



Preface

Fluorine is an omnipresent chemical element in our everyday life. The last two decades have witnessed a spectacular growth of interest in selectively fluorinated molecular compounds. Nowadays, several hundreds of thousands molecules contain at least one fluorine atom. These molecules found essential applications in life sciences, medicine, pharmacology, medical imaging, agricultural chemistry, materials, etc. The manifold facets of fluorinated biomaterials and drugs are illustrated by examples ranging from inorganic ceramics to perfluorinated organic molecules. The applications include neuroleptics, anti-cancer, antibiotics, PET imaging for an early detection of tumors, etc. In the cornerstone field of energy storage and conversion, fluorine constitutes a key-element because most devices devoted to the storage of the energy (lithium-ion batteries, fuel cells) use fluoride materials as electrodes, electrolytes containing a fluoride salt, fluoromembranes, etc. Another illustration is the impact of this element in the nuclear cycle *via* the synthesis of uranium hexafluoride which is an unavoidable step toward uranium enrichment. Through these examples, it is clear that whatever its state, fluorine has a significant societal impact.

In France, in the Henri Moissan's trail, the research in the field of fluorine chemistry has been traditionally important, as well in organic as in polymeric, or inorganic chemistry. The applied aspects of fluoride products have been also largely developed since the discovery of this element. Nowadays, several industrial groups are key-players of the World Fluorine Chemistry. The major activities related to F-element of the most important industry groups located in France are given below, together with addresses and contacts.

Until the creation of the French Fluorine Network, researchers involved in the fluorine chemistry developed their activities without the assistance of a federative structure capable of making the interface not only between the various involved laboratories but also, and especially, between the academic and industrial worlds. In 2002, the first steps for the creation of *French National Network on Fluorine Chemistry* were undertaken under the aegis of the Chemistry Department (now Institute of Chemistry) of CNRS (National Center for Scientific Research). The main objective of the network is to identify clear scientific orientations which could have an important societal impact, in particular in terms of public health and to recommend the implementation and the development of interdisciplinary works. Thus, its first vocation is to promote the activities connected to fluorine and fluoride-based products in the varied sectors of chemistry and new technologies (energy control, electronics and opto-electronics, life sciences, environment (for

instance CFC substitutes, green chemistry, etc.)). Today, about forty laboratories belong to the network, in which the scientific animation is insured through five thematic sectors:

1. methodology in organic synthesis, catalysis,
2. methodology in inorganic chemistry and materials science,
3. polymers and surfactants; physical chemistry and modeling; surface treatments,
4. fluorine and life sciences,
5. fluorine, energy and new technologies.

For additional information about the *French National Network in Fluorine Chemistry*, we suggest the reader to visit the network website (<http://www.reseau-fluor.fr/>).

1. Major industrial activities related to F-element in France

Arkema [1], a key-player of the world chemistry, the first French chemist, has a long experience in the search and the production of molecules and fluoride materials at the world level. Their activity range includes:

- HFC (hydrofluorocarbons) and HCFC (hydrochlorofluorocarbons) marketed under the brand Forane[®], related to a long industrial experience of fluorocarbons, dating back 1949. They are intended for various uses: refrigerants for the refrigeration and the air-conditioning (business, building, automobile); expansion agents for the manufacturing of polymer foams (polyurethanes and polystyrene); raw materials for the manufacturing of fluoropolymers; solvents for degreasing, cleaning or drying.
- Boron trifluoride (BF₃) and bromotrifluoromethane (BTFM), fine chemistry products, used as catalysts in the chemical industry.
- PVDF (polyvinylidene difluoride) marketed under the brand Kynar[®], regularly manufactured since 1965. The product is used in numerous industries such as chemical industry, petroleum industry or buildings. Its high strength makes of this polymer a coating or a key-material for chemical engineering, electric cable-manufacturing, high protection coating for metallic surfaces. Among the last Kynar's applications, we can quote electrodes of lithium-ion batteries, photovoltaic panels, or roofing. Kynar Aquatec[®] without solvent allows to realize covers of roofs reflecting the solar radiation, with long life expectancy, and contributing to a sustainable air conditioning and the energy-efficiency of the buildings. This product received in 2010 the "Pierre Potier Award", a prize dedicated to innovative companies in the field of the sustainable development.

Major player of the conversion of uranium at the international level, Comurhex [2], a subsidiary of Areva company, transforms, in several stages, the mining uranium concentrate into uranium hexafluoride. The first stage of conversion of “yellow cake” concentrate into uranium tetrafluoride is realized by acidic dissolution followed by hydrofluorination at the Malvési plant. In the Pierrelatte plant, uranium tetrafluoride is converted into hexafluoride (UF_6) by contact of gaseous fluorine with powdered UF_4 at high-temperature in a flame reactor. So, being gaseous at 65 °C, (UF_6) can be enriched (as ^{235}U) by gaseous diffusion or by centrifugation. Besides enriched UF_6 , that is further transformed into nuclear fuel, depleted hexafluoride is transformed into oxide in a defluorination plant which is the only one worldwide to realize this type of process at the industrial scale. F_2 -gas, the raw material required for the conversion process is continuously produced by electrolysis of KH_2F_3 in HF medium.

Since the first half of the twentieth century, DuPont [3] has been a significant contributor to advances in fluorine chemistry. This long history has led to a variety of products such as fluorinated gases (refrigeration, air conditioning, etc.), fluoropolymers (plastic materials or coatings with high chemical and thermal resistance such as polytetrafluoroethylene, PTFE), or fluorotelomers (unique surface properties). Fluorotelomers are short perfluorinated chains attached to an ethylene spacer that when coupled to a polar group yield a fluorinated surfactant. The polymerization of a monomer (e.g., acrylate) containing fluorotelomer functionality yields a comb-shaped fluorinated polymer with a hydrocarbon backbone. The “tines” of the comb contain the fluorotelomer functionality. These fluorinated polymers are utilized as oil and water repellent impregnating agents for textiles, leather or construction materials. Fluoropolymers and fluorotelomer-based polymers that meet specific end-use performance requirements when incorporated into articles (e.g., non-stick cookware, clothing) may qualify for Teflon® brand certification. In 2002, DuPont acquired Elf Atochem’s fluorotelomer operations. With this acquisition, DuPont now operates a modern plant in France that produces fluorotelomer-based surfactant and polymeric products. Building upon decades of Elf Atochem research at the Pierre Bénite and Levallois-Perret sites, the DuPont technology group develops new products and processes at a state of the art R&D and Technical Service laboratory established in 2003, 40 miles outside of Paris. New short chain surfactants and polymeric products marketed under the trade name Capstone® are developed here in collaboration with DuPont’s global R&D center located in Wilmington, Delaware.

Fluorination process during fuel tank blow molding is currently developed by INERGY Automotive Systems [4], consisting in the treatment of monolayer HDPE parts using a mixture of fluorine and nitrogen in order to lower the permeability of these parts to hydrocarbon vapours. Fluorination increases the quality of the barrier properties of the automotive fuel tanks to fuel and makes the polyethylene less permeable to gasoline fuel by modifying the polymer surface.

The difluorinated semi-synthetic vinca alkaloid derivative, vinflunine ditartrate, manufactured at Laboratoires Pierre Fabre [5] has been approved in Europe since 2009 in the treatment of cancer of the gall bladder. Further clinical trials are in progress to assess its efficacy in the treatment of breast cancer. The discovery of this novel compound through a collaboration between the French pharmaceutical group, Pierre Fabre Médicament, and the French national research agency, the CNRS, has been well documented (Fahy et al., J. Amer. Chem. Soc. 119 (1997) 8576; Jacquesy et al., J. Fluor. Chem. 114 (2002) 139). Super-acid conditions (HF/SbF_5) were used to introduce two fluorine atoms into a region of the bis indole skeleton that had previously proved inaccessible, resulting in a significant modification of the pharmacological properties of the molecule. A key challenge in

the development of this molecule was the establishment of a safe and robust manufacturing process for the supply of material to support clinical trials and commercial launch. This challenge was met and the compound is currently manufactured with a validated process under cGMP conditions at the Pierre Fabre Médicament facility at Gaillac, north of Toulouse.

Since July 2010, Rhodia Group [6] is organized around 11 global business units (GBU). The Aroma Performance Global Business Unit (GBU), part of Rhodia’s consumer chemicals cluster, includes the diphenol and fluorinated intermediates operations, comprising three main market segments: aroma ingredients, inhibitor solutions and crop protection, health and specialties. Fluorine chemistry is based on core technologies that Rhodia masters since several years in its Salindres plant, and is the heart of the portfolio and innovations of the crop protection health and specialties segment. Rhodia Aroma Performance has developed a unique range of chemical intermediates for pharmaceuticals and agrochemicals. Based on its expertise in gas and liquid fluorination technologies, Rhodia offers the largest portfolio of fluoroaliphatics building blocks: trifluoroacetic acid and triflic acid derivatives, manufactured combining environmentally sustainable and competitive integrated processes. Rhodia is proposing new key compounds in the electronic industry, a fast growing market. Rhodia is the only player integrated through the whole trifluoroacetic acid–potassium trifluoromethanesulfonate–triflic acid chain. A recently launched product rapidly gaining importance is LiTFSI, a fluorinated lithium salt that can be used in antistatic applications, in batteries or, with other cations than Li, as powerful and promising Lewis acid catalyst. Rhodia has proprietary methods to produce difluoroacetic acid and derivatives, key building blocks used in a new family of agrochemical and pharmaceutical blockbusters, in which the Company aims to become worldwide leader. Continuously striving to offer to its customers new molecules allowing to get innovative properties, Rhodia Aroma Performance is developing a new product family based on difluoromethane-sulfonylchloride chemistry, which could be the molecule of tomorrow.

From fluorspar to functionalized polymers – Solvay Fluor, a Division of Solvay Chemicals [7], integrates the activities of fluorine chemistry of the group. Products are made worldwide in about ten plants. The application range extends from hydrofluoroalkanes used as refrigerants, foaming, or precision solvent agents to special reagents for the electronics such as F_2 , C_4F_6 , COF_2 . The ethylene monofluorocarbonate is used as additive in the electrolytes of Li-ion batteries. SF_6 serves as an insulating gas in the electric installations of middle and high voltages. Several fluoroaluminosilicates have revolutionized the brazing of aluminium parts, and organic intermediates serve as source of fluorine for the pharmaceutical and agrochemical industries.

Among the products that are commercialized by Solvay Solexis, a Division of Solvay Plastics [8], one of the world leaders in fluoromaterials, we can quote:

- Various types of perfluoropolyethers used as lubricants, surface treatment agents, heat transfer reagents.
- Fluoro- and perfluoroelastomers particularly adapted to the severe conditions of the aeronautical, spatial industries, and resist to high thermal and chemical constraints.
- A wide range of fluoride coatings based on either amorphous or crystalline copolymers, for high chemical and thermal strengths.
- Fluoride copolymers entering the composition of membranes for fuel cells and batteries.
- Various types PTFE.

Two recent companies which are dedicated to the synthesis of new fluoro-products can be also quoted:

Innov'Orga [9] is a chemical company specialized in the field of fluorine organic chemistry, working essentially on the search and development of new fluorinated organic building blocks. The introduction of fluorine atoms in molecules is obtained via different techniques: nucleophilic or electrophilic direct fluorination, nucleophilic trifluoromethylation, electrophilic trifluoromethylation, etc.

Specific Polymers [10] have been developing the synthesis of functionalized fluorinated monomers and polymers. These new products can be used for various properties: low refraction index, thermostability, hydrophoby and oleophoby. The applications range includes aeronautics, cosmetics, electronics, energy, pharmacy, surface treatments, etc.

The aim of this special issue is to highlight the high level of activities of French laboratories involved in Fluorine Sciences, through papers in which, after a brief presentation of the current activity of each group in the field of Fluorine Chemistry, original results recently obtained will be presented. We do hope that after reading this special issue, you will be convinced that research in this particular field of Chemistry is very active in France on both academic and industrial sides.

References

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