PFPE Phosphate: A Multifunctional Material

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Key words

Perfluoropolyether, perfluoropolyether phosphate, water/oil repellency, water resistance of sunscreens, skin irritation, microbial challenge, emulsion

Abstract

Chemically modifying a Z-type perfluoropolyether by introducing phosphate groups yields a multifunctional material useful for preparing aqueous solutions, hydrogels and emulsions. Formulation guidelines and cosmetic properties of the material are discussed.

Chemical modification of a Z-type perfluoropolyether by introducing phosphate groups yields a multifunctional material useful for preparing aqueous solutions, hydrogels and emulsions. In this article we discuss the material's formulation guidelines, and report results of tests on its water/oil repellency, its water resistance, its skin irritation and its antimicrobial activity.

Perfluoropolyether Phosphates

PFPE: The development of perfluoropolyethers (PFPEs) represents a major contribution of organo-fluorine chemistry to advanced technology in many industrial sectors, including the cosmetics industry. The importance of combining the film-forming and protective properties of polymeric materials with the typical properties of perfluorinated compounds (such as water and oil repellency, insolubility in common solvents, low surface tension, high chemical and thermal stability, safety and aesthetics) is self-evident.

Since the mid-1980s, Ausimont (formerly Montefluos) has pioneered and patented the use of PFPEs as ingredients of cosmetic preparations, particularly emulsions and detergents. Ausimont chemistry involves the UV-light activated oxidative polymerization of perfluoro-olefins to yield liquid polymers, which are fractionated by molecular distillation. Two main classes of PFPEs are manufactured:

- The Y-type, prepared from exafluoropropene, has a random structure, with a much larger proportion of hexafluoropropene oxide units, and minor amounts of difluoromethylene oxide units.
- The Z-type, prepared from tetrafluoroethylene, has a random structure too, with similar proportions of tetrafluoroethylene oxide units and difluoromethylene oxide units.

Z-PFPE: In the Z-PFPEs, the higher content of carbon-oxygen-carbon ethereal bonds and the absence of trifluoromethyl side groups results in higher flexibility of the molecules, and consequently in lower viscosity and pour point. In the choice of a PFPE structure for cosmetic applications, these enhanced properties do not compensate the Y-type advantages (such as the wider range of available grades, including a volatile one, and the higher fluorine content). And indeed Y-PFPEs, known to cosmetic chemists as "perfluoropolymethylisopropyl ether" (recently renamed "polyperfluoromethylisopropyl ether" by the International Nomenclature Committee of the Cosmetic, Toiletry and Fragrance Association) are perfectly suitable as multipurpose cosmetic ingredients.[1-4]

However, the insolubility of PFPEs in any cosmetic material can be viewed as a limit on the formulating potential. To overcome this limit, the most rational approach is to modify chemically the PFPE structure, with the introduction of non-fluorinated groups. A systematic evaluation program[5] of chemically modified PFPEs envisaged the following features:

- Presence of hydrophilic groups (such as hydroxy or phosphate) or of lipophilic groups (in particular alkyl chains);
- Solubility (or solubilization possibility) and dispersability in common cosmetic ingredients;
- Liquid physical form (preferred);
- Safety;
- Aesthetics (comparable to those of unmodified PFPEs).

Most chemically modified PFPEs, prepared on a laboratory scale from a Z-type PFPE dicarboxylic acid ester with a varying perfluorinated chain length of 1000 to 4000, gave liquid or low-melting materials, confirming that the chain flexibility is a critical factor as far as the physical form is concerned.

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Among the groups suitable for the chemical modification of the PFPE chain, the phosphoric group appeared as an excellent candidate. This strong polar group has the ability to impart binding, emulsifying, and solubility properties to an inert chain, without affecting most of its typical attributes, including the toxicological profile. A few examples are sufficient to support the rationale of this approach. Organic esters of orthophosphoric acid are widely used as wetting agents, surfactants, and emulsifiers in cosmetic applications. Dimethicone phosphate esters show enhanced properties compared to dimethicone, being more substantive to skin and hair. Lecithin is one of the many naturally occuring phosphoric esters and, on the industrial side, some perfluoroalkylphosphates are approved by the US Food and Drug Administration (FDA) for use in food-contact paper.

Therefore, we prepared Z-PFPE phosphates as the first class of a new generation of chemically modified PFPEs for cosmetics. Then we investigated their toxicological, formulating and application characteristics.

PFPE phosphate: In combining a PFPE chain with a phosphate group, both stability and solubility are a concern.

Certain chemical contraints must be taken into account to achieve adequate stability. The phosphate group must be linked to the ends of the PFPE chain and it must be shielded from the perfluorinated chain by a short hydrocarbon chain.

In addition, processing conditions must be optimized to achieve adequate solubility:

- The esterification conditions must ensure the complete reaction of the chemical intermediate, a PFPE alcohol, which is much less soluble than the corresponding phosphate.
- The phosphatation agent must maximize the monosubstitution, with only minor amounts of the disubstitute derivative and no insoluble trisubstitute derivative.
- The molecular weight of the PFPE chain must be in the range from 800 to 2500.

With these contraints in mind, we prepared a compound basically corresponding to the chemical structure shown in Figure 1. The specific INCI name "Polyperfluoroethoxymethoxy Difluoroethyl PEG Phosphate" was assigned to this structure. A simpler designation is perfluoropolyether phosphate or PFPE phosphate.

Materials

We prepared a PFPE phosphate identified as PFPE-1000 phosphate. It had a PFPE chain molecular weight of 1400. For comparison, we also prepared a homologue material identified

Table 1. Main properties of perfluoropolyether phosphate (PFPE-1000 phosphate)

Property	Value
Perfluoropolyether chain (average molcular weight)	1400
PFPE-1000 phosphate (average molecular weight)	2500
Difunctional content	93%
Kinematic viscosity	35000
Density	1.72 g/mL
Refractive index	1.33
Surface tension	32 mN/m
Thermal stability	up to 250°C

$$(HO)_2PO\text{-}O\text{-}(CH_2CH_2O)_n\text{-}CH_2CF_2\text{-}R_f\text{-}CF_2CH_2\text{-}(OCH_2CH_2)_n\text{-}O\text{-}PO(OH)_2$$

where:

$n = 1.0 \div 2.0$

$R_f = -(CF_2CF_2O)_p(CF_2O)_q-$

$p/q = 0.5 \div 3.0$, where "p" is the number of CF_2CF_2O groups in the molecule and "q" is the number of CF_2O groups in the molecule. PFPE-1000 phosphate and PFPE-2000 phosphate have different values of "p" and "q", but the ratio is characteristic for the chain, so it does not change with the molecular weight.

INCI Name: Polyperfluoroethoxymethoxy Difluoroethyl PEG Phosphate

Figure 1. Chemical structure of perfluoropolyether phosphate (PFPE phosphate)

as PFPE-2000 phosphate that had a PFPE chain of higher molecular weight (approximately 2200).

PFPE-1000 phosphate is a viscous transparent yellowish liquid polymer, chemically and thermally very stable (Table 1). It is insoluble in water, mineral oil, silicone oils, fatty substances (alcohols, acids, esters), and even in unmodified PFPEs. However, it is very soluble in ethanol (and in other volatile solvents, such as isopropanol, acetone and methylal), in low-molecular-weight glycols (such as propylene glycol and pentylene glycol) and ether-alcohols (such as PPG-2-methylether).

PFPE-2000 phosphate is quite similar to its lower-molecular-weight homologue in appearance, viscosity and solubility, because the longer chain is counterbalanced by a lower content of phosphate groups.

Formulation Guidelines

Insoluble PFPE phosphate: Either unmodified PFPEs or PFPE phosphate (1000 and 2000 grades) can be formulated as a material that is insoluble in water and oils. The procedure—the same in either case—yields three-phase emulsions.

Solubilization in polar solvents: The solubility of PFPE phosphate in alcohols, glycols and other polar solvents is such that concentrated solutions (up to 40-50%) can be prepared and used to formulate this material.

To improve the quality of these premixes, it is generally advantageous to add some water carefully while mixing. The PFPE phosphate, solvent and water should be in a ratio of approximately 1:1:1. The addition of small amounts of hot water helps to maximize the transparency (in the case of alcohols), to increase the viscosity (in the case of propylene glycol), and to obtain complete solubilization (in the case of pentylene glycol, acetone and other solvents). Often, added hot water is also useful to increase the compatibility of the solutions with other water-based components, and with water itself.

Unexpectedly, diluted solutions of PFPE phosphate (down to concentrations of 1-5% and lower) can be obtained without separation by further gradual addition of water to the premixes, while maintaining the agitation. Because of the strong acidity of unneutralized PFPE phosphate, even diluted solutions have low pH of 2 to 3.

These concentrated and diluted solutions can be used to prepare several types of compositions, with a water content ranging from very high (gels), to medium (emulsions), to very low (soaps and pastes). The solutions can be unneutralized, or they can be partially or totally neutralized to achieve a pH closer to the physiological conditions suitable for skin applications.

Solubilization by neutralization: PFPE phosphate can be solubilized directly in water without using solvents by neutralizing with sodium hydroxide or another base. Adding approximately 4 g of sodium hydroxide to 100 g of PFPE-1000 phosphate dispersed in water while mixing will yield 5% transparent solutions with a pH of approximately 5.4. These solutions can be used to prepare gels, emulsions and other aqueous systems.

Similarly, with a smaller amount of sodium hydroxide, diluted aqueous solutions of PFPE-2000 phosphate can also be obtained and used to prepare aqueous systems.

PFPE phosphate as a primary emulsifier: The foaming activity of aqueous solutions of PFPE-1000 phosphate suggests that it can work as a surfactant, and possibly as an emulsifier. Indeed, 1-2% aqueous solutions of neutralized PFPE-1000 phosphate are effective to prepare o/w emulsions.

Adding oils (20-30%) to this solution, under vigorous mixing, gives fine and very fluid emulsions. Adding more oil (up to 40-50%) increases the viscosity. This seems to indicate that the oils constitute the internal phase.

When the emulsion contains a high level (10-20%) of a low-polarity oil (mineral oil), separation occurs at rest, but very light shaking is sufficient to restore an homogeneous system. Higher stability can be obtained either by increasing the oil content or, preferably, by replacing the low-polarity oil with oils of medium polarity (such as octylpalmitate or octylstearate). Although this gives stable emulsions at rest and at 45°C or 4°C for a week, it is not sufficient to pass a centrifugation test at 5000 rpm. Centrifugation stability can be obtained by adding a thickener, such as 0.1-0.2% carbomer. However, similar amounts of oils (20-50%) can be emulsified even when the pH is acidic (pH=3) by presolubilizing PFPE-1000 phosphate in a solvent such as pentylene glycol. When neutralized to pH 5.5, these emulsions can be used to prepare foams or sprays.

PFPE-2000 phosphate also shows some emulsifying activity, but the emulsions are less stable, and separation occurs easily.

Tests

Water/oil repellency test: We developed a very simple test to evaluate whether a preparation containing PFPE phosphate can impart water and oil repellency. On a filter paper, we apply approximately 0.5 mL of a preparation (solution, gel, emulsion) containing this active. We allow the paper to dry for approximately 20 minutes and then place a drop of water and a drop of mineral oil on the treated area. An untreated area, or an area treated with a reference preparation, is used as control. We observe the shape, the transparency and, above all, the absorption time of the drops.

Water and oil repellency can be considered "excellent" when the absorption time is greater than 4 hours; "good" when greater than 30 minutes; and "mediocre" when less than 5 minutes. Obviously, the absorption times change depending upon the different porosity of the filter paper and therefore the test must be considered simply as qualitative.

This test can be also used to evaluate the substantivity by comparing water/oil repellency before and after three immersions (20 minutes each) in hot water (60°C).

Water resistance test: The FDA has proposed a method to appraise the water resistance and waterproof potential of sunscreen preparations by testing on volunteers.[6] In this method, the sun protection factor (SPF) is determined before and after repeated periods of immersion in fresh water.[a] A sunscreen preparation that can withstand 40 minutes or 80 minutes of immersion may claim to be "water resistant" or "waterproof," respectively.

Based on this FDA protocol, we developed a new method with some modifications:

- Our test area is on the arm, not on the back.
- We test a minimum of three volunteers, not 20, in view of the fact that rather subjective determinations (SPF) are replaced by analytical measures.
- We replace SPF determinations with UV spectroscopy measurements.

With these modifications, we test preparations containing a UV filter to determine the retention of the filter on the skin following immersion in water. A preparation is described as "water resistant" or "waterproof" if more than 90% of the UV filter remains on the skin after 40 or 80 minutes, respectively.

We spread 100 mg of the sunscreen preparation over a 50 cm^2 test area of the volar aspect of both forearms. After 20 minutes, the volunteer immerses the right arm in a waterbath, where water is at constant temperature (25°C) and circulating to simulate moderate activity. After an immersion period of 20 minutes, the arm is allowed to dry for 20 minutes. The immersion/drying cycle is repeated, to have a total immersion time of 40 minutes.

With alcohol, we remove the preparation from the arms. Spectroscopy measures allow us to determine the content of UV filter. The ratio of the absorbance values of the immersed arm and of the non-immersed arm gives the UV filter retention. A mean percentage retention is calculated from data on at least four volunteers.

One should note that the absorbance values can also be used to calculate the expected SPF values by the method of Diffey and Robson.[7] This allows comparison of the two methods.

Irritation test on humans: In this procedure,[8] samples of the preparations are placed into aluminum Finn chambers and applied to the skin of the forearm or the back of 20 volunteers. Aqueous samples are left to absorb to Whatman 3 filter blotting paper disks similar in size to the aluminum chambers. Creams and lotions are directly applied into the Finn chambers by using an insulin syringe. The skin area involved is cleaned with a 70% alcoholic solution. Plasters are applied on the forearm or to the paravertebral zone at the interscapula level. The preparations are left in contact with the skin surface for 48 hours.

The experimenter removes the Finn chamber and cleans residual preparation from the area. At 15 minutes and again at

Table 2. Classification of erythema or edema[8]

Class	Appearance of erythema or edema
0	absent
1	very light (hardly visible)
2	clearly visible
3	moderate
4	strong

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[a] *Note: This testing in fresh water is more severe than in salt water, which has a lower dissolving power due to its salt content.*

24 hours after removing the Finn chambers, the experimenter evaluates the skin reaction according to the scale of Table 2.

Microbial challenge test: Microbial challenge tests[9] were conducted at the Institute of Microbiology, University of Ferrara, Italy. Each preparation is challenged separately with the following microorganisms:

Escherichia coli
Staphylococcus aureus
Pseudomonas aeruginosa
Candida albicans

Bacterial challenge levels are 10^6 to 10^7 CFU/mL of preparation. Candida albicans (a yeast) is challenged at 10^5 to 10^6 CFU/mL of preparation. All challenged preparations are incubated at room temperature during the test over 28 days.

The microbial content of each preparation is essayed at 0 (20 minutes), 1, 7, 14 and 28 days. Triptone Soya Agar[b] plus 1.5% polysorbate 80 is used for bacterial and yeast recovery. At each assay time, 1 mL of preparation is diluted in 9 mL of sterile double-reverse-osmosis water; then 1 mL of the diluted preparation is pour plated into 10 mL of agar medium. The pour plates are incubated at 30°C for 3 days.

Results

Water/oil repellency: According to the filter paper test, the capability of a preparation containing PFPE phosphate to impart water repellency ranges from excellent to mediocre depending on the pH and on the other ingredients.The concentration of PFPE phosphate is not decisive, provided it is not lower than 0.5%. Furthermore, a PFPE phosphate concentration higher than 5% can even cause a decrease of the water repellency.

Hydroalcoholic solutions containing 30% alcohol have their highest water repellency when the pH is lower than 3.5. At higher pH values, water repellency decreases dramatically: the absorption time is less than 5 minutes.

Hydroglycolic solutions containing 0.5-2% PFPE-1000 phosphate (and the same amount of propylene glycol or of pentylene glycol) show a similar behavior. Their highest water repellency occurs when the pH is between 3.5 and 5.0: the absorption time is between 5 minutes and 4 hours.

Aqueous solutions containing 2% PFPE-1000 phosphate show high water repellency when the pH is between 5.5 and 7.0. The addition of ingredients to transform the aqueous solutions of PFPE-1000 phosphate into hydrogels (with xanthan gum or carbomer) or into emulsions (with oils) causes a decrease in water repellency, much more remarkable in the former than in the latter.

For hydrogels and aqueous, hydroalcoholic and hydroglycolic solutions, the oil repellency is very high in a broad pH range of 2.5 to 7, even at concentrations of PFPE-1000 phosphate down to 0.5%. For preparing emulsions, the addition of oils reduces only partially the oil repellency, as shown in Table 3.

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[b] *Unipath Ltd, Basingstoke, UK*

With respect to water and oil repellency, PFPE-2000 phosphate behaves very similarly to PFPE-1000 phosphate.

Water resistance test: We prepared a sprayable o/w emulsion containing PFPE-1000 phosphate and a common emulsion of similar composition (Table 4). Both had the same content of a UVB filter. We compared the UV filter retention of the two emulsions after two 20-minute water immersion/drying cycles, according to the procedure described above for the water resistance classification of a sunscreen preparation. The UVB filter retention ratio was calculated as a mean average based on data from four volunteers.

As shown in Table 5, the UV filter retention ratio was 96.5% for the sprayable sunscreen emulsion containing PFPE-1000 phosphate, but only 35.1% for the comparable emulsion without PFPE-1000 phosphate. Thus, the emulsion with PFPE-1000 phosphate can be classified "water resistant", while the emulsion with common emulsifiers cannot.

Irritation test: In irritation tests on 20 humans, the tested preparations containing 5% PFPE-1000 phosphate had a low irritation index (Table 6), compared to the index of a xanthan gum gel that contained lactic acid instead of the phosphate. Recall that PFPE-1000 phosphate is a phosphoric acid ester, and that the acidity of the most protonic hydrogen atom of the phosphate group is even higher than that of the corresponding hydrogen atom in orthophosphoric acid.

PFPE-2000 phosphate would be expected to give results in line with a lower acidity, because 5% preparations of PFPE-2000 phosphate have a pH higher than 3.

Challenge tests: Challenge tests were carried out to evaluate the biological behavior of carbomer gels containing 1% PFPE-1000 phosphate and various amounts of propylene glycol, in the pH range between 5.50 and 5.70.

These tests show that PFPE-1000 phosphate increases significantly the antimicrobial effectiveness of the solvent, without exhibiting such activity on its own (Table 7). This synergistic effect is higher when pentylene glycol replaces propylene glycol. The latter is in turn more effective than PPG-2 methyl ether and methylal. Finally, there are no effects with propylene carbonate, notwithstanding a manufacturer's study[10] reporting that this solvent is more effective as such than glycols (excluding pentylene glycol).

The synergistic effects of the PFPE-1000 phosphate/pentylene glycol combination are noticeable only when PFPE-1000 phosphate is combined with and presolubilized in the glycol, as shown in Table 7. It is not sufficient to add the two ingredients separately.

Data not shown in Table 7 indicates that adding pigments (15% iron oxides) or surfactants (20% cocoglucoside) to gels containing 1% PFPE-1000 phosphate significantly decreases the antimicrobial activity. On the other hand, adding an oil (20%

Table 3. Compositions containing PFPE-1000 phosphate and their ability to impart water and oil repellency as determined by a filter paper test (E = Excellent; G = Good; M = Mediocre)

Formulation method	Composition	Example	Repellency Oil	Repellency Water
Solubilization in a solvent	hydroalcohol solutions	3% PFPE phosphate 30% ethanol pH 2.50	E	E
Solubilization in a solvent	xanthan gum hydroalcoholic gels	3% PFPE phosphate 30% ethanol pH 2.83	E	M
Solubilization in a solvent	carbomer hydroglycolic gels	1% PFPE phosphate 1% propylene glycol pH 5.43	E	G
Solubilization in a solvent	fluid emulsions	1% PFPE phosphate 1% pentylene glycol 25% octylpalmitate pH 2.70	G	M
Neutralization	aqueous solutions	1% PFPE phosphate pH 5.46	E	E
Neutralization	fluid emulsions	1% PFPE phosphate 25% octylpalmitate pH 5.35	G	G
Neutralization	viscous emulsions	1% PFPE phosphate 25% octylpalmitate 0.3% carbomer pH 5.90	G	M

Table 4. Composition of sunscreen emulsions in the water resistance test

Ingredient	Sunscreen emulsion with PFPE-1000 phosphate % w/w	Sunscreen emulsion with common emulsifiers % w/w
Octylmethoxycinnamate	5.0	5.0
PFPE-1000 phosphate	2.0	-
PEG-400 stearate (and) steareth-2	-	4.0
Steareth-21	-	2.0
Mineral oil *(paraffinum liquidum)*	12.5	20.0
Octylpalmitate	12.5	-
Cetearyl alcohol	-	1.0
Sodium hydroxide	0.04	-
Water *(aqua)*	67.96	68.00
	~~100.00~~	~~100.00~~
Acidity (pH)	5.56	5.78
Viscosity	10 mPas.s (10 rpm, spindle 21, 25°C)	25000 mPas.s (10 rpm, spindle 29, 25°C)

Table 5. Absorbance of the sunscreen emulsions in the water resistance test, and calculated UV filter retention

	Absorbance values* of sunscreen emulsions	
Absorbance measured	with PFPE-1000 phosphate	with common emulsifiers
Applied emulsion**	0.899 (1.05 mg UV filter)	0.890 (1.05 mg UV filter)
Emulsion from immersed arm	0.863 (1.01 mg UV filter)	0.312 (0.36 mg UV filter)
Emulsion from non-immersed arm	0.894 (1.04 mg UV filter)	0.888 (1.03 mg UV filter)
	UV filter retention = 96.5	**UV filter retention = 35.1**

* Absorbance measured at 311 nm

** 20 mg of emulsion were applied to the arm. 100 mL of alcohol were used to remove the emulsion from the arm; if less than 100 mL were required for emulsion removal, additional alcohol was added to make up the 100 mL volume from which concentration was measured and compared.

Table 6. Mean irritation index of acid compositions containing 5% PFPE-1000 phosphate applied in single dose as an occlusive patch on the healthy skin of 20 volunteers

	Alcohol	pH	Mean irritation index	
Composition	(%)		after 15 minutes	after 24 hours
Hydroalcoholic solution	5	2.6	0.70	0.55
Hydroalcoholic solution	60	2.7	0.85	0.75
Xanthan gum gel	15	2.5	0.15	0.15
Xanthan gum gel	15	3.3	0.05	0.15
Xanthan gum gel	15	4.7	0.10	0.05
Xanthan gum gel	30	2.8	0.05	0.15
Xanthan gum gel (with lactic acid)	30	2.8	1.20	1.30

Note: Based on the mean irritation index, the composition can be classed as follows:

< 0.5 = non-irritating
0.5 – 2.0 = slightly irritating
2.0 – 5.0 = moderately irritating
5.0 – 8.0 = highly irritating

octyl-palmitate) has no effect on antimicrobial activity. A paper on these data is being prepared for publication.

The high antimicrobial activity of the PFPE-1000 phosphate/pentylene glycol combination has been indeed confirmed by challenge tests comparing emulsions based on hydrophobically modified polyacrylates[b].

In PFPE phosphate/solvent systems in which PFPE-2000 phosphate replaces PFPE-1000 phosphate, the antimicrobial activity becomes practically negligible.

Discussion

Formulation methods: In addition to the already known methods to obtain three-phase emulsions of unmodified PFPEs, we developed two new formulation methods:

- Solubilization in polar solvents, and dilution with water;
- Solubilization by neutralization with a base.

This work showed how critical the procedure and the presence of specific ingredients can be in influencing the functionalities of the preparations.

Water and oil repellency: The protective properties are a consequence of the capability of preparations containing PFPE phosphate to impart water and oil repellency. The potential to protect against lipophilic irritants can be added to a range of preparations, including hydrogels, emulsions, sprays and wipes. These preparations can also have antisoil and soil-repellant properties and allow an easy cleansing of the skin because of the antiadhesion properties of PFPE phosphate.

The choice of the technical form is more restricted when the target is a protective preparation with excellent water and oil repellency, because water repellency depends critically on the formulation. In particular, one must keep a low con-

Table 7. Challenge tests on a series of carbomer gels

Test	1% PFPE-1000 phosphate	Solvent	pH	Micro-organism*	Microbial activity (CFU/mL) 20 min	1 day	7 days	14 days
1	none	1% propylene glycol	5.69	P. aeruginosa	4.9x10^7	1.2x10^6	8.2x10^5	7.8x10^2
				S. aureus	6.2x10^7	1.3x10^6	7.4x10^4	3.1x10^3
				P. aeruginosa	9.8x10^7	1.2x10^6	5.3x10^4	7.2x10^2
				C. albicans	1.5x10^7	2.5x10^5	2.8x10^4	1.6x10^2
2	added separate	1% propylene glycol	5.64	E. coli	3.8x10^7	3x10^5	6.8x10^3	1.9x10^3
				S. aureus	4.6x10^7	1.9x10^5	4.5x10^3	$< 10^2$
				P. aeruginosa	8.1x10^7	2.7x10^4	3.2x10^4	$< 10^2$
				C. albicans	2.0x10^7	2.3x10^4	2.2x10^3	4.6x10^2
3	solubilized in solvent	1% propylene glycol	5.50	E. coli	4.4x10^7	7.8x10^5	2.4x10^2	< 10
				S. aureus	6.9x10^7	5.2x10^5	6.3x10^2	< 10
				P. aeruginosa	8.1x10^7	6x10^5	1.8x10^3	< 10
				C. albicans	1.7x10^7	1.6x10^4	9x10	< 10
4	solubilized in solvent	1% PPG-2 methyl ether	5.54	E. coli	4.5x10^7	1.4x10^4	2.1x10^3	$< 10^2$
				S. aureus	3.2x10^7	$< 10^3$	6.8x10^3	$< 10^2$
				P. aeruginosa	2.2x10^7	3.1x10^4	$< 10^2$	$< 10^2$
				C. albicans	1.5x10^7	1.1x10^3	7.2x10^4	$< 10^2$
5	solubilized in solvent	1% methylal	5.57	E. coli	4.5x10^7	1.4x10^4	2.1x10^3	$< 10^2$
				S. aureus	3.2x10^7	$< 10^3$	6.8x10^3	$< 10^2$
				P. aeruginosa	2.2x10^7	3.1x10^4	$< 10^2$	$< 10^2$
				C. albicans	1.5x10^7	1.1x10^3	7.2x10^4	$< 10^2$
6	solubilized in solvent	1% pentylene glycol	5.57	E. coli	2.3x10^7	7.2x10^5	$< 10^2$	< 10
				S. aureus	3.1x10^7	7.6x10^5	$< 10^2$	< 10
				P. aeruginosa	1.8x10^7	4.7x10^4	$< 10^2$	< 10
				C. albicans	1.2x10^7	3.2x10^5	< 10	< 10

Note: At 28 days, the microbial activity for all gels was less than 10 CFU/mL.

* The micro-organisms and their collections are as follows:
Escherichia coli ATCC 25922
Staphylococcus aureus ATCC 25923
Pseudomonas aeruginosa ATCC 27853
Candida albicans ATCC 10231

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[b] *Acrylates/C10-C30 alkyl acrylate crosspolymer (Pemulen TR-1, The BF Goodrich Co., Brecksville, OH)*

tent of non-volatile hydrophilic ingredients such as solvents, thickeners and surfactants. Therefore, solutions, aerosols and wipes impregnated with fluid emulsions are the most suitable preparations. Foams can exploit both the foaming properties of PFPE-1000 phosphate and the fact that fluid emulsions can be prepared with it as a primary emulsifier.

We saw an obvious relation between water repellency and water resistance in a sunscreen preparation's UV filter retention on skin. Considering this relation, it is not surprising that a fluid o/w emulsion containing PFPE-1000 phosphate (as a primary emulsifier) can be classified as "water resistant". This result suggests the use of PFPE-1000 phosphate as an ingredient of water-resistant and waterproof sunscreen preparations.

Unexpected functionality: Concerning a first unexpected functionality, we recall that PFPE phosphate is a phosphoric acid ester formally derived by monosubstitution/disubstitution of orthophosphoric acid, and prepared using a high excess of a phosphatation agent. The acidity of the most protonic hydrogen atom of the phosphate group is even higher than that of the corresponding hydrogen atom in orthophosphoric acid. While dispersions of PFPE-1000 phosphate in water, without the addition of sodium hydroxide (and therefore without solubilization), are almost neutral (pH>6), solutions containing 0.5-5.0% PFPE-1000 phosphate, obtained by presolubilization with a solvent, have pH values from 3 to 2, depending mainly on the content of PFPE-1000 phosphate, and much less on the content of the solvent. From an application point of view, "acidity" is a factor of particular importance.

We found an unexpectedly low order of irritation of high-acidity gels (and of hydroalcoholic solutions) containing PFPE-1000 phosphate. This low order of irritation, combined with the protective properties of PFPEs, suggests potential advantages for use in, say, aftershaves or AHA-based peeling preparations.

Another unexpected functionality is the antimicrobial activity of the PFPE-1000 phosphate/solvent combination. To obtain preservation, solvents such as alcohols, glycols and ether-glycols must be used at relatively high concentrations, with evident drawbacks. For example, pentylene glycol is effective only at concentrations higher than 5%, and even then it has no action against gram-positive bacteria.[11] Combined with PFPE-1000 phosphate, pentylene glycol is effective at 1% against a broad spectrum of micro-organisms, including gram-positive bacteria. Therefore, non-conventional preservative systems are obtained.

Molecular weight dependence: We found some slight differences in solubility and viscosity depending on the molecular weight (1400 vs. 2200) of the perfluoropolyether chain. However, these differences do not seem decisive in respect to formulations and procedures, or regarding protective and sensorial properties. On the contrary, the two unexpected functionalities (emulsifying activity and antimicrobial activity) seem primarily dependent on the molecular weight, with the PFPE-2000 phosphate being less effective in both instances.

Summary

Chemically modifying a Z-type PFPE by introducing phosphate groups yields a multifunctional material that may have interesting uses in the cosmetic sector. The modification increases the compatibility with aqueous and non-aqueous carriers, allowing preparation of aqueous solutions, hydrogels and emulsions without the use of a primary emulsifier. Unmodified PFPEs have protective and sensorial properties related to the fluorine content and the polymeric chain. In the modified PFPE, these properties are retained despite the widening latitude of the formulations. Finally, preparations containing PFPE phosphate show unexpected effects.

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