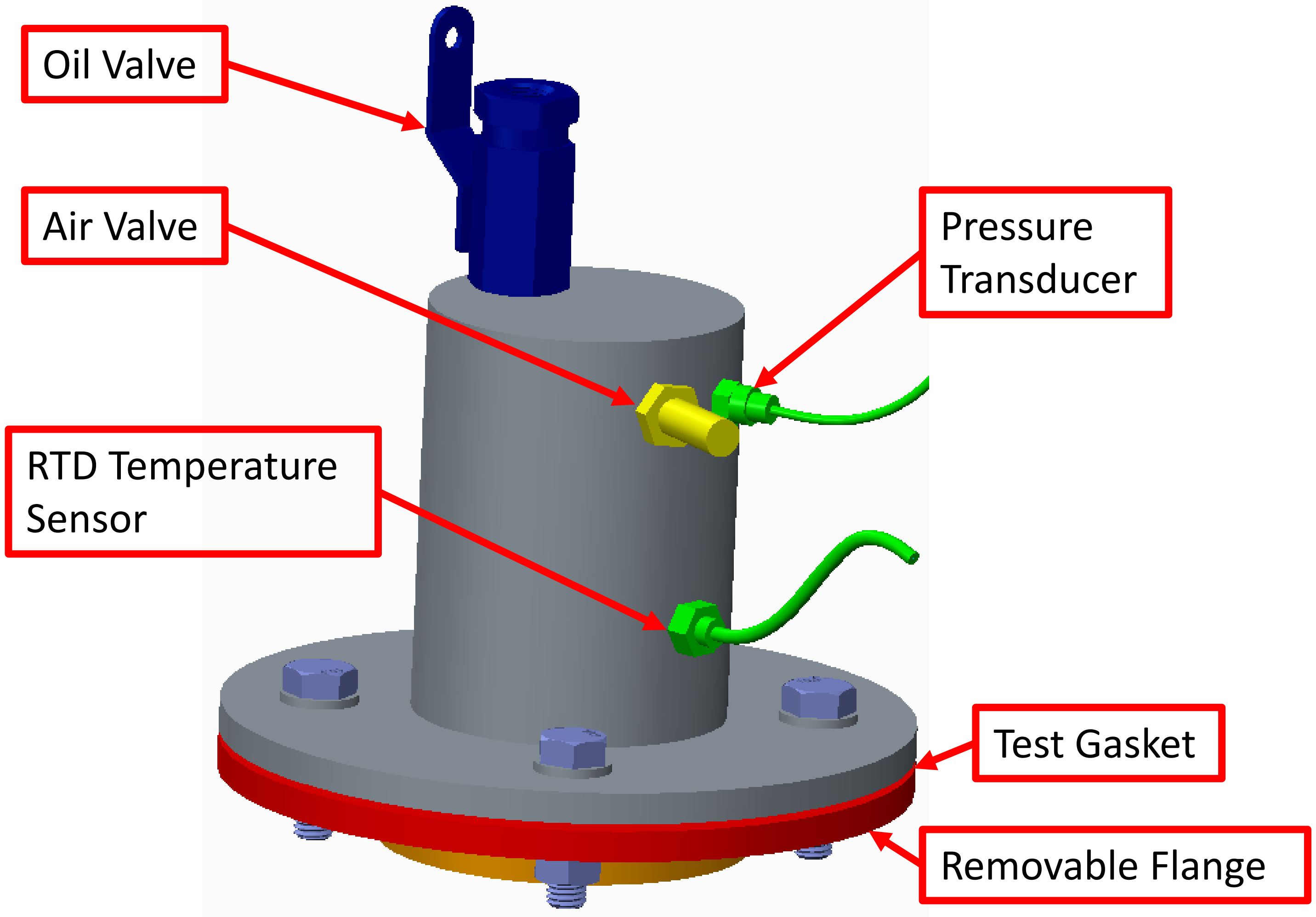

Figure 6. Previous Test Rig Concept

Update: Measuring Clamping Pressure

- Previously had not identified accurate and economical method of measuring the clamping load
- Identified the ability to install strain gauges within the bolts themselves
  - Cummins Inc. agreed to install and calibrate the strain gauges within the bolts
  - Requires:
    - M10 Bolts
    - At least 2” before thread engagement

Figure 7. Modified strain gauge bolt

Update: Pressure Relief Valve

- Previous design relied on user adjustment to initial air pressure using the Air Inlet Valve
- Pressure Relief Valve preset at 2.5 psi
  - Allows for consistent initial pressure for testing
  - Prevents over pressurizing the pressure transducer

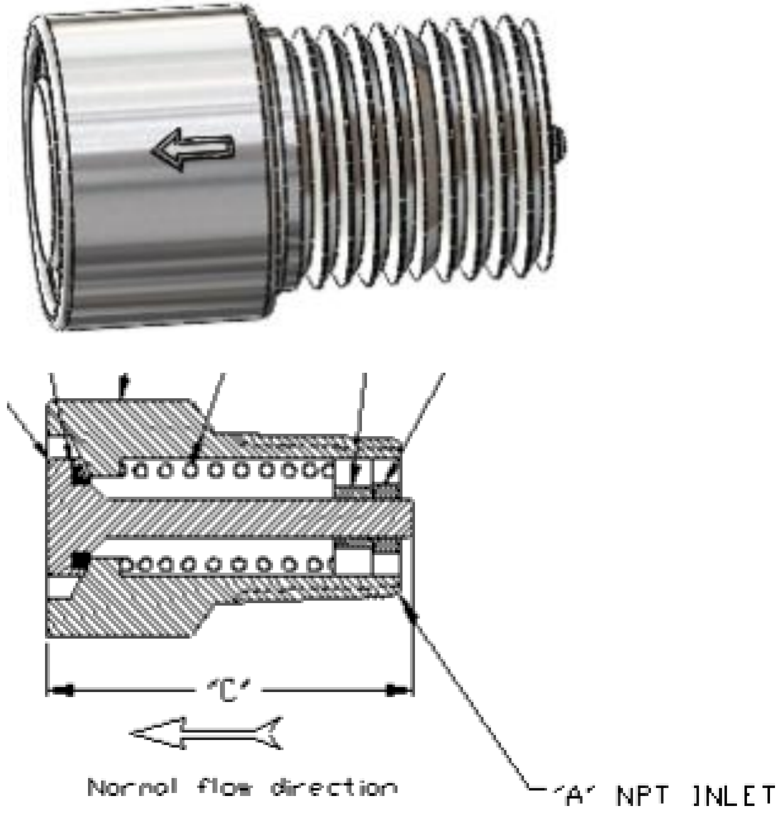

Figure 8. Straval 1/8” Rva05-01T Pressure Relief Valve

Test Rig Updated Design

- Updated Items:
  - Replaced M8 bolts with M10 bolts
  - Added 1.5” Spacer for the bolts
  - Added a Pressure Relief Valve

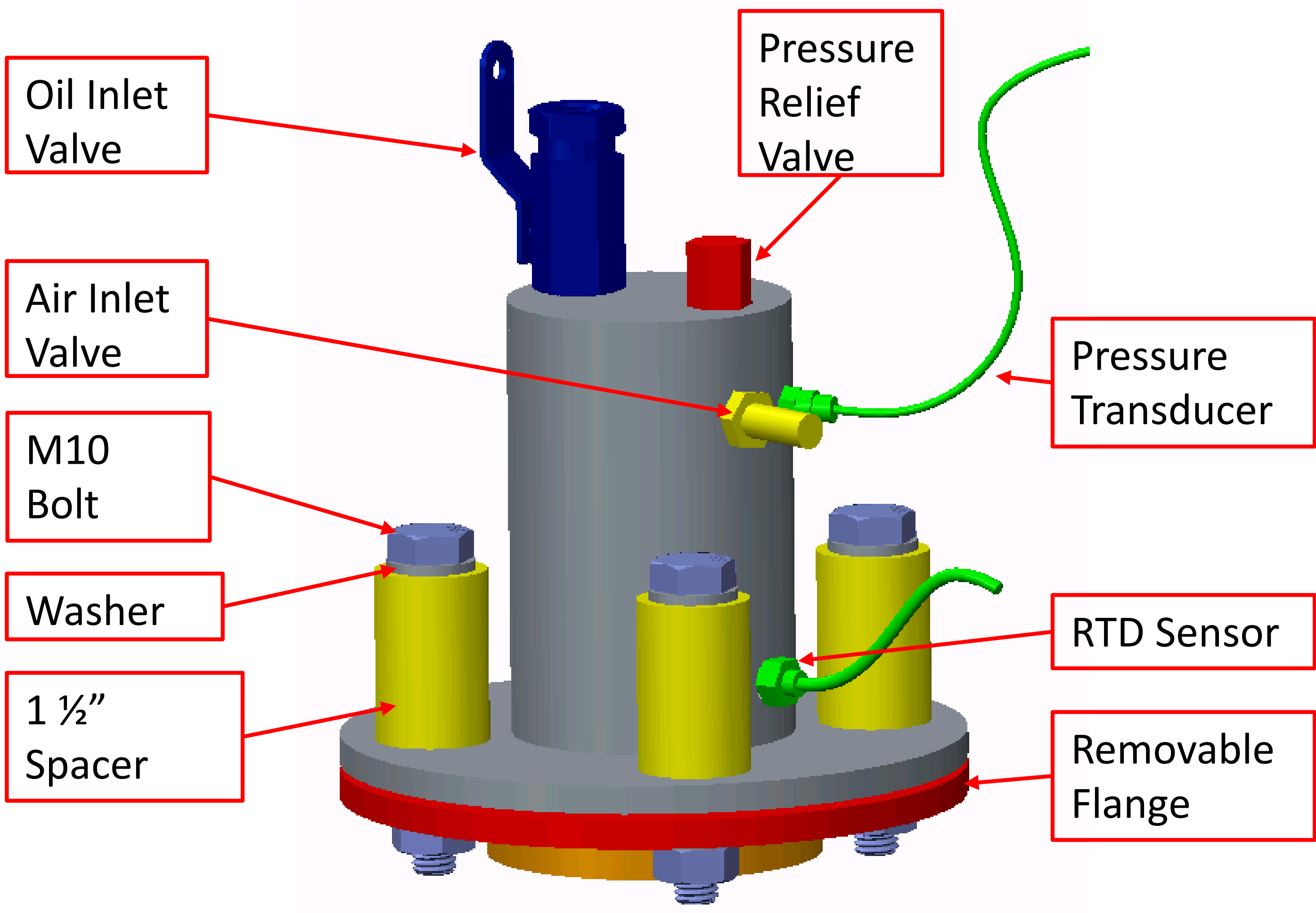

Figure 9. Final Test Rig Concept

Internal Features of Test Rig

- RTD sensor completely submerged in oil
- Pressure transducer and air valve open to air cavity
- All material is 6.34 mm (0.25 in)

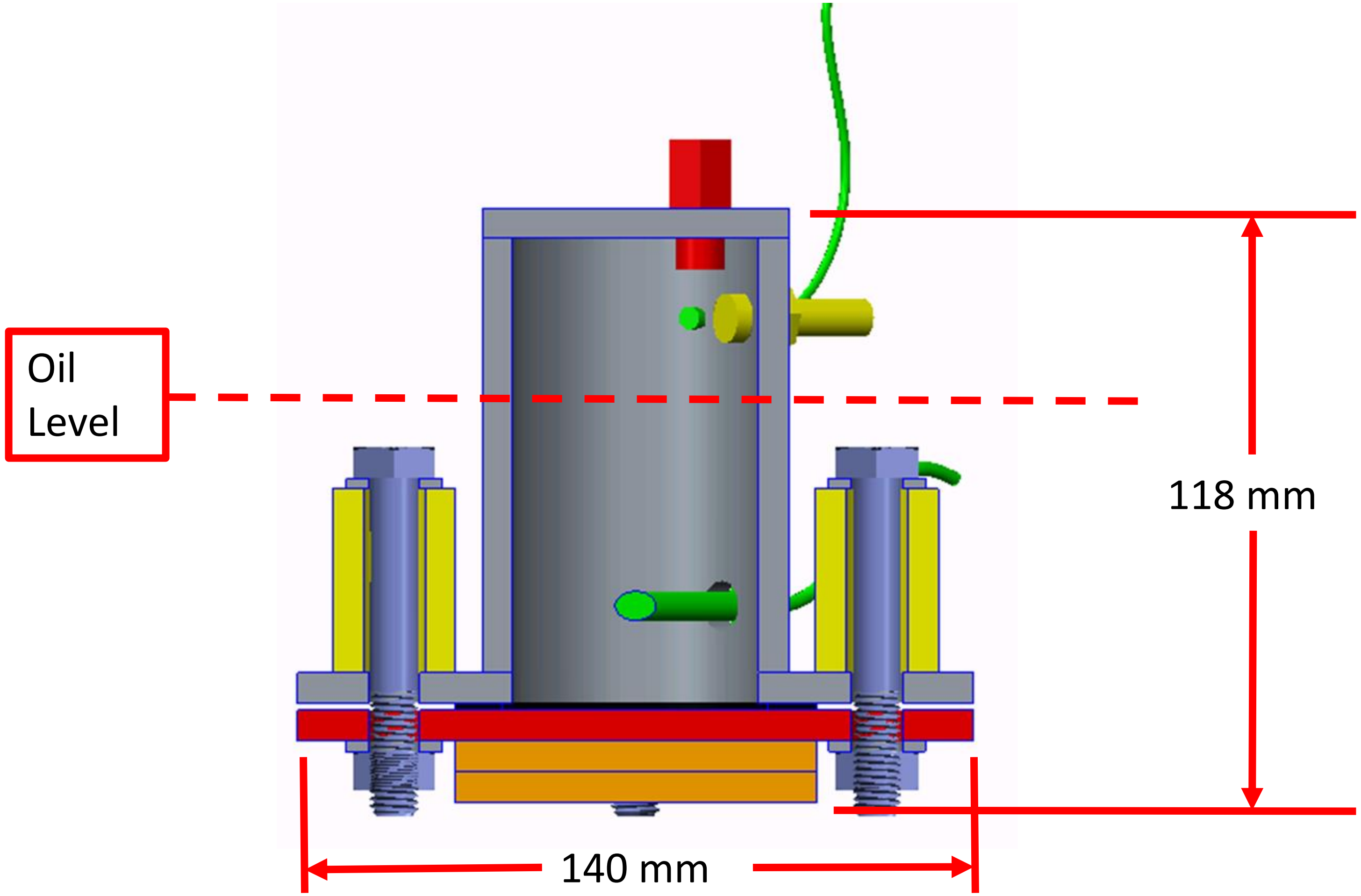

Figure 10. Internal Configuration of the Test Rig

Making Oleophobic Gaskets

- Standard methods of making oleophobic surfaces
  - Spray
    - Using a sprayer such as an air brush or paint gun to apply a consistent and constant spray
  - Impregnator solution
    - Sealer that penetrates the surface to allow for protecting from dense liquids such as oil
- Non-traditional gaskets
  - Teflon gaskets
    - Naturally has oil repellent properties
  - Coat a high density fabric or other material with an oleophobic solution to create a unique oleophobic gasket

Baseline Gasket Material Testing

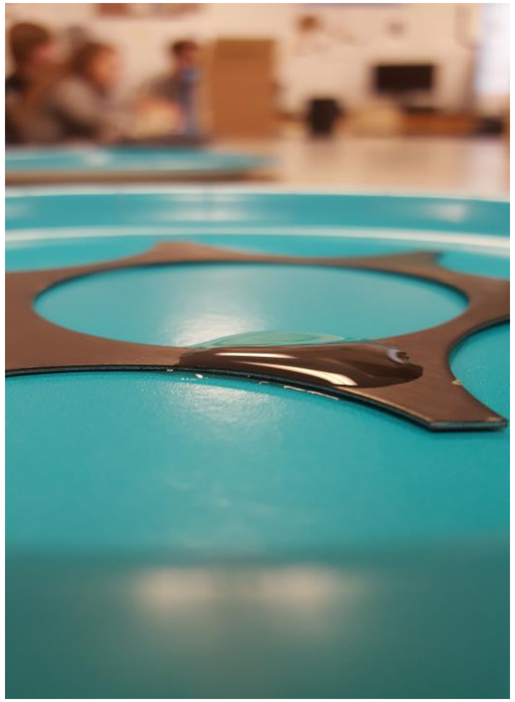

Figure 11. RCM gasket without any solution

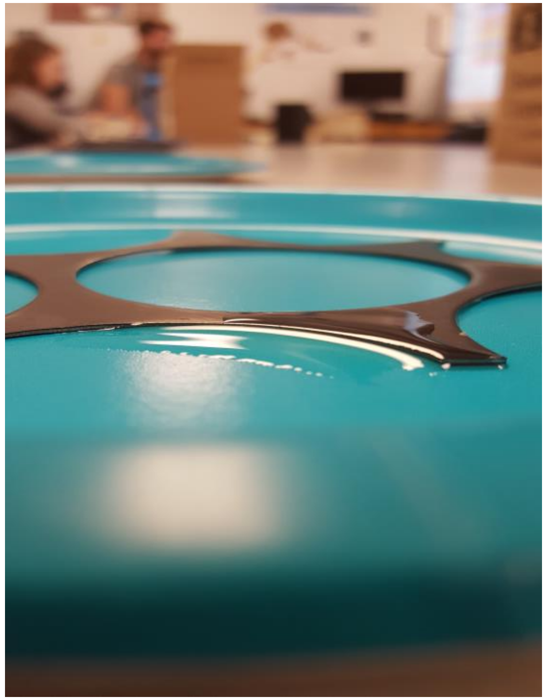

Figure 12. RCM gasket after attempted oil removal

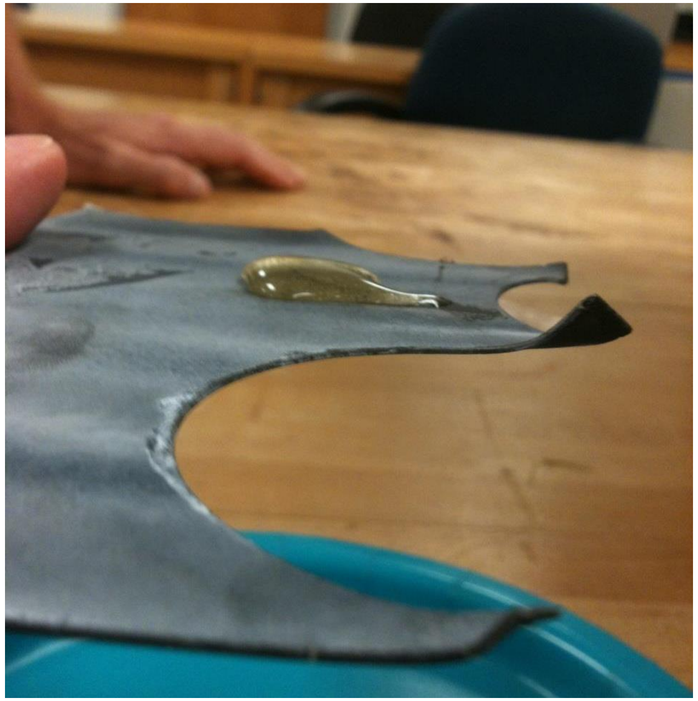

Figure 13. RCM gasket after spray and oil droplet dispersed

Baseline Gasket Material Testing

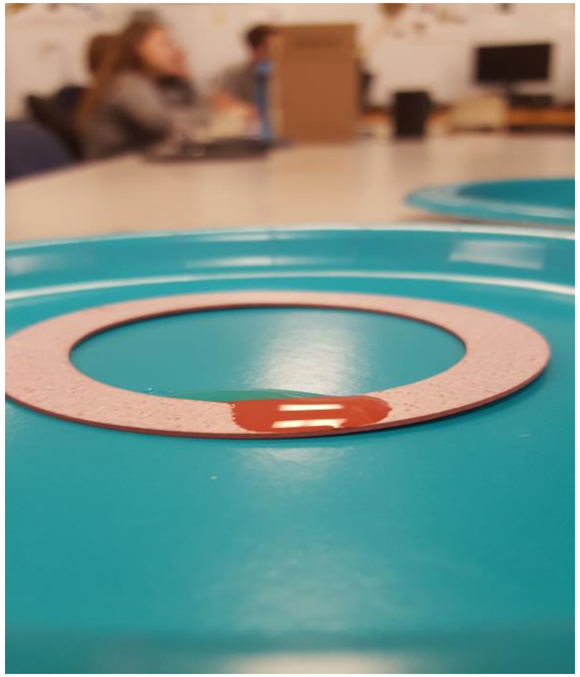

Figure 14. Paper gasket without solution

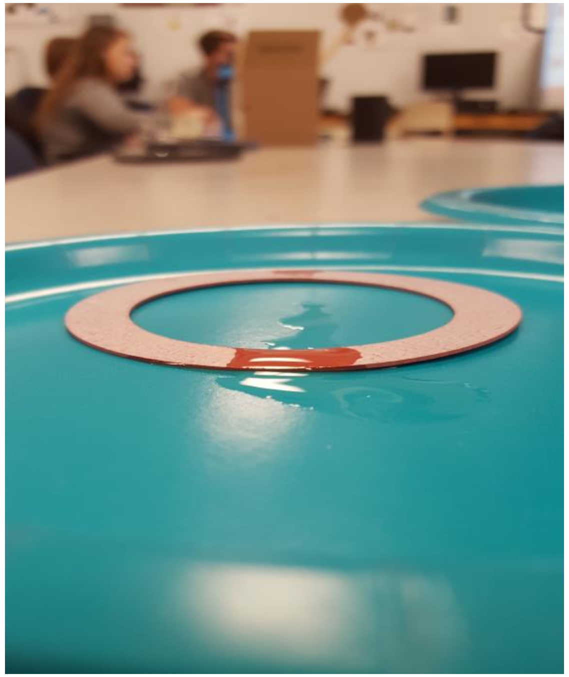

Figure 15. Paper gasket after attempted oil removal

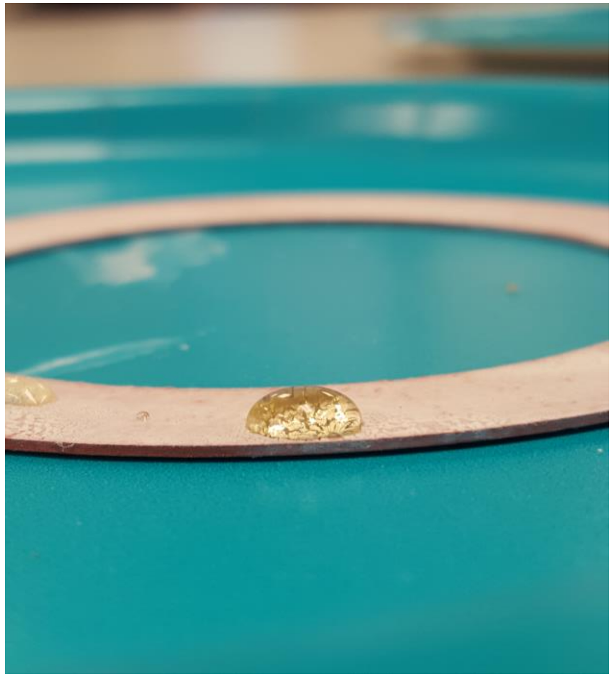

Figure 16. Paper gasket after impregnation and oil droplet dispersed

Baseline Gasket Material Testing

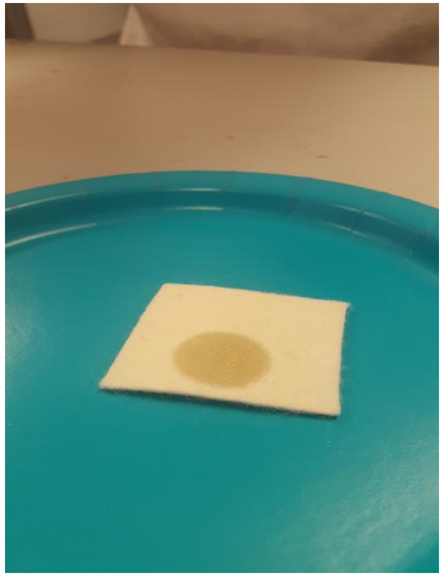

Figure 17. Top view of fiber felt without any solution

Figure 18. Bottom view of fiber felt without any solution

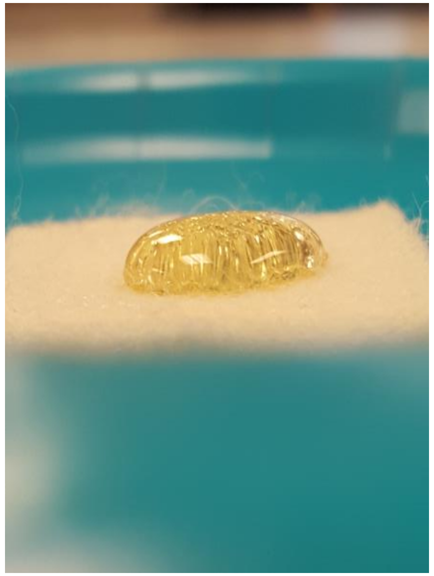

Figure 19. Fiber felt after impregnation and oil droplet dispersed

Figure 20. Fiber felt after spray application and oil droplet dispersed

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Baseline Gasket Material Testing

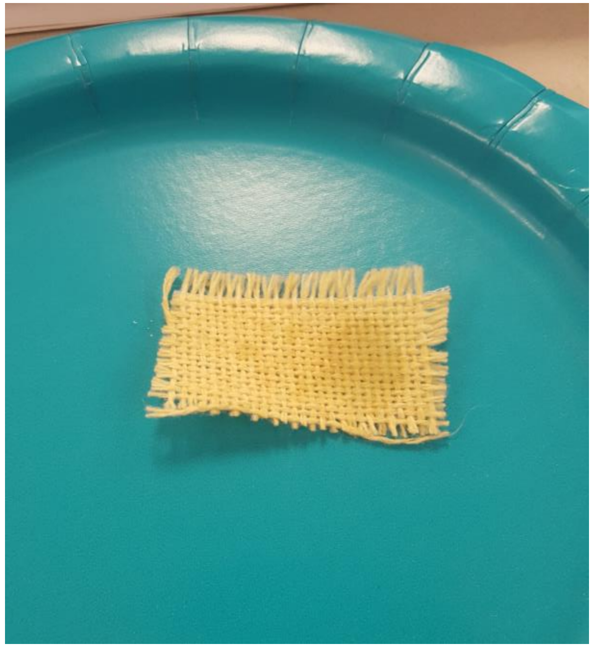


Figure 21. Top view of fiber cloth without solution

Figure 22. Bottom view of fiber cloth without solution

Figure 23. Fiber cloth material after impregnation and oil droplet dispersed

Updated Gasket Testing: Teflon

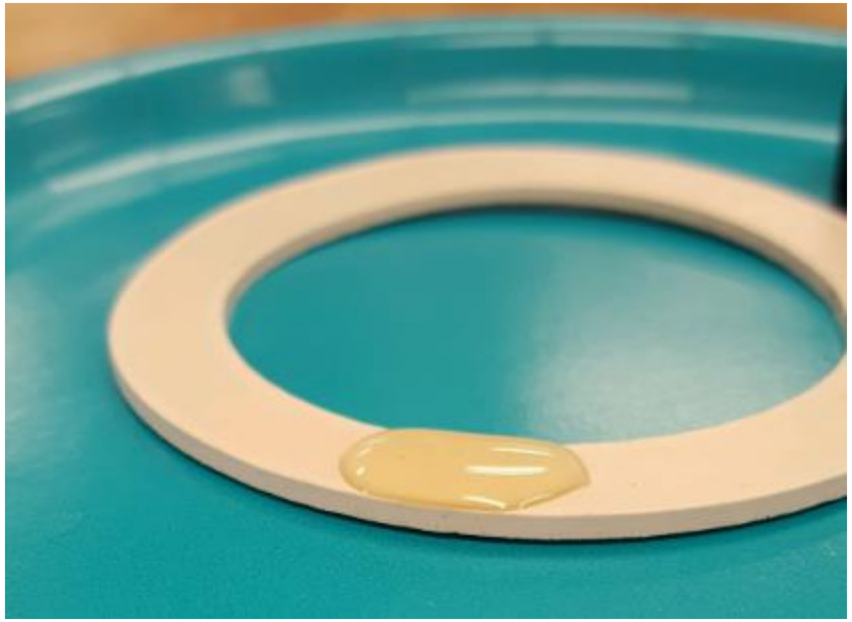


Figure 24. Teflon gasket with oil

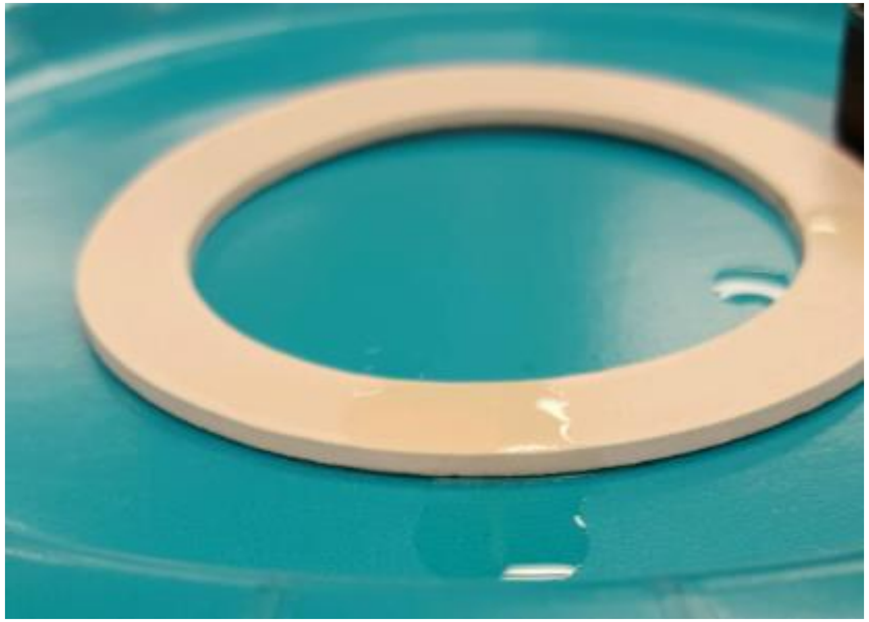
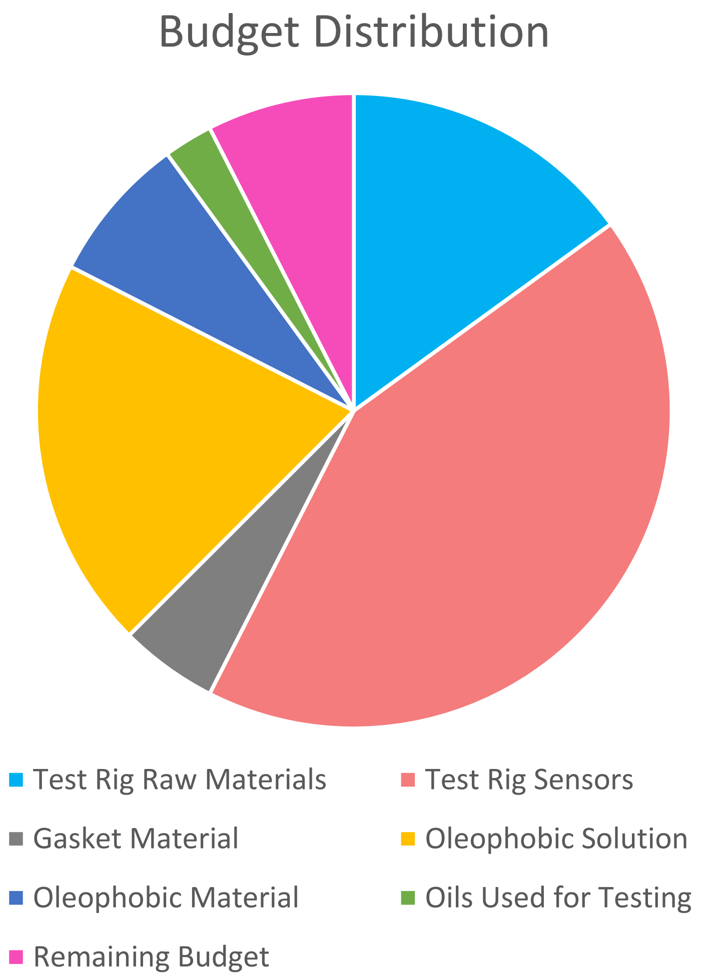


Figure 25. Teflon gasket after oil removal

Budget Forecast

- Budget provided: $2,000
- Total estimated cost: $1,850

Item	Maximum Estimated Cost
Test Rig Raw Materials	$300.00
Test Rig Sensors	$850.00
Gasket Materials	$100.00
Oleophobic Solutions	$400.00
Oleophobic Material	$150.00
Oils Used for Testing	$50.00
Remaining Budget	$150.00



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Updated Purchased Items

Budget Category	Item	Quantity	Cost
Test Rig Material	M8 Class 10.9 Cap Screw	1(Pack of 25)	$7.91
Test Rig Material	M8 General Purpose Steel Washer	1 (Pack of 100)	$6.09
Test Rig Material	M8 Class 10 Steel Nut	1 (Pack of 100)	$10.48
Test Rig Material	M10 General Purpose zinc plated steel washer	1 (Pack of 100)	$4.36
Test Rig Material	M10 Class 8 Zinc Plated Steel Hex Nut	1 (Pack of 100)	$10.48
Test Rig Material	Zinc-Plated Steel Unthreaded Spacer	4	$55.32
Test Rig Material	M10x1.5 70mm long class 8.8 cap screw	1 (Pack of 10)	$8.58
Test Rig Material	Pressure Relief Valve	1	$48.00
Test Rig Material	Compact High-Pressure Brass Ball Valve	1	$11.34
Test Rig Material	Brass Air Fill Valve Straight	1	$4.40
Test Rig Material	1ft x 1ft x ¼ in Thick A36 Steel Plate	1	$15.41
Test Rig Material	1ftLong 2-1/2 OD x 2 ID Round Steel Tube	1	$36.04
Test Rig Sensors	Short RTD Probe	1	$66.00
Test Rig Sensors	Compression Fitting	1	$20.00
Test Rig Sensor	Pressure Transducer	1	$618.00
Oleophobic Material	Teflon Gaskets	20	$170.00
Oil Used for Testing	T Triple Protection CJ-4 15W-40 Motor Oil	1 (Gallon)	$13.44
Purchased	**Total**		**$1,105.85**

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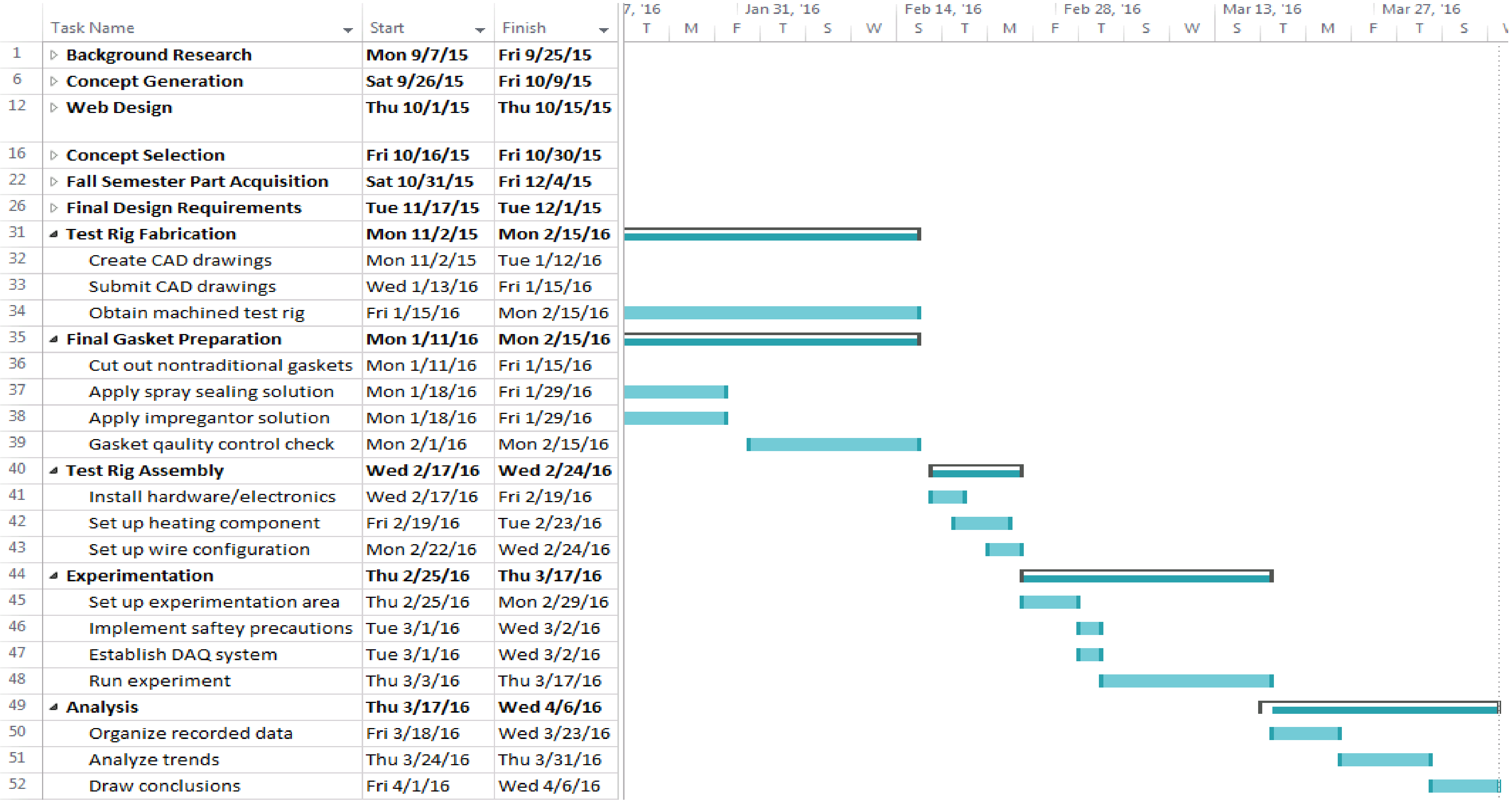
Spring Projected Schedule



	Task Name	Start	Finish
1	▷ **Background Research**	**Mon 9/7/15**	**Fri 9/25/15**
6	▷ **Concept Generation**	**Sat 9/26/15**	**Fri 10/9/15**
12	▷ **Web Design**	**Thu 10/1/15**	**Thu 10/15/15**
16	▷ **Concept Selection**	**Fri 10/16/15**	**Fri 10/30/15**
22	▷ **Fall Semester Part Acquisition**	**Sat 10/31/15**	**Fri 12/4/15**
26	▷ **Final Design Requirements**	**Tue 11/17/15**	**Tue 12/1/15**
31	◢ **Test Rig Fabrication**	**Mon 11/2/15**	**Mon 2/15/16**
32	Create CAD drawings	Mon 11/2/15	Tue 1/12/16
33	Submit CAD drawings	Wed 1/13/16	Fri 1/15/16
34	Obtain machined test rig	Fri 1/15/16	Mon 2/15/16
35	◢ **Final Gasket Preparation**	**Mon 1/11/16**	**Mon 2/15/16**
36	Cut out nontraditional gaskets	Mon 1/11/16	Fri 1/15/16
37	Apply spray sealing solution	Mon 1/18/16	Fri 1/29/16
38	Apply impregantor solution	Mon 1/18/16	Fri 1/29/16
39	Gasket qaulity control check	Mon 2/1/16	Mon 2/15/16
40	◢ **Test Rig Assembly**	**Wed 2/17/16**	**Wed 2/24/16**
41	Install hardware/electronics	Wed 2/17/16	Fri 2/19/16
42	Set up heating component	Fri 2/19/16	Tue 2/23/16
43	Set up wire configuration	Mon 2/22/16	Wed 2/24/16
44	◢ **Experimentation**	**Thu 2/25/16**	**Thu 3/17/16**
45	Set up experimentation area	Thu 2/25/16	Mon 2/29/16
46	Implement saftey precautions	Tue 3/1/16	Wed 3/2/16
47	Establish DAQ system	Tue 3/1/16	Wed 3/2/16
48	Run experiment	Thu 3/3/16	Thu 3/17/16
49	◢ **Analysis**	**Thu 3/17/16**	**Wed 4/6/16**
50	Organize recorded data	Fri 3/18/16	Wed 3/23/16
51	Analyze trends	Thu 3/24/16	Thu 3/31/16
52	Draw conclusions	Fri 4/1/16	Wed 4/6/16

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Future Work

- Complete preliminary testing of gasket materials
- Fabrication of the test rig
- Set standard procedure for leak rate measurement testing
- Collection, manipulation and analysis of data
- Final experimental comparison/deduction

Summary

- Goal:
  - Determine the effectiveness of oleophobic gaskets through the use of a designed test rig
- Completed Tasks:
  - Test rig analysis
  - Final design of test rig
  - Hardware/Sensor purchasing
  - Clamping load measurement method
- Key next steps:
  - Complete the fabrication process
  - Design the experimental procedure

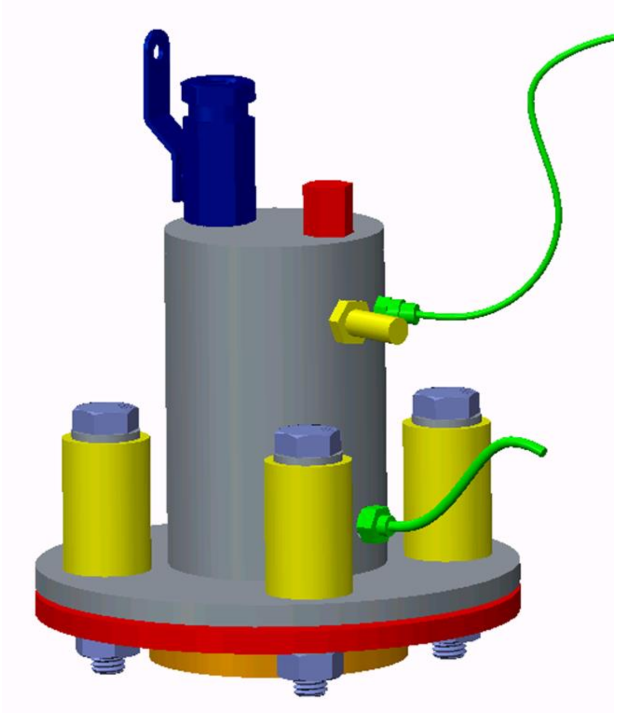


Figure 26. Test Rig Design

References

[1]http://pubs.rsc.org/en/content/articlehtml/2014/cs/c3cs60415b

[2]http://store.jamesgaskets.com/product_info.php?products_id=742&osCsid=4s6r9tgqtdt3s1tfi5q7puf9t2

[3]https://www.omega.com/subsection/voltage-output-pressure-transducers.html

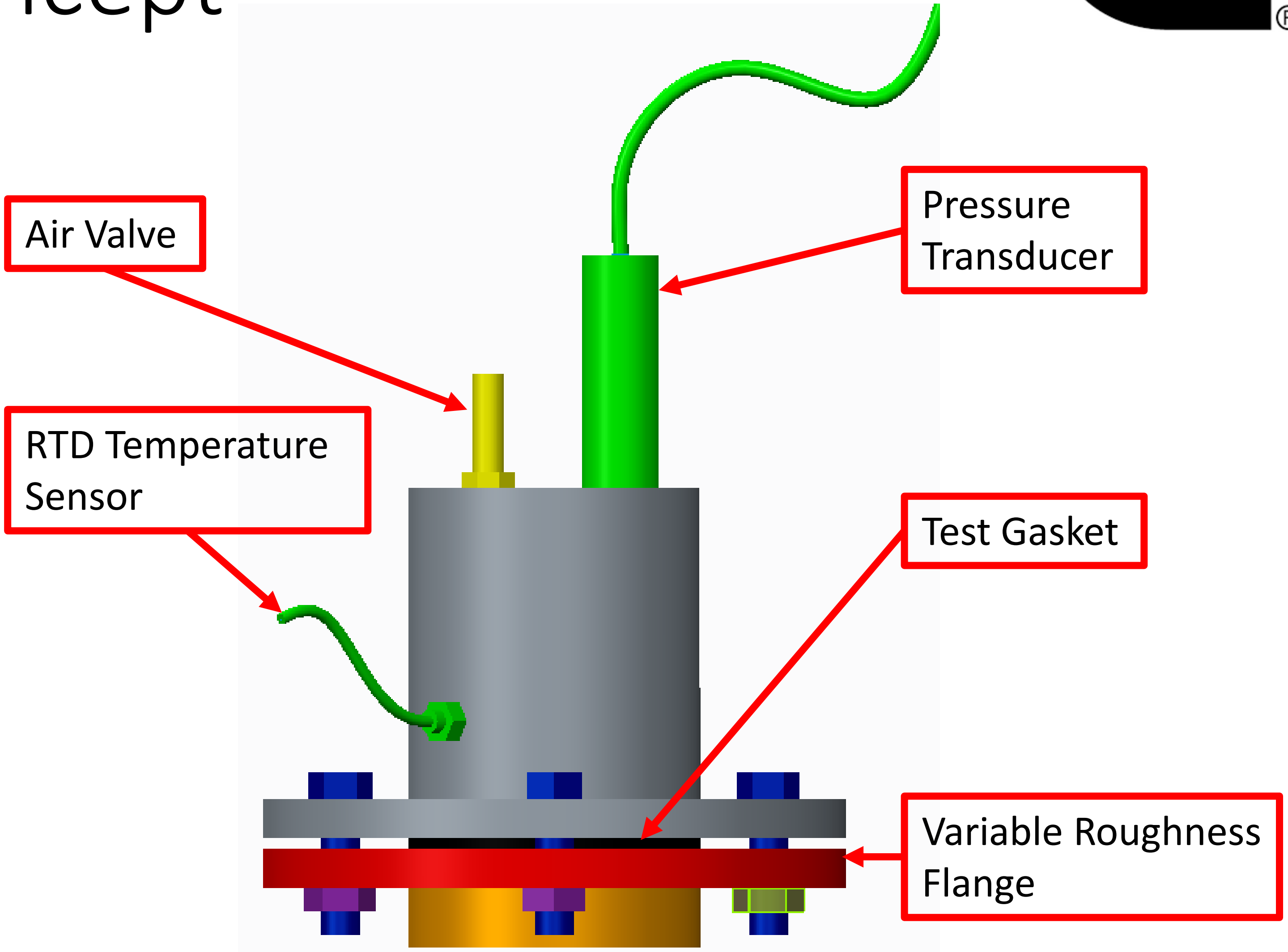
[4]http://www.omega.com/pptst/PR-20.html

[5]http://www.kulite.com/products.asp?p=4-1

Appendix

Original Chosen Concept

- RTD temperature sensor mounted to the side face
- Bottom flange (red) will be interchanged
- Four M8 bolts used to create a clamping load on the gasket
- Bottom spacer used to keep bolts off bottom face



FMEA Table

Component	Mode Of Failure	Cause	Probability	Effect	Severity	Recommended Action
Flanges	Bending	Torque	4	Increase in leak rate	2	Monitor torque wrench
	Surface Roughness	Machining Flaw	2			Follow machining standards
Gasket	Blowout	Material selection	1	Safety hazard	5	Material testing
	Oil leak	Improper materials	4	Increase in leak rate	4	Material testing
		Leak paths	6		2	Design selection
Pressure Vessel	Crack/break	Material selection	1	Blowout	6	Factor of Safety
		Tolerances	2			
Sensors	Overload	Improper selection	1	Inaccurate results	6	Consult sensor data sheet
	Accuracy					

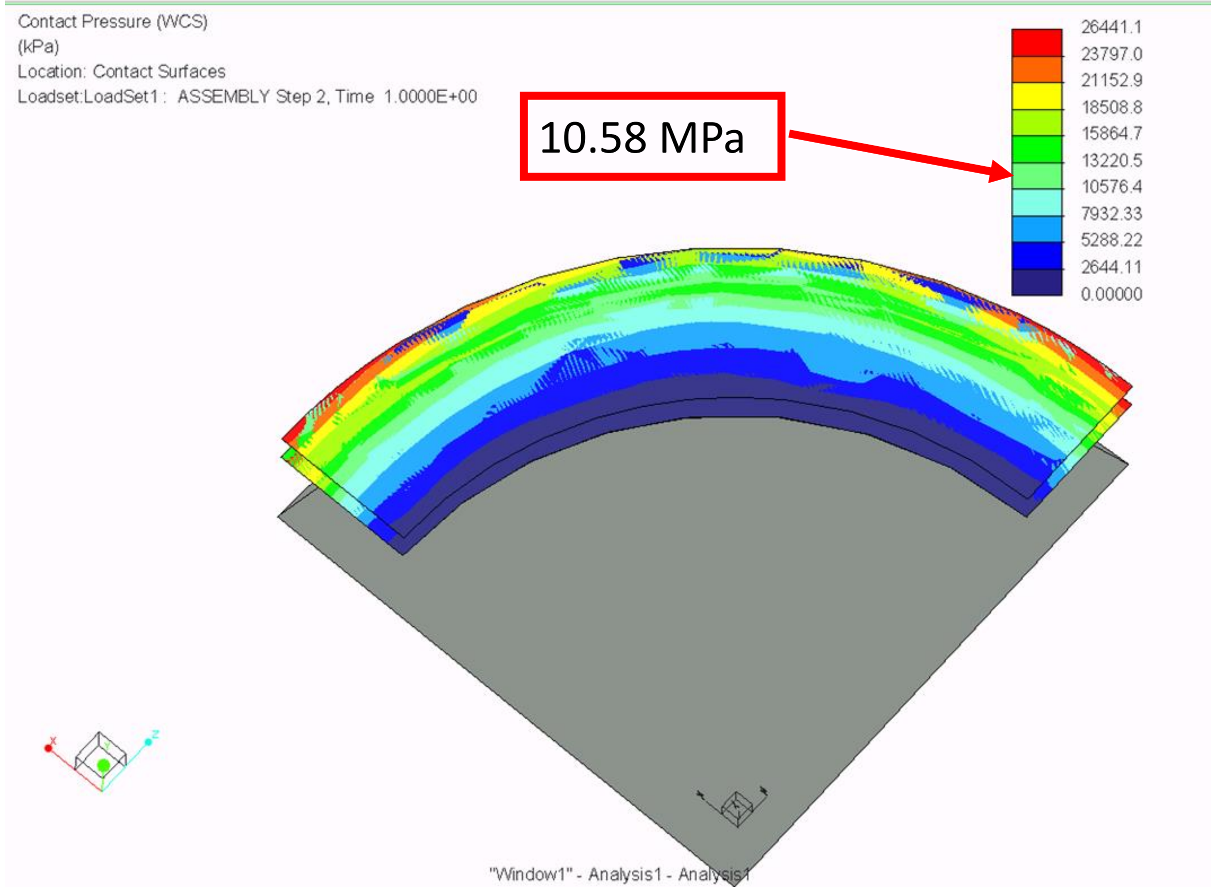
Ranking Scale: 1-6; 1 = Low 6 = High

Gasket Pressure Distribution FEA

- Needed to confirm four bolts was suitable for design

Desired Gasket Clamping Pressure (MPa)	Calculated Required Bolt Load (kN)
0.5	0.255
2	1.020
10	5.100

- Results confirmed that the use of four bolts was sufficient
  - Gasket face never had a path of less than desired clamping pressure



10.58 MPa

Figure 5. FEA of the pressure distribution along the gasket due to the bolt load of 5.1 kN (10 MPa clamping pressure)

Material Thickness Verification

- Minimum bottom flange thickness
  - Material chosen: A36 Steel
  - Green section: internal stress limited ($\sigma_{\text{max internal}}$ = 2.5 psi)
  - Blue section: clamping bolt pressure ($\sigma_{\text{max bolt}}$ = 10 MPa)

Section	**Minimum Thickness (mm)**
Internal	0.31
Bolt	4.94
Overall Bottom Flange	4.94

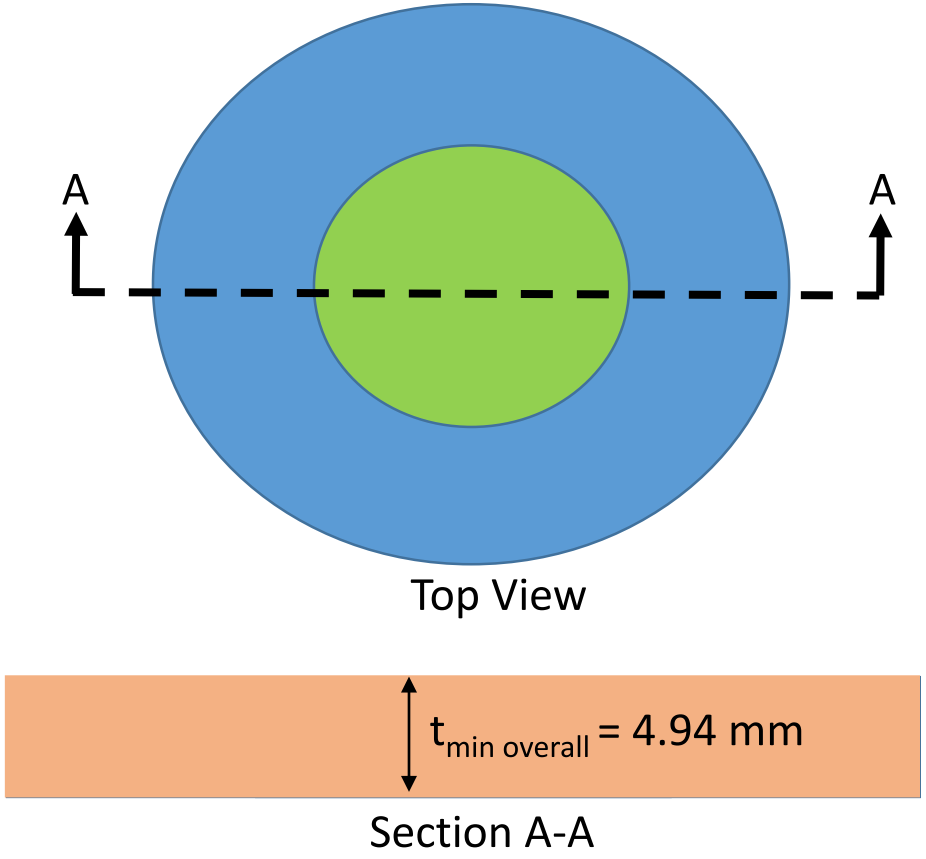


Figure 6. Bottom removable flange

Material Thickness

$\sigma_{clamping} := 10MPa$

$\sigma_{vessel} := 2.5psi = 0.017 \cdot MPa$

$ID := 50mm$

$OD := 150mm$

$D_{gasket} := 75mm$

$A_{vessel} := \pi \cdot \left(\frac{ID}{2}\right)^2 = 2.376 \times 10^{-3} \cdot m^2$

A36 Steel

$nu_{steel} := 0.26$

$A_{flange} := \pi \cdot \left[\left(\frac{OD}{2}\right)^2 - \left(\frac{ID}{2}\right)^2\right] = 0.015\,m^2$

$\sigma_{failuresteel} := 322.5MPa$

$density_{steel} := 7.85 \cdot 10^6 \frac{gm}{m^3}$

$P_{atm} := 14.696psi = 0.101 \cdot MPa$

$\Delta P_{vessel} := P_{atm} - \sigma_{vessel} = 0.084 \cdot MPa$

$\Delta P_{flange} := \sigma_{clamping} - (P_{atm}) = 9.899 \cdot MPa$

A36 Steel

$$m_{vesselsteel} := \left[\frac{3 \cdot (1 + nu_{steel}) \cdot \Delta P_{vessel} \cdot \left(\frac{ID}{2}\right)^6 \cdot \pi^2}{8}\right]^{\frac{1}{2}} \cdot \left(\frac{density_{steel}}{\sigma_{failuresteel}^{\frac{1}{2}}}\right) = 5.693 \times 10^{-3}\,kg$$

$m_{vesselsteel} = 5.693 \times 10^{-3}\,kg$

$$t_{vesselsteel} := \frac{m_{vesselsteel}}{density_{steel} \cdot A_{vessel}}$$

$\boxed{t_{vesselsteel} = 0.305 \cdot mm}$

$$\sigma_{failuresteel} = \frac{3 \cdot (3 + nu_{steel}) \cdot \Delta P_{flange}}{8 \cdot t_{flange}^2}$$

$m_{flangesteel} = density_{steel} \cdot A_{flange} \cdot t_{flangesteel}$

$$m_{flangesteel} := \left[\frac{3 \cdot (3 + nu_{steel}) \cdot \Delta P_{flange} \cdot \left[\left(\frac{D_{gasket}}{2}\right)^2 - \left(\frac{ID}{2}\right)^2\right] \cdot \pi^2}{8}\right]^{\frac{1}{2}} \cdot \left[\frac{density_{steel}}{(\sigma_{failuresteel})^{\frac{1}{2}}}\right] \cdot \left[\left(\frac{OD}{2}\right)^2 - \left(\frac{ID}{2}\right)^2\right] = 0.593\,kg$$

$m_{flangesteel} = 0.593\,kg$

$$t_{flangesteel} := \frac{m_{flangesteel}}{density_{steel} \cdot A_{flange}}$$

$\boxed{t_{flangesteel} = 4.939 \cdot mm}$