Polyvinyl Chloride

Polyvinyl chloride, (IUPAC **Poly(chloroethanediyl)**) commonly abbreviated **PVC**, is a thermoplastic polymer. It is a vinyl polymer constructed of repeating vinyl groups (ethenyls) having one of their hydrogens replaced with a chloride group.

Polyvinyl chloride is the third most widely produced plastic, after polyethylene and polypropylene. [3] PVC is widely used in construction because it is cheap, durable, and easy to assemble. PVC production is expected to exceed 40 million tons by 2016. [4]

It can be made softer and more flexible by the addition of plasticizers, the most widely used being phthalates. In this form, it is used in clothing and upholstery, and to make flexible hoses and tubing, flooring, to roofing membranes, and electrical cable insulation. It is also commonly used in figurines and in inflatable products such as waterbeds, pool toys, and inflatable structures.

Preparation

Polyvinyl chloride is produced by polymerization of the vinyl chloride monomer (VCM), as shown. Since about 57% of its mass is chlorine, creating a given mass of PVC requires less petroleum than many other polymers. However, because PVC also has a much higher density than hydrocarbon polymers, and chlorine production has its own energy requirements, this ends up being of little practical relevance in the production of most solid objects.

By far the most widely used production process is suspension polymerization. In this process, VCM and water are introduced into the polymerization reactor and a polymerization initiator, along with other chemical additives, are added to initiate the polymerization reaction. The contents of the reaction vessel are continually mixed to maintain the suspension and ensure a uniform particle size of the PVC resin. The reaction is exothermic, and thus requires a cooling mechanism to maintain the reactor contents at the appropriate temperature. As the volumes also contract during the reaction (PVC is denser than VCM), water is continually added to the mixture to maintain the suspension.

Once the reaction has run its course, the resulting PVC slurry is degassed and stripped to remove excess VCM (which is recycled into the next batch) then passed though a centrifuge to remove most of the excess water. The slurry is then dried further in a hot air bed and the resulting powder sieved before storage or pelletization. In normal operations, the resulting PVC has a VCM content of less than 1 part per million.

Other production processes, such as micro-suspension polymerization and emulsion polymerization, produce PVC with smaller particle sizes (10 μm vs. 120-150 μm for suspension PVC) with slightly different properties and with somewhat different sets of applications.

The product of the polymerization process is unmodified PVC. Before PVC can be made into finished products, it almost always requires conversion into a compound by the incorporation of additives such as heat stabilizers, UV stabilizers, lubricants, plasticizers, processing aids, impact modifiers, thermal modifiers, fillers, flame retardants, biocides, blowing agents and smoke suppressors, and, optionally pigments. [5]

History

PVC was accidentally discovered at least twice in the 19th century, first in 1835 by Henri Victor Regnault and in 1872 by Eugen Baumann. On both occasions the polymer appeared as a white solid inside flasks of vinyl chloride that had been left exposed to sunlight. In the early 20th century the Russian chemist Ivan Ostromislensky and Fritz Klatte of the German chemical company Griesheim-Elektron both attempted to use PVC (polyvinyl chloride) in commercial products, but difficulties in processing the rigid, sometimes brittle polymer blocked their efforts. Waldo Semon and the B.F. Goodrich Company developed a method in 1926 to plasticize PVC by blending it with various additives. The result was a more flexible and more easily processed material that soon achieved widespread commercial use.

Applications

PVC's intrinsic properties make it suitable for a wide variety of applications. It is biologically and chemically resistant, making it the plastic of choice for most household sewerage pipes and other pipe applications where corrosion would limit the use of metal.

With the addition of impact modifiers and stabilizers, it becomes a popular material for window and door frames. By adding plasticizers, it can become flexible enough to be used in cabling applications as a wire insulator.

Clothing

PVC has become widely used in clothing, to either create a leather-like material or at times simply for the effect of PVC. PVC clothing is common in Goth, Punk and alternative fashions. PVC is cheaper than rubber, leather, and latex and so it is more widely available and worn.

PVC fabric has a sheen to it and is waterproof. It is commonly used in coats, shoes, jackets, aprons, and bags because of this.

Electric wires

PVC is commonly used as the insulation on electric wires; the plastic used for this purpose needs to be plasticized.

In a fire, PVC-coated wires can form HCl fumes; the chlorine serves to scavenge free radicals and is the source of the material's fire retardance. While HCl fumes can also pose a health hazard in their own right, HCl dissolves in moisture and breaks down onto surfaces, particularly in areas where the air is cool enough to breathe, and is not available for inhalation. [6] Frequently in applications where smoke is a major hazard (notably in tunnels and communal areas)

PVC-free cable insulation is preferred, such as low smoke zero halogen (LSZH) insulation.

Pipes

Roughly half of the world's polyvinyl chloride resin manufactured annually is used for producing pipes for various municipal and industrial applications. [7] In the water distribution market it accounts for 66% of the market in the US, and in sanitary sewer pipe applications, it accounts for 75%. [8] Its light weight, high strength, and low reactivity make it particularly well-suited to this purpose. In addition, PVC pipes can be fused together using various solvent cements, or heat-fused (butt-fusion process, similar to joining HDPE pipe), creating permanent joints that are virtually impervious to leakage.

In February, 2007 the California Building Standards Code was updated to approve the use of chlorinated polyvinyl chloride (CPVC) pipe for use in residential water supply piping systems. CPVC has been a nationally accepted material in the US since 1982; California, however, has permitted only limited use since 2001. The Department of Housing and Community Development prepared and certified an Environmental Impact Report resulting in a recommendation that the Commission adopt and approve the use of CPVC. The Commission's vote was unanimous and CPVC has been placed in the 2007 California Plumbing Code.

In the United States and Canada, PVC pipes account for the largest majority of pipe materials used in buried municipal applications for drinking water distribution and wastewater mains.[9]

Portable electronic accessories

PVC is finding increased use as a composite for the production of accessories or housings for portable electronics. Through a fusing process, it can adopt cleaning properties possessed by materials such as wool or cotton which can absorb dust particles and bacteria. Its inherent ability to absorb particles from the LCD screen and its form fitting characteristics make it effective.

Signs

Polyvinyl chloride is formed in flat sheets in a variety of thicknesses and colors. As flat sheets, PVC is often expanded to create voids in the interior of the material, providing additional thickness without additional weight and minimal extra cost (see Closed-cell PVC foamboard). Sheets are cut using saw and rotary cutting equipment. Plasticized PVC is also used to produce thin, colored, or clear, adhesive-backed films referred to simply as vinyl. These films are typically cut on a computer-controlled plotter or printed in a wide-format printer. These sheets and films are used to produce a wide variety of commercial signage products and markings on vehicles.

Joining

PVC Cements are available at plumbing supply houses. The cement softens the material to a gel state until the adhesive layer cures. This has another practical application of being able to hand-machine with a razor blade the PVC pipe to change the wall thickness to allow assembly of nonstandard radius arc segments of electrical conduit large radius elbows.

Ceiling tiles

PVC Ceiling Tiles are an alternative ceiling tiles that are easy to install over any flat surface. They can be glued onto an existing ceiling with a reasonably flat surface.

Unplasticized polyvinyl chloride (uPVC)

uPVC or Rigid PVC is often used in the building industry as a low-maintenance material, particularly in Ireland, the UK, and in the United States where it is known as vinyl, or vinyl siding.[10][11] The material comes in a range of colors and finishes, including a photo-effect wood finish, and is used as a substitute for painted wood, mostly for window frames and sills when installing double glazing in new buildings, or to replace older single glazed windows. It has many other uses including fascia, and siding or weatherboarding. The same material has almost entirely replaced the use of cast iron for plumbing and drainage, being used for waste pipes, drainpipes, gutters and downpipes.[12]

Due to environmental concerns use of PVC is discouraged by some local authorities in countries such as Germany and the Netherlands.[13][14] This concerns both flexible PVC and rigid uPVC as not only the plasticizers in PVC are seen as a problem but also the emissions from manufacturing and disposal.

Health and safety

Phthalate plasticizers

Many vinyl products contain additional chemicals to change the chemical consistency of the product. Some of these additional chemicals called additives can leach out of vinyl products. Plasticizers that must be added to make PVC flexible have been additives of particular concern.

Because soft PVC toys have been made for babies for years, there are concerns that these additives leach out of soft toys into the mouths of the children chewing on them. Phthalates mimic human hormones and also affect various life forms including fish and invertebrates adversely. Additionally, adult sex toys have been demonstrated to contain high concentrations of the additives.[15] In January 2006, the European Union placed a ban on six types of phthalate softeners, including DEHP (diethylhexyl phthalate), used in toys.[16] In the U.S. most companies have voluntarily stopped manufacturing PVC toys with DEHP and in 2003 the US Consumer Product Safety Commission (CPSC) denied a petition for a ban on PVC toys made with an alternative plasticizer, DINP (diisononyl phthalate).[17] In April 2006, the European Chemicals Bureau of the European Commission published an assessment of DINP which found risk "unlikely" for children and newborns.[18]

Vinyl IV bags used in neo-natal intensive care units have also been shown to leach DEHP. In a draft guidance paper published in September 2002, the US FDA recognizes that many medical devices with PVC containing DEHP are not used in ways that result in significant human exposure to the chemical.[19] The FDA, however, suggests that manufacturers consider eliminating DEHP in certain devices that can result in high aggregate exposures for sensitive patient populations such as neonates.

Other vinyl products including car interiors, shower curtains, and flooring initially release chemical gases into the air. Some studies indicate that this outgassing of additives may contribute to health complications, and have resulted in a call for banning the use of DEHP on shower curtains, among other uses.[20] The Japanese car companies Toyota, Nissan, and Honda have eliminated PVC in their car interiors starting in 2007.

In 2004 a joint Swedish-Danish research team found a statistical association between allergies in children and indoor air levels of DEHP and BBzP (butyl benzyl phthalate), which is used in vinyl flooring.[21] In December 2006, the European Chemicals Bureau of the European Commission released a final draft risk assessment of BBzP which found "no concern" for consumer exposure including exposure to children.[22]

In November, 2005 one of the largest hospital networks in the U.S., Catholic Healthcare West, signed a contract with B.Braun for vinyl-free intravenous bags and tubing.[23] According to the Center for Health, Environment & Justice in Falls Church, VA,[24] which helps to coordinate a "precautionary" PVC Campaign,[25] several major corporations including Microsoft, Wal-Mart, and Kaiser Permanente announced efforts to eliminate PVC] from products and packaging in 2005. [26] Target is reducing its sale of items with PVC. [27]

The FDA Paper titled "Safety Assessment of Di(2-ethylhexyl)phthalate (DEHP)Released from PVC Medical Devices" states that [3.2.1.3] Critically ill or injured patients may be at increased risk of developing adverse health effects from DEHP, not only by virtue of increased exposure, relative to the general population, but also because of the physiological and pharmacodynamic changes that occur in these patients, compared to healthy individuals. [28]

In 2008 the European Union's Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR) reviewed the safety of DEHP in medical devices. The SCENIHR report states that certain medical procedures used in high risk patients result in a significant exposure to DEHP and concludes there is still a reason for having some concerns about the exposure of prematurely born male babies to medical devices containing DEHP. [29] The Committee said there are some alternative plasticizers available for which there is sufficient toxicological data to indicate a lower hazard compared to DEHP but added that the functionality of these plasticizers should be assessed before they can be used as an alternative for DEHP in PVC medical devices.

Vinyl chloride monomer

In the early 1970s, Dr. John Creech and Dr. Maurice Johnson were the first to clearly link and recognize the carcinogenicity of vinyl chloride monomer to humans when workers in the polyvinyl chloride polymerization section of a B.F. Goodrich plant near Louisville, Kentucky, were diagnosed with liver angiosarcoma also known as hemangiosarcoma, a rare disease. [30] Since that time, studies of PVC workers in Australia, Italy, Germany, and the UK have all associated certain types of occupational cancers with exposure to vinyl chloride. The link between angiosarcoma of the liver and long-term exposure to vinyl chloride is the only one that has been confirmed by the International Agency for Research on Cancer. All the cases of angiosarcoma developed from exposure to vinyl chloride monomer were in workers who were exposed to very high VCM levels, routinely, for many years. These workers cleaned accretions in reactors, a practice that has now been replaced by automated high-pressure water jets.
A 1997 U.S. Centers for Disease Control and Prevention (CDC) report concluded that the development and acceptance by the PVC industry of a closed loop polymerization process in the late 1970s "almost completely eliminated worker exposures" and that "new cases of hepatic angiosarcoma in vinyl chloride polymerization workers have been virtually eliminated." [31]

According to the EPA, "vinyl chloride emissions from polyvinyl chloride (PVC), ethylene dichloride (EDC), and vinyl chloride monomer (VCM) plants cause or contribute to air pollution that may reasonably be anticipated to result in an increase in mortality or an increase in serious irreversible, or incapacitating reversible illness. Vinyl chloride is a known human carcinogen that causes a rare cancer of the liver." [32] EPA's 2001 updated Toxicological Profile and Summary Health Assessment for VCM in its Integrated Risk Information System (IRIS) database lowers EPA's previous risk factor estimate by a factor of 20 and concludes that "because of the consistent evidence for liver cancer in all the studies...and the weaker association for other sites, it is concluded that the liver is the most sensitive site, and protection against liver cancer will protect against possible cancer induction in other tissues." [33]

A 1998 front-page series in the Houston Chronicle claimed the vinyl industry has manipulated vinyl chloride studies to avoid liability for worker exposure and to hide extensive and severe chemical spills into local communities. [34]

Retesting of community residents in 2001 by the U.S. Agency for Toxic Substances and Disease Registry (ATSDR) found dioxin levels similar to those in a comparison community in Louisiana and to the U.S. population. [35] Cancer rates in the community were similar to Louisiana and US averages. [36]

Dioxins

Main article: Polychlorinated dibenzodioxins

The environmentalist group Greenpeace has advocated the global phase-out of PVC because they claim dioxin is produced as a byproduct of vinyl chloride manufacture and from incineration of waste PVC in domestic garbage. [37]

PVC produces HCl upon combustion almost quantitatively related to its chlorine content. Extensive studies in Europe indicate that the chlorine found in emitted dioxins is not derived from HCl in the flue gases. Instead, most dioxins arise in the condensed solid phase by the reaction of inorganic chlorides with graphitic structures in char-containing ash particles. Copper acts as a catalyst for these reactions. [38]

According to a 1994 report by the British firm, ICI Chemicals & Polymers Ltd., "It has been known since the publication of a paper in 1989 that these oxychlorination reactions [used to make vinyl chloride and some chlorinated solvents] generate polychlorinated dibenzodioxins (PCDDs) and dibenzofurans (PCDFs). The reactions include all of the ingredients and conditions necessary to form PCDD/PCDFs.... It is difficult to see how any of these conditions could be modified so as to prevent PCDD/PCDF formation without seriously impairing the reaction for which the process is designed." In other words, dioxins are an undesirable byproduct of producing vinyl chloride and eliminating the production of dioxins while maintaining the oxychlorination reaction may be difficult. Dioxins created by vinyl chloride production are released by on-site incinerators, flares, boilers, wastewater treatment systems and even in trace quantities in vinyl resins. [39] The US EPA estimate of dioxin releases from the PVC industry was 13 grams TEQ in 1995, or less than 0.5% of the total dioxin emissions in the US; by 2002, PVC industry dioxin emissions had been further reduced by 23%. [40]

Studies of household waste burning indicate consistent increases in dioxin generation with increasing PVC concentrations. [41] According to the EPA dioxin inventory, landfill fires are likely to represent an even larger source of dioxin to the environment. A survey of international studies consistently identifies high dioxin concentrations in areas affected by open waste burning and a study that looked at the homologue pattern found the sample with the highest dioxin concentration was "typical for the pyrolysis of PVC". Other EU studies indicate that PVC likely "accounts for the overwhelming majority of chlorine that is available for dioxin formation during landfill fires." [41]

The next largest sources of dioxin in the EPA inventory are medical and municipal waste incinerators. [42] Various studies have been conducted that reach contradictory results. For instance a study of commercial-scale incinerators showed no relationship between the PVC content of the waste and dioxin emissions. [43][44] Other studies have shown a clear correlation between dioxin formation and chloride content and indicate that PVC is a significant contributor to the formation of both dioxin and PCB in incinerators. [45]

In February 2007, the Technical and Scientific Advisory Committee of the US Green Building Council (USGBC) released its report on a PVC avoidance related materials credit for the LEED Green Building Rating system. The report concludes that "no single material shows up as the best across all the human health and environmental impact categories, nor as the worst" but that the "risk of dioxin emissions puts PVC consistently among the worst materials for human health impacts." [46]

Bans

The State of California is currently considering a bill that would ban the use of PVC in consumer packaging due to the threats it poses to human and environmental health and its effect on the recycling stream. [47] Specifically, the language of the bill analysis [48] stipulates that EPA has listed PVC as a carcinogen. It also further cites that there are concerns about the leaching of phthalates and lead from the PVC packaging.

Recycling

Post-consumer PVC is not typically recycled due to the prohibitive cost of regrinding and recompounding the resin compared to the cost of virgin (unrecycled) resin.

Some PVC manufacturers have placed vinyl recycling programs into action, recycling both manufacturing waste back into their products, as well as post consumer PVC construction materials to reduce the load on landfills.

The thermal depolymerization process can safely and efficiently convert PVC into fuel and minerals, according to the company that developed it. It is not yet in widespread use.

A new process of PVC recycling is being developed in Europe called Texiloop. [49] This process is based on a technology already applied industrially in Europe and Japan, called Vinyloop, which consists of recovering PVC plastic from composite materials through dissolution and precipitation. It strives to be a closed loop system, recycling its key solvent and hopefully making PVC a future technical nutrient.

See also

- Chlorinated polyvinyl chloride
- Polyvinylidene chloride
- Polyvinyl fluoride
- Polyvinylidene fluoride
- Plastic recycling

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External links

The Association between Asthma and Allergic Symptoms in Children and Phthalates in House Dust: A Nested Case-Control Study

The European PVC Portal (European Council of Vinyl Manufacturers)

Uni-Bell PVC Pipe Association

An introduction to vinyl

The Vinyl Council of Canada