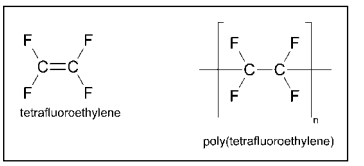
89. Tetrafluoroethylene



CHEMICAL NAME = tetrafluoroethene
poly(tetrafluoroethene)
CAS NUMBER = 116–14–3 (TFE) 9002–84–0 (PTFE)
MOLECULAR FORMULA = C_2F_4
MOLAR MASS = 100.0 g/mol
COMPOSITION = C(24%) O(76%)
MELTING POINT = –142.5°C (TFE) 327°C (PFTE)
BOILING POINT = –76.3°C (TFE) 400°C (PFTE)
DENSITY = 0.0051 g/cm^3 (3.9, air = 1) (TFE) 2.2 g/cm^3 (PTFE)

Tetrafluoroethylene (TFE), also known as perfluoroethylene, is a colorless, flammable, toxic gas. It is the monomer used for polytetrafluoroethylene (PTFE), which is sold under the DuPont tradename of Teflon. TFE is co-polymerized with other compounds to produce a variety of Teflons. TFE is produced by heating chlorodifluoromethane ($CHClF_2$, Freon-22) or trifluoromethane (CHF_3, Freon-23). TFE is used almost exclusively as a monomer in the production of PTFE. PTFE is a vinyl polymer, which means it is made from a monomer with carbon-carbon double bonds. PTFE is made from TFE by free radical polymerization.

The polymerized form of TFE was discovered accidentally by researchers at DuPont in 1938. During the mid-1930s, DuPont was investigating the development of new chlorofluorocarbons (CFCs) for use as refrigerants. DuPont joined with General Motors to form a company called Kinetic Chemicals to combine their efforts in this area. Roy J. Plunkett (1910–1944) was one of the chemists assigned to the project. Plunkett was using TFE as a reactant to produce CFCs and stored it in pressurized canisters. Plunkett cooled the TFE canisters with dry ice to reduce the risk of explosion (TFE can explode owing to spontaneous polymerization at high temperatures). On the morning of April 6, Plunkett and his laboratory technician, Jack Rebok, attempted unsuccessfully to deliver TFE from one of the cylinders. After discovering that the valve was not plugged and the gas had not escaped, Plunkett removed the valve and observed a white solid material. Plunkett and Rebok then

sawed open several of the TFE storage containers and observed that they were coated with a white waxy substance. Plunkett noted that the TFE had polymerized. Over the next year Plunkett examined the properties of the substance. He discovered that the substance was inert to other chemicals, had a high melting point, and was very slippery. Plunkett also worked on duplicating the conditions necessary to produce it from TFE. He applied for a patent for polytetrafluoroethylene polymers in 1939, which was granted in 1941 (U.S. Patent 2230654). He assigned the patent to Kinetic Chemicals. DuPont registered the term Teflon in 1945 and introduced Teflon products the next year.

PTFE's unique physical properties are due to its chemical structure. PTFE consists of long chains of carbon atoms surrounded by fluorine atoms. The fluorine atoms act as a protective barrier that shields the carbon-carbon bond from chemical attack. The fluorine atoms repel other atoms, making it difficult for anything to stick to PTFE. PTFE resins have very low coefficients of friction (< 0.1). The strong fluorine-to-carbon bonds and high electronegativity of fluorine make PTFE very stable. The long chains of PTFE pack closely together to give a dense crystalline solid. The packing, which can be compared to stacking boards, produces little cross-linking.

Teflon is best known for its use in cookware, but its use in this area followed original industrial applications in gaskets, sealers, tape, and electrical insulation. These applications were a direct result of the use of PTFE for military purposes during World War II.

The use of Teflon in cookware was stimulated by a French inventor named Marc Grégoire (1905–1996). Grégoire used Teflon to coat his fishing gear to prevent tangles. His wife, Colette, thought Teflon could be applied to her frying pans and Grégoire was successful in this endeavor. He was granted a patent for the process in 1954 and began selling coated pans out of his home in the 1950s. In 1956, he formed the company Tefal for the production of Teflon-coated cookware and made plans to build a factory. In the late 1950s, Thomas G. Hardie, a businessman from the United States, met Grégoire in Paris and became convinced that Teflon cookware could be marketed in the United States. Upon returning to the United States, Hardie tried to convince American cookware producers to adopt Grégoire's technology, but he met with resistance. This led Hardie to import Teflon goods from Grégoire's French factory and market them under the name T-fal. Hardie met with DuPont executives and tried to accelerate their Teflon cookware plans. DuPont continued to conduct research on Teflon's safety in cookware and sought approval from the Food and Drug Administration (FDA) for its use in this application. Meanwhile, Hardie's T-fal sales soared in the early 1960s, leading him to build his own plant for production in the United States. The FDA approved Teflon's use in cookware in 1962. As Hardie's success with T-fal continued, other manufacturers started to produce Teflon cookware, which flooded the market with Teflon cooking items.

Teflon's marketing success for a non-stick cooking items was accompanied by concerns about the safety of cooking with Teflon products. These concerns continue today and have intensified in recent years. The concerns involve workers who produce Teflon, as well as general public use of Teflon cookware. A larger issue involves the use of perfluorooctanoic acid, $C_8HF_{15}O_2$ (PFOA). This chemical, also called C8, is used in small amounts during the polymerization of PTFE, and trace amounts of it may remain in the final product. PFOA (and its salt ammonium perfluorooctanoate) is a persistent chemical and likely human carcinogen. At high enough temperatures, residual PFOA may be released from Teflon products in fumes or can migrate into foods. Birds are particularly susceptible to PFOA. The exact temperature where

PFOA is mobilized is unknown; environmental groups and manufacturers cite temperatures that can vary by more than 100°C. Leading cookware manufacturers have recommended a maximum temperature of 260°C. Recommended frying temperature is 190°C. DuPont reached a $16.5 million settlement with the Environmental Protection Agency in 2005 over allegations that it covered up the health risks of PFOA. DuPont officials claimed the settlement was done to avoid protracted litigation and they had done nothing illegal. Class action lawsuits filed on behalf of consumers against DuPont are seeking billions of dollars in damages. These suits claim that DuPont concealed information about the health risks of Teflon. In response to the concern about C8, DuPont and cookware manufacturers plan to phase out the use of PFOA in Teflon over the next several years.

PTFE is used in hundreds of applications in addition to cookware. PTFE-based powders are use in inks, plastics, coatings, and lubricants. PTFE resins can be molded into gaskets, seals, bearings, gears, and other machine parts. Films of PTFE materials are used as liners, insulation, membranes, and adhesives. Teflon tape is commonly used in plumbing work. PTFE is used to produce rainproof garments. Gore-Tex, a PTFE material, was developed by Wilbert Gore (1912–1986) and his wife, Genevieve, in their basement. Gore was a DuPont engineer who worked on Teflon and started his business in 1958 after failing to persuade DuPont executives to pursue PTFE fabrics. The Gores mortgaged their home to start their business, and Gore-Tex outdoor clothing became a well-known product beginning in the 1980s.