Electrical properties of the FLUTEC® liquids

The FLUTEC® liquids are marketed as insulants for electrical equipment; they have been selected to combine high dielectric strength and resistivity with low values of permittivity and dielectric loss.

In contrast to the conventional coolant oils, the FLUTEC® liquids may be employed in both the liquid and the vapour phase. Choice of an appropriate product (or mixture of products) from the range of FLUTEC® liquids makes it possible to control the vapour pressure and thus the insulating properties of the vapour phase. They are not flammable.

Dielectric strength

It is usual to find that liquids of high dielectric strength have high viscosities; fluorocarbon liquids are unique in combining high dielectric strength with low viscosity, so that they can be readily pumped, and thus are efficient coolants. Like all insulating liquids, the FLUTEC® liquids must be kept free from dust, particles of which can act as charge carriers to initiate breakdown.

The electrical properties of the liquids are not affected to any great extent by the presence of dissolved air or moisture below the saturation solubility. Indeed we have operated an electronic device successfully whilst submerged in FLUTEC PP2 with a layer of water floating on top.

The vapour of the FLUTEC® liquids has the high dielectric strength characteristic of non-polar compounds. As in the case of sulphur hexafluoride, the perfluorocarbon molecule can trap slow electrons to form negative ions, thus tending to quench incipient electrical discharge.

The dielectric strength at 50 Hz was measured by the procedure of BS 148, 1972, results are given in Table 1. For dielectric strength of the vapours see Table 2.

Resistivity

The FLUTEC™ liquids are excellent insulants with resistivities in excess of 10^{15} Ω m. Even in the presence of moisture, or prolonged use under conditions of high voltage, the resistivity remains far above the normal requirements for insulation in high voltage systems.

Measurements were made using a "CIGRE" three electrode cell.

Permittivity (dielectric constant) and loss tangent

As might be anticipated for such non-polar molecules and consistent with very low values for refractive index, perfluorocarbons have low permittivities, and very low dielectric loss. These characteristics are retained at frequencies up to 3 GHz. The FLUTEC™ liquids are therefore suitable coolants for a variety of high frequency equipment. The electrical properties are given in Table 1.

The vapours have exceptionally low permittivity, in the region of 1.0002 at normal temperature and pressure.

Table 1 *Electrical properties of the FLUTEC® liquids*

	PP2	PP3	PP6	PP9
Dielectric Strength (kV/mm)	23	22	20	20
50 Hz (BS 148/72)				
Dielectric strength (Pulsed)[a] (kV/mm)	83			
Resistivity, Wm	10^{15}	10^{15}	10^{15}	10^{15}
Permittivity				
50 Hz	1.83	1.92	1.94	
100 k Hz	1.82	1.93	1.95	1.99
1 MHz				2.00
10 M Hz	1.83			
0.9 G Hz	1.83	1.83		1.90
3 G Hz	1.53	1.73		2.29
Loss tangent (x 10^4)				
100 k Hz	<1	<1	<1	<1
10 M Hz	<1	<1	<1	<1
0.9 G Hz	8.2	27		84
3 G Hz	39	75		66

[a]For details see 'Electronic letters' 5, p. 460 (1969)

***Table 2** Dielectric strength of vapours (kV mm ~ 20%)*

Conditions: Parallel Disk electrodes with rounded edges 2.5 cm dia Electrode spacing: 1.5 mm Voltage: Continuously increasing D.C.

Pressure (m bar)	FLUTEC™ liquid			
	PP2	PP3	PP6	PP9
50	6	6	3	3
250	12	10	8	8
500	16	15	14	14
750	23	18	22	20

Electrical stability of the FLUTEC® liquids

The FLUTEC® liquids are not known to be affected by electrical or magnetic fields, or by corona discharge. Not surprisingly however, breakdown does occur in the presence of high temperature arc or spark discharges.

It is quite difficult to maintain a continuous arc (DC or AC) between electrodes immersed in a perfluorocarbon liquid. The discharge tends to stop, and, although dark coloured products may arise, carbon or other electrically conducting material has not been detected. Perfluorocarbons are 'self healing' in that electrical discharges tend to be quenched; 'tracking' does not occur.

The principal effects of arc breakdown of perfluorocarbons are the formation of gas, the formation of coloured solids ('polymer') and occasionally the detection of acid. Typical results are given in Tables 3 and 4.

The gas contains small molecules resulting from the recombination of •CF, •CF_2 and •CF_3 radicals, present in the arc plasma. In contrast with the mixture of methane and hydrogen from the breakdown of hydrocarbon oils, the perfluorocarbon gas mixture is not flammable. The presence of unsaturated perfluorocarbons (C_2F_4, C_3F_6, etc.) indicates that the gas may be toxic. The presence of oxygen appears to cause a decrease in the proportion of these compounds. Solid products from perfluorocarbon breakdown include yellow 'wax-like' polymers, and also black polymer. Both polymers are electrical insulators. Although the acidic products have not been identified, it is believed that they originate from carbonyl fluoride (COF_2), produced from dissolved oxygen, moisture or carbon dioxide.

***Table 3** Effect of DC discharge*

Conditions PTFE Test cell, 3 ml. capacity, Point-plane electrodes (stainless steel)

Discharge: 30 second, 2 mA/20 kV DC, across 3mm gap

Analysis of Product (Mol. %)

Breakdown product	PP2	PP3	PP6	PP9
CF4	23.0	23.0	22.0	17.0
C2F4	46.0	26.0	42.0	43.0
C2F6	6.6	21.0	12.0	13.0
C3F6	10.0	18.0	8.4	10.0
C3F8	1.1	3.6	2.2	2.6
Mixture of C4 and C5 Fluorocarbons	1.5	2.8	4.0	3.6
C6F12	15	1.8		
Polymers				
Waxy (C6F12)n	1.4	2.4	2.5	2.4
Black (C3F6)n	4.5	8.8	7.5	7.0

Approximately 0.05 to 0.2 g of fluorocarbon liquid was decomposed during the 30 second discharge

Table 4 *Effect of AC discharge*

Conditions Borosilicate glass cell, 2 ml. capacity tungsten wire electrodes

Discharge (estimated): 5 mA/10.0 kV 50 Hz, across 1 mm gap

	PP2	PP3	PP6	PP9
Time (min.)	80	100	142	88
Total acid (milliequivalents)	1.64	1.0	1.16	1.16
Gas volume (ml.)	500	500	500	500
Colour of liquid	Yellow	Orange	Brown	Brown
Fluorocarbon consumed	~2g	~2g	~2g	~2g

Coloured polymer was soluble in acetone and non-conducting

Identifiable components in gas from PP3 with AC discharge are CF_4 (12%), C_2F_4 (12.7%), C_3F_6 (54.8%), cC_4F_8 (6.7%), cC_4F_6 (0.7%).

Nitric oxide or oxygen, in large proportions decreased the production of unsaturated compounds and of wax polymer. The presence of hydrogen or water gave rise to hydrogen fluoride.

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