# Environmental Oil Based Subsea Control Fluid (HT/HP)

# TECHNICAL SUMMARY

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# 1.0 PRODUCT OVERVIEW

## CLEO High Temperature Environmental Oil

CLEO is a High Temperature Environmental Oil based Subsea Control Fluid.

CLEO was developed to bridge the technology gap between water based fluids and the extreme HT/HP developments of the future by providing a very stable high temperature fluid capable of maintaining temperatures in excess of 250 °C for a project lifetime.

In addition, with the potential future requirements for closed loop systems in some sectors this environmental oil is not only acceptable for direct discharge to sea but is designed to offer all the properties of traditional oil based fluids in closed loop systems.

CLEO has a comparatively low viscosity for an oil based fluid which is useful when the fluid is to be used in fields with long step-outs.

CLEO is fully compatible with Brayco Micronic SV3 (and SV/B) and can be used to replace such fluids in existing systems where a stronger focus on environmental discharge is required.

This manual summarises some of the key technical parameters of the fluid established to date and will be updated regularly as fresh data becomes available.

## DOCUMENT REVISION HISTORY

| Issue | Revision | Issue Date | Authorised by | Position |
|---|---|---|---|---|
| 1 | 0 | August 2012 | D. Gleeson | R&D Manager |
| 2 | 0 | October 2012 | D. Gleeson | R&D Manager |
| 3 | 0 | April 2015 | D. Gleeson | R&D Manager |
| 4 | 0 | July 2016 | D. Gleeson | R&D Manager |

**Please note that this document is subject to revision on a regular basis. Please ensure you have the latest revision before using this data in applications of a critical nature**.

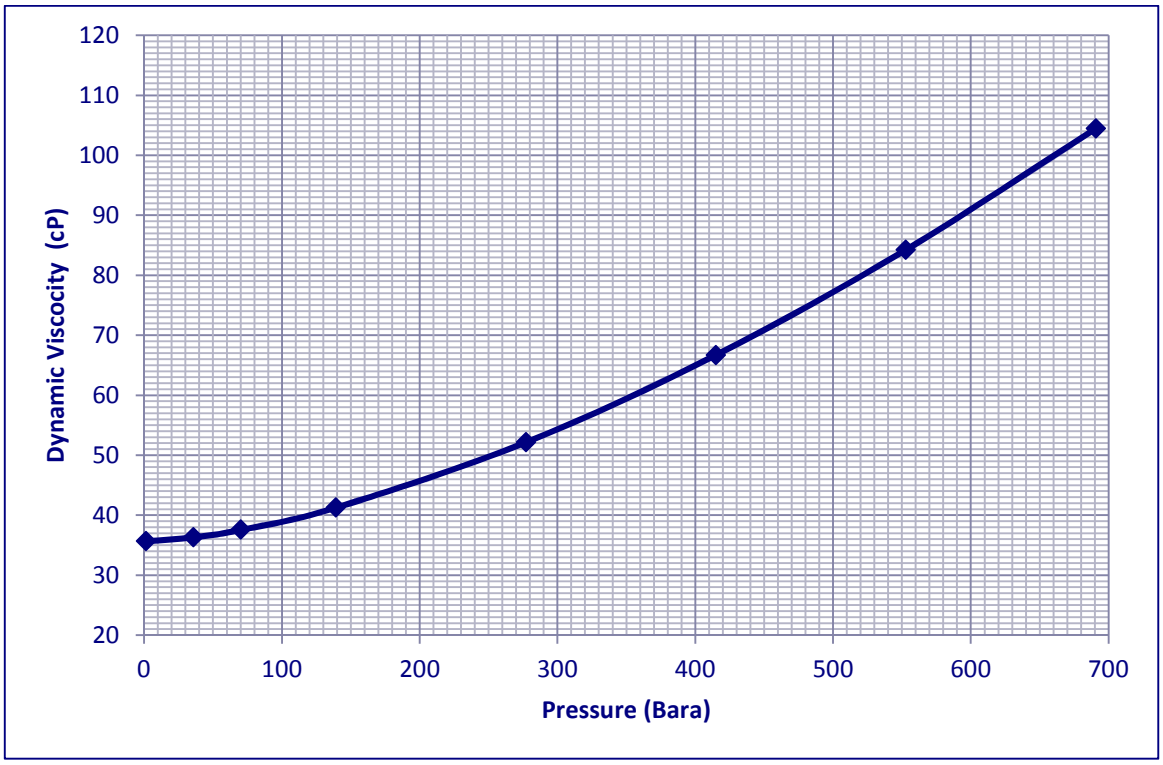
# TABLE OF CONTENTS

## 2.0 PHYSICAL PROPERTIES SUMMARY

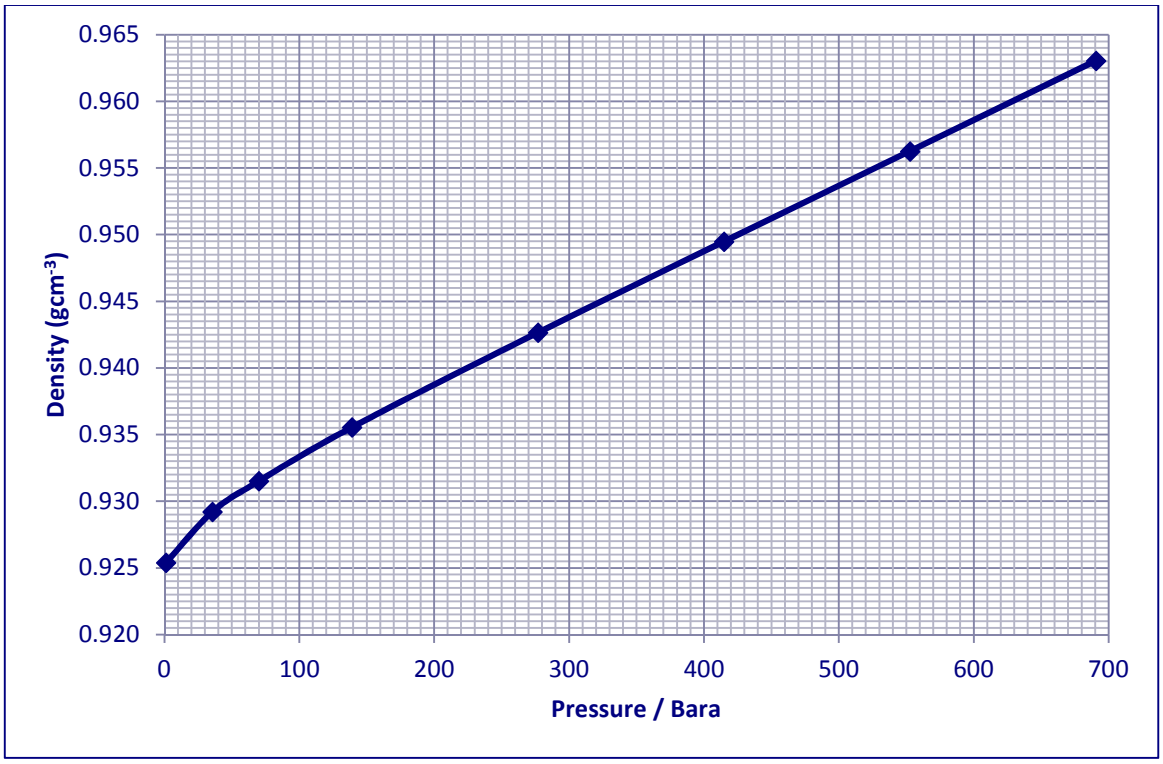
| Property | CLEO | Test Method |
|---|---|---|
| **Viscosity (cSt)** | | ASTM D445<br>IP71<br>ISO 3104 |
| @ -20 °C | 154 | |
| @ 0 °C | 37.0 | |
| @ 20 °C | 14.6 | |
| @ 40 °C | 8.5 | |
| @ 60 °C | 5.3 | |
| @ 100 °C | 2.3 | |
| **Pour Point** | <-40 °C | IP15 |
| **Specific Gravity ($gcm^{-3}$)** | | |
| 20 | 0.914 | IP365 |
| **Appearance** | Transparent, colourless / pale yellow liquid | |
| **Flash Point /°C** | >200 °C | ASTM D92 / IP36 |
| **Upper Temperature Stability** | 250 °C | |
| **Cleanliness Level (Minimum)** | 17/14/12 | ISO 4406 |
| | NAS 6 | NAS 1638 |
| | 6B/6C/6D/6E/6F | SAE AS4059 |
| **Shell 4 Ball** | Mean Wear Scar Diameter 0.600 mm | IP239/01 1 hour duration, 1475rpm rotation, 30 kgf load |
| **Solubility in Water** | Insoluble | |
| **Solubility in Mineral / Crude Oil** | Soluble | |
| **Coefficient of Thermal Expansion $m^3/m^3$ °C** | 0.0008 | |
| **Bulk Modulus $N/m^2$ ($x10^9$)** | 1.73 | |

Falex, Shell 4 Ball, coefficient of thermal expansion and bulk modulus testing were all conducted by independent laboratories.

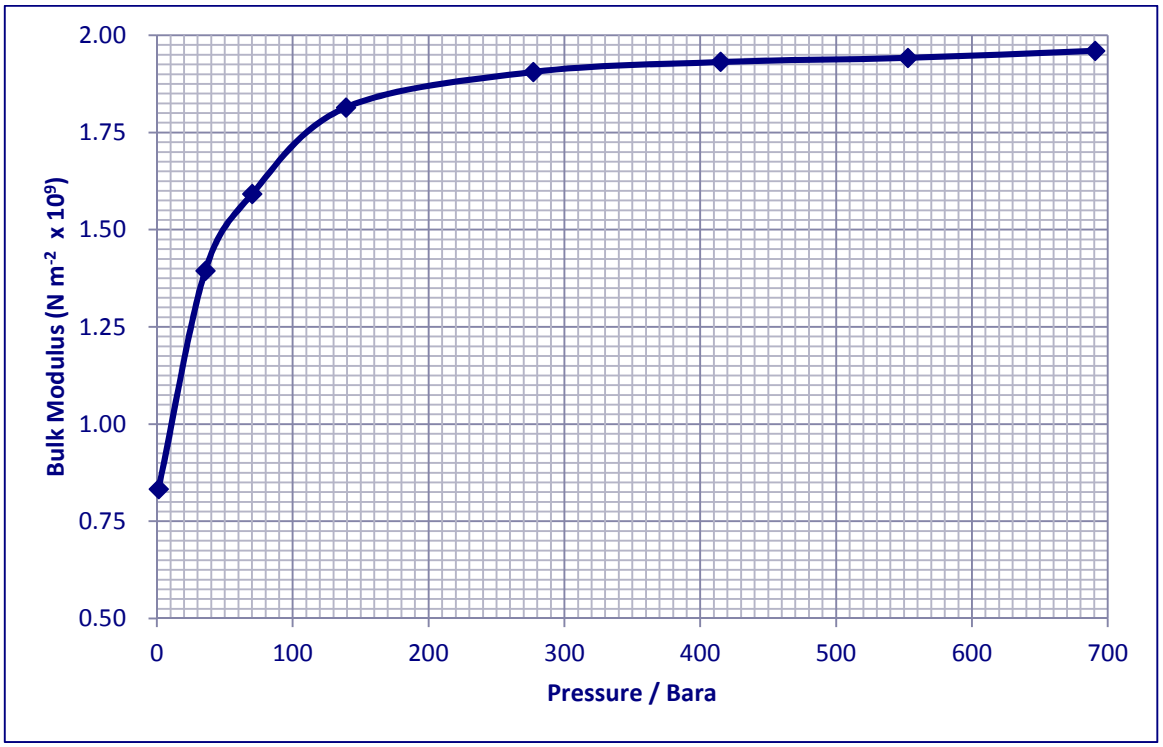
## 2.1 DYNAMIC VISCOSITY VERSUS PRESSURE PROFILE @ 4 °C



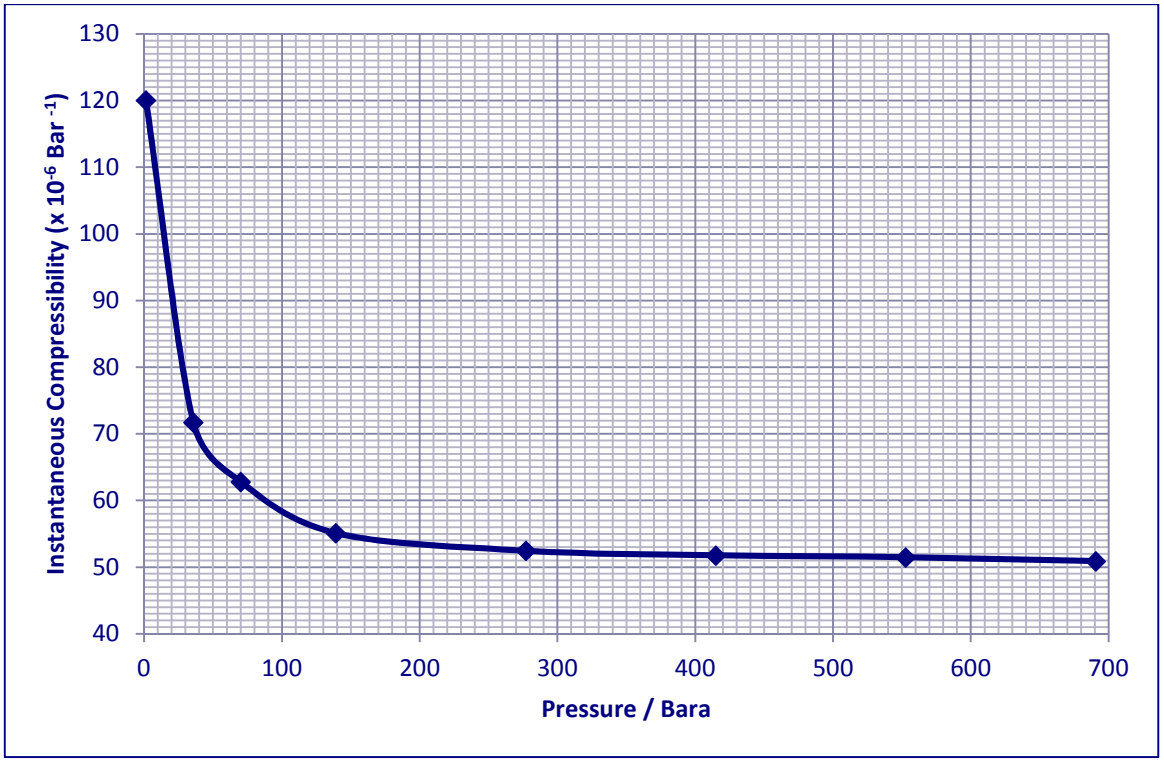

## 2.2 DENSITY VERSUS PRESSURE PROFILE @ 4 °C



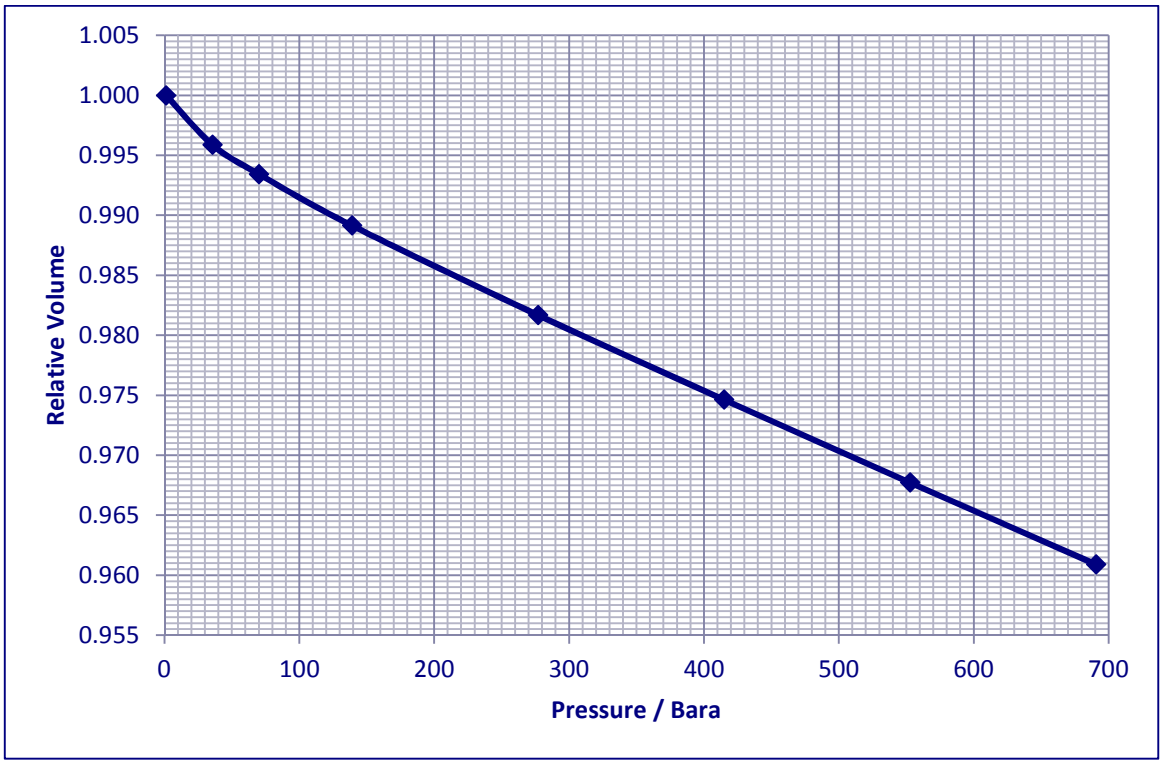
## 2.3 BULK MODULUS VERSUS PRESSURE PROFILE @ 4 °C




## 2.4 INSTANTANEOUS COMPRESSIBILITY VERSUS PRESSURE PROFILE @ 4 °C



## 2.5 RELATIVE VOLUME VERSUS PRESSURE PROFILE @ 4 °C



# 3.0 PRODUCT TESTING

## 3.1 THERMAL STABILITY

CLEO has undergone extensive accelerated aging testing based on the procedures laid out in ISO 13628-6 and is considered fit for service at temperatures as high as 250 °C as shown in the 6 months aging data below.

| Aging Temp /°C | Aging Time | Appearance (relative to unused fluid) | Qualitative description of separation in fluid | Weight of solids recovered (mg/L of fluid) | Specific Gravity @ 20 °C | Lubricity (IP239 Shell 4 ball, 1 h wear test, 30 kg load, 1460 rpm) Mean Wear Scar Diameter | Viscosity @ 40 °C / cSt |
|---|---|---|---|---|---|---|---|
| None | None | Clear and bright colourless / pale yellow fluid | None | n/a | 0.916 | 0.600 mm | 8.4 |
| 250 | Six months | Clear and bright yellow fluid | None | n/a | 0.912 | 0.627 mm | 8.6 |

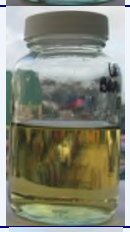
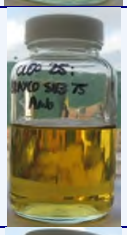
Low temperature stability studies have also been undertaken, with CLEO remaining visually unchanged after aging at -25 °C for 6 months.

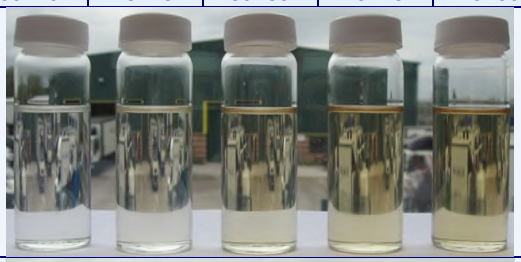
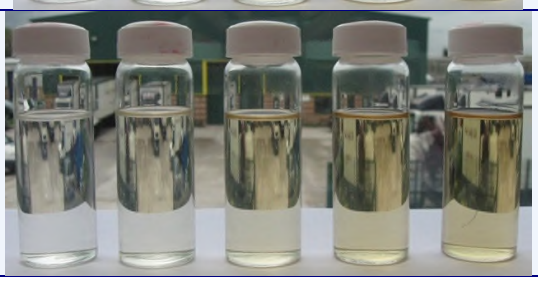
## 3.2 COMPATIBILITY WITH BRAYCO MICRONIC SV/3 AND SV/B

Extensive compatibility studies have been undertaken with Brayco Micronic SV/3 and SV/B in accordance with the ISO 13628-6 specification including: -

- Compatibility at 4, 20, 70 °C for 1 month.
- %v/v mixing ratios of 90:10, 75:25, 50:50, 25:75 and 10:90 at each temperature.

In all cases, no changes in the mixtures of CLEO and Brayco Micronic SV/3 or SV/B have been observed, with the fluids remaining clear and bright and fully compatible after 1 month as shown in the table overleaf. All viscosities remained within 5% of the original values after the aging period in compliance with the ISO 13628-6 Specification.

| Time | Ratio CLEO : Brayco Micronic SV/3 | | | | |
|---|---|---|---|---|---|
| | 90 : 10 | 75 : 25 | 50 : 50 | 25 : 75 | 10 : 90 |
| Initial |  |  |  |  |  |
| 5 °C |  |  |  |  |  |
| 20 °C |  |  |  |  |  |
| 70 °C |  |  |  |  |  |

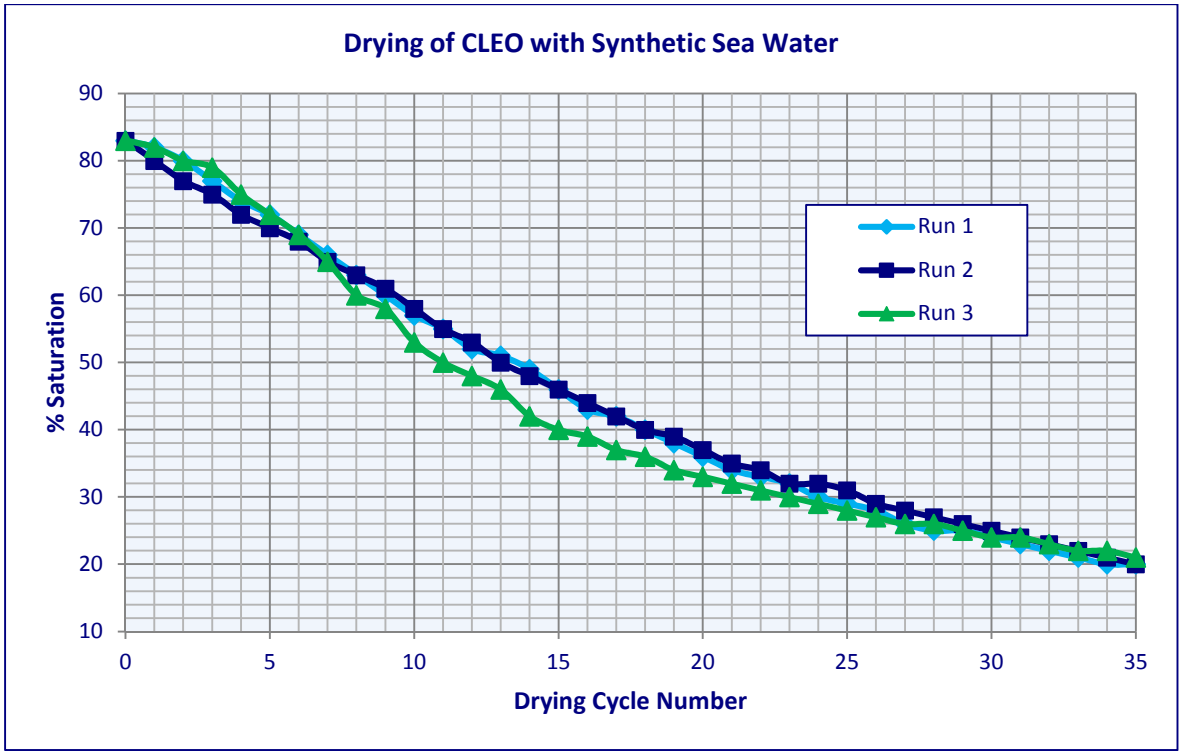
| Aging Temperature | % v/v Ratio of CLEO : Brayco Micronic SV/B | | | | |
|---|---|---|---|---|---|
| | 90 : 10 | 75 : 25 | 50 : 50 | 25 : 75 | 10 : 90 |
| 4 °C |  | | | | |
| 20 °C |  | | | | |
| 70 °C |  | | | | |

## 3.3 DEWATERING CAPABILITY OF SYNTHETIC FLUID

The purpose of this section is to verify that the moisture absorption process is reversible.

Water content (ppmw) and % saturation is measured by suitable methods; the testing was carried out using a Pall HPN021 oil drying unit, with a fluid flow rate of 21 L min-1 and a typical vacuum of 0.7 Bar. The moisture level equivalent to 80% saturation of CLEO was determined as 2500 ppm water, with 30% saturation equivalent to 200 ppm water. The fluid was run through the drying equipment at 20 °C (±5 °C), and samples taken periodically for % saturation, using the moisture sensor and water content (ppmw). Testing was undertaken in triplicate.

**Drying of CLEO versus Saturation**




The data above shows that CLEO meets the acceptance criteria laid out in ISO 13628-6 as the water content is reduced from >80% saturation to <30% saturation within the 35 cycle limit.

## 3.4 COMPATIBILITY WITH CONTROL, COMPLETION AND OPERATIONAL FLUIDS

Extensive compatibility studies have been undertaken with a range of commonly used control, completion and operational fluids. Testing was undertaken either in accordance with ISO 13628-6 or using a procedure with similar aging times, mixture ratios, and temperatures. Fluids tested for compatibility include:

- Pelagic 100, Pelagic 100 HC, Oceanic HW443, Transaqua HT-2 and Transaqua HC10.
- Calcium chloride and bromide brines, zinc chloride and bromide brines, potassium and caesium formate, Hycal II, Hycal III brines.
- Brayco Micronic SV/B, Brayco Micronic SV/3, HDEO.
- 35% Hydrochloric Acid, Methanol, Monoethylene Glycol, Silicon Oil.
- Diesel Fuel, MEGA 600 Lubricant, Greasil 4000, Ambergrease SIL, Molykote G Rapid Plus
- Mobil EAL Envirosyn 32H, Panolin Atlantis 32, Shell Cornea Oil, Shell Tellus S2V 32

Please refer to the main technical manual for detailed compatibility results for each fluid.

## 3.5 METAL COMPATIBILITY

CLEO has been shown to be compatible with a wide range of metals in testing based on ISO 13628-6.

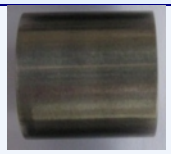
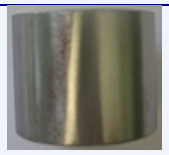
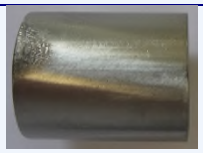
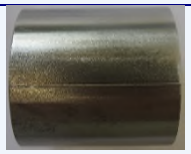
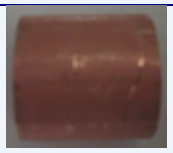
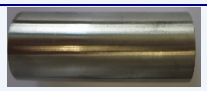
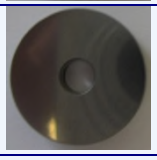
A summary of the results after aging at 70 °C for 12 weeks are shown overleaf, showing that CLEO has excellent compatibility wide as wide range of metals as reported.

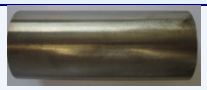
A summary of the results after aging at 150 °C for 12 weeks are given in this section, showing that CLEO has excellent compatibility wide as wide range of metals as reported.

A summary of the results after aging at 250 °C for 6 months are also given in this section, showing that CLEO has excellent compatibility wide as wide range of metals as reported.

The results for metals tested at temperatures 150 °C and 250 °C are included to show that these materials have been tested and pass the test when tested as these temperatures. The 3 months aging test at 150 °C and 250 °C **does not** qualify these materials for service at these temperatures and we recommend that further testing is undertaking before approving these materials for service at these elevated temperatures.

## Metal compatibility after 6 months immersed in CLEO at 250 °C

| Metal | Appearance of metal | | Appearance of fluid (solids / sludge) | Initial Weight / g | Aged Weight / g | Weight Loss / mg | Corrosion rate (µm per annum) |
|---|---|---|---|---|---|---|---|
| 17 – 4 – PH (UNS S17400) | Dulled, slight black surface deposits |  | Slightly darkened, no solids seen | 99.7460 | 99.73760 | 8.4 | 0.71 |
| ASTM A182 F51 Super Duplex (UNS S31803) | Trace dulling at ends. |  | Slightly darkened, no solids seen | 78.0342 | 78.0335 | 0.7 | 0.07 |
| ASTM A182 F53 Super Duplex (UNS S32750) | Trace dulling at ends. |  | Slightly darkened, no solids seen | 61.1536 | 61.1510 | 2.6 | 0.33 |
| ASTM A182 F55 Super Duplex (UNS S32760) | Trace dulling at ends. |  | Slightly darkened, no solids seen | 105.3844 | 105.3816 | 2.8 | 0.25 |
| Aluminium Bronze (UNS C63000) | Slight darkening |  | Slightly darkened, no solids seen | 95.1396 | 95.1258 | 13.8 | 1.17 |
| Becol (UNS C17200) | Slight dulling |  | Slightly darkened, no solids seen | 105.9809 | 105.9832 | -2.3 | -0.18 |
| DGS 1043 (UNS C63200) | Dulled |  | Slightly darkened, no solids seen | 4.8788 | 4.8688 | 10.0 | 2.72 |
| Inconel 625 (UNS N06625) | Trace dulling at ends. |  | Slightly darkened, no solids seen | 174.7023 | 174.7030 | -0.7 | -0.04 |
| Inconel 718 (UNS N07718) | Clear and bright |  | Slightly darkened, no solids seen | 9.7341 | 9.7338 | 0.3 | 0.09 |
| Inconel 725 GV 50H (UNS N07725) | Clear and bright |  | Slightly darkened, no solids seen | 10.6182 | 10.6192 | -1.0 | -0.08 |
| Inconel 825 (UNS N08825) | Trace dulling at ends. |  | Slightly darkened, no solids seen | 137.3619 | 137.3610 | 0.9 | 0.06 |
| Monel 400 (UNS N04400) | Trace dulling at ends. |  | Slightly darkened, no solids seen | 149.0963 | 149.0933 | 3.0 | 0.17 |

| Metal | Appearance of metal | | Appearance of fluid (solids / sludge) | Initial Weight / g | Aged Weight / g | Weight Loss / mg | Corrosion rate (µm per annum) |
|---|---|---|---|---|---|---|---|
| Monel K500 (UNS N05500) | Trace dulling |  | Slightly darkened, no solids seen | 173.9285 | 173.9303 | -1.8 | -0.10 |
| MP35N (UNS R30035) | Clear and bright |  | Slightly darkened, no solids seen | 10.0162 | 10.0161 | 0.1 | 0.03 |
| Nitronic 50 (UNS S20910) | Clear and bright |  | Slightly darkened, no solids seen | 0.7675 | 0.7674 | 0.1 | 0.09 |
| Stainless Steel 304 (UNS S30400) | Clear and bright |  | Slightly darkened, no solids seen | 48.7893 | 48.7874 | 1.9 | 0.10 |
| Stainless Steel 316 (UNS S31600) | Clear and bright |  | Slightly darkened, no solids seen | 22.5269 | 22.5267 | 0.2 | 0.03 |
| Stainless Steel 316Ti (UNS S31635) | Clear and bright |  | Slightly darkened, no solids seen | 9.2877 | 9.2876 | 0.1 | 0.03 |
| Toughmet 3 AT110 (UNS C72900) | Dulled |  | Slightly darkened, no solids seen | 31.6074 | 31.6000 | 7.4 | 0.96 |

The results for metals tested at temperatures 250 °C are included to show that these materials have been tested and pass the test when tested as these temperatures. The 3 months aging test at 250 °C **does not** qualify these materials for service at these temperatures and we recommend that further testing is undertaking before approving these materials for service at these elevated temperatures.

## Metals compatibility after 12 weeks immersed in CLEO at 150 °C

| Metal | Aging time / weeks | Metal Test Piece to ISO 13628-6 | Appearance of Fluid to ISO 13628-6 |
|---|---|---|---|
| 17 – 4 – PH (UNS S17400) | 12 | Pass | Pass |
| 735 A50 | 12 | Pass | Pass |
| A182 F51 UNS S31803 / A890 GR4A (Super Duplex) | 12 | Pass | Pass |
| A182 F53 UNS S32750 (Super Duplex) | 12 | Pass | Pass |
| A182 F55 UNS S32760 (Super Duplex) | 12 | Pass | Pass |
| AISI A29 4340 | 12 | Pass | Pass |
| AISI A29 4340 | 12 | Pass | Pass |
| AISI A350 LF2 Carbon Steel | 12 | Pass | Pass |
| AISI 410 | 12 | Pass | Pass |
| AISI 420 | 12 | Pass | Pass |
| AISI 440C | 12 | Pass | Pass |
| AISI 1040 | 12 | Pass | Pass |
| AISI 4130 | 12 | Pass | Pass |
| AISI 4140 | 12 | Pass | Pass |
| AISI 6150 | 12 | Pass | Pass |
| Aluminium Bronze HM9843 | 12 | Pass | Pass |
| Aluminium Bronze UNS C63000 | 12 | Pass | Pass |
| Carbon Steel UNS K02401 | 12 | Pass | Pass |
| Chrome Core | 12 | Pass | Pass |
| Copper | 12 | Pass | Pass |
| CuAl10Ni | 12 | Pass | Pass |
| DGS1043 | 12 | Pass | Pass |
| Duplex 9490 | 12 | Pass | Pass |
| Electroless Nickel Plated | 12 | Pass | Pass |
| Elgiloy | 12 | Pass | Pass |
| Inconel 625 | 12 | Pass | Pass |
| Inconel 718 | 12 | Pass | Pass |
| Inconel 718 Silver Coated | 12 | Pass | Pass |
| Inconel 718 Gold Coated | 12 | Pass | Pass |
| Inconel 725 GV50H | 12 | Pass | Pass |
| Inconel 725 Silver Coated | 12 | Pass | Pass |
| Inconel 825 | 12 | Pass | Pass |
| Inconel 925 | 12 | Pass | Pass |
| KR16 | 12 | Pass | Pass |
| Mild Steel | 12 | Pass | Pass |
| Monel 400 | 12 | Pass | Pass |
| Monel K500 | 12 | Pass | Pass |
| MP35N | 12 | Pass | Pass |
| Nitronic 50 | 12 | Pass | Pass |
| Phosphor Bronze PB102 | 12 | Pass | Pass |
| Super Duplex AM8831 | 12 | Pass | Pass |
| Silicon Nitride | 12 | Pass | Pass |
| Stainless Steel 304 | 12 | Pass | Pass |
| Stainless Steel 316 | 12 | Pass | Pass |
| Stainless Steel 316 Ti | 12 | Pass | Pass |
| Stainless Steel 416 | 12 | Pass | Pass |
| Stainless Steel 431 | 12 | Pass | Pass |
| Super Duplex (OEM) | 12 | Pass | Pass |
| Titanium | 12 | Pass | Pass |
| Toughmet 3 AT110 (UNS C72900) | 12 | Pass | Pass |
| Tungsten Carbide (6% Nickel Bonded) | 12 | Pass | Pass |
| Tungsten Carbide (10% Nickel Bonded) | 12 | Pass | Pass |
| Umbilical TP19D | 12 | Pass | Pass |
| Zirconia | 12 | Pass | Pass |

The results for metals tested at temperatures 150 °C are included to show that these metals have been tested and pass the test when tested as these temperatures. The 3 months aging test at 150 °C **does not** qualify these materials for service at these temperatures and we recommend that further testing is undertaking before approving these materials for service at these elevated temperatures.

## Metals compatibility after 12 weeks immersed in CLEO at 70 °C

| Metal | Aging time / weeks | CLEO (No Sea Water) | | CLEO (10% v/v Sea Water) | |
|---|---|---|---|---|---|
| | | Metal Test Piece to ISO 13628-6 | Appearance of Fluid to ISO 13628-6 | Metal test piece to ISO 13628-6 | Appearance of Fluid to ISO 13628-6 |
| 17 – 4 – PH UNS S17400 | 12 | Pass | Pass | Pass | Pass |
| A182 F51 UNS S31803 / A890 GR4A (Super Duplex) | 12 | Pass | Pass | Pass | Pass |
| A182 F53 UNS 32750 (Super Duplex) | 12 | Pass | Pass | Pass | Pass |
| AlCNC10 | 12 | Pass | Pass | Pass | Pass |
| AISI A29 4340 Gas Nitrided | 12 | Pass | Pass | Pass | Pass |
| AISI A29 4340 | 12 | Pass | Pass | Pass | Pass |
| AISI A350 LF2 Carbon Steel | 12 | Pass | Pass | Pass | Pass |
| AISI 410 | 12 | Pass | Pass | Pass | Pass |
| AISI 420 | 12 | Pass | Pass | Pass | Pass |
| AISI 440C | 12 | Pass | Pass | Pass | Pass |
| AISI 1040 | 12 | Pass | Pass | Pass | Pass |
| AISI 4130 | 12 | Pass | Pass | Pass | Pass |
| AISI 4140 | 12 | Pass | Pass | Pass | Pass |
| AISI 6150 | 12 | Pass | Pass | Pass | Pass |
| Aluminium Bronze HM9843 | 12 | Pass | Pass | Pass | Pass |
| Aluminium Bronze UNS C63000 | 12 | Pass | Pass | Pass | Pass |
| Aluminium Bronze ASTM B418 | 12 | Pass | Pass | Pass | Pass |
| Alloy 3 | 12 | Pass | Pass | Pass | Pass |
| Becol UNS C17200 | 12 | Pass | Pass | Pass | Pass |
| Carbon Steel UNS K02401 | 12 | Pass | Pass | Pass | Pass |
| Chrome Core | 12 | Pass | Pass | Pass | Pass |
| Copper | 12 | Pass | Pass | Pass | Pass |
| CuAl10Ni | 12 | Pass | Pass | Pass | Pass |
| DGS1043 | 12 | Pass | Pass | Pass | Pass |
| Duplex 9490 | 12 | Pass | Pass | Pass | Pass |
| Electroless Nickel Plated | 12 | Pass | Pass | Pass | Pass |
| Elgiloy | 12 | Pass | Pass | Pass | Pass |
| Inconel 625 | 12 | Pass | Pass | Pass | Pass |
| Inconel 718 | 12 | Pass | Pass | Pass | Pass |
| Inconel 718 Silver Coated | 12 | Pass | Pass | Pass | Pass |
| Inconel 718 Gold Coated | 12 | Pass | Pass | Pass | Pass |
| Inconel 725 GV50H | 12 | Pass | Pass | Pass | Pass |
| Inconel 725 Silver Coated | 12 | Pass | Pass | Pass | Pass |
| Inconel 825 | 12 | Pass | Pass | Pass | Pass |
| Inconel 925 | 12 | Pass | Pass | Pass | Pass |
| KR16 | 12 | Pass | Pass | Pass | Pass |
| Mild Steel | 12 | Pass | Pass | Pass | Pass |
| Monel Alloy 400 | 12 | Pass | Pass | Pass | Pass |
| Monel Alloy K500 | 12 | Pass | Pass | Pass | Pass |
| MP35N | 12 | Pass | Pass | Pass | Pass |
| Nitronic 50 | 12 | Pass | Pass | Pass | Pass |
| Phosphor Bronze PB102 | 12 | Pass | Pass | Pass | Pass |
| Super Duplex AM8831 | 12 | Pass | Pass | Pass | Pass |
| Super Duplex UNS S32760 | 12 | Pass | Pass | Pass | Pass |
| Silicon Nitride | 12 | Pass | Pass | Pass | Pass |
| Stainless Steel 304 | 12 | Pass | Pass | Pass | Pass |
| Stainless Steel 316 | 12 | Pass | Pass | Pass | Pass |
| Stainless Steel 316 Ti | 12 | Pass | Pass | Pass | Pass |
| Stainless Steel 416 | 12 | Pass | Pass | Pass | Pass |
| Stainless Steel 431 | 12 | Pass | Pass | Pass | Pass |
| Super Duplex (OEM) | 12 | Pass | Pass | Pass | Pass |
| Titanium | 12 | Pass | Pass | Pass | Pass |
| Toughmet 3 AT110 (UNS C72900) | 12 | Pass | Pass | Pass | Pass |
| Umbilical TP19D | 12 | Pass | Pass | Pass | Pass |
| Zirconia | 12 | Pass | Pass | Pass | Pass |

## Metals compatibility after 12 weeks immersed in CLEO at 70 °C continued

| Metal | Aging time / weeks | CLEO (No Sea Water) | | CLEO (10% v/v Sea Water) | |
|---|---|---|---|---|---|
| | | Metal Test Piece to ISO 13628-6 | Appearance of Fluid to ISO 13628-6 | Metal test piece to ISO 13628-6 | Appearance of Fluid to ISO 13628-6 |
| Zn plated Washer | 12 | Pass | Pass | Pass | Pass |
| 6% Ni Bonded Tungsten Carbide | 12 | Pass | Pass | Pass | Pass |
| 10% Ni Bonded Tungsten Carbide | 12 | Pass | Pass | Pass | Pass |

## Coatings Compatibility after 12 weeks immersed in CLEO at 70 °C

| Coated Metal | Aging time / weeks | CLEO (No Sea Water) | | CLEO (10% v/v Sea Water) | |
|---|---|---|---|---|---|
| | | Metal Test Piece to ISO 13628-6 | Appearance of Fluid to ISO 13628-6 | Metal test piece to ISO 13628-6 | Appearance of Fluid to ISO 13628-6 |
| Everslik 1201 | 12 | Pass | Pass | Pass | Pass |
| Everslik 1301 | 12 | Pass | Pass | Pass | Pass |
| Everslik 1201/1301 | 12 | Pass | Pass | Pass | Pass |
| Sermaguard 1105/1280 | 12 | Pass | Pass | Pass | Pass |
| Xylan 1014 | 12 | Pass | Pass | Pass | Pass |
| Xylan 1052 | 12 | Pass | Pass | Pass | Pass |
| Xylan 1212 | 12 | Pass | Pass | Pass | Pass |
| Xylan 1213 | 12 | Pass | Pass | Pass | Pass |
| Xylan 1400 | 12 | Pass | Pass | Pass | Pass |
| Xylan 1424 | 12 | Pass | Pass | Pass | Pass |

## 3.6 ELASTOMER COMPATIBILITY

CLEO has been shown to be compatible with a range of elastomers in testing based on the ISO 13628-6 specification with the results after aging at 70 °C for 3 months as tabulated below.

CLEO shows excellent compatibility with a wide range for elastomeric materials.

CLEO has been found to be incompatible with silicone and EPDM materials tested to date, which is typical for these types of fluids.

Please note that while testing based on ISO 13628-6 (Annex C) is considered one of the most robust standard elastomer testing regimes available, this does not qualify elastomers for use at 70 °C and is instead an accelerated screen test to provide compatibility information at typical storage and operational temperatures. To be more specific, in line with the Arrhenius rate equation, testing for 3 months at 70 °C provides an accelerated compatibility profile covering up to 2 years at 40°C during storage, and 20+ years at seabed temperatures. If materials are to be used at temperatures above 40°C for periods in excess of 2 years, then further testing at elevated temperatures would be recommended to confirm compatibility.

The results for elastomers tested at temperatures ≥ 150 °C and 250 °C are included to show that these elastomers have been tested and pass the test when tested as these temperatures. The 3 months aging test at ≥ 150 °C and 250 °C **does not** qualify these materials for service at these temperatures and we recommend that further testing is undertaking before approving these materials for service at these elevated temperatures.

## Elastomer compatibility at 70 °C for CLEO

| Elastomer | Aging time | CLEO | | |
|---|---|---|---|---|
| | | Swell | Hardness | ISO 13628-6 |
| Acetal (OEM) | 3 months | Pass | Pass | Pass |
| Acrylic (Direct Plastics) | 3 months | Pass | Pass | Pass |
| Aflas (Clwyd) | 3 months | Pass | Pass | Pass |
| Carbon Fibre (Carbon Fibre Seal Company) | 3 months | Pass | Pass | Pass |
| Chemraz 510 (Green Tweed) | 3 months | Pass | Pass | Pass |
| Chemraz 600 (Green Tweed) | 3 months | Pass | Pass | Pass |
| Ducoflex Hose Grade 350-13-33-06T (Duco) | 3 months | Pass | Pass | Pass |
| Ecoflon 4 25% Carbon Filled PTFE (Economos) | 3 months | Pass | Pass | Pass |
| Elastolion 101 HNBR (James Walker) | 3 months | Pass | Pass | Pass |
| Elastolion 280LF HNBR (James Walker) | 3 months | Pass | Pass | Pass |
| FFKM PFR06HC 90 Shore A (Solvay) | 3 months | Pass | Pass | Pass |
| FFKM PKR95HT 90 Shore A (Solvay) | 3 months | Pass | Pass | Pass |
| FKM 70.16-14 (Angst and Pfister) | 3 months | Pass | Pass | Pass |
| FKM FOR 7352(Solvay) | 3 months | Pass | Pass | Pass |
| FKM FOR 9381 92 Shore A (Solvay) | 3 months | Pass | Pass | Pass |
| FKM FR20-90 (James Walker) | 3 months | Pass | Pass | Pass |
| FKM FR58-90 James Walker | 3 months | Pass | Pass | Pass |
| FKM Mix 80 (FCH) | 3 months | Pass | Pass | Pass |
| FKM NT 80.7-70 (Angst and Pfister) | 3 months | Pass | Pass | Pass |
| FKM P757 92 Shore A (Solvay) | 3 months | Pass | Pass | Pass |
| FKM P959 93 Shore A (Solvay) | 3 months | Pass | Pass | Pass |
| FKM PL855 91 Shore A (Solvay) | 3 months | Pass | Pass | Pass |
| FKM VBR X856 90 Shore A (Clwyd) | 3 months | Pass | Pass | Pass |
| FKM V70GA 70 Shore A (Trelleborg) | 3 months | Pass | Pass | Pass |
| FKM V75J Shore 75 A (Precision Polymer Engineering) | 3 months | Pass | Pass | Pass |
| FKM VPL85540 92 Shore A (Solvay) | 3 months | Pass | Pass | Pass |
| FKM VPL 85730 91 Shore A (Solvay) | 3 months | Pass | Pass | Pass |
| FKM PL958 91 Shore A (Solvay) | 3 months | Pass | Pass | Pass |
| FKM V1238-95 95 Shore A (Parker) | 3 months | Pass | Pass | Pass |
| Flourel (Parker) | 3 months | Pass | Pass | Pass |
| Hallite 53 | 3 months | Pass | Pass | Pass |
| Hallite T506 | 3 months | Pass | Pass | Pass |
| HNBR 2269-90 (Parco) | 3 months | Pass | Pass | Pass |
| HNBR 4007 90 Shore A (Parker) | 3 months | Pass | Pass | Pass |
| HNBR KB163 90 Shore A (Parker) | 3 months | Pass | Pass | Pass |
| HNBR 453702 90 Shore A (Freudenberg) | 3 months | Pass | Pass | Pass |
| HNBR H9T40 90 Shore A (Trelleborg) | 3 months | Pass | Pass | Pass |
| Hytrel 5556 Shore 55D Thermoplastic Polyester (Dupont) | 3 months | Pass | Pass | Pass |
| Hytrel 6356 Shore 63D Thermoplastic Polyester (Dupont) | 3 months | Pass | Pass | Pass |
| Lexan Margard (Sabic) | 3 months | Pass | Pass | Pass |
| LNP-PDX 82429 Carbon Filled Teflon (OEM) | 3 months | Pass | Pass | Pass |
| NBR K09G 90 Shore A (Pimseal) | 3 months | Pass | Pass | Pass |
| NBR N107-90 (Parker) | 3 months | Pass | Pass | Pass |
| NBR N300-90 (Parker) | 3 months | Pass | Pass | Pass |
| NBR431 (Otto Gherkins) | 3 months | Pass | Pass | Pass |
| NBR N552-90 90 Shore A (Parker) | 3 months | Pass | Pass | Pass |
| NBR N674-70 70 Shore A (Parker) | 3 months | Pass | Pass | Pass |
| NBR N702-90 (Parker) | 3 months | Pass | Pass | Pass |
| NBR N756-75 (Parker) | 3 months | Pass | Pass | Pass |
| NBR N1059-90 (Parker) | 3 months | Pass | Pass | Pass |
| NBR N1444-90 (Parker) | 3 months | Pass | Pass | Pass |
| NBR N7003 70 Shore A (Trelleborg) | 3 months | Pass | Pass | Pass |
| NBR N7022 70 Shore A (Trelleborg) | 3 months | Pass | Pass | Pass |
| NBR N7023 70 Shore A (Trelleborg) | 3 months | Pass | Pass | Pass |
| NBR N7083 70 Shore A (Trelleborg) | 3 months | Pass | Pass | Pass |
| NBR N9002 90 Shore A (Trelleborg) | 3 months | Pass | Pass | Pass |
| NBR PB80 80 Shore A (James Walker) | 3 months | Pass | Pass | Pass |
| NBR 70 (Ramsey Services) | 3 months | Pass | Pass | Pass |
| NBR70 K6 (GAPI Compounds) | 3 months | Pass | Pass | Pass |
| NBR 70 (Eriks Seals) | 3 months | Pass | Pass | Pass |
| Nylon 6 (Skiffy) | 3 months | Pass | Pass | Pass |

## Elastomer compatibility at 70 °C for CLEO continued

| Elastomer | Aging time | CLEO | | |
|---|---|---|---|---|
| | | Swell | Hardness | ISO 13628-6 |
| Nylon 6,6 (Direct Plastics) | 3 months | Pass | Pass | Pass |
| Nylon TLO (OEM) | 3 months | Pass | Pass | Pass |
| Nylon XLPE (OEM) | 3 months | Pass | Pass | Pass |
| Orkot C338 (Trelleborg) | 3 months | Pass | Pass | Pass |
| Orkot C380 (Trelleborg) | 3 months | Pass | Pass | Pass |
| Orkot TLM (Trelleborg) | 3 months | Pass | Pass | Pass |
| Orkot TXMM (Trelleborg) | 3 months | Pass | Pass | Pass |
| PEEK 450G (Victrex) | 3 months | Pass | Pass | Pass |
| PEEK 450CA30 (30% Carbon Filled) (Victrex) | 3 months | Pass | Pass | Pass |
| PEEK 1000 (OEM) | 3 months | Pass | Pass | Pass |
| PEEK W4685 (Parker) | 3 months | Pass | Pass | Pass |
| PEEK W4738 (Parker) | 3 months | Pass | Pass | Pass |
| Polyamide Imide AMS 3670-1 (OEM) | 3 months | Pass | Pass | Pass |
| Polyamide Imide AMS 3670-4 (OEM) | 3 months | Pass | Pass | Pass |
| Polypropylene (Direct Plastics) | 3 months | Pass | Pass | Pass |
| Polyurethane (OEM) | 3 months | Pass | Pass | Pass |
| POM (polyoxymethylene) (OEM) | 3 months | Pass | Pass | Pass |
| PTFE (OEM) | 3 months | Pass | Pass | Pass |
| PTFE (25% Carbon Filled) (OEM) | 3 months | Pass | Pass | Pass |
| PTKC (OEM) | 3 months | Pass | Pass | Pass |
| PVDF (OEM) | 3 months | Pass | Pass | Pass |
| Turcite B Slydway (Trelleborg) | 3 months | Pass | Pass | Pass |
| Turcon M12 (Trelleborg) | 3 months | Pass | Pass | Pass |
| Turcon T05 (Trelleborg) | 3 months | Pass | Pass | Pass |
| Turcon T12 (Trelleborg) | 3 months | Pass | Pass | Pass |
| Turcon T19 (Trelleborg) | 3 months | Pass | Pass | Pass |
| Turcon T29 Step Seal (Trelleborg) | 3 months | Pass | Pass | Pass |
| Turcon T40 (Trelleborg) | 3 months | Pass | Pass | Pass |
| Turcon T42 (Trelleborg) | 3 months | Pass | Pass | Pass |
| Turcon T46 (Trelleborg) | 3 months | Pass | Pass | Pass |
| Turcon T51 (Trelleborg) | 3 months | Pass | Pass | Pass |
| UHMWPE (Direct Plastics) | 3 months | Pass | Pass | Pass |
| Viton 70 (OEM) | 3 months | Pass | Pass | Pass |
| Viton 90 (OEM) | 3 months | Pass | Pass | Pass |
| Viton A 9009-75 (OEM) | 3 months | Pass | Pass | Pass |
| Viton Extreme 90 Shore A (Clwyd) | 3 months | Pass | Pass | Pass |
| Viton HTV90-A2 90 Shore A (Dupont) | 3 months | Pass | Pass | Pass |
| Viton V747-75 (Parker) | 3 months | Pass | Pass | Pass |
| Viton V858-95 (Parker) | 3 months | Pass | Pass | Pass |
| Viton VG109-90 (Parker) | 3 months | Pass | Pass | Pass |
| Viton V9T40 (Trelleborg) | 3 months | Pass | Pass | Pass |
| Zurcon Z25 (Trelleborg) | 3 months | Pass | Pass | Pass |
| Zurcon Z43 (Trelleborg) | 3 months | Pass | Pass | Pass |
| Zurcon Z52 (Trelleborg) | 3 months | Pass | Pass | Pass |
| Zurcon Z80 (Trelleborg) | 3 months | Pass | Pass | Pass |

Please note that while testing based on ISO 13628-6 (Annex C) is considered one of the most robust standard elastomer testing regimes available, this does not qualify elastomers for use at 70 °C and is instead an accelerated screen test to provide compatibility information at typical storage and operational temperatures. To be more specific, in line with the Arrhenius rate equation, testing for 3 months at 70 °C provides an accelerated compatibility profile covering up to 2 years at 40°C during storage, and 20+ years at seabed temperatures. If materials are to be used at temperatures above 40°C for periods in excess of 2 years, then further testing at elevated temperatures would be recommended to confirm compatibility.

## Elastomer compatibility at 150 °C for CLEO

| Elastomer | Aging time | CLEO | | |
|---|---|---|---|---|
| | | Swell | Hardness | ISO 13628-6 |
| Chemraz 510 (Green Tweed) | 3 months | Pass | Pass | Pass |
| Chemraz 600 (Green Tweed) | 3 months | Pass | Pass | Pass |
| Ecoflon 4 25% Carbon Filled PTFE (Economos) | 3 months | Pass | Pass | Pass |
| FFKM PFR06HC 90 Shore A (Solvay) | 3 months | Pass | Pass | Pass |
| FFKM PKR95HT 90 Shore A (Solvay) | 3 months | Pass | Pass | Pass |
| FKM P959 93 Shore A (Solvay) | 3 months | Pass | Pass | Pass |
| FKM VPL85540 92 Shore A (Solvay) | 3 months | Pass | Pass | Pass |
| FKM VPL 85730 91 Shore A (Solvay) | 3 months | Pass | Pass | Pass |
| FKM PL958 91 Shore A (Solvay) | 3 months | Pass | Pass | Pass |
| Nylon 6,6 (Direct Plastics) | 3 months | Pass | Pass | Pass |
| PEEK 450G (Victrex) | 3 months | Pass | Pass | Pass |
| PEEK 450CA30 (30% Carbon Filled) (Victrex) | 3 months | Pass | Pass | Pass |
| PEEK 1000 (OEM) | 3 months | Pass | Pass | Pass |
| PEEK W4685 (Parker) | 3 months | Pass | Pass | Pass |
| PEEK W4738 (Parker) | 3 months | Pass | Pass | Pass |
| PTFE (OEM) | 3 months | Pass | Pass | Pass |
| PTFE (25% Carbon Filled) (OEM) | 3 months | Pass | Pass | Pass |
| Turcon M12 (Trelleborg) | 3 months | Pass | Pass | Pass |
| Turcon T05 (Trelleborg) | 3 months | Pass | Pass | Pass |
| Turcon T12 (Trelleborg) | 3 months | Pass | Pass | Pass |
| Turcon T19 (Trelleborg) | 3 months | Pass | Pass | Pass |
| Turcon T29 Step Seal (Trelleborg) | 3 months | Pass | Pass | Pass |
| Turcon T40 (Trelleborg) | 3 months | Pass | Pass | Pass |
| Turcon T42 (Trelleborg) | 3 months | Pass | Pass | Pass |
| Turcon T46 (Trelleborg) | 3 months | Pass | Pass | Pass |
| Turcon T51 (Trelleborg) | 3 months | Pass | Pass | Pass |
| Viton Extreme 90 Shore A (Clwyd) | 3 months | Pass | Pass | Pass |
| Zurcon Z43 (Trelleborg) | 3 months | Pass | Pass | Pass |

Further compatibilities of selected elastomers have also been undertaken at 250 °C and are tabulated below.

## Elastomer compatibility at 250 °C for CLEO

| Elastomer | Aging time | CLEO | | |
|---|---|---|---|---|
| | | Swell | Hardness | ISO 13628-6 |
| PEEK 450G (Victrex) | 3 months | Pass | Pass | Pass |
| PTFE (OEM) | 3 months | Pass | Pass | Pass |

PTFE and PEEK both meet the requirements of ISO 13628-6 after aging for 3 months at 250 °C.

The results for elastomers tested at temperatures 150 °C and 250 °C are included to show that these elastomers have been tested and pass the test when tested as these temperatures. The 3 months aging test at 150 °C and 250 °C **does not** qualify these materials for service at these temperatures and we recommend that further testing is undertaking before approving these materials for service at these elevated temperatures.

## 3.7 FLUID LUBRICITY AND WEAR

### 3.7.1 Shell 4 Ball Test

Lubricity testing using the Shell 4 ball method as described in the ISO 13628-6 specification have been undertaken by an independent testing laboratory and are outlined below.

### 3.7.1.a One Hour 4 Ball Wear Test

The results obtained for the one-hour wear tests at 30 kg load at 1475 (+/-25) rpm are shown below in table 2 with the mean wear scar diameters measured for CLEO demonstrating 50% less wear than the acceptance criteria of 1.2 mm.

| Lubricant | Scar Diameter Rubbing Direction Ball 1 (mm) | Scar Diameter Right Angle Direction Ball 1 (mm) | Scar Diameter Rubbing Direction Ball 2 (mm) | Scar Diameter Right Angle Direction Ball 2 (mm) | Scar Diameter Rubbing Direction Ball 3 (mm) | Scar Diameter Right Angle Direction Ball 3 (mm) | Average Scar Diameter MWSD (mm) | Comments |
|---|---|---|---|---|---|---|---|---|
| CLEO | 0.72 | 0.48 | 0.70 | 0.48 | 0.72 | 0.50 | 0.600 | Wear scars asymmetric |

### 3.7.1.b 4 Ball Weld Point Load

The results obtained for the one-hour wear tests at 30 kg load at 1475 (+/-25) rpm are shown below with the mean wear scar diameters measured for CLEO demonstrating 50% less wear than the acceptance criteria of 1.2 mm as specified in ISO 13628-6.

| Lubricant | Initial Test Load (kg) | Initial Seizure Load* (kg) | Weld Point Load (kg) | Duration of Load steps (sec) | RPM | Comments |
|---|---|---|---|---|---|---|
| CLEO | 10 | 80 | >120 | 10 | 1470 | Wear scars asymmetric |

* measured from friction traces

The initial test load showed that CLEO passes the ISO 13628-6 specification requiring a weld load of >120 kg.

## 3.8 FILTERABILITY

300 ml (18.3 $in^3$) of control fluid is filtered under specified conditions through a 0.8 µm filter membrane at a controlled pressure drop of 0.05 MPa (7.25 psi). Filterability is calculated from the ratio of filtration near the start of filtration, to the filtration rate at specified higher filtered volume.

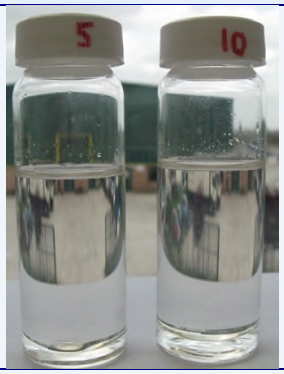
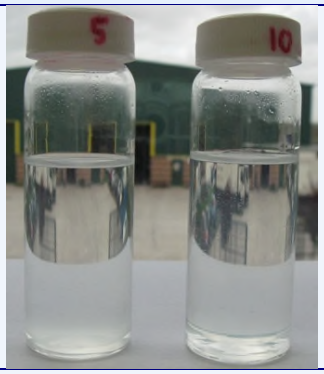
The results for CLEO are tabulated below, and show that both the dry and wet oil exceed the requirements required in ISO 13628-6. Indeed, both the wet and dry oil give filterability results > 80%.

| Fluid | Test 1 | Test 2 | Test 3 | Average Filterability | ISO 13628-6 |
|---|---|---|---|---|---|
| CLEO (dry) | 90.5% | 89.2% | 86.3% | 88.7% | Pass |
| CLEO (wet) +0.5% Sea Water | 89.0% | 84.2% | 85.8% | 86.3% | Pass |

## 3.9 SEA WATER CONTAMINATION

Extensive compatibilities of CLEO with 5 and 10% sea water in accordance with ISO 13628-6 have been undertaken across a range of temperatures and the results after 4 weeks ageing are shown below, in each case, the sample with 5% sea water is shown on the left, and with 10% sea water the right. Further testing is on-going.

CLEO shows only a slight haze in the oil phase upon cooling from 70 °C.

| Temperature | 5 °C | 20 °C | 70 °C |
|---|---|---|---|
| CLEO |  |  |  |
| | Both phases clear and bright | Both phases clear and bright | Both phases clear and bright |

## 3.10 BACTERIAL CONTAMINATION

Bacterial and Fungal resistance was tested by mixing CLEO with synthetic seawater (prepared to ASTM D1141-98) at a ratio of 50:50 v/v, with mixture aged at ambient and or 40 °C as follows: -

- CLEO with fresh sea water, static – ambient and 40 °C.
- CLEO with contaminated sea water, static – ambient and 40 °C.

Both sets of tests showed no evidence of bacterial or fungal growth after 12 months aging.