Extreme Pressure

HDEO EP

HIGH DENSITY ENVIRONMENTAL OIL

TECHNICAL SUMMARY MANUAL

Issue 04: 25/02/2019

Prepared by David Gleeson

Offshore Environmental Oils

tech@offshore-oils.com
www.offshore-oils.com
+44 (0) 8452 967751

Aspul Court, Moss Industrial Estate
Leigh, Lancashire, WN7 3PT, UK

1.0 PRODUCT OVERVIEW

HDEO^{EP} High Density Environmental Oil Key Competitive Parameters

HDEO^{EP} (Extreme Pressure) is our mainstream High Density Environmental Oil.

HDEO^{EP} is a High Density Environmental Oil designed for applications where a specific gravity greater than seawater is required, particularly in equipment with a heavy load distribution.

Typical applications include use as a displacement fluid in subsea valves and other applications where displacement of seawater (or water) is desirable.

HDEO^{EP} offers outstanding environmental properties and is OCNS E (with no substitutable components) for UK discharge and a Yellow Y1 environmental classification for use in Norwegian waters.

HDEO^{EP} exhibits excellent corrosion protection, stability, microbiological protection, material compatibility and all round technical performance. HDEO^{EP} also offers acceptable freeze protection and is insoluble in seawater/water.

HDEO^{EP} offers excellent lubrication and anti-wear properties.

HDEO^{EP} was specifically developed to offer acceptable compatibility with high quality elastomers/seals commonly used in Subsea and Topside Control Systems.

DOCUMENT REVISION HISTORY

Issue No.	Revision	Issue Date	Authorised by	Position
1	0	June 2012	D. Gleeson	R&D Manager
2	0	March 2015	D. Gleeson	R&D Manager
3	0	February 2018	D. Gleeson	R&D Manager
4	0	February 2019	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.

Information given in this publication is based on Technical Data gained in our own and other laboratories and is believed to be true. However, if the material is used in conditions beyond our control, we can assume no liability for results obtained or damaged incurred through the application of the data present herein.

Certified ISO 9001-2015
For the Development, Manufacture and Supply of Speciality Chemicals

ISOQAR REGISTERED
UKAS MANAGEMENT SYSTEMS 0026

Certificate No 2906- QMS-001

TABLE OF CONTENTS

	Page
1.0 Product Overview	**2**
2.0 Typical Physical Properties	**4**
2.1 Key Physical Properties Summary	4
2.1.1 Physical Properties As A Function Of Pressure At 4 °C	5
3.0 Product Testing	**5**
3.1 Thermal Stability	5
3.2 Metal Compatibility	5
3.4 Compatibility with Actuator Spring Steel	6
3.5 Elastomer Compatibility	6
3.6 Compatibility with Control, Completion and Operational Fluids	7
3.9 Fluid Lubricity and Wear	7
3.9.1 Shell One Hour 4 Ball Wear Test (IP 239)	7
3.9.2 Power Screw Testing	7
3.9.2.2 Power Screw Rig Setup	7
3.9.2.3 Test Procedure	9
3.9.2.1 Power Screw Testing Results	9
3.10 Bacterial & Fungal Resistance with Seawater	9
3.11 Compatibility of HDEO and $HDEO^{EP}$	10
3.12 Sea Water Compatibility Under Static Conditions	10

2.0 TYPICAL PHYSICAL PROPERTIES

2.1 KEY PHYSICAL PROPERTIES SUMMARY

Property	HDEO[EP]	Test Method
Viscosity (cSt)		
@ -10 °C	8280	ASTM D445 IP71 ISO 3104
@ 0 °C	2805	
@ 5 °C	1850	
@ 20 °C	630	
@ 40 °C	182	
@ 80 °C	36	
Pour Point	-30 °C [a]	IP15
Minimum recommended operating temperature	-10 °C [a]	
Specific Gravity (gcm^{-3})		
0	1.080	IP365
20	1.063	
Appearance	Pale Yellow Liquid	
Steel Corrosion	Pass	ASTM D665 Part A
Flash Point / °C	>200	ASTM D92 / IP36
Cleanliness Level (Minimum)	19/17/14	ISO 4406
	NAS 8	NAS 1638
	8B/8C/8D/8E/8F	SAE AS4059
Shell 4 Ball Wear Test	Mean Wear Scar Diameter 0.623 mm Symmetric Wear Scar	IP239/01, 1 hour test, 1475rpm rotation, 30 kgf load
Torque @3600 N	378	Power screw testing
Solubility in Water	Insoluble	
Coefficient of Thermal Expansion	0.00077 1/°C	
Bulk Modulus @ 4 °C, 1 Bara	1.09 (Nm^{-2} x 10^{9})	
Instantaneous Compressibility @ 4 °C, 1 Bara	91.6 (bar^{-1} x 10^{-6})	
Specific Heat Capacity		
10 – 25 °C	2.12 MJ/m^{3}K	
25 – 40 °C	2.19 MJ/m^{3}K	
60 – 80 °C	2.33 MJ/m^{3}K	
80 – 100 °C	2.42 MJ/m^{3}K	
Thermal Conductivity		
Mean Temperature 25 °C	0.159 W/(m.K)	ISO 9301
Mean Temperature 70 °C	0.164 W/(m.K)	
Mean Temperature 100 °C	0.162 W/(m.K)	

[a] Whilst the pour point of HDEO[EP] is -30 °C, Offshore Environmental Oils recommends a minimum operating temperature of -10 °C due to the rapid increase in viscosity upon cooling below -10 °C.

Shell 4 Ball, Bulk Modulus, Instantaneous Compressibility, Thermal Properties and Thermal Expansion tests were conducted by independent laboratories.

Note these properties are typical for the product and do not constitute a product specification.

2.1.1 PHYSICAL PROPERTIES AS A FUNCTION OF PRESSURE AT 4 °C

The physical properties of HDEO^{EP} as a function of pressure at 4 °C are tabulated below.

Pressure / Bara	Relative volume	Density / g cm^{-3}	Instantaneous Compressibility / x 10^{-6} bar^{-1}	Bulk Modulus / x 10^{9} N m^{2}	Dynamic Viscosity / cP
1.1	1	1.0735	91.6	1.09	2819
35.5	0.9969	1.0769	59.5	1.68	2949
70	0.9948	1.0791	49.9	2.01	3178
138.9	0.9914	1.0828	44.3	2.26	3807
276.8	0.9854	1.0894	39.1	2.56	5539
414.7	0.9801	1.0953	37.4	2.67	7737
552.6	0.9751	1.1009	36.2	2.76	10307
690.5	0.9702	1.1064	35.5	2.82	13193

3.0 PRODUCT TESTING

3.1 THERMAL STABILITY

HDEO^{EP} has undergone accelerated aging testing based on the procedures laid out in API 17F and meets the requirements of specification after aging at 70 °C for 12 months.

HDEO^{EP} has also undergone low temperature stability testing based on the procedures laid out in API 17F and remains visually unchanged after aging at 5 °C and -25 °C for 24 months and unchanged after 6 months at -50 °C which is well below the pour point of the fluid.

3.2 METAL COMPATIBILITY

HDEO^{EP} has been shown to be compatible with a wide range of metals in testing based on API 17F.

Metals compatibility after 12 weeks immersed in HDEOEP at 70 °C

9Cr1Mo Alloy 18 - 22 C	Aluminium Bronze (UNS C63000)	SIS 2387
17-4-PH (UNS S17400)	Becol (UNS C17200)	Silicon Nitride
ASTM A182 F51 Super Duplex (UNS S31803)	Carbon Steel UNS K02401	Stainless Steel 304
ASTM A182 F53 Super Duplex (UNS S32750)	Chrome Core	Stainless Steel 316
A182 F55 UNS S32760 (Super Duplex)	Copper	Stainless Steel 316 Ti
ALCNC10	DGS1043	Stainless Steel 416
AISI A29 4340 (Gas Nitrided)	Duplex 9490	Stainless Steel 431
AISI A350 LF2 Carbon Steel	Elgiloy	Super Duplex (OEM)
AISI 410	Inconel 718	Super Duplex AM8831
AISI 420	Inconel 725 GV50H	Titanium
AISI 440C	Inconel 825	Toughmet 3 AT110 (UNS C72900)
AISI 1040	KR16	Tungsten Carbide (6% Nickel Bonded)
AISI 4130	Monel 400	Tungsten Carbide (10% Nickel Bonded)
AISI 4140	Monel K500	Tungum (UNS C699100)
AISI 6150	MP35N	Umbilical TP19D
Alloy 3	Nitronic 50	Zirconia
Aluminium Bronze AISI B418	Phosphor Bronze PB102	Zinc Plated Washer
Aluminium Bronze HM9843		

Coatings compatibility after 12 weeks immersed in HDEOEP at 70 °C

36CrNiMo4 (OEM)	Molycoat D-7409 (CWST)	Xylan 1014
Electroless Nickel Plated	Niklad ELV811 Coated A182 F22	Xylan 1052
Everslik 1201 (OEM Specification)	Rislan	Xylan 1212
Everslik 1201 (CWST)	Sermagard 1105 (CWST)	Xylan 1213
Everslik 1301 (CWST)	Sermagard 1105 + 1280 (OEM Specification)	Xylan 1400
Inconel 718 Gold Coated	Sermagard 1105 + Everslik 1201 (CWST)	Xylan 1424
Inconel 718 Silver Coated	Sermagard 1105 + Everslik 1201 + Xylan 1400 (CWST)	Zinc Phosphate Coated Mild Steel
Inconel 725 Silver Coated		Zinc Coated Washer

3.4 COMPATIBILITY WITH ACTUATOR SPRING STEEL

The compatibility of HDEO^{EP} with actuator spring material and the potential to form hydrogen (potentially giving hydrogen embrittlement issues) has been undertaken.

Briefly, HDEO^{EP} was degassed at 60 °C prior to the start of the test. A piece of the coated spring material was then immersed in the fluid, covered with a funnel and any gasses evolved collected in a micro centrifuge tube and vials as shown below.

After 24 months aging at 60 °C HDEO^{EP} shows no evolution of gas.

It should be noted that the actuator spring steel tested was selected from material available in-house and is not meant to represent an official qualification.

3.5 ELASTOMER COMPATIBILITY

HDEO^{EP} has been shown to be compatible with a range of elastomers in accordance with testing based on the procedures laid out in API 17F. A summary of the elastomers which are known to be compatible with HDEO^{EP} is given below.

AC 155 (Accuseal)	Hytrel 5556 Shore 55D (Dupont)	Polypropylene (Direct Plastics)
AC 157 (Accuseal)	Hytrel 6356 Shore 63D (Dupont)	POM (polyoxymethylene) (OEM)
AC 173 (Accuseal)	Hytrel 7246 Shore 72D (Dupont)	PTFE (OEM)
Acetal (OEM)	Lexan Margard (Sabic)	PTFE (25% Carbon Filled) (OEM)
Acylic (Direct Plastics)	LNP-PDX 82429 Carbon Filled PTFE (OEM)	Turcon M12 (Trelleborg)
Aflas (Clywd)	NBR N107-90 (Parker)	Turcon T05 (Trelleborg)
Arlon 1555 (Greene Tweed)	NBR N299-90	Turcon T12 (Trelleborg)
Carbon Fibre (Carbon Fibre Seal Company)	NBR N552-90 90 Shore A (Parker)	Turcon T19 (Trelleborg)
Ecoflon 4 25% Carbon Filled PTFE (Economos)	NBR N674-70 70 Shore A (Parker)	Turcon T29 Step Seal (Trelleborg)
	NBR N702-90 (Parker)	Turcon T40 (Trelleborg)
Elastolion 101 HNBR (James Walker)	NBR N1059-90 (Parker)	Turcon T42 (Trelleborg)
FFKM PFR06HC 90 Shore A (Solvay)	NBR N7023 70 Shore A (Trelleborg)	Turcon T46 (Trelleborg)
FFKM PKR95HT 90 Shore A (Solvay)	NBR N9002 90 Shore A (Trelleborg)	Turcon T51 (Trelleborg)
FKM FR58-90 James Walker	Nylon 6 (Skiffy)	Ultra High Molecular Weight Polyethylene (UHMWPE)
FKM FOR 9381 92 Shore A (Solvay)	Nylon 6,6 (Direct Plastics)	
FKM P959 93 Shore A (Solvay)	PEEK 450G (Victrex)	Viton V9T82 (Trelleborg)
FKM VBR X856 90 Shore A (Clwyd)	PEEK 450CA30 (30% Carbon Filled) (Victrex)	Viton V9T84 (Trelleborg)
FKM V70GA 70 Shore A (Trelleborg)		Viton VG109-90 (Parker)
FKM VPL85540 92 Shore A (Solvay)	PEEK 1000 (OEM)	Zurcon Z25 (Trelleborg)
FKM VPL 85730 91 Shore A (Solvay)	PEEK W4685 (Parker)	Zurcon Z43 (Trelleborg)
FKM V1238-95 95 Shore A (Parker)	PEEK W4685 (Parker)	Zurcon Z52 (Trelleborg)
HNBR 4007 90 Shore A (Parker)	PEEK W4738 (Parker)	Zurcon Z80 (Trelleborg)

Please note that while testing based on API 17F (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.*

3.6 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 API 17F or using a procedure with similar aging times, mixture ratios, and temperatures. Fluids tested for compatibility include:

- Pelagic 100, Pelagic 100 HC, Transaqua HT-2, Oceanic HW443, Oceanic HW740R
- Brayco Micronic SV/B, Brayco Micronic SV/3, CLEO, USF04, OB200
- Calcium chloride and bromide brines, Zinc bromide brine, Potassium and Caesium formate brines.
- 35% Hydrochloric acid, Methanol, Silicon Oil, Mono Ethylene Glycol

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

3.9 FLUID LUBRICITY AND WEAR

HDEO^{EP} has excellent Extreme Pressure lubrication properties and was especially developed for equipment and applications requiring a heavy load distribution.

3.9.1 SHELL ONE HOUR 4 BALL WEAR TEST (IP 239)

The 1 hour 4 ball wear test was undertaken in accordance with API 17F by an independent laboratory. The results obtained for the one-hour wear tests at 30 kg load at 1475 (+/-25) rpm are shown below and the mean wear scar diameters measured are less 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
HDEO^{EP}	0.64	0.62	0.62	0.64	0.60	0.62	0.623	Symmetric Wear Scars

3.9.2 POWER SCREW TESTING

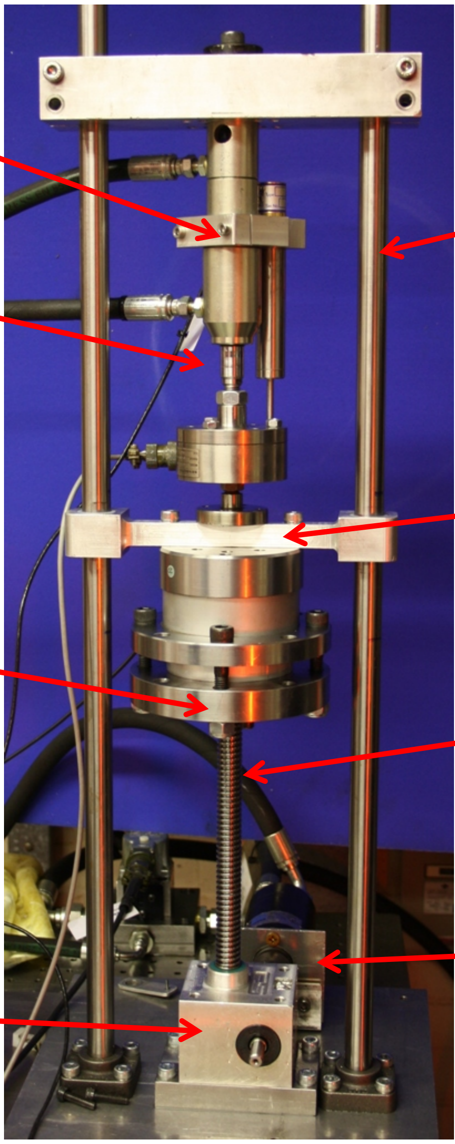
ESR Technology's National Centre of Tribology (NCT) constructed a specialist test rig, to carry out a series of lubricants developed for power screw applications.

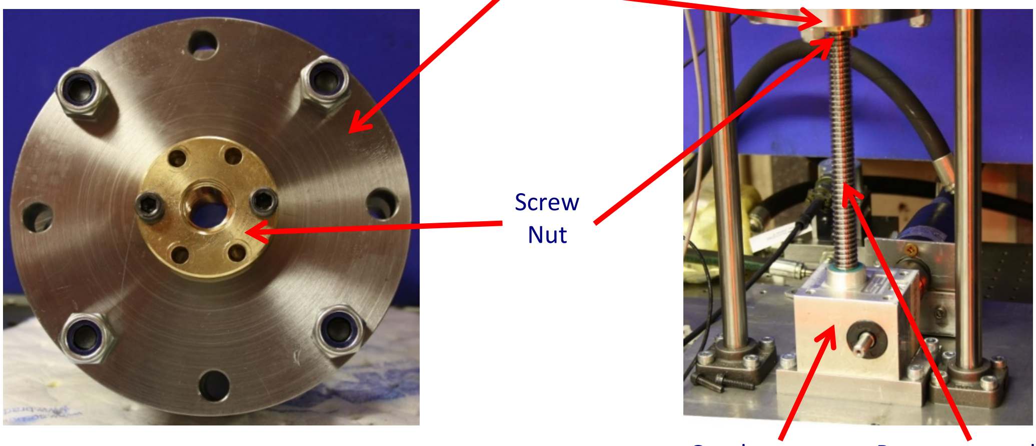
3.9.2.2 POWER SCREW RIG SETUP

ESR Technology's National Centre of Tribology (NCT) constructed a test rig, consisting of a standard screw jack mounted in a loading frame, to carry out a series of comparative lubricant tests on fluids used and developed for power screws.

One side of the power jack gearbox input shaft was connected to a rotary hydraulic motor via a flexible coupling to provide motive power for the tests. The torque cell reacts against a cross beam onto which either dead weights or a hydraulic cylinder acted through a calibrated load cell to provide the screw/nut loading.

The major components of the power screw test rig are shown overleaf.



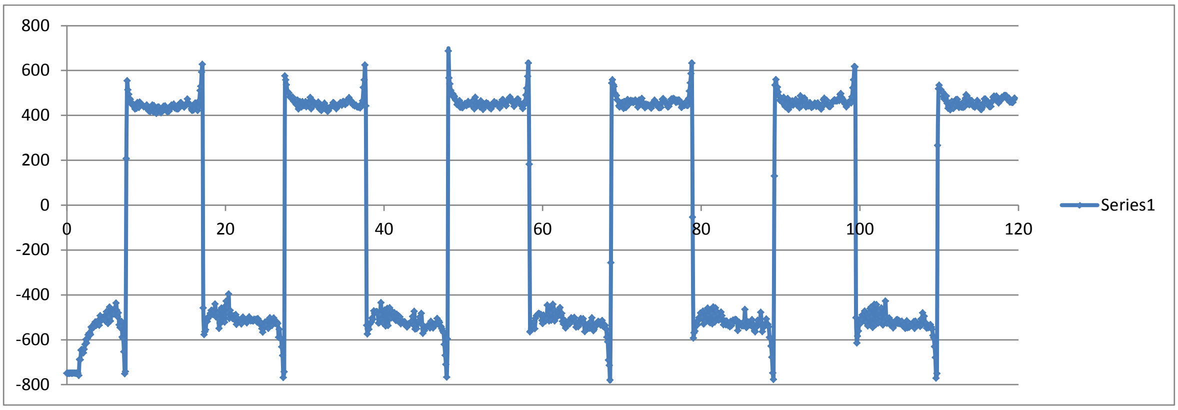


3.9.2.3 TEST PROCEDURE

Square wave constant velocity motion of the nut up and down the screw was used. The output of the torque cell was then recorded together with time, position and load signals from the software in the digital controller for each stage of testing on the fluids.

Multiple tests per fluid were carried out until only a small variation in the torque result was determined for 3 sequential tests. Each set of test data was then analysed to produce a mean torque during each interval of testing.

Examples of the torque traces produced, and the mean torque levels determined for fluids of interest at the various levels of load are shown below.



The standard deviation on the torque levels calculated can be seen to small and indicative of the level of repeatability that is obtainable between subsequent tests.

3.9.2.1 POWER SCREW TESTING RESULTS

The results for the Power Screw testing at different loads are tabulated below.

Parameter	900 N Load	3600 N Load
Run 1	107.1	376.9
Run 2	106.3	377.8
Run 3	102.8	378
Average Torque	**105.4**	**377.57**
Standard Deviation	2.3	0.6

3.10 BACTERIAL & FUNGAL RESISTANCE WITH SEAWATER

Bacterial and Fungal resistance was tested by mixing $HDEO^{EP}$ 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 with uncontaminated sea water. The results are tabulated below.

No bacterial or contamination has been after 12 weeks aging when mixing $HDEO^{EP}$ with uncontaminated sea water. Extensive mould is formed in the sea water only sample aged in the absence of any displacement fluids. This suggests that $HDEO^{EP}$ does not support or promote the growth of bacteria or fungi in the presence of sea water.

3.11 COMPATIBILITY OF HDEO AND HDEO^{EP}

Mixtures of HDEO and HDEO^{EP} have been aged at 4 and 70 °C for 6 months showing HDEO and HDEO^{EP} are completely miscible giving a single phase. No deposit formation or incompatibilities have been observed.

3.12 SEA WATER COMPATIBILITY UNDER STATIC CONDITIONS

Static testing of HDEO^{EP} with 5 and 10% Sea water at 5, 20 and 70 °C for up to 3 months has been undertaken and the results reported below.

In all tests conducted all fluids yielded similar/identical results.

HDEO^{EP} with 5% sea water at different temperatures

Aging Temp / °C	Aging Time / weeks	Appearance
N/A	N/A	Two distinct phases, clear sea water floating on surface of yellow coloured HDEO^{EP}
5	1	Two distinct phases, clear sea water floating on surface of yellow coloured HDEO^{EP}
5	2	Two distinct phases, clear sea water floating on surface of yellow coloured HDEO^{EP}
5	4	Two distinct phases, clear sea water floating on surface of yellow coloured HDEO^{EP}
5	12	Two distinct phases, clear sea water floating on surface of yellow coloured HDEO^{EP}
20	1	Two distinct phases, clear sea water floating on surface of yellow coloured HDEO^{EP}
20	2	Two distinct phases, clear sea water floating on surface of yellow coloured HDEO^{EP}
20	4	Two distinct phases, clear sea water floating on surface of yellow coloured HDEO^{EP} with very fine flocculation
20	12	Two distinct phases, clear sea water floating on surface of yellow coloured HDEO^{EP} with very fine flocculation.
75	1	Two distinct phases, clear sea water floating on surface of yellow coloured HDEO^{EP}
75	2	Two distinct phases, clear sea water floating on surface of hazy, yellow coloured HDEO^{EP}
75	4	Two distinct phases, clear sea water floating on surface of yellow coloured HDEO^{EP} with very fine flocculation.

HDEO^{EP} with 10% sea water at different temperatures

Aging Temp/ °C	Aging Time / weeks	Appearance
N/A	N/A	Two distinct phases, clear sea water floating on surface of yellow coloured HDEO^{EP}
5	1	Two distinct phases, clear sea water floating on surface of yellow coloured HDEO^{EP}
5	2	Two distinct phases, clear sea water floating on surface of yellow coloured HDEO^{EP}
5	4	Two distinct phases, clear sea water floating on surface of yellow coloured HDEO^{EP}
5	12	Two distinct phases, clear sea water floating on surface of yellow coloured HDEO^{EP}
20	1	Two distinct phases, clear sea water floating on surface of yellow coloured HDEO^{EP}
20	2	Two distinct phases, clear sea water floating on surface of yellow coloured HDEO^{EP}
20	4	Two distinct phases, clear sea water floating on surface of yellow coloured HDEO^{EP} with very fine flocculation.
20	12	Two distinct phases, clear sea water floating on surface of yellow coloured HDEO^{EP} with very fine flocculation.
75	1	Two distinct phases, clear sea water floating on surface of yellow coloured HDEO^{EP}
75	2	Two distinct phases, clear sea water floating on surface of hazy, yellow coloured HDEO^{EP}
75	4	Two distinct phases, clear sea water floating on surface of yellow coloured HDEO^{EP} with very fine flocculation.
75	12	Two distinct phases, clear sea water floating on surface of yellow coloured HDEO^{EP} with very fine flocculation.

Sea Water Testing – Cylinders Appearance

Further testing to evaluate the separation of HDEO^{EP} and sea water as a function of time and temperature was undertaken as follows. HDEO^{EP} (70 ml) and sea water made to ASTM D1141-98 (30ml) were added to a stoppered, glass measuring cylinder after being preheated to the relevant temperature. The mixtures were then aged at 4, ambient and 60 °C, and monitored weekly for appearance. After 2 weeks aging, all the fluids remained completely separate, with both phases clear and bright at all temperatures. After 3 weeks aging, the 4 °C and ambient samples remain separate, with both phases clear and bright. At 60 °C, the phases are still fully separated, however the HDEO^{EP} phase has a cloudy appearance. The detailed results are presented below.

Sea Water Testing – Cylinders Appearance

Aging Time	Fluid	Aging Temperature		
		4 °C	**Ambient**	**60 °C**
2 weeks	HDEO ^{EP}	Both phases clear & bright, complete separation	Both phases clear & bright, complete separation	Both phases clear & bright, complete separation
3 weeks	HDEO ^{EP}	Both phases clear & bright, complete separation	Both phases clear & bright, complete separation	HDEO ^{EP} slight hazy, sea water clear and bright
1 month	HDEO ^{EP}	Both phases clear & bright, complete separation	Both phases clear & bright, complete separation	HDEO ^{EP} slight hazy, sea water clear and bright

The appearance of fluids after 1 months aging at the different temperatures is shown below.

Aging Temperature		
4 °C	**20 °C**	**60 °C**
		
Both layers fully separated, clear and bright in appearance.	Both layers fully separated, clear and bright in appearance.	Both layers remain separated, water layer is clear and bright, HDEO^{EP} layer is hazy in appearance.