Technical

O-ring electrical resistance in wet conditions

By Allan Zhong
and Bryan Philpott
Halliburton Co.

Executive summary

An O-ring's primary function is to restrict the movement of fluid or gas, such as prevention of fluid from leaking from a location, or prevention of fluid communication between locations, or sealing in general.

In some applications, O-rings also play roles in electrical insulation. A simple test is set up to study the electrical resistance across an O-ring seal in a conductive fluid environment: O-rings were positioned underneath a PEEK press-head and squeezed into the bottom of a smooth glass basin. The PEEK press-head had a hole in the bottom to allow it to be filled with water simultaneously with the glass basin.

Several factors are investigated to see their influences on O-ring electrical resistance. The factors include O-ring sizes, O-ring cross-section diameters, O-ring materials and applied force that generate sealing pressures at sealing surfaces. The trend of influence from individual factors is clear, but a comprehensive physical interpretation of all test observations is elusive.

A dimensional analysis-based data analysis technique is used to evaluate the test results, and a master curve for the data is established. The master curve accounted for all four parameters in the physical tests, captured all trends observed simultaneously, and can be used to guide O-ring selection in real applications qualitatively.

An O-ring's primary function is to restrict the movement of fluid or gas, such as prevention of fluid from leaking from a location, or prevention of fluid communication between locations, or sealing in general. In some applications, for example, downhole wet disconnect of electrical circuits (Izetti et al (2014), Schnitzler et al. (2022), O-rings play roles in electrical insulation.

TECHNICAL NOTEBOOK
Edited by John Dick

In this study, we aim to understand the physics of how rubber O-rings can play a role in this type of application, including the effects of O-ring geometric design, material selection and loading on the O-ring influence its insulation capability.

Rubber is an insulator, but in a wet environment, the water films at interfaces between O-ring and sealing surfaces can provide conduit for electricity as illustrated in **Fig. 1**. Our hypothesis is that higher squeeze between O-ring and sealing surfaces will reduce fluid film cross-sectional area, and thus increase the electrical resistance across the O-ring.

A simple test is set up to study the electrical resistance across an O-ring seal in a conductive fluid environment. The paper is organized as following. The test setup is described first in the following section. Several factors are investigated to see their influences on O-ring electrical resistance. The factors include O-ring sizes, O-ring cross-section diameters, O-ring materials and applied force that generate sealing pressures at sealing surfaces.

The experimental measurements are then summarized and analyzed, including using dimensional analysis to analyze the data. It is shown that the parameters we studied interact with each other to determine the electrical resistance.

Experimental setup and method

As shown in **Fig. 2**, the test fixture includes a non-conductive water tank, a scale, a smaller non-conductive container with a hole at the bottom, Arbor-brand press, shunt resistor, oscilloscope and a multimeter.

O-rings were positioned underneath a PEEK press-head and squeezed into the bottom of a smooth glass basin. The squeeze force was varied manually using an Arbor press and monitored by a scale placed under the press. The PEEK press-head had a hole in the bottom to allow it to be filled with water simultaneously with the glass basin. The O-rings were positioned to surround the hole in the press-head such that water transfer would be sealed off between the PEEK press-head ID and the basin.

The only conductive path remaining would be through the water film at the O-ring interfaces with the press-head and the basin. Wires were run to the inner chamber of the press-head and into the basin. Fifty volts was applied across the wires and the electrical current returning to the power supply was measured with an oscilloscope and a multimeter via a shunt resistor (4.065 MΩ).

The main measurement is the electrical resistance across the O-ring under different loads on the O-ring. Different sizes of O-rings were used in the tests to evaluate the effects of O-ring dimensions. The following are the simple formulas for basic calculations with Supply Voltage = V_{total} = 50 V and Shunt Resistance = R_{shunt} = 4.065 MΩ:

$$\text{Leakage Current} = \frac{V_{shunt}}{R_{shunt}} \quad (1)$$

$$\text{Resistance Across Seal} = R_{total} - R_{shnt} = R_{shunt}\left(\frac{V_{total}}{V_{shunt}} - 1\right) \quad (2)$$

Test samples include different sizes of O-rings with different hardness (60, 75 and 90 Duro). We use F for force applied on the O-ring, OD for O-ring average diameter, t for O-ring cross-section thickness. Furthermore, we use C_{10} to represent O-ring rubber modulus, IR (insulation resistance) to represent electrical resistance across the O-ring, and ρ rubber resistivity. Based on dimensional analysis, we have the following general dimensionless relation between the various parameters:

$$z = f(x,y) \quad (3)$$

$$\text{Where } z = \frac{IR\,t}{\rho},\ x = \frac{t}{OD},\ y = \frac{F}{C_{10}OD^2}$$

Test results and analysis—single O-ring

Several sets of tests were conducted to look into: 1) effect of rubber hardness for the same size O-ring; and 2) effect of O-ring size (both thickness and average diameter) for the same hardness rubber.

For each set of tests, we measured the electric resistance change with the applied load. In **Fig. 3**, the results for tests on a single 013 O-ring are shown. Some qualitative trends are obvious: a) higher load leads to higher electrical resistance; and b) 90 duro O-ring has lower resistance, and 60 Duro and 75 Duro O-rings have similar electrical resistance. Similar trends are observed for 018 O-ring with 60, 75 and 90 Duro rubber.

Tests on O-rings of the same hardness but different sizes are shown in **Figs. 4 and 5**. **Fig. 4** showed results for different size 75 Duro O-rings. **Fig. 5** showed results for another size group 75 Duro O-rings.

It seems that larger thickness O-rings have marginally higher electrical resistance. All single O-ring tests results are plotted in **Fig. 6** according to the dimensionless relation (**Equation 3**).

Overall, the electrical resistance surface z=f(x,y) is not monotonic, but we do observe an overall trend of larger x and larger y leading to higher dimensionless resistance.

We can further reduce the data into a one-dimensional relation.

$$z = g(x) \quad (4)$$

$$\text{Where } \tilde{x} = \left(\frac{t}{OD}\right)\left(\frac{F}{C_{10}OD^2}\right)^{0.18}$$

There is a clear trend in the scaled electrical resistance. The larger the $\tilde{x}$, the larger the dimensionless electrical resistance. It seems that there exists a threshold value 0.06 for $\tilde{x}$ When $\tilde{x}$ >0.06, electrical resistance is established. But we also observed large scatter of dimensionless electrical resistance when $\tilde{x}$ in between (0.06, 0.15).

There are two main reasons for these observations: 1) the different parameters, length, hardness and sizes, they interact with each to determine the electrical resistance; and 2) material property scatter, in particular C_{10}, is not captured in the data. There was no measurement of material modulus for test samples in the test program.

From another O-ring related study by Zhong and Glaesman (2020), we know that rubber modulus change, even for one batch of rubber, can scatter a lot. The scatter in the "master curve" is related to modulus variation in rubber materials. If we had real modulus value for each rubber O-ring used at different hardness, we should be able to improve the "tightness" or reduce the scatter of the test data against trendline "master curve," as observed in Zhong and Glaesman (2020).

Test results and analysis—double O-rings

Following the single O-ring

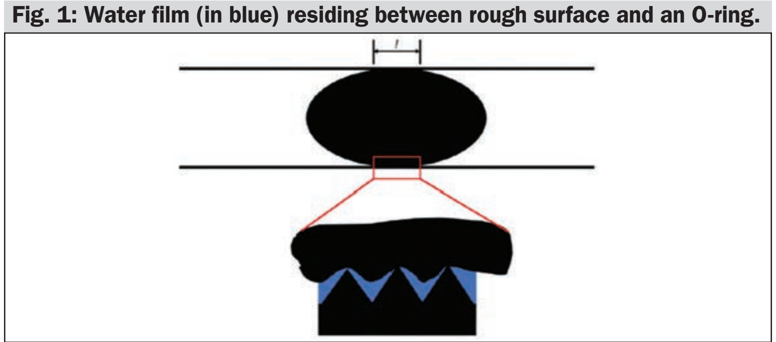


Fig. 1: Water film (in blue) residing between rough surface and an O-ring.

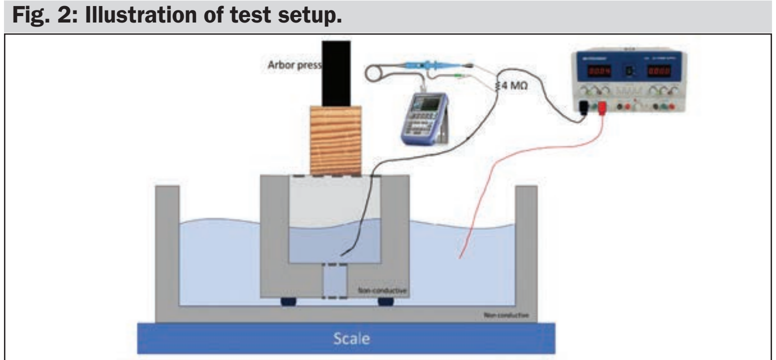


Fig. 2: Illustration of test setup.

Fig. 3: 013 O-ring with 60, 75 and 90 Duro rubber electric resistance change with applied force in water.

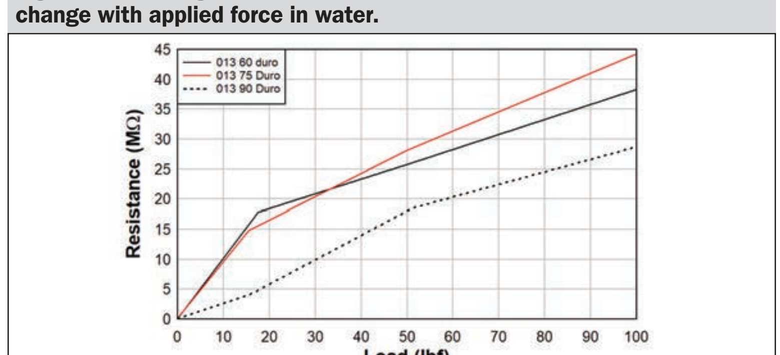
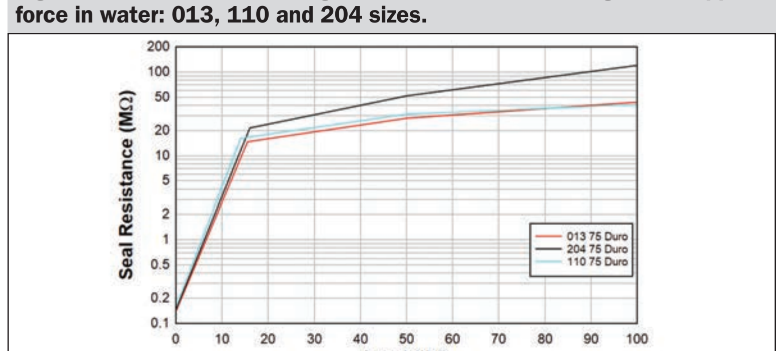


Fig. 4: 75 Duro rubber O-ring electric resistance change with applied force in water: 013, 110 and 204 sizes.



Zhong

Philpott

The authors

Allan Zhong is a Halliburton Co. distinguished scientist with expertise in engineering mechanics and computational modeling. He has 28 years of industry experience. He was granted 22 U.S. patents and published over 80 technical papers.

Prior to Halliburton, Zhong worked at Goodyear, where he developed an industry leading fracture mechanics-based truck tire durability model. He is a fellow of the American Society of Mechanical Engineers and a member of the Society of Petroleum Engineers.

He earned a doctorate in applied mechanics from California Institute of Technology.

Bryan Philpott is an electro-mechanical systems engineer for Halliburton, with 10 years of experience in the design and development of downhole completion tools for long-term deployment in oil and gas wells.

In recent years, his focus has included the development of wet connect devices to enable connection and disconnection of electrical devices while submerged in well-bore fluids at elevated pressure and temperature conditions. This work has given rise to significant challenges and learnings in the behaviors of elastomeric seals, and the conditions under which they may be used for adequate performance in sealing hydraulic and/or electrical chambers in downhole tools.

tests, we performed double O-ring tests. The test setup is the same as before, except that two O-rings were included in the tests, as illustrated in **Fig. 8**.

From an electrical perspective, the O-ring resistances are acting in series, so they will be added together. The O-ring resistances were measured individually first, then together, so that a calculated combined resistance could be plotted alongside the actual measured resistance and verify the series resistor behavior.

Three runs were performed with different O-rings. In Run #1, the O-rings were chosen blindly. In Run #2, the O-rings were chosen to be about the same thickness. In Run #3, the -110 O-ring was selected to be just barely thicker than the -116. The predicted combined resistance calculations used intermediate values determined via a curve fit.

It is noted that in the double O-ring test, the force on each O-ring is not the same, they are shared by each O-ring's axial stiffness. Load distribution between two concentric O-rings under transverse load F is proportional to their axial stiffness = $K = \frac{EA}{L}$ for this case, A is defined as:

$$F_i = \frac{A_i}{A_1 + A_2} F \quad (5)$$

Where $D_i = (D_{od} + D_{id})/2$, $A_i \approx \pi D_i\, t$

Three sets of such tests were performed, and the results for set 1 (Run 1) are shown in **Fig. 9**.

Large O-ring 116 (average OD 0.84") has much lower resistance than smaller O ring 110 (average OD 0.465") when we compared to measurements from first sets of tests (set 0) (**Fig. 10**).

In the set 0 tests, the difference in electrical resistances between 110 O-ring and 116 O-ring is marginal, as expected (longer length of the O-ring circumference in 116, but lower contact pressure at the interface—these two factors counteract each other, and vice versa for 110 O-ring).

The reason 110 O-ring has a much higher electric resistance in this set of tests is most likely due to the lower rubber modulus in 110 O-ring of the second set of tests, and thus larger contact width, and higher electrical resistance.

This assertion is further supported by calculating the dual O-ring test electrical resistance from corresponding single O-ring test. When we use Equation 5 on the single O-ring test and calculate the total electric resistance of the double O-ring tests, the calculated electrical resistance is within 2 percent of measurement when lower modulus C_{10} was used (70psi) vs. 14 percent with C_{10} of 82.1 psi (default).

Summary

Rubber O-ring electrical resistance in wet conditions depends on rubber O-ring material stiffness, O-ring geometric dimension and contact forces applied on the O-ring. Generally, the higher the contact force, the higher the electrical resistance because the water film between O-ring and sealing surface is squeezed out. Quantitatively the electrical resistance, which depends on nonlinear interaction of O-ring dimensions and O-ring material properties, can be reasonably captured by the dimensionless "master curve."

Data analysis also demonstrated the need to account for rubber O-ring modulus variations for the same hardness rubber in order to have a good characterization of rubber O-ring electrical resistance in wet conditions.

References

—Izetti, R. et al. (2014), Downhole Electrical Disconnect Tool Enables the Parting and Subsequent Re-Connection of the Upper Completion Containing an ESP from the Lower Intelligent Completion, SPE-172193-MS, SPE Saudi Arabia Section Annual Technical Symposium and Exhibition held in Al-Khobar, Saudi Arabia, 21-24 April 2014.

—Schnitzler, E. et al. (2022), Full Open Hole Intelligent Completion: A Game Changer in Brazilian Pre-Salt, OTC-31894-MS, presented at the Offshore Technology Conference held in Houston, TX, USA, 2-5 May, 2022.

—Zhong, A., Glaesman, C. (2020), O-ring Extrusions Under High Pressure High Temperature Conditions, presented at the 198th Technical Meeting of the Rubber Division, ACS, Virtual Technical Meeting, October 20-22, 2020, ISSN: 1,547-1,977.

Fig. 5: 75 Duro rubber O-ring electric resistance change with applied force in water: 018, 116 and 209 sizes.

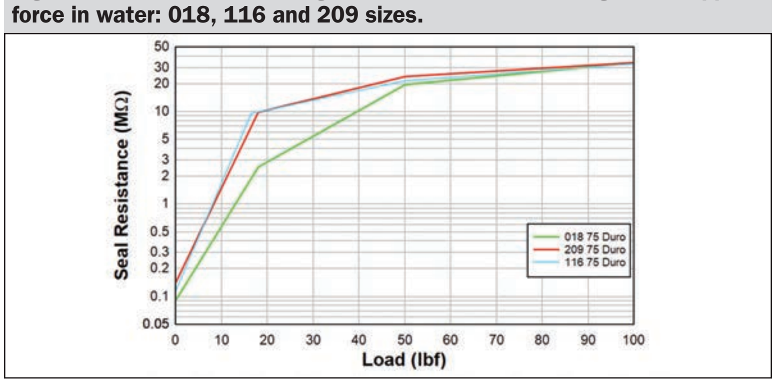


Fig. 6: Scaled resistance vs. dimensionless parameters (Equation 3).

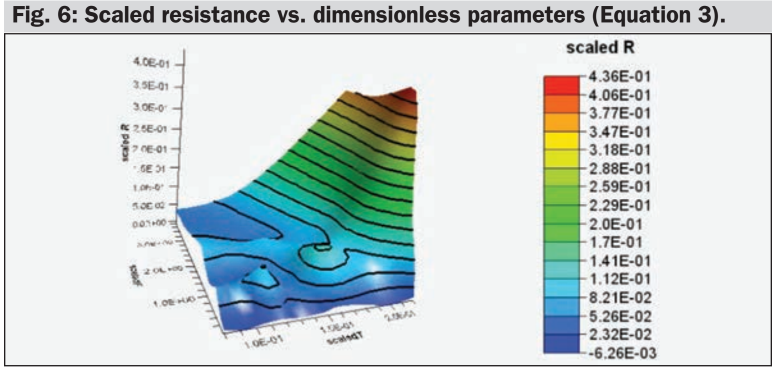


Fig. 7: Scaled resistance vs. dimensionless parameter $\tilde{x}$ – master curve for the tests.

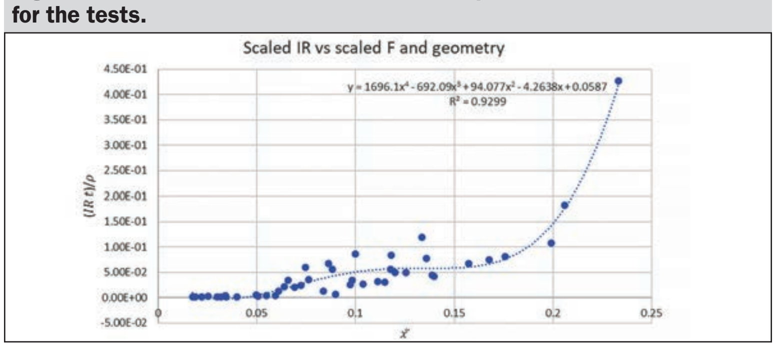


Fig. 8: The set up for the double O-ring test.

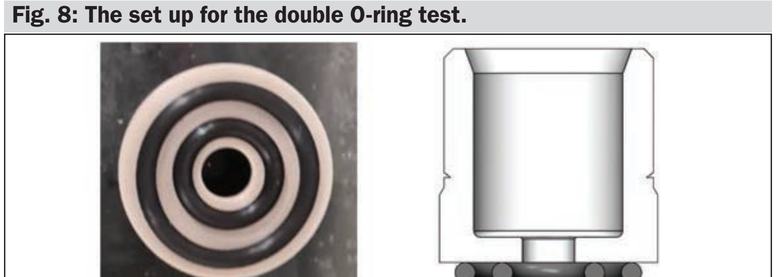


Fig. 9: Test measurements for single O-ring and double O-ring electrical resistance.

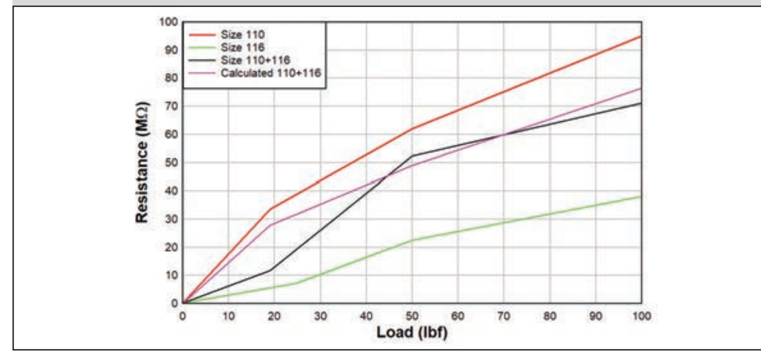


Fig. 10: Test measurements for single O-rings of different samples.