

Teflon

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(Background

Teflon is the registered trade name of the highly useful plastic material polytetrafluoroethylene (PTFE). PTFE is one of a class of plastics known as fluoropolymers. A polymer is a compound formed by a chemical reaction which combines particles into groups of repeating large molecules. Many common synthetic fibers are polymers, such as polyester and nylon. PTFE is the polymerized form of tetrafluoroethylene. PTFE has many unique properties, which make it valuable in scores of applications. It has a very high melting point, and is also stable at very low temperatures. It can be dissolved by nothing but hot fluorine gas or certain molten metals, so it is extremely resistant to corrosion. It is also very slick and slippery. This makes it an excellent material for coating machine parts which are subjected to heat, wear, and friction, for laboratory equipment which must resist corrosive chemicals, and as a coating for cookware and utensils. PTFE is used to impart stain-resistance to fabrics, carpets, and wall coverings, and as weatherproofing on outdoor signs. PTFE has low electrical conductivity, so it makes a good electrical insulator. It is used to insulate much data communication cable, and it is essential to the manufacture of semi-conductors. PTFE is also found in a variety of medical applications, such as in vascular grafts. A fiberglass fabric with PTFE coating serves to protect the roofs of airports and stadiums. PTFE can even be incorporated into fiber for weaving socks. The low friction of the PTFE makes the socks exceptionally smooth, protecting feet from blisters.

(History

PTFE was discovered accidentally in 1938 by a young scientist looking for something else. Roy Plunkett was a chemist for E.I. du Pont de Nemours and Company (Du Pont). He had earned a PhD from Ohio State University in 1936, and in 1938 when he stumbled upon Teflon, he was still only 27 years old. Plunkett's area was refrigerants. Many chemicals that were used as refrigerants before the 1930s were dangerously explosive. Du Pont and General Motors had developed a new type of non-flammable refrigerant, a form of Freon called refrigerant 114. Refrigerant 114 was tied up in an exclusive arrangement with General Motor's Frigidaire division, and at the time could not be marketed to other manufacturers. Plunkett endeavored to come up with a different form of refrigerant 114 that would get around Frigidaire's patent control. The technical name for refrigerant 114 was tetrafluorodichloroethane. Plunkett hoped to make a similar refrigerant by reacting hydrochloric acid with a compound called tetrafluoroethylene, or TFE. TFE itself was a little known substance, and

Plunkett decided his first task was to make a large amount of this gas. The chemist thought he might as well make a hundred pounds of the gas, to be sure to have enough for all his chemical tests, and for toxicological tests as well. He stored the gas in metal cans with a valve release, much like the cans used commercially today for pressurized sprays like hair spray. Plunkett kept the cans on dry ice, to cool and liquefy the TFE gas. His refrigerant experiment required Plunkett and his assistant to release the TFE gas from the cans into a heated chamber. On the morning of April 6, 1938, Plunkett found he could not get the gas out of the can. To Plunkett and his assistant's mystification, the gas had transformed overnight into a white, flaky powder. The TFE had polymerized.

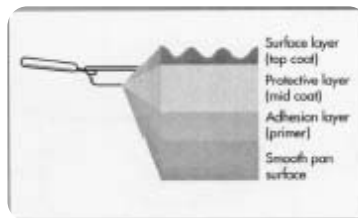
Polymerization is a chemical process in which molecules combine into long strings. One of the best known polymers is nylon, which was also discovered by researchers at Du Pont. Polymer science was still in its infancy in the 1930s. Plunkett believed that TFE could not polymerize, and yet it had somehow done so. He sent the strange white flakes to Du Pont's Central Research Department, where teams of chemists analyzed the stuff. The polymerized TFE was curiously inert. It did not react with any other chemicals, it resisted electric currents, and it was extremely smooth and slick. Plunkett was able to figure out how the TFE gas had accidentally polymerized, and he took out a patent for the polymerized substance, polytetrafluoroethylene, or PTFE.

PTFE was initially expensive to produce, and its value was not clear to Plunkett or the other scientists at Du Pont. But it came into use in World War II, during the development of the atomic bomb. Making the bomb required scientists to handle large amounts of the caustic and toxic substance uranium hexafluoride. Du Pont provided PTFE-coated gaskets and liners that resisted the extreme corrosive action of uranium hexafluoride. Du Pont also used PTFE during the war for making nose cones of certain other bombs. Du Pont registered the trademark name Teflon for its patented substance in 1944, and continued to work after the war on cheaper and more effective manufacturing techniques. Du Pont built its first plant for the production of Teflon in Parkersburg, West Virginia in 1950. The company marketed Teflon after the war's end as a coating for machined metal parts. In the 1960s, Du Pont began marketing cookware coated with Teflon. The slick Teflon coating resisted the stickiness of even scorched food, so cleaning the pans was easy. The company marketed Teflon for a variety of other uses as well. Other

related fluoropolymers were developed and marketed in ensuing decades, some of which were easier to process than PTFE. Du Pont registered another variant of Teflon in 1985, Teflon AF, which is soluble in special solvents.

(Raw Materials

PTFE is polymerized from the chemical compound tetrafluoroethylene, or TFE.



A non-stick pan is composed of varying non-stick layers.

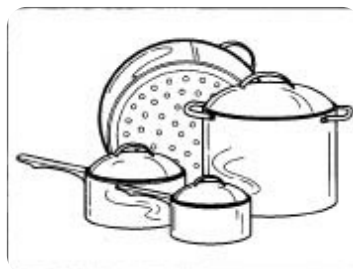
TFE is synthesized from fluorspar, hydrofluoric acid, and chloroform. These ingredients are combined under high heat, an action known as pyrolysis. TFE is a colorless, odorless, nontoxic gas which is, however, extremely flammable. It is stored as a liquid, at low temperature and pressure. Because of the difficulty of transporting the flammable TFE, PTFE manufacturers also manufacture their own TFE on site. The polymerization process uses a very small amount of other chemicals as initiators. Various initiators can be used, including ammonium persulfate or disuccinic acid peroxide. The other essential ingredient of the polymerization process is water.

The Manufacturing Process

PTFE can be produced in a number of ways, depending on the particular traits desired for the end product. Many specifics of the process are proprietary secrets of the manufacturers. There are two main methods of producing PTFE. One is suspension polymerization. In this method, the TFE is polymerized in water, resulting in grains of PTFE. The grains can be further processed into pellets which can be molded. In the dispersion method, the resulting PTFE is a milky paste which can be processed into a fine powder. Both the paste and powder are used in coating applications.

Making the TFE

- 1 Manufacturers of PTFE begin by synthesizing TFE. The three ingredients of TFE, fluorspar, hydrofluoric acid, and chloroform are combined in a chemical reaction chamber heated to between 1094-1652°F (590-900°C). The resultant gas is then cooled, and distilled to remove any impurities.



Teflon can be used on a wide variety of cookware.

Suspension Polymerization

- 2 The reaction chamber is filled with purified water and a reaction agent or initiator, a chemical that will set off the formation of the polymer. The liquid TFE is piped into the reaction chamber. As the TFE meets the initiator, it begins to polymerize. The resulting PTFE forms solid grains that float to the surface of the water. As this is happening, the reaction chamber is mechanically shaken. The chemical reaction inside the chamber gives off heat, so the chamber is cooled by the circulation of cold water or another coolant in a jacket around its outsides. Controls automatically shut off the supply of TFE after a certain weight inside the chamber is reached.

The water is drained out of the chamber, leaving a mess of stringy PTFE which looks somewhat like grated coconut.

- 3 Next, the PTFE is dried and fed into a mill. The mill pulverizes the PTFE with rotating blades, producing a material with the consistency of wheat flour. This fine powder is difficult to mold. It has "poor flow," meaning it cannot be processed easily in automatic equipment. Like unsifted wheat flour, it might have both lumps and air pockets. So manufacturers convert this fine powder into larger granules by a process called agglomeration. This can be done in several ways. One method is to mix the PTFE powder with a solvent such as acetone and tumble it in a rotating drum. The PTFE grains stick together, forming small pellets. The pellets are then dried in an oven.
- 4 The PTFE pellets can be molded into parts using a variety of techniques. However, PTFE may be sold in bulk already pre-molded into so-called billets, which are solid cylinders of PTFE. The billets may be 5 ft (1.5 m) tall. These can be cut into sheets or smaller blocks, for further molding. To form the billet, PTFE pellets are poured into a cylindrical stainless steel mold. The mold is loaded onto a hydraulic press, which is something like a large cabinet equipped with weighted ram. The ram drops down into the mold and exerts force on the PTFE. After a certain time period, the mold is removed from the press and the PTFE is unmolded. It is allowed to rest, then placed in an oven for a final step called sintering.
- 5 The molded PTFE is heated in the sintering oven for several hours, until it gradually reaches a temperature of around 680°F (360°C). This is above the melting point of PTFE. The PTFE particles coalesce and the material becomes gel-like. Then the PTFE is gradually cooled. The finished billet can be shipped to customers, who will slice or shave it into smaller pieces, for further processing.

Dispersion polymerization

- 6 Polymerization of PTFE by the dispersion method leads to either fine powder or a paste-like substance, which is more useful for coatings and finishes. TFE is introduced into a water-filled reactor along with the initiating chemical. Instead of being vigorously shaken, as in the suspension process, the reaction chamber is only agitated gently. The PTFE forms into tiny beads. Some of the water is removed, by filtering or by adding chemicals which cause the PTFE beads to settle. The result is a milky substance called PTFE dispersion. It can be used as a liquid, especially in applications like fabric finishes. Or it may be dried into a fine powder used to coat metal.

Nonstick cookware

- 7 One of the most common and visible uses of PTFE is coating for nonstick pots and pans. The pan must be made of aluminum or an aluminum alloy. The pan surface has to be specially prepared to receive the PTFE. First, the pan is washed with detergent and rinsed with water, to remove all grease. Then the pan is dipped in a warm bath of hydrochloric acid in a process called etching. Etching roughens the surface of the metal. Then the pan is rinsed with water and dipped again in nitric acid. Finally it is washed again with deionized water and thoroughly dried.
- 8 Now the pan is ready for coating with PTFE dispersion. The liquid coating may be sprayed or rolled on. The coating is usually applied in several layers, and may begin with a primer. The exact makeup of the primer is a proprietary secret held by the manufacturers. After the primer is applied, the pan is dried for a few minutes, usually in a convection oven. Then the next two layers are applied, without a drying period in between. After all the coating is applied, the pan is

dried in an oven and then sintered. Sintering is the slow heating that is also used to finish the billet. So typically, the oven has two zones. In the first zone, the pan is heated slowly to a temperature that will evaporate the water in the coating. After the water has evaporated, the pan moves into a hotter zone, which sinters the pan at around 800°F (425°C) for about five minutes. This gels the PTFE. Then the pan is allowed to cool. After cooling, it is ready for any final assembly steps, and packaging and shipping.

(Quality Control

Quality control measures take place both at the primary PTFE manufacturing facility and at plants where further processing steps, such as coatings, are done. In the primary manufacturing facility, standard industrial procedures are followed to determine purity of ingredients, accuracy of temperatures, etc. End products are tested for conformance to standards. For dispersion PTFE, this means the viscosity and specific gravity of the dispersion is tested. Other tests may be performed as well. Because Teflon is a trademarked product, manufacturers who wish to use the brand name for parts or products made with Teflon PTFE must follow quality control guidelines laid down by Du Pont. In the case of nonstick cookware manufacturers, for example, the cookware makers adhere to Du Pont's Quality Certification Program, which requires that they monitor the thickness of the PTFE coating and the baking temperature, and carry out adhesion tests several times during each shift.

(Byproducts/Waste

Though PTFE itself is non-toxic, its manufacture produces toxic byproducts. These include hydrofluoric acid and carbon dioxide. Work areas must be adequately ventilated to prevent exposure to gases while PTFE is being heated, or when it cools after sintering. Doctors have documented a particular illness called polymer fume fever suffered by workers who have inhaled the gaseous byproducts of PTFE manufacturing. Workers must also be protected from breathing in PTFE dust when PTFE parts are tooled.

Some waste created during the manufacturing process can be reused. Because PTFE was at first very expensive to produce, manufacturers had high incentive to find ways to use scrap material. Waste or debris generated in the manufacturing process can be cleaned and made into fine powder. This powder can be used for molding, or as an additive to certain lubricants, oils, and inks.

Used PTFE parts should be buried in landfills, not incinerated, because burning at high temperatures will release hydrogen chloride and other toxic substances. One study released in 2001 claimed that PTFE also degrades in the environment into one substance that is toxic to plants. This is trifluoroacetate, or TFA. While current levels of TFA in the environment are low, the substance persists for a long time. So TFA pollution is possibly a concern for the future.

(Where to Learn More

Books

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Angela Woodward

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