



Envirotemp[™] FR3[™] Fluid

Test Summary

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R2030

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Envirotemp™ FR3™ fluid has undergone one of the most comprehensive testing regimen of any alternative dielectric fluid. Since its formulation was selected, Envirotemp FR3 fluid has been subjected to over 250 series of tests as outlined below, and the results prove that it is the dielectric fluid of choice for the 21st century, enabling safer equipment that lasts longer while helping to protect our environment. No other choice offers the industry a better answer to reliability, sustainability, and conservation of raw materials.

Table 1 – Specifications

Property	Method	3 rd Party
Appearance	ASTM D1524	yes
	IEC 60296	yes
Color	ASTM D1500	yes
	ISO 2211	yes
Dielectric Strength	ASTM D877	yes
	ASTM D1816, 1 mm gap	yes
	ASTM D1816, 2 mm gap	yes
	IEC 60156	yes
Dissipation Factor	ASTM D924	yes
	IEC 60247	yes
Impulse Breakdown	ASTM D3300	yes
Gassing Tendency	ASTM D2300	yes
Flash Point	ASTM D92	yes
	ISO 2592	yes
Fire Point	ASTM D92	yes
	ISO 2592	yes
Viscosity	ASTM D445	yes
	ISO 3104	yes
Pour Point	ASTM D97	yes
	ISO 3016	yes
Relative Density	ASTM D1298	yes
	ISO 3675	yes
Water Content	ASTM D1533B	yes
	IEC 60814	yes
Acid Number	ASTM D974	yes
	IEC 61099 9.11	yes
PCB Content	ASTM D4059	yes
	IEC 61619	yes
Corrosive Sulfur	ASTM D1275	yes
	DIN 51353	yes

Table 2 – Electrical Characterization

Test		Method	3 rd Party
Dielectric Strength	<i>versus</i> temperature	ASTM D877 ASTM D1816	
	<i>versus</i> water content	ASTM D1816	yes
	1% Weibull	ASTM D1816	yes
Dissipation Factor	<i>versus</i> temperature	ASTM D924	
Volume Resistivity		ASTM D1169 IEC 60247	yes yes
	<i>versus</i> temperature	ASTM D1169	yes
	DC Leakage	CPS	
Dielectric Constant		ASTM D924 IEC 60427	yes
	<i>versus</i> temperature	ASTM D924	yes
	Impulse Withstand	point – sphere	ASTM D3300
sphere – sphere		ASTM D3300	
<i>versus</i> water content		ASTM D3300	yes
Solid Insulation paper	50 Hz withstand	Univ. of Manchester	yes
	impulse breakdown	ASTM D3426	yes
	cylinder – cylinder	ASTM D3300	yes
pressboard	full wave impulse	positive	GE
		negative	GE
epoxy/fiberglass board	full wave impulse	positive	CPS
		negative	CPS
	60 Hz withstand	CPS	
Partial Discharge Inception		Univ. of New South Wales	yes
		Univ. of Manchester	yes
		Univ. of Hannover	yes
Gassing Tendency		ASTM D2300	yes

Table 3 – Electrical Clearance Design

Test		Method		3 rd Party	
Oil Gap	60 Hz Withstand (3–150mm)		IEEE Std. 4, IEC 60060-1	yes	
			EHV Weidmann	yes	
	50 Hz Withstand		Univ. of Hannover	yes	
			Univ. of Stuttgart ASTM D149	yes yes	
Oil Gap	full wave impulse (3–150mm)	negative	IEEE Std. 4, IEC 60060-1 IEC 60060-1	yes yes	
		positive	IEEE Std. 4, IEC 60060-1	yes	
	switching surge impulse (3–150mm)	negative	IEEE Std. 4, IEC 60060-1	yes	
		positive	IEEE Std. 4, IEC 60060-1	yes	
	chopped wave impulse (3-50mm)	negative	IEEE Std. 4, IEC 60060-1	yes	
		positive	IEEE Std. 4, IEC 60060-1	yes	
	Creep Gap	full wave impulse (10–50mm)	negative	Univ. of Stuttgart EHV Weidmann	yes yes
			1% Weibull positive	EHV Weidmann Univ. of Stuttgart EHV Weidmann	yes yes yes
1% Weibull		EHV Weidmann	yes		
60 Hz Withstand (10–45mm)			IEEE Std. 4, IEC 60060-1	yes	
			EHV Weidmann	yes	
		1% Weibull	EHV Weidmann	yes	



Table 4 – Fire Safety and Flammability Characterization

Test		Method	3 rd Party
FLAMMABILITY CHARACTERIZATION			
Flash Point	Cleveland open cup	ASTM D92	yes
		ISO 2592	yes
	Pensky-Martens closed cup	ASTM D93	
Fire Point		ASTM D92	yes
		ISO 2592	yes
Auto-Ignition Point		ASTM E659	yes
Net Calorific Value		ISO 1716	yes
		ISO 1928	yes
FIRE SAFETY			
Transformer Oil Fire – Full Scale		Union Fenosa	yes
	arc ignition & spray mist ¹	FM Global	yes
	hot metal ignition ²	FM Global	yes
	retrofill ²	FM Global	yes
Under-Oil Ignition		CPS	
Bayonet Fusing	interruption rating	UL	yes
	gas generation	UL	yes

¹ Less Flammable Fluid per NEC, using full scale distribution class transformer tanks

² Relieve fire safeguard requirements for FM Approved Fluids in medium power transformers

Table 5 – Environmental

Test		Method	3 rd Party
Total Life Cycle Environmental Impact Analysis		NIST BEES 4.0e	yes
TOXICITY			
Acute Aquatic Toxicity		OECD 203 Environment Canada	yes yes
Acute Oral Toxicity		OECD 420	yes
BIODEGRADATION			
Aquatic	2-stroke outboard oil in water ¹	CEC L-33-A-93	yes
	aerobic ready	EPA OPPTS 835.3100 EPA OPPTS 835.3110	yes yes
Oxygen Demand	biological oxygen demand chemical oxygen demand oxidation depletion	BOD ₅ COD Univ. of Cincinnati	yes yes yes
SITE ASSESSMENT			
Total Petroleum Hydrocarbons	fuel recoverable extractable	SW-846 Modified 8015B EPA 600/4-79/020 418.1 MADEP-EPH-04-1.1	yes yes yes
Total Recoverable Oil & Grease	gravimetric spectrophotometric	EPA 600/4-79/020 413.1 EPA 600/4-79/020 413.2	yes yes
Target Compound List	semi-volatile organics volatile organics	EPA SW-846 8270C EPA SW-846 8260B	yes yes
Toxicity Characteristic Leaching Procedure	metals semi-volatiles volatiles	EPA SW-846 1311, 7000 series EPA SW-846 1311, 3510 EPA SW-846 1311, 5030, 8260	yes yes yes
Total Threshold Limit Concentration	metals	EPA SW-846 6010, 7000 series	yes
Total Organic Halides (TOX)		EPA SW-846 9020B	yes
Leachable Fluoride		EPA 600/4-79/020 340.2	yes
Cyanides	reactive in waste	EPA SW-846 7.3.3 ASTM D5049	yes yes
Sulfides	reactive in waste	EPA SW-846 7.3.4 ASTM D4978	yes yes
Polynuclear Aromatic Hydrocarbons		EPA SW 846 - Modified 8100	yes
Soil and Waste pH		EPA SW-846 9045C	yes
Heat of Combustion		ASTM D240	yes
Ignitability	flash point - Pensky-Martens flash point - Setaflash auto-ignition point	EPA SW-846 1010 EPA SW-846 1020A ASTM E659	yes yes yes
Specific Gravity		SM 2710F	yes

¹ no longer supported by CEC



Table 6 – Thermal Design and Physical Characterization

Test		Method	3 rd Party
THERMAL DESIGN			
Viscosity	<i>versus</i> temperature <i>versus</i> time	ASTM D445 CPS	
Density	<i>versus</i> temperature	ASTM D1298	
Specific Heat	<i>versus</i> temperature	ASTM D2766 DSC	
Heat Capacity	<i>versus</i> temperature	ASTM E1269	yes
Thermal Conductivity	<i>versus</i> temperature	ASTM D5334 ASTM D2717	yes
Thermal Expansion		ASTM D1903 CPS	yes
PHYSICAL CHARACTERIZATION			
Pour Point	<i>versus</i> time	CPS	
Cloud Point		ASTM D2500 ISO 3015	
	<i>versus</i> time	CPS	
Phase Change	heat of melting	CPS	
	heat of crystallization	CPS	
	melting peak temperature	CPS	
	crystallization temperature	CPS	
Cold Storage		CPS	
Freeze & Thaw		CPS	
Relative Density	<i>versus</i> time	ASTM D4052	
	<i>versus</i> temperature	CPS	
Lubricity	four-ball wear	ASTM D4172B	yes
Refractive Index		ASTM D1807 ISO 6320	
Infrared Absorption		FTIR	
Average Molecular Weight		Gel Permeation	
Fatty Acid Distribution		AOCS Ce-1e-91	yes
Total Fatty Acids		AOAC Method 969.33	yes
Phenolic Antioxidants		AOAC Method 983.15	yes
Polymers and Oxidation Products		AOAC Method 977.17	yes

Table 7 – Chemical Characterization

Test		Method	3 rd Party
Water Saturation	<i>versus</i> temperature	CPS Doble	yes
Water/Paper Equilibrium	Piper chart	CPS	
Corrosive Sulfur		ASTM D1275 A ASTM D1275 B Doble/Cooper Modified	yes yes yes
Acid Number		ISO 660	
Interfacial Tension		ASTM D971 ISO 6295	yes yes
Aniline Point		ASTM D611	yes
Acidity	pH	EPA SW 9045C	yes
Gas Solubility	partition coefficients Ostwald coefficients	ASTM D3612 IREQ	yes yes
Dissolved Gases	sampling & analysis	ASTM D3612 IEC 60567	yes yes
	interpretation	IEEE C57.104 IEC 60559	yes yes
Envirotemp FR3 fluid-specific Duval triangle		Duval	yes
	Fault gases	EPRI Univ. of Manchester CPS	yes yes yes
Furanic Compounds		ASTM D5837 Modified ASTM D5837 IEC 61198 CPS	yes
Peroxide Value		AOCS Cd 8-53	
Particles		ASTM D6786 Univ. of Manchester	yes yes
Inhibitor Content	infra-red gas chromatography	ASTM D2668 ASTM D4768	yes yes
Oxidation Stability	mineral oil methods	rotating bomb ASTM D2112 bubbling oxygen ASTM D2440 bubbling air modified ASTM D2440 IEC 61125C	yes yes yes yes
	Sludge-free life	Doble	yes
	Power factor-valued oxidation	Doble PFVO	yes
	Oxidation induction time ¹	DSC CPS	
		Pressure DSC CPS	

¹ proposed ASTM standard test method (WK 216165)



Table 8 – Material Compatibility and Aging

Test		Method	3 rd Party
Gaskets		ASTM D471 CPS	
Transformer Materials		CPS	
Greases		CPS	
Paints		CPS	
Elbow Elastomers		CPS	
Coking Tendency		CPS	
Solid Insulation Impregnation Rates		EHV Weidmann Univ. of Manchester	yes yes
Termination Chamber	cable oil lead/paper cable	CPS CPS	
Envirotemp FR3 fluid/Mineral Oil Blends		multiple	yes
Thermal Evaluation			
Transformers	standard ¹ extended ² dissolved gas evolution	IEEE C57.100 modified IEEE C57.100 modified IEEE C57.100	
Sealed Tube	plain Kraft cotton/Kraft retrofill mineral oil blends thermally upgraded Kraft	IEEE C57.100 IEEE C57.100 IEEE C57.100 IEEE C57.100 IEEE C57.100	
Per Unit Life Aging	“A” factor ³	IEEE C57.91	

¹ qualification of Envirotemp™ FR3™ fluid/TUK paper as 65 K rise (110°C hottest spot) insulation system

² qualification of Envirotemp™ FR3™ fluid/TUK paper as 75 K rise (120°C hottest spot) insulation system

³ sealed tube results used to calculate “A” factor and qualify Envirotemp™ FR3™ fluid/TUK paper as 85 K rise (130°C hottest spot) insulation system

Table 9 – Certifications

Type	Agency	Approval	Listing
General Fire Safety	Underwriter’s Laboratories	Dielectric Medium Classification	EOUV
NEC Compliance	Underwriter’s Laboratories FM Global	Transformer Fluid Classification Less Flammable Transformer Fluid	EOVK 6933
Environmental	California EPA US EPA/California EPA US Dept. of Agriculture	Environmental Technology Certification Environmental Technology Verification BioPreferred	03-01-040 EPA 600/R-02/042 Envirotemp FR3 Fluid

Table 10 – CPS Four Position Sectionalizing Loadbreak Switch, 12.5 kA

Test			Method	Certified Test Report
Interrupting Current	load current	200 A	IEEE C37.71 Clause 6.2.1	yes
		300 A	IEEE C37.71 Clause 6.2.1	yes
		600 A	IEEE C37.71 Clause 6.2.1	yes
Magnetizing current		15.5 kV	IEEE C37.71 Clause 6.2.2	yes
		27.0 kV	IEEE C37.71 Clause 6.2.2	yes
		38.0 kV	IEEE C37.71 Clause 6.2.2	yes
Cable charging current		15.5 kV	IEEE C37.71 Clause 6.2.3	yes
		27.0 kV	IEEE C37.71 Clause 6.2.3	yes
		38.0 kV	IEEE C37.71 Clause 6.2.3	yes
Momentary current	15.5 kV		IEEE C37.71 Clause 6.3.1	yes
		27.0 kV	IEEE C37.71 Clause 6.3.1	yes
		38.0 kV	IEEE C37.71 Clause 6.3.1	yes
Making current	15.5 kV		IEEE C37.71 Clause 6.3.2	yes
		27.0 kV	IEEE C37.71 Clause 6.3.2	yes
		38.0 kV	IEEE C37.71 Clause 6.3.2	yes
AC Withstand	15.5 kV		IEEE C37.71 Table 1	yes
		27.0 kV	IEEE C37.71 Table 1	yes
		38.0 kV	IEEE C37.71 Table 1	yes
Thermal	630A	new switch	IEEE C37.71 Clause 5.3.1&2	yes
		aged switch	IEEE C37.71 Clause 6.5.5	yes
Mechanical Operations	15.5 kV		IEEE C37.71 Clause 6.6	yes
		27.0 kV	IEEE C37.71 Clause 6.6	yes
		38.0 kV	IEEE C37.71 Clause 6.6	yes
			IEC 60265-1 Clause 6.102	yes
Impulse Withstand	15.5 kV		IEEE C37.71 Table 1	yes
		27.0 kV	IEEE C37.71 Table 1	yes
		38.0 kV	IEEE C37.71 Table 1	yes
DC Withstand	15.5 kV		IEEE C37.71 Table 1	yes
		27.0 kV	IEEE C37.71 Table 1	yes
		38.0 kV	IEEE C37.71 Table 1	yes
One Second Current	630 A		IEEE C37.71 Clause 6.3.3	yes

Table 11 – CPS Four Position Sectionalizing Loadbreak Switch, 16 kA

Test			Method	Certified Test Report
Switching	active load break	630 A, 15 kV	IEC 60265-1 Clause 6.101	yes
		400 A, 24 kV	IEC 60265-1 Clause 6.101	yes
		200 A, 36 kV	IEC 60265-1 Clause 6.101	yes
	capacitive circuit	630 A, 15 kV	IEC 60265-1 Clause 6.101.8.4	yes
		400 A, 24 kV	IEC 60265-1 Clause 6.101.8.4	yes
		200 A, 36 kV	IEC 60265-1 Clause 6.101.8.4	yes
	earth fault		IEC 60265-1 Clause 6.101 & 6.101.8.4	yes
	cable & line charging		IEC 60265-1 Clause 6.101 & 6.101.8.4	yes
	short time & peak withstand		IEC 60265-1 Clause 6.6	yes
short circuit making		IEC 60265-1	yes	
Dielectric	impulse withstand	1.2 x 50µ Sec Wave	IEC 60694 Table 1a, 1b	yes
		Chopped wave	IEEE	yes
	power frequency withstand		IEC 60265-1	yes
Thermal			IEC 60265-1	yes

Table 12 – Design Tests for Bayonet Cartridge/Fuse Assembly

Test			Method	Certified Test Report
Interruption	interruption rating	-25°C	CPS	yes
		-10 – 5°C	CPS	yes
		25°C	CPS	yes
Switching		160 A, 10.0 kV	CPS	yes
		150 A, 15.5 kV	CPS	yes
		80 A, 26.7 kV	CPS	yes
		20 A, 34.5 kV	CPS	yes
Impulse Withstand	1.2x50 µsec 150kV, positive	-25°C	IEEE C37.41, IEEE C57.12	yes
		25°C	IEEE C37.41, IEEE C57.12	yes
	1.2x50 µsec 150kV, negative	-25°C	IEEE C37.41, IEEE C57.12	yes
		25°C	IEEE C37.41, IEEE C57.12	yes
60 Hz Withstand		-25°C	IEEE C37.41, IEEE C57.12	yes
		-15°C	IEEE C37.41, IEEE C57.12	yes
		25°C	IEEE C37.41, IEEE C57.12	yes



Table 13 – Cold Ambient Electrical Performance of DV and Tap Changer Switches

150% Induced Potential Voltage		Method	Certified Test Report	
Tap Changer: 19.9 kV, 150 kV BIL, CPS# 2237500C07, Transformer: CPS# EMUL411199Y25R4				
"E" position	-20°C	7days	IEEE C57.12.90	yes
	-20°C	14days	IEEE C57.12.90	yes
	-30°C	7 days	IEEE C57.12.90	yes
	-30°C	14 days	IEEE C57.12.90	yes
"C" position	-20°C	7 days	IEEE C57.12.90	yes
	-20°C	14days	IEEE C57.12.90	yes
	-30°C	7 days	IEEE C57.12.90	yes
	-30°C	14 days	IEEE C57.12.90	yes
Diverter: 7200 V x 2400 V, CPS# 2237434C03M, Transformer: CPS# ETPP111072A25R4				
	-20°C	7 days	IEEE C57.12.90	yes
	-20°C	14 days	IEEE C57.12.90	yes
	-30°C	7 days	IEEE C57.12.90	yes
	-30°C	14 days	IEEE C57.12.90	yes
Diverter: 19920 V x 7620 V, CPS# 2237435C03M, Transformer: CPS# EMUL111199E50R4				
	-20°C	7 days	IEEE C57.12.90	yes
	-20°C	14 days	IEEE C57.12.90	yes
	-30°C	7 days	IEEE C57.12.90	yes
	-30°C	14 days	IEEE C57.12.90	yes
Diverter: 14400 V x 7200 V, CPS# 2237501C83, Transformer: CPS# ETPP111144D25R4				
	-20°C	7 days	IEEE C57.12.90	yes
	-20°C	14 days	IEEE C57.12.90	yes
	-30°C	7 days	IEEE C57.12.90	yes
	-30°C	14 days	IEEE C57.12.90	yes



Table 14 – Cold Ambient Mechanical Performance of DV and Tap Changer Switches

Mechanical Operation			Method	Certified Test Report
Tap Changer: 19.9 kV, 150 kV BIL, CPS# 2237500C07, Transformer: CPS# EMUL411199Y25R4				
“E” position	-20°C	7days	IEEE C57.12.90	yes
	-20°C	14days	IEEE C57.12.90	yes
	-30°C	7 days	IEEE C57.12.90	yes
“C” position	-20°C	7 days	IEEE C57.12.90	yes
	-20°C	14days	IEEE C57.12.90	yes
	-30°C	7 days	IEEE C57.12.90	yes
Diverter: 7200 V x 2400 V, CPS# 2237434C03M, Transformer: CPS# ETPP1111072A25R4				
	-20°C	7 days	IEEE C57.12.90	yes
	-20°C	14 days	IEEE C57.12.90	yes
	-30°C	7 days	IEEE C57.12.90	yes
Diverter: 19920 V x 7620 V, CPS# 2237435C03M, Transformer: CPS# EMUL111199E50R4				
	-20°C	7 days	IEEE C57.12.90	yes
	-20°C	14 days	IEEE C57.12.90	yes
	-30°C	7 days	IEEE C57.12.90	yes
Diverter: 14400 V x 7200 V, CPS# 2237501C83, Transformer: CPS# ETPP111144D25R4				
	-20°C	7 days	IEEE C57.12.90	yes
	-20°C	14 days	IEEE C57.12.90	yes
	-30°C	7 days	IEEE C57.12.90	yes

Table 15 – Other Full-Scale Tests

Test			Method	3 rd Party
Stationary Switch Contact Life			Hopkinson ¹	yes
Switch Certification, 23 kV, 600 A			IEEE C37.71	yes
Retrofill Switch Load Break			LADWP	yes
Transformer Cold Start			CPS	
			Møre Trafo	yes
Radiator Cold Start			CPS	
Prototype Transformers	3P pad	new (1996)	ASTM, IEEE	yes
		retrofill (1997)	ASTM, IEEE	yes
	1P pole	new (1996)	ASTM, IEEE	
Voltage Regulators	contact life		CPS	
	arc quenching		CPS	
OLTC	certification		WES	yes
OLTC Contact Rod	60 Hz withstand		MR	yes
	50 Hz withstand		MR	yes
	full wave impulse		MR	yes

¹ proposed IEEE test method