Determining the Effectiveness of Oleophobic Gaskets

Final Presentation

Sponsor: Cummins Inc.

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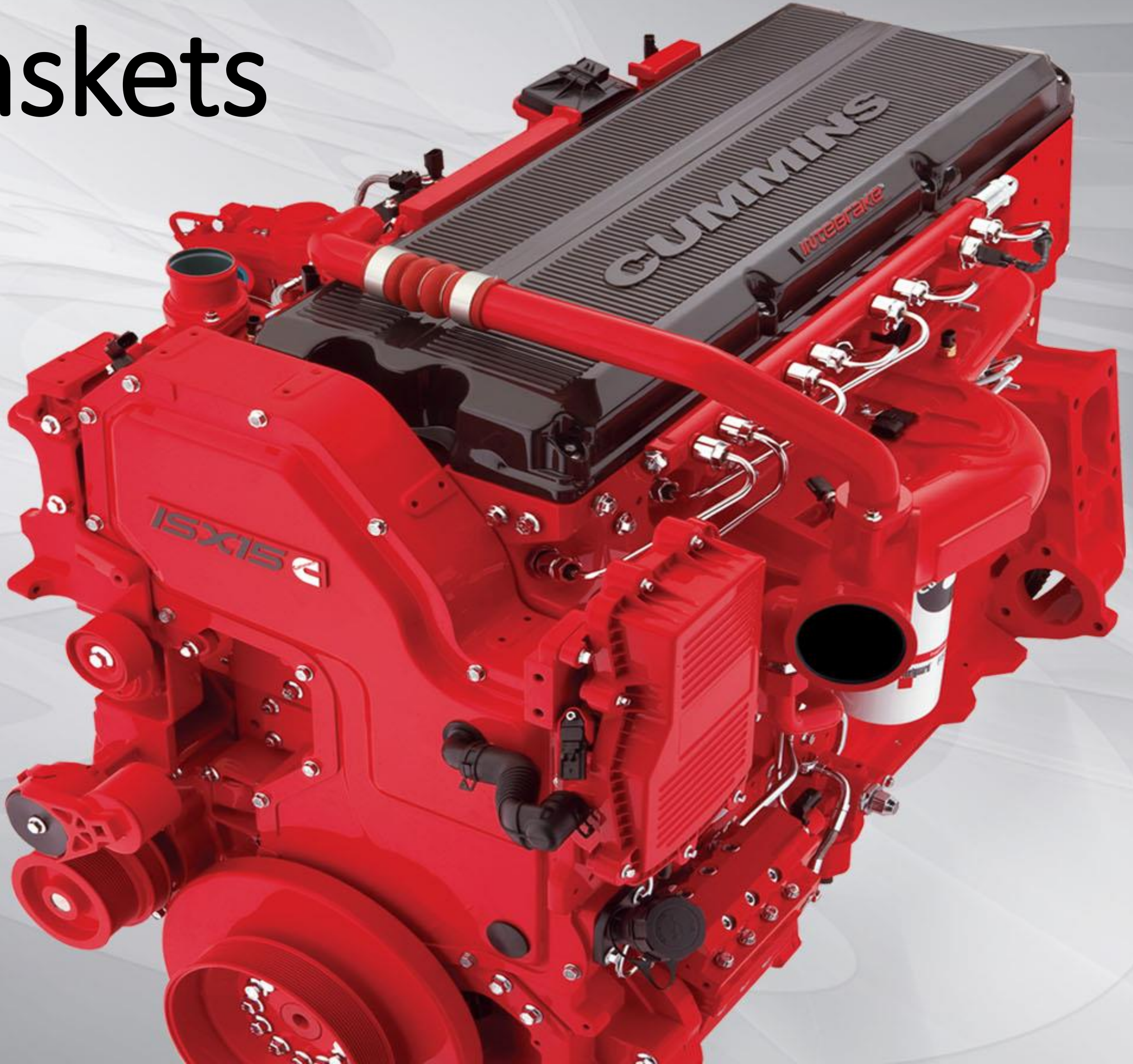
Date: 4/14/2016



Agenda

- Project Background/Definition
- Test Rig Conceptual Design
- Design Analysis
- Final Design
- Preliminary Oleophobic Gasket Testing
- Design of Experiment
- Results
- Procurement
- Summary

Presenter: Norris McMahon

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

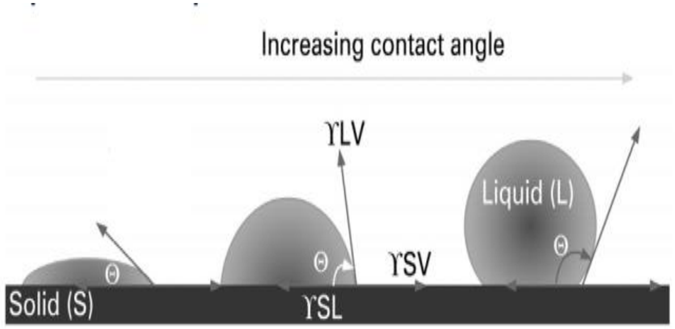


Figure 1. Substance beads up with a high contact angle[1]

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
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

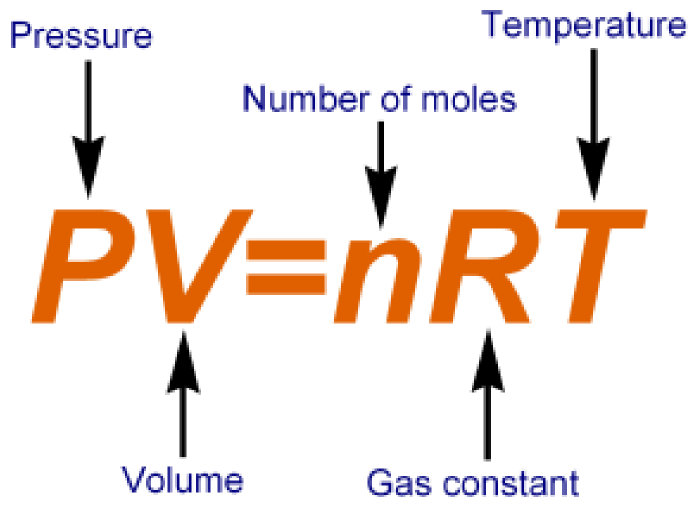
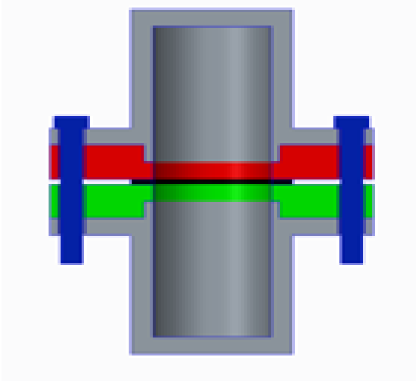
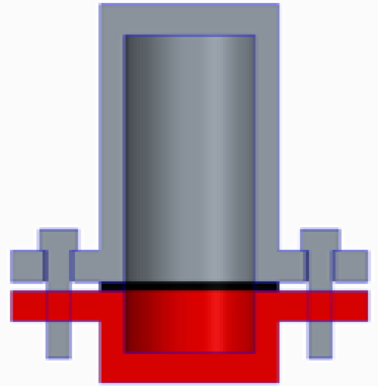
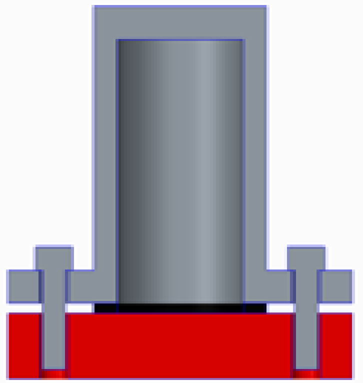
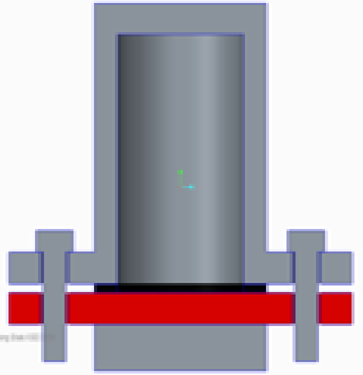


Figure 3. Ideal gas law[3]

Presenter: Norris McMahon

Test Rig Concept Selection

			NPT Threaded Removable Flanges			
	Weight	#1	#2	#3	#4	#5
Number of Leak Paths	0.25	0	0.3	1.3	2.0	2.0
Ease of Assembly	0.1	0	-0.3	1.0	1.3	1.0
Machinability	0.1	0	-0.7	1.3	1.7	1.7
Temperature Variation	0.2	0	0.0	0.3	0.7	1.0
Pressure Variation	0.2	0	0.0	0.0	0.3	0.7
Durability	0.1	0	-0.3	1.0	0.0	1.0
Cost	0.05	0	-0.3	1.0	1.3	1.7
Total	1	0	-0.1	0.8	1.1	1.3
Rank		4	5	3	2	1

FMEA Table

Component	Mode Of Failure	Cause	Probability	Effect	Severity	Recommended Action
Flanges	Bending	Excessive Load	4	Increase in leak rate	2	Monitor Bolt Load
	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	0.25
2	1.02
10	5.01

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

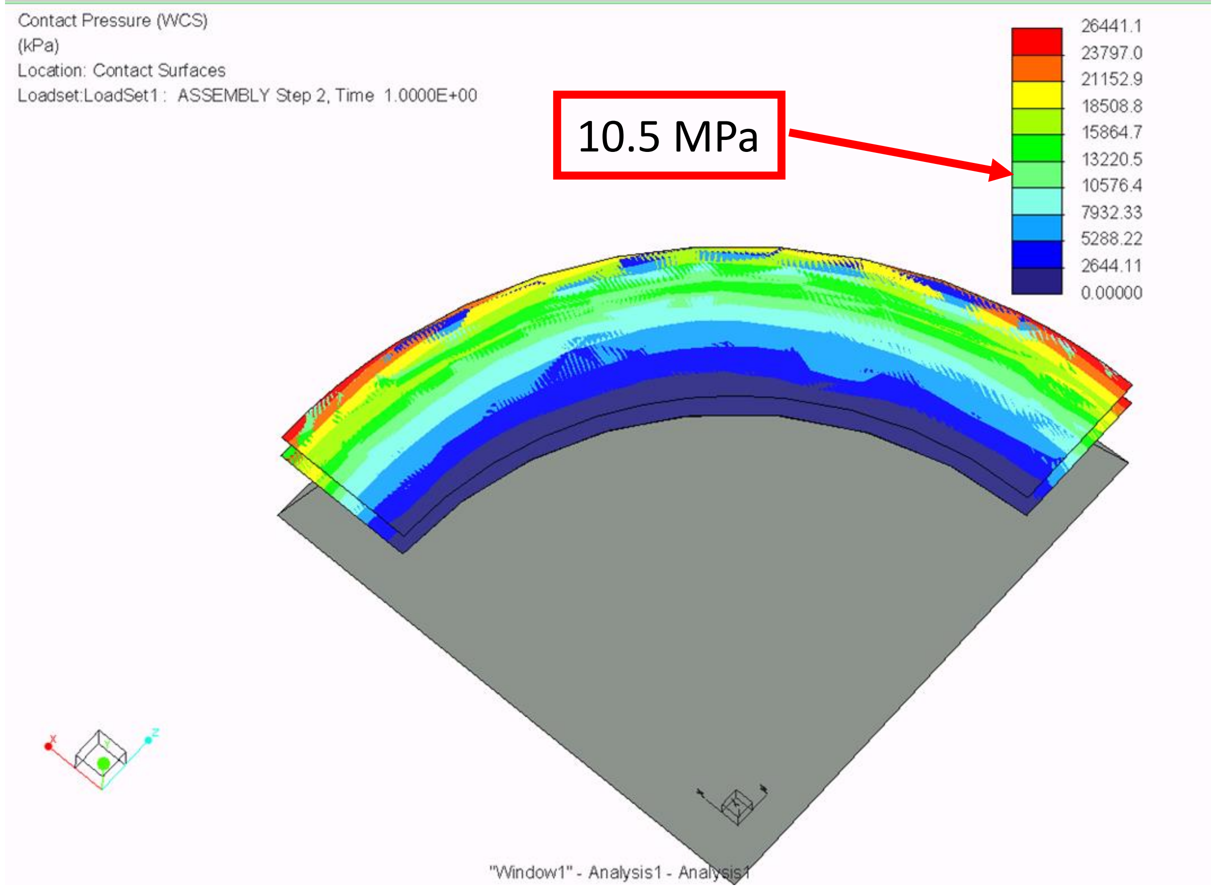


Figure 4. FEA of the pressure distribution along the gasket due to the bolt load of 5.01 kN (10 MPa clamping pressure)

Material Thickness Verification

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

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

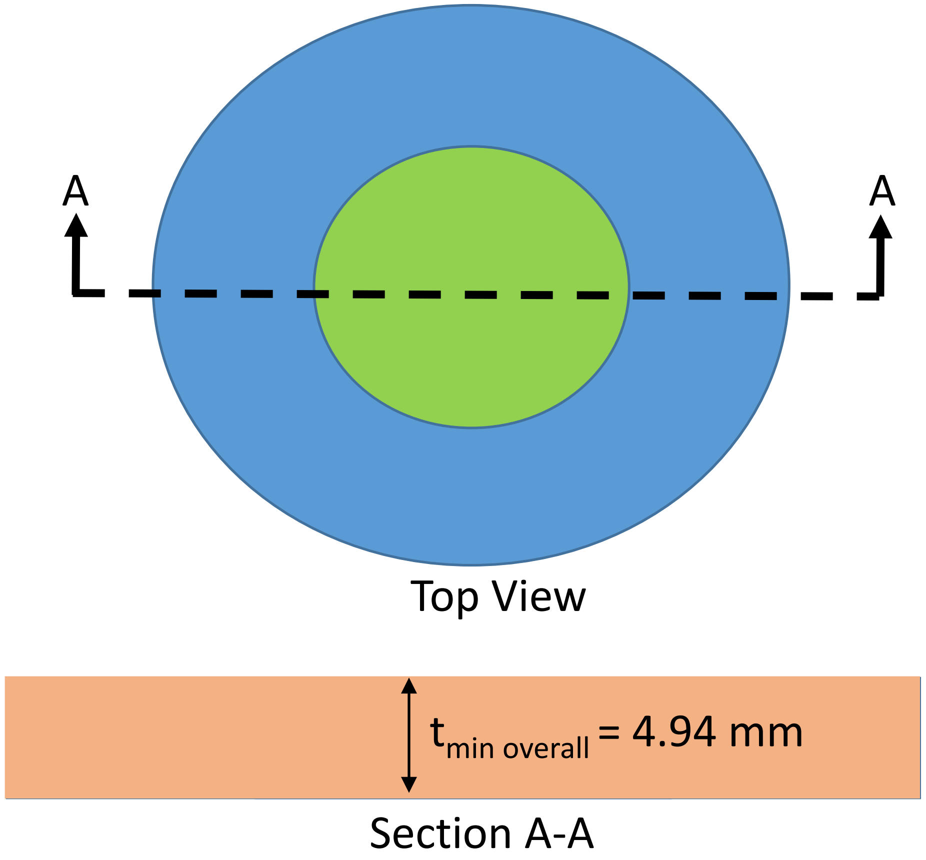


Figure 5. Bottom removable flange

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
  - Resolution: Dependent on DAQ
    - Used in further leak measurement calculations

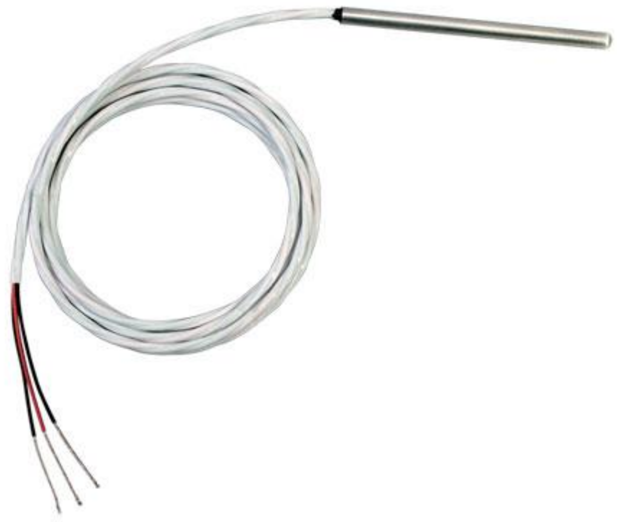


Figure 6. Short RTD probe (PR-20-2-100-3/16-2-E-T)[4]

Figure 7. Pressure Transducer (XT-123B-190-5G)[5]

Measuring Clamping Pressure

- Needed a method to accurately measure clamping pressure via bolt load
- Decided to use strain gauges on the bolts
- Cummins Inc. agreed to install and calibrate the strain gauges within the bolts
  - Requirements:
    - M10 Bolts
    - At least 2” before thread engagement

Figure 8. Modified strain gauge bolt

Pressure Relief Valve

- Pressure Relief Valve preset at 2.5 psi
  - Allows for consistent initial pressure for testing
  - Prevents over pressurizing the pressure transducer

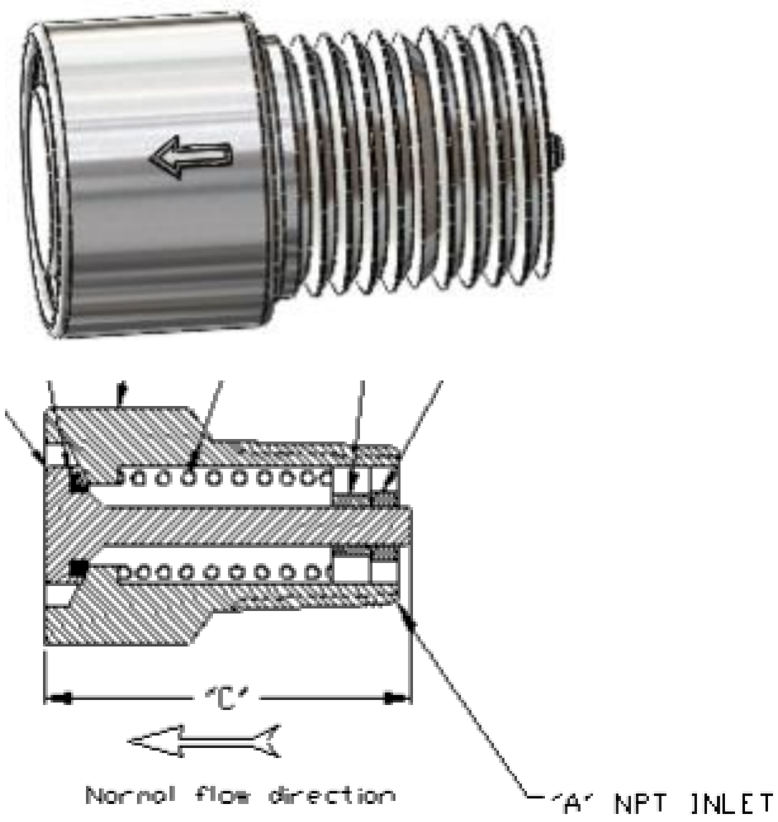


Figure 9. Straval 1/8" Rva05-01T Pressure Relief Valve

Test Rig Final Design

- Oil inlet valve and pressure relief valve on top surface
- RTD temperature sensor, pressure transducer, and air valve are mounted to the side face
- Bottom flange (red) will be removable
- Four M10 bolts with strain gauges used to create a clamping load on the gasket

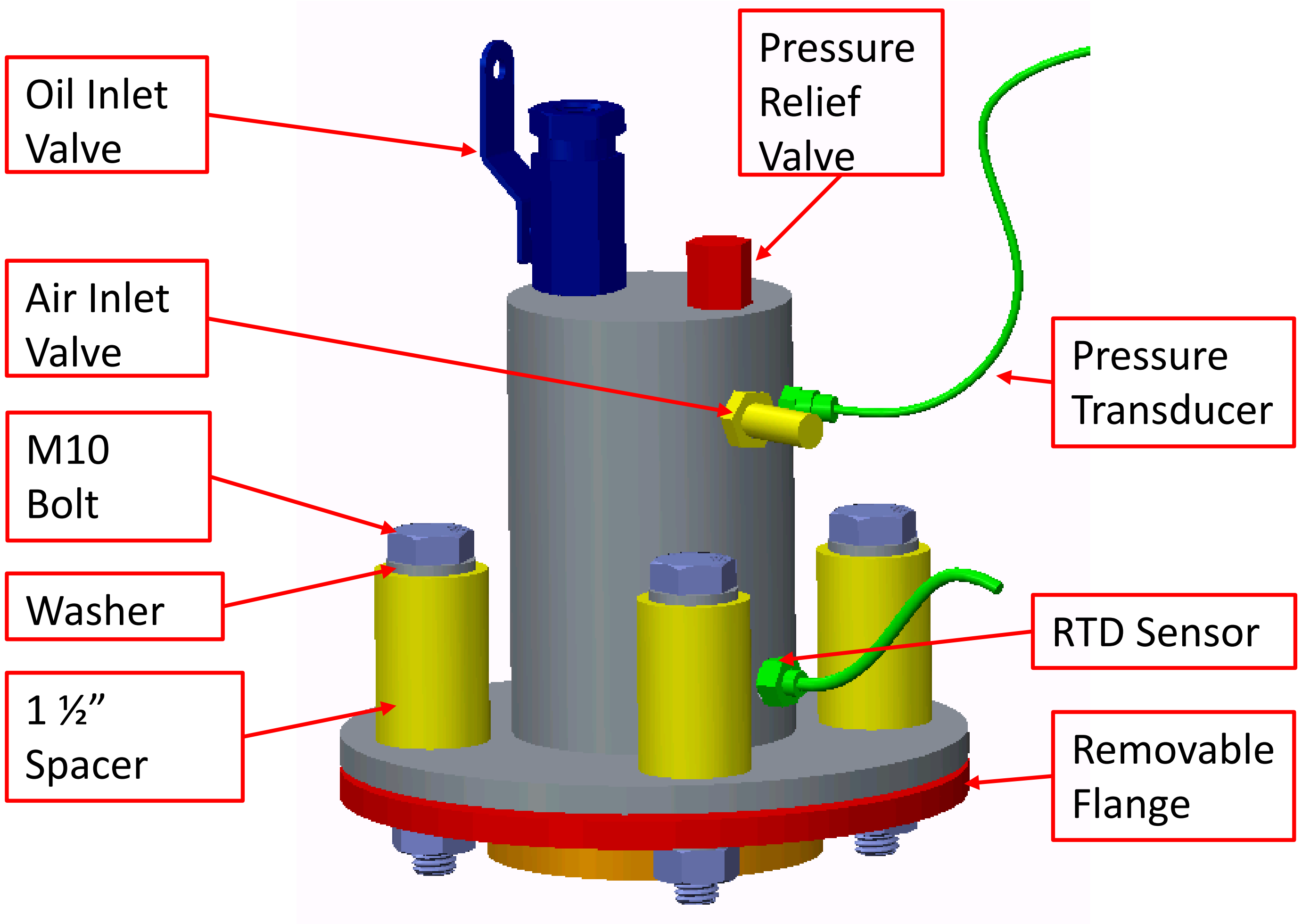


Figure 10. Final Test Rig Concept

Presenter: Erik Spilling

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)

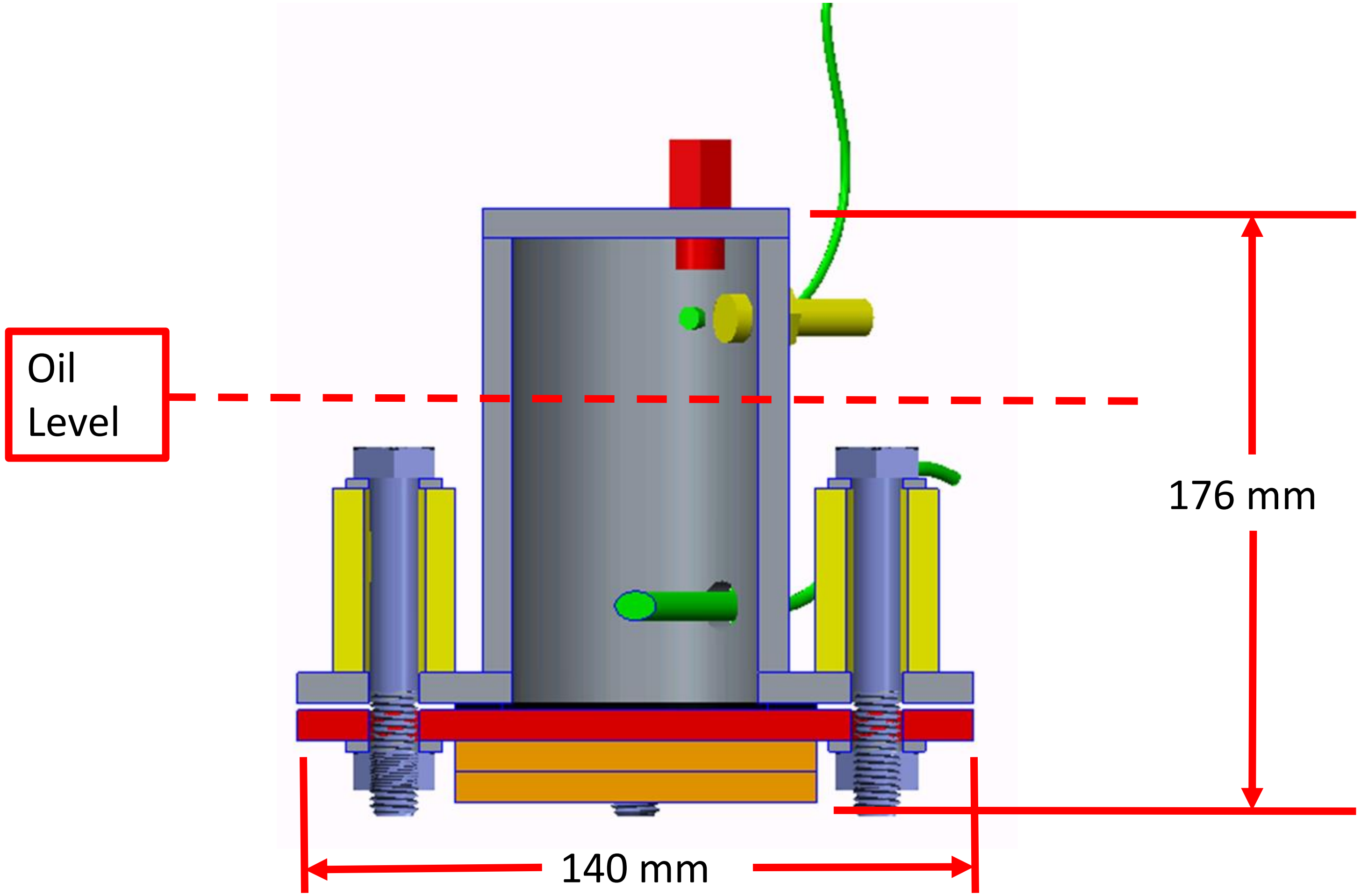


Figure 11. Internal Configuration of the Test Rig

Fabricated Components

- Test rig had to be resent to the COE Machine Shop to fix a welding issue
  - No delay in the schedule
- Cummins Inc. requires less than 3.2 microns RA surface roughness
- Coherix -- ShaPix S150 Sensor
  - HPMI – Dr. Hui Wang
  - Mounted on XY gantry system
  - Creates 3-D image of surface

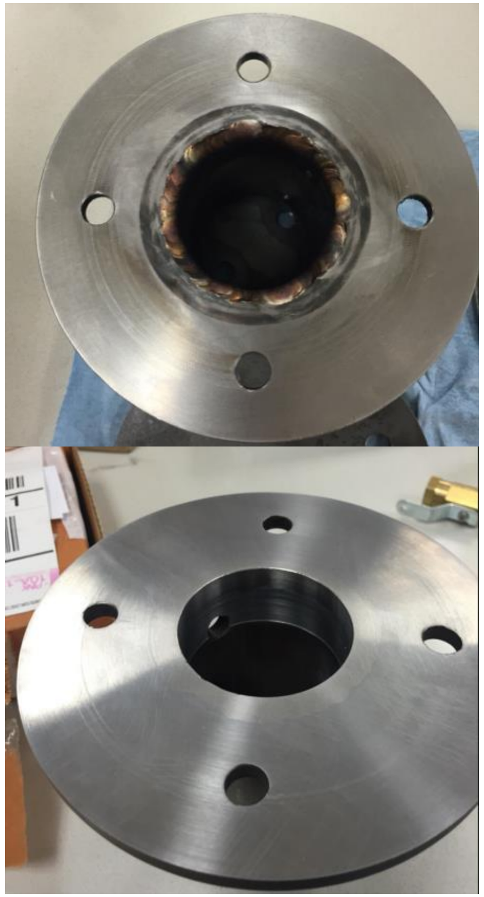


Figure 12. Fabricated top flange from the machine shop

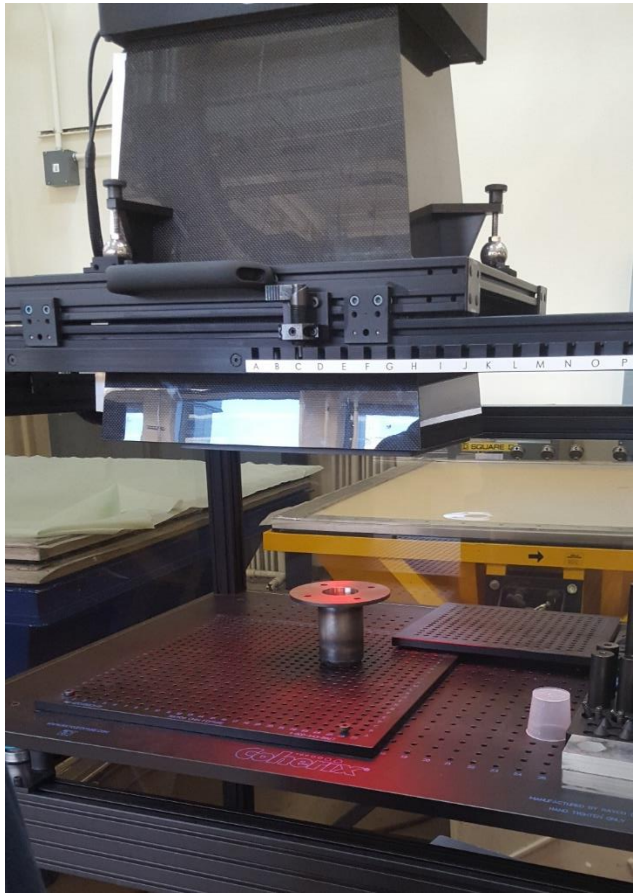


Figure 13. Surface roughness measurement of flange

Surface Roughness Results

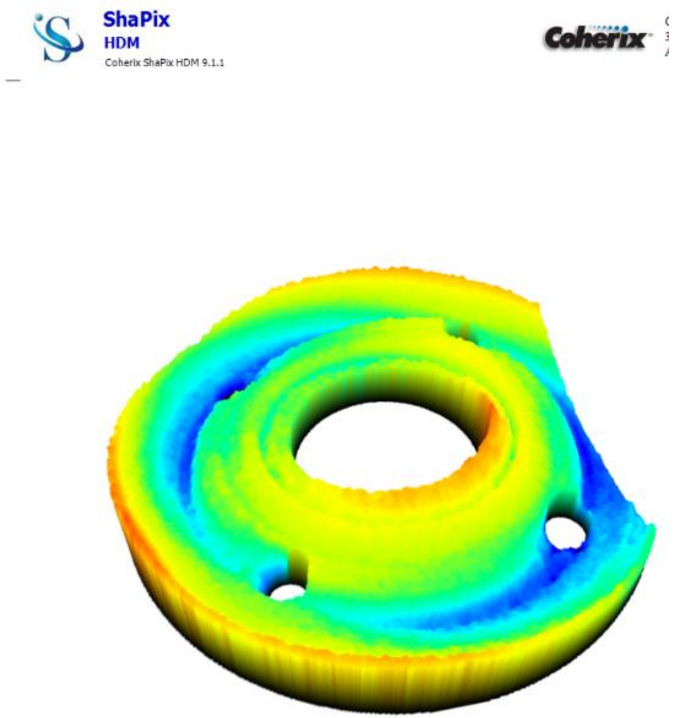


Figure 14. Welded Flange
2.90 microns RA

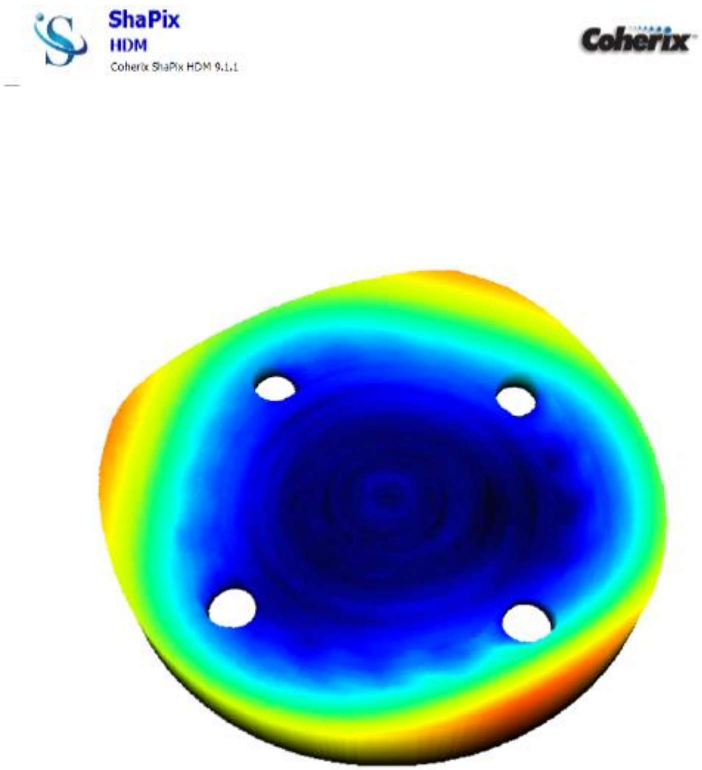


Figure 15. Bottom Flange
2.03 microns RA

Test Rig Assembly

- Test Rig was fabricated at the COE Machine Shop
- Assembly was performed by the design team
- Sensors
  - Calibrated to ensure accurate measurement values
  - Connected to a DAQ system to record the measurements

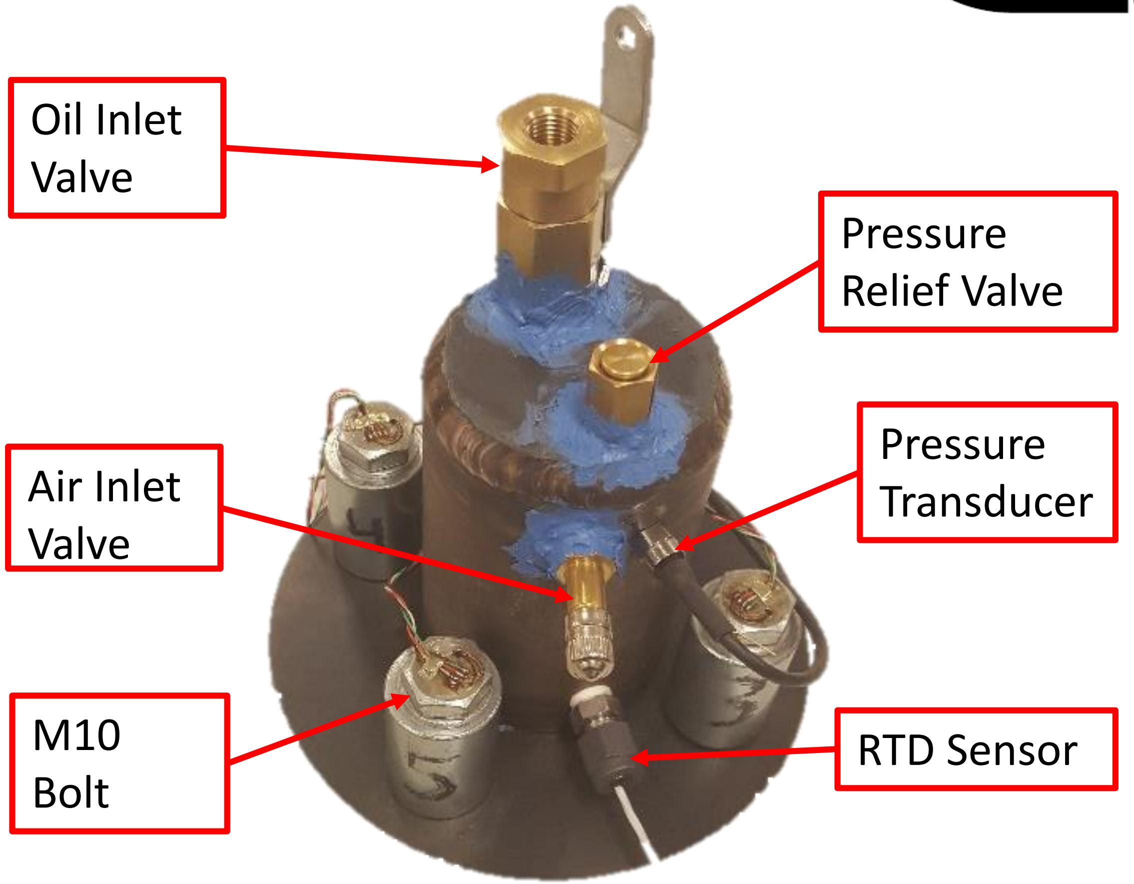


Figure 16. Final test rig assembly

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

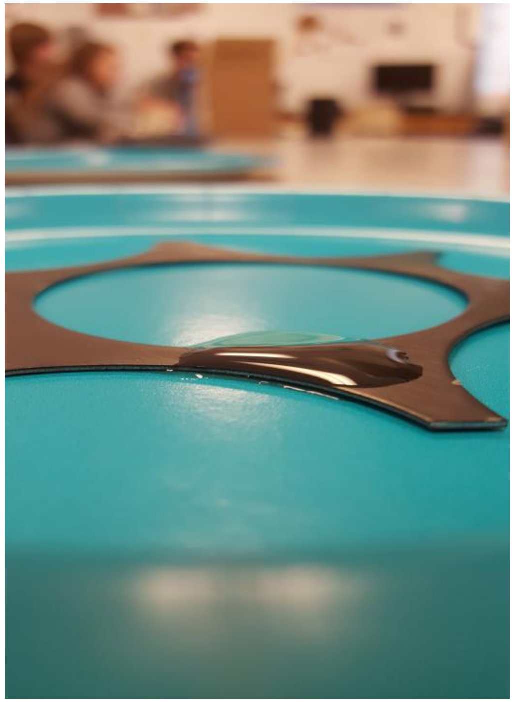


Figure 17. RCM gasket without any solution

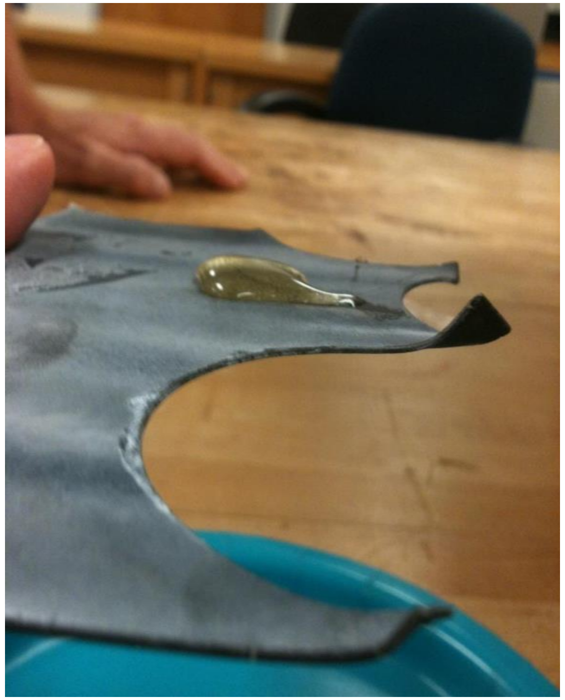


Figure 18. RCM gasket after spray and oil droplet dispersed

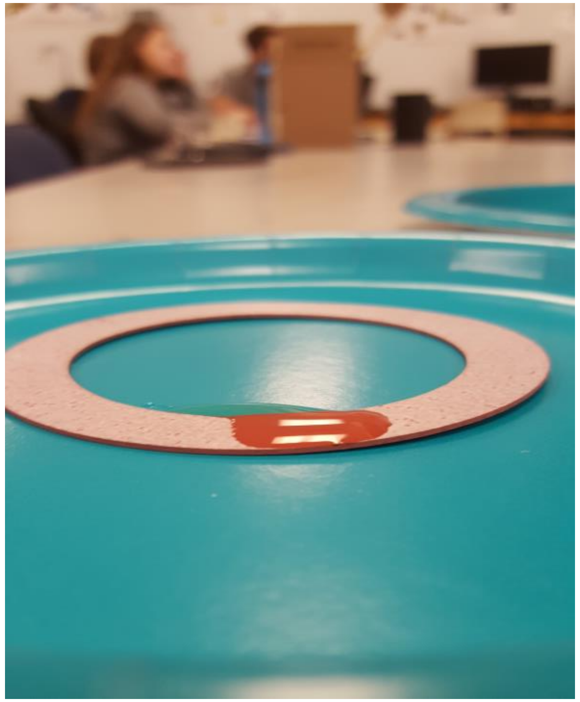


Figure 19. Paper gasket without solution

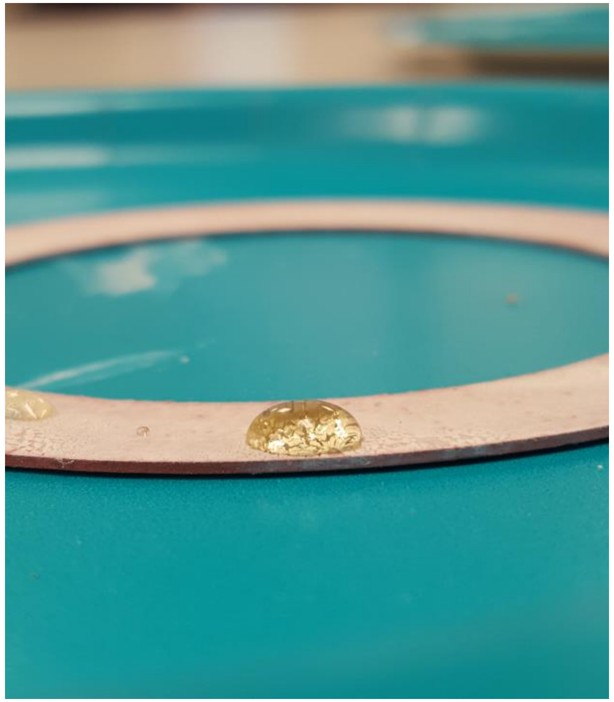


Figure 20. Paper gasket after impregnation and oil droplet dispersed

Baseline Gasket Material Testing

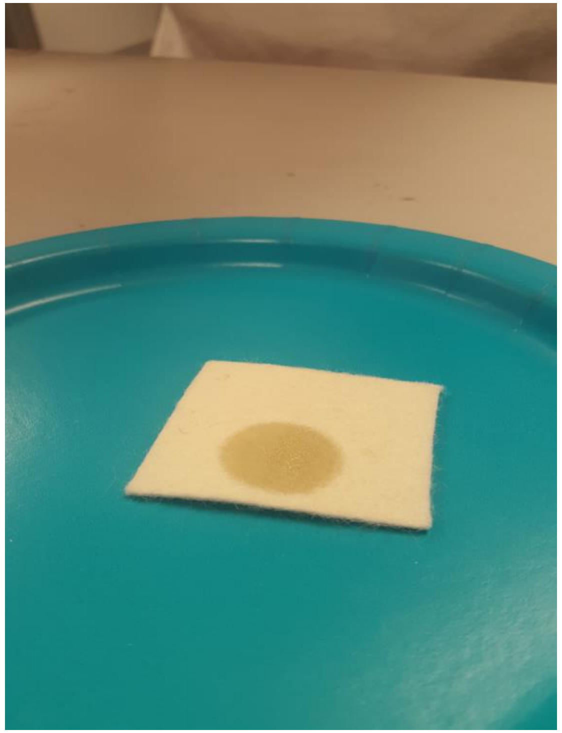


Figure 21. Top view of fiber felt without any solution

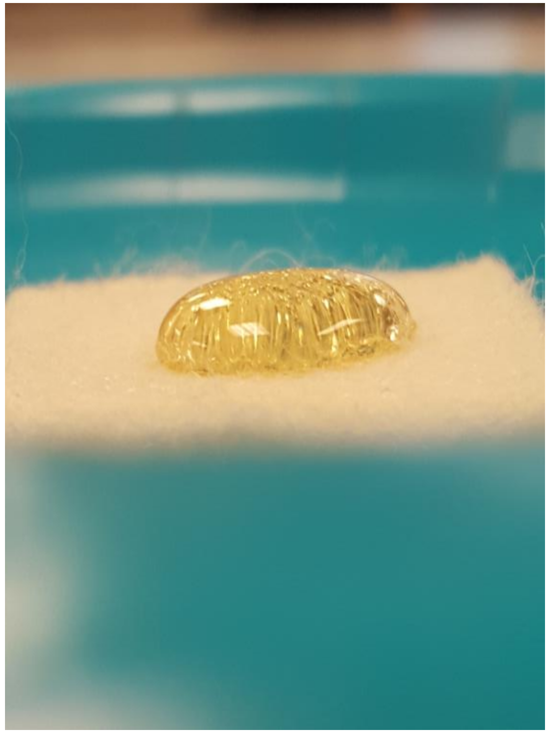


Figure 22. Fiber felt after impregnation and oil droplet dispersed

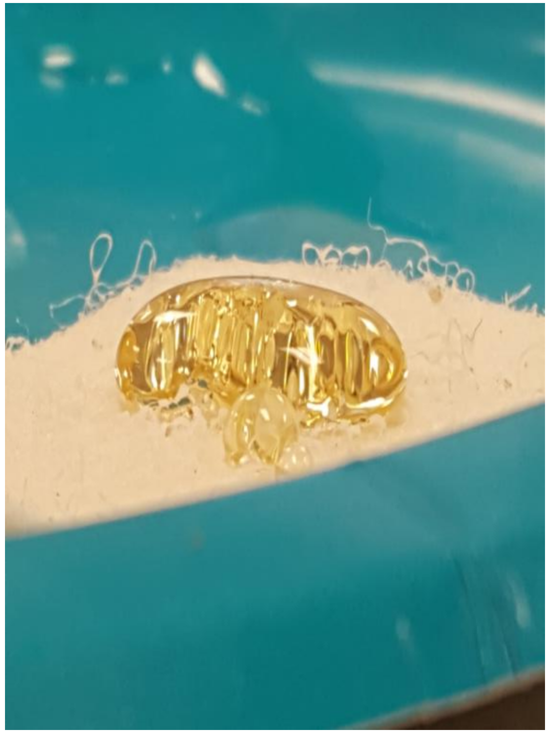


Figure 23. Fiber felt after spray application and oil droplet dispersed

Baseline Gasket Material Testing

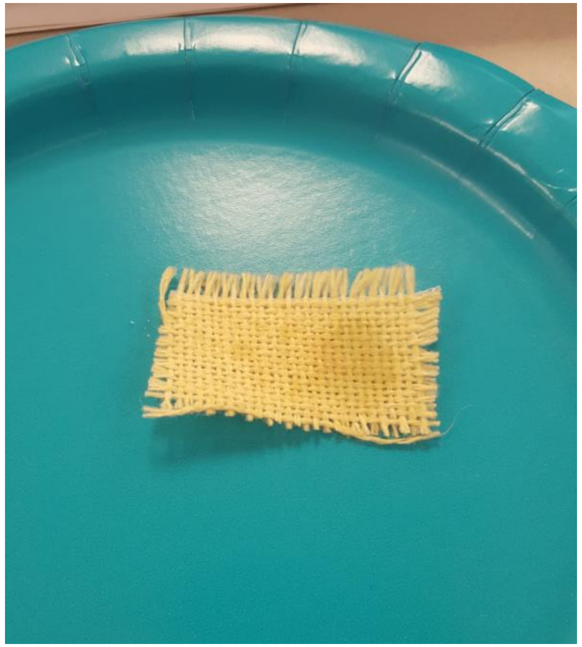


Figure 24. Top view of fiber cloth without solution

Figure 25. Fiber cloth material after impregnation and oil droplet dispersed

Figure 26. Teflon gasket with oil

Figure 27. Teflon gasket after oil removal

Planned Number of Experiments

Gasket Types	
	RCM
	Paper
	Sprayed RCM
	Impregnated Paper
	Felt
	Woven
	Teflon
	Sprayed Flange

	Planned Gaskets
Number of Gasket Types	8
Number of Temperatures	2
Number of Clamping	3
Total Test	48

Temperatures	
	22°C
	120°C

Clamping Loads	
	0.5 MPa
	2 MPa
	10 MPa

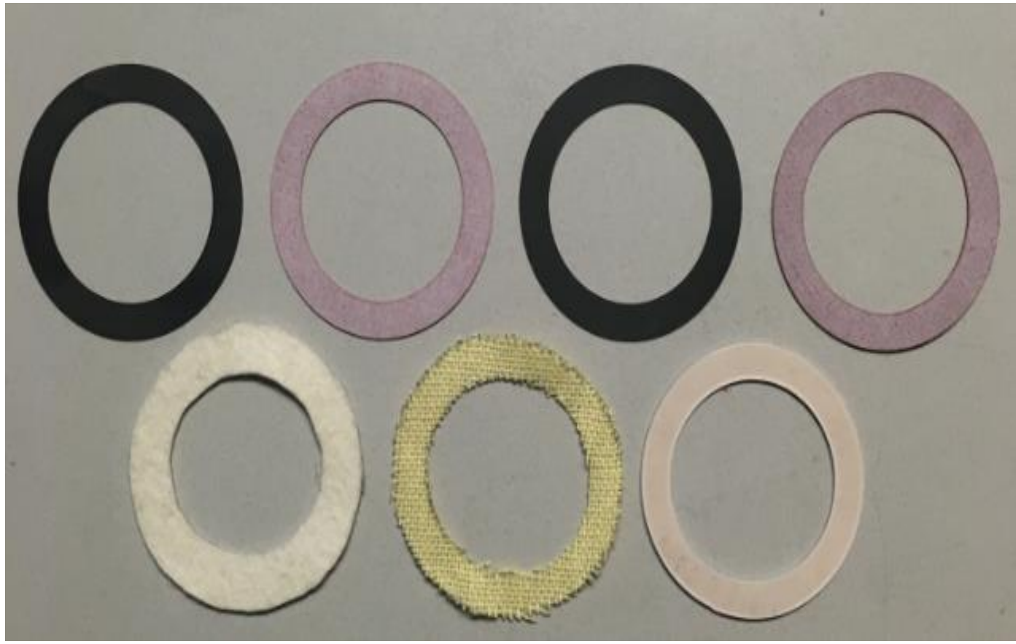
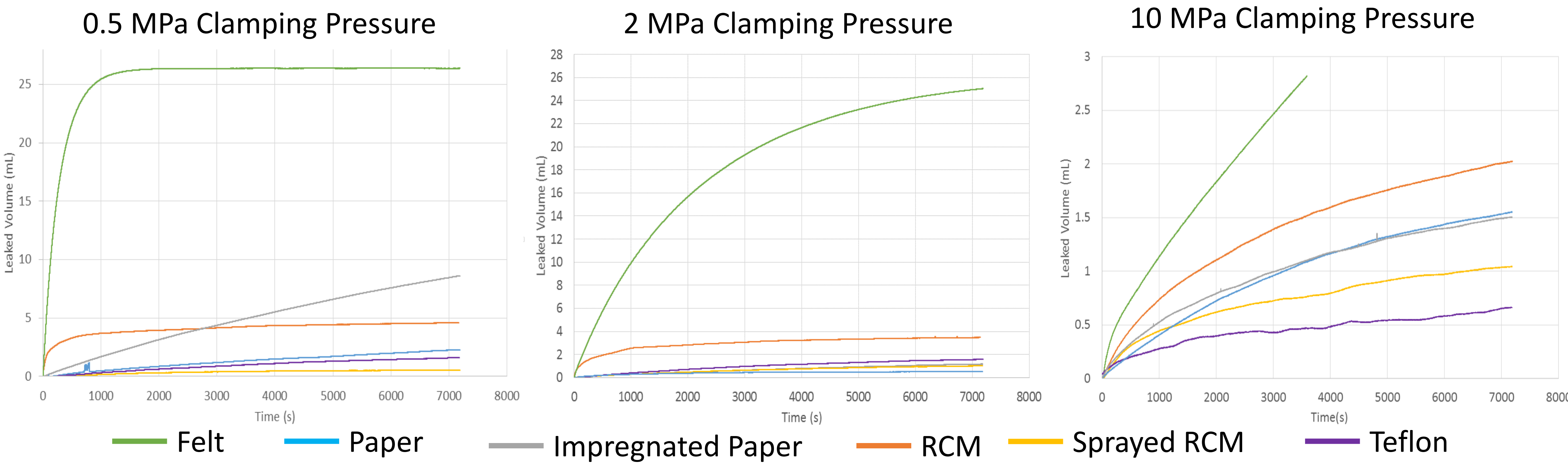


Figure 28. Gasket testing specimens

Overview of Testing Procedure

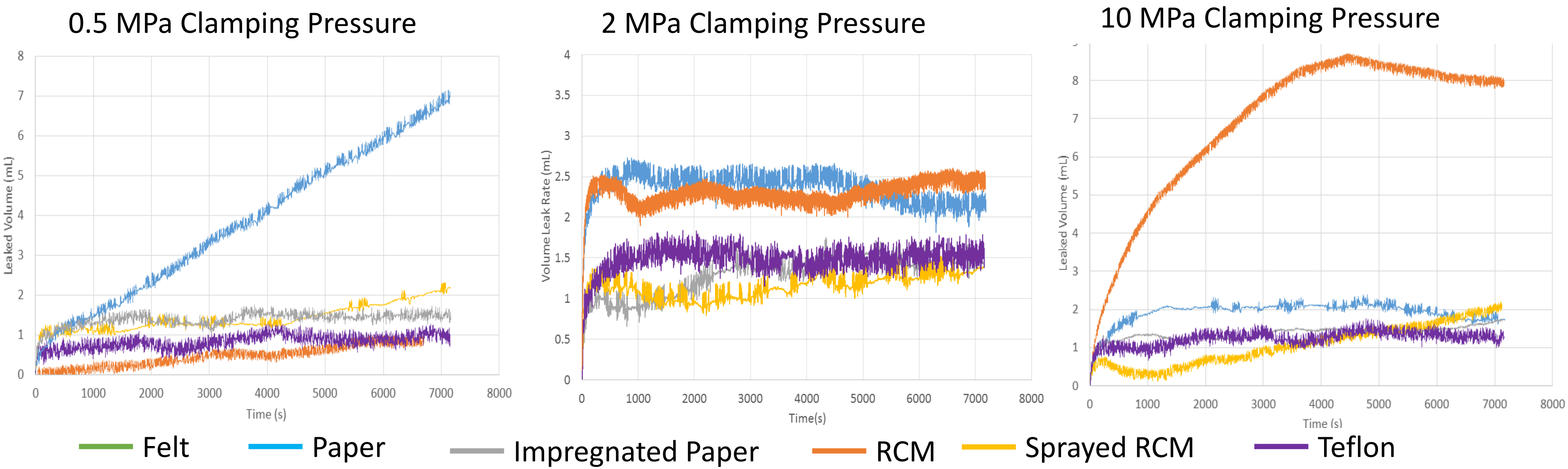
1. Install gaskets and hardware to test rig
2. Tighten bolts to specified bolt load
3. Add oil
4. For hot oil testing, heat the system with the hot plate
5. Pressurize the test rig to 2.5 psi using compressed air
6. Begin collecting data on the DAQ system
7. Upon test completion, remove internal pressure and drain remaining oil
8. Clean the inside of the test rig

Room Temperature (22°C) Results



- Felt gasket failed
- Sprayed RCM gasket outperformed standard RCM gasket
- Standard paper gasket either outperformed or matched performance of impregnated paper gasket
- Teflon gasket performed well relative to the other gaskets

Elevated Temperature (120°C) Results



- Felt gasket not tested due to catastrophic failure at room temperature tests
- Sprayed RCM gasket outperformed standard RCM gasket except at 0.5 MPa clamping pressure
- Impregnated paper gasket outperformed standard paper gasket
- Teflon gasket performed well relative to the other gaskets

Testing Conclusions

- Impregnated paper not a viable gasket due to room temperature failure
- Sprayed RCM is worth investigating further due to its overall success
- Felt gaskets are not viable even with oleophobic solutions
  - Woven gasket never tested
- Teflon gaskets performed well
  - Cost of Teflon makes it unrealistic in mass production
- Sprayed flange failed

Material	Temperature (°C)	Leakage (mL)		
		0.5MPa	2MPa	10MPa
Paper	22	2.28	0.48	1.55
	120	7.12	2.03	1.73
Impregnated Paper	22	8.62	1.18	1.50
	120	1.56	1.46	1.74
RCM	22	4.62	3.48	2.02
	120	0.93	2.31	7.81
Sprayed RCM	22	0.50	1.00	1.05
	120	2.16	1.39	2.05
Teflon	22	1.64	1.58	0.66
	120	1.07	1.45	1.22
Felt	22	26.35	25.03	2.83 (1 hr)

Presenter: David Dawson

Gasket Appearance: Post Testing

- RCM Sprayed Gasket
  - Oleophobic solution wore off once removed from flange
- Impregnated Paper
  - Gasket melted onto the flange during elevated temperature testing

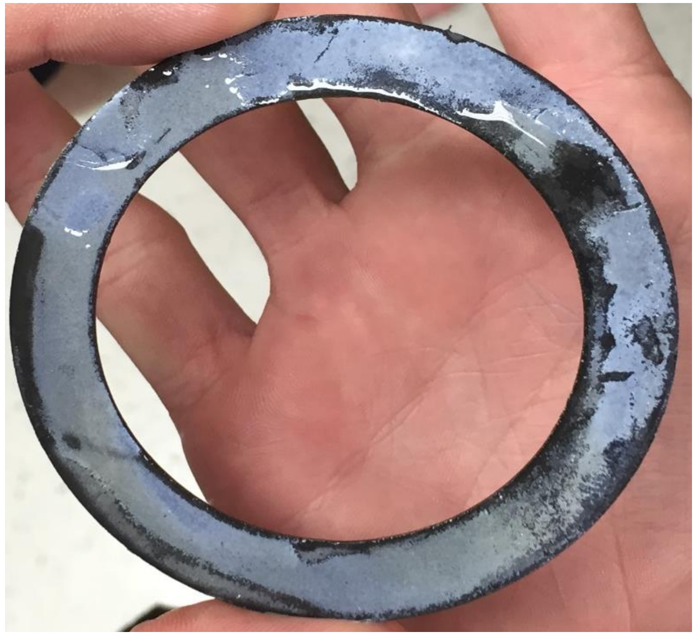


Figure 29. Sprayed RCM Gasket

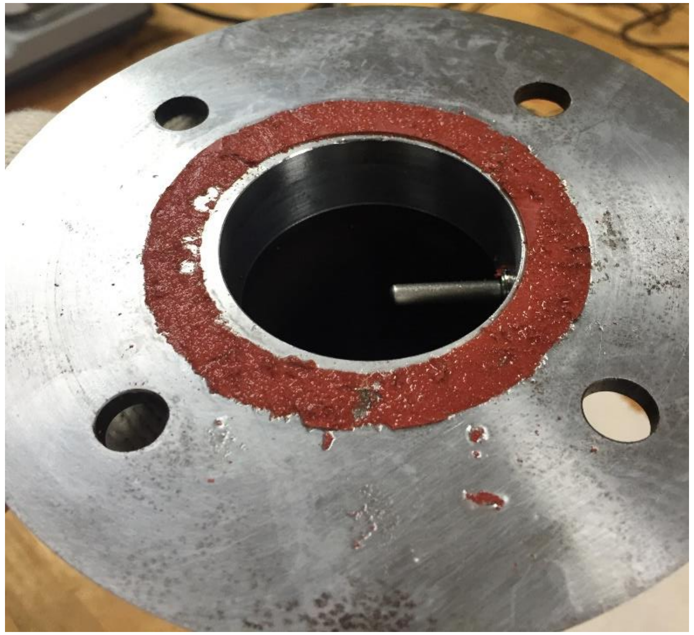
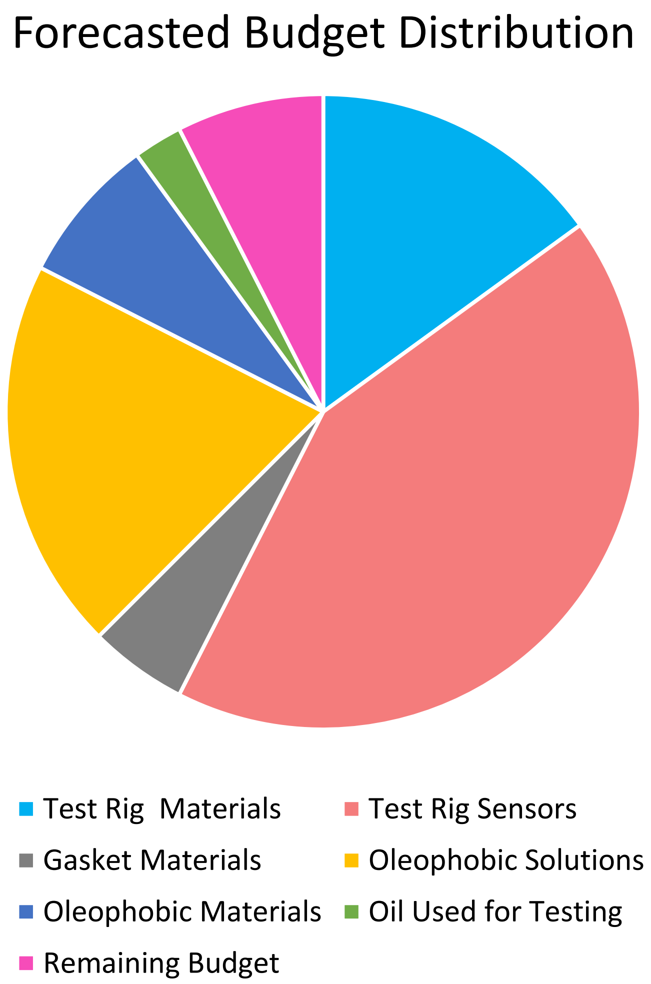


Figure 30. Impregnated Paper Gasket

Budget Forecast

- Budget provided: $2,000.00
- Total estimated cost: $1,850.00
- Total actual cost: $1,245.83

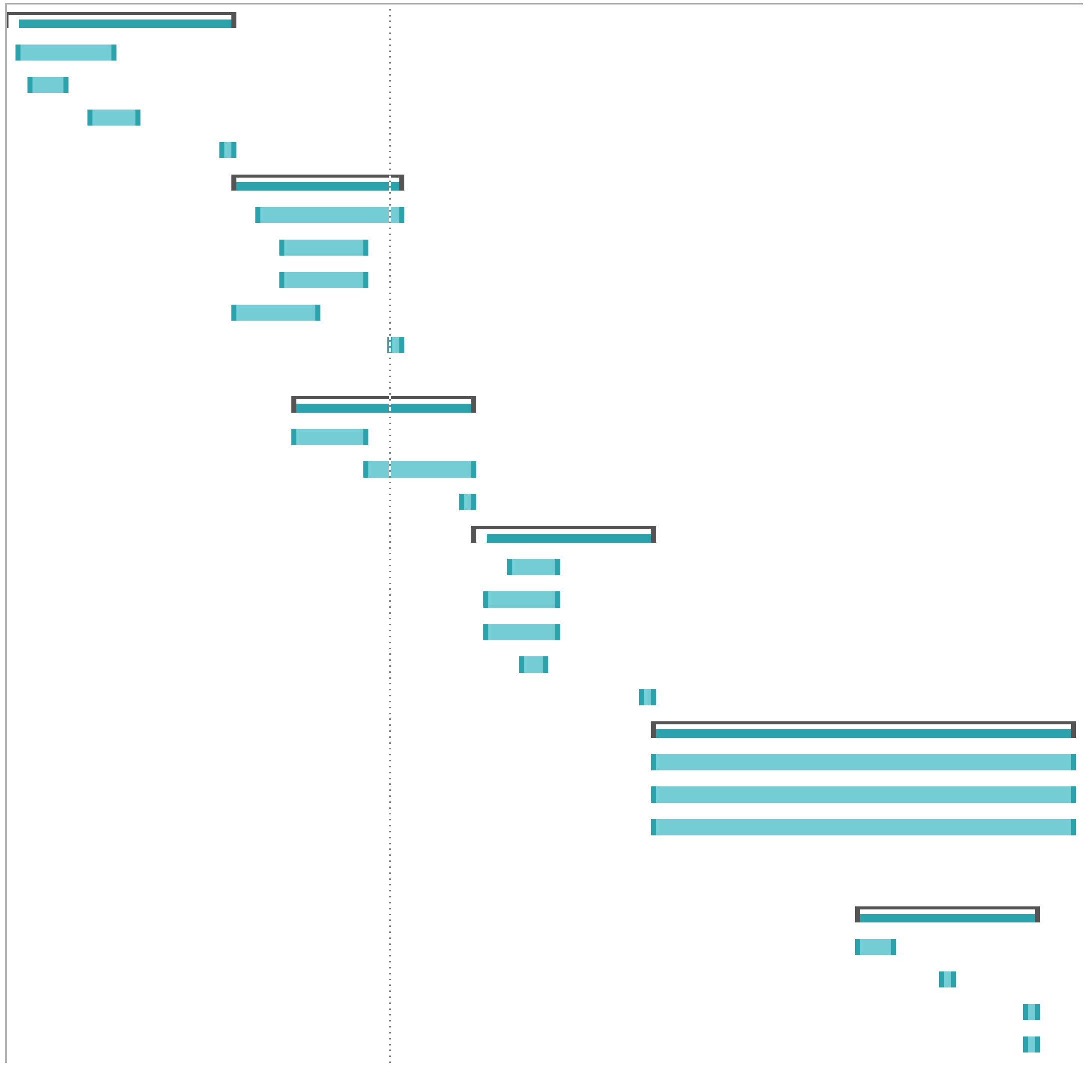
Item	Maximum Estimated Cost	Actual Amount Spent	Percentage Used
Test Rig Materials	$300.00	$258.39	86%
Test Rig Sensors	$850.00	$704.00	83%
Gasket Materials	$100.00	$0.00	0%
Oleophobic Solutions	$400.00	$100.00	25%
Oleophobic Materials	$150.00	$170.00	113%
Oil Used for Testing	$50.00	$13.44	27%
Remaining Budget	$150.00	$754.17	503%



Presenter: David Dawson

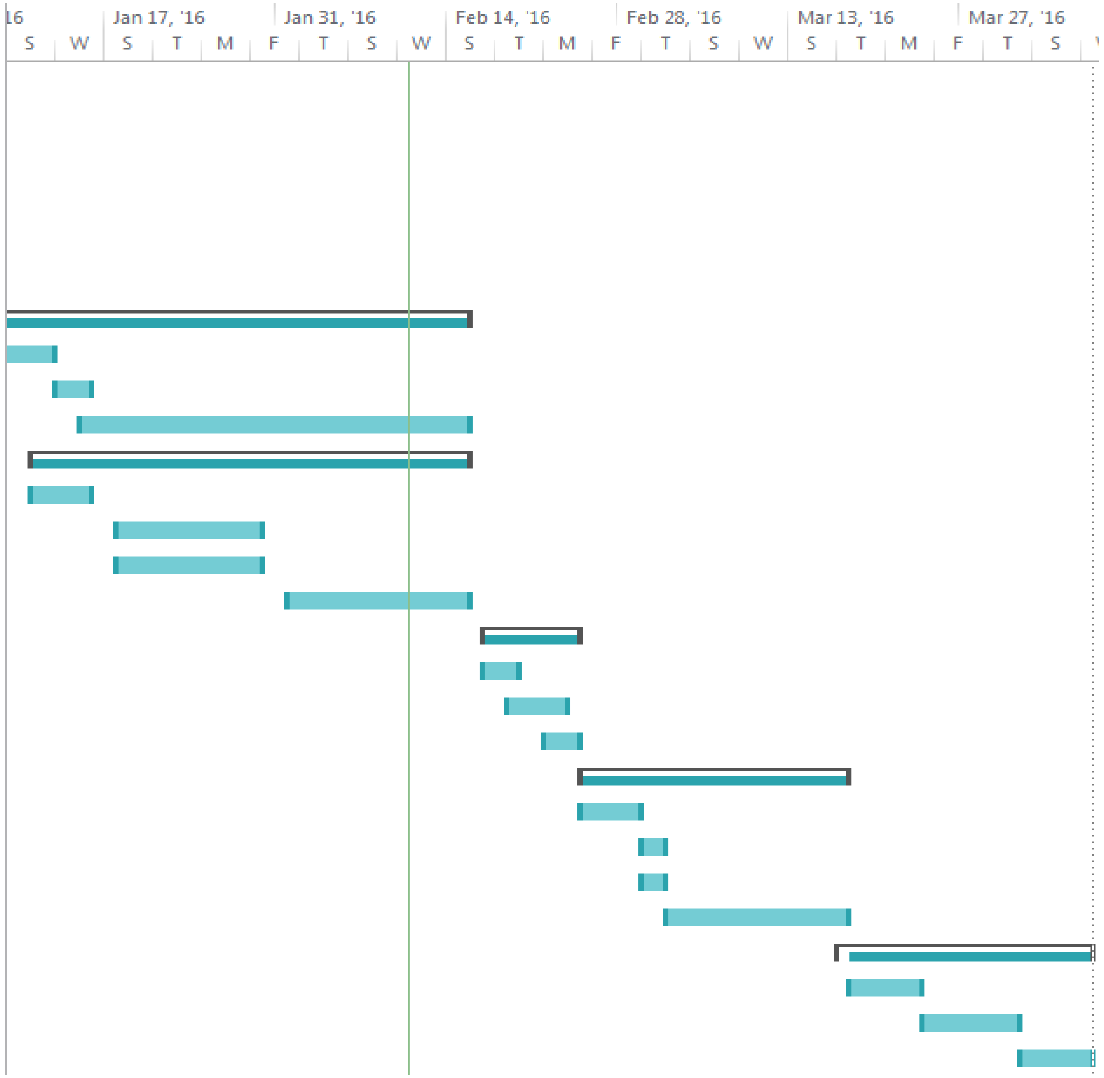
Fall Schedule

Background Research	**Mon 9/7/15**	**Fri 9/25/15**
Oleophobic Solutions	Tue 9/8/15	Tue 9/15/15
Gasket Materials	Wed 9/9/15	Fri 9/11/15
Science of Oleophobicity	Mon 9/14/15	Thu 9/17/15
Needs Assessment	Fri 9/25/15	Fri 9/25/15
Concept Generation	**Sat 9/26/15**	**Fri 10/9/15**
Material Calculations	Mon 9/28/15	Fri 10/9/15
Mathcad Bolt Calculations	Wed 9/30/15	Tue 10/6/15
CAD Drawings	Wed 9/30/15	Tue 10/6/15
Hardware Research	Sat 9/26/15	Fri 10/2/15
Project Plans and Product Specifications	Fri 10/9/15	Fri 10/9/15
Web Design	**Thu 10/1/15**	**Thu 10/15/15**
Template Selection	Thu 10/1/15	Tue 10/6/15
Populate Web Page	Wed 10/7/15	Thu 10/15/15
Initial Web Page Design	Thu 10/15/15	Thu 10/15/15
Concept Selection	**Fri 10/16/15**	**Fri 10/30/15**
Final Test Rig Design	Mon 10/19/15	Thu 10/22/15
Hardware Selection	Sat 10/17/15	Thu 10/22/15
Sealing Solution Selection	Sat 10/17/15	Thu 10/22/15
Midterm Presentation I	Tue 10/20/15	Wed 10/21/1
Midterm Report I	Fri 10/30/15	Fri 10/30/15
Fall Semester Part Acquisition	**Sat 10/31/15**	**Fri 12/4/15**
Test Rig Material	Sat 10/31/15	Fri 12/4/15
Hardware	Sat 10/31/15	Fri 12/4/15
Sealing Solutions	Sat 10/31/15	Fri 12/4/15
Final Design Requirements	**Tue 11/17/15**	**Tue 12/1/15**
Midterm Presentation II	Tue 11/17/15	Thu 11/19/15
Final Web Page Design	Tue 11/24/15	Tue 11/24/15
Final Design Poster	Tue 12/1/15	Tue 12/1/15
Final Report	Tue 12/1/15	Tue 12/1/15



Spring 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 impregnator solution	Mon 1/18/16	Fri 1/29/16
39	Gasket quality 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



Future Work

- Perform multiple trials of current testing conditions to verify results
- Investigate the longevity of current spray oleophobic solution to abrasion
- Research other oleophobic solutions on the market

Lessons Learned

- Sticking to the project schedule is the key to success
- Identifying effective communication techniques early on is important
- Testing doesn’t always go as smoothly as expected
- Be ready to adapt to overcome challenges

Summary

- Goal:
  - Determine the effectiveness of oleophobic gaskets through the use of a designed test rig
- Completed Tasks:
  - Designed/fabricated a gasket test rig
  - Created oleophobic gaskets
  - Tested oleophobic and standard gaskets with the test rig
  - Determined that sprayed RCM gaskets have potential
  - Impregnated paper and felt gaskets were not successful

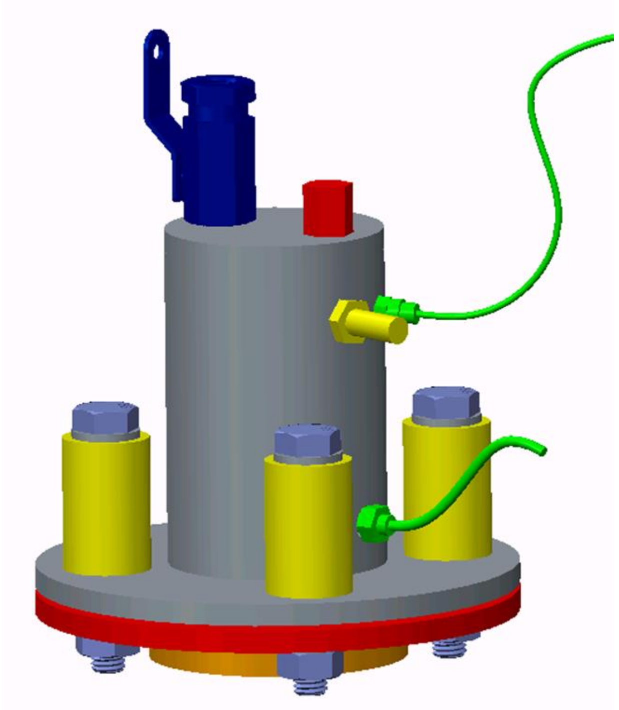


Figure 31. Test Rig Design

References

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

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