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A review on the Uses and Thermal Degradation of PVC (Polyvinyl Chloride)

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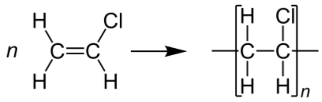
Abstract : Polyvinyl chloride is the world's most widely produced synthetic polymer of plastic. About 40 million tons of PVC is produced each year. PVC comes in rigid and flexible forms. Rigid PVC is used in construction for pipes, doors, windows, plumbing, electrical cable insulation, flooring, signage, phonograph records, inflatable products, and in rubber substitutes etc. Thermal degradation of polyvinyl chloride (PVC) occurs in two steps viz Dehydrochlorination and Decomposition of the polyene chain this paper aims to analyse about the uses and thermal degradation of Polyvinyl Chloride. The dehydrochlorination of PVC mainly happed at low temperature of 250-320. °C. The process of PVC dehydrochlorination can catalyze and accelerate the biomass pyrolysis. The intermediates from dehydrochlorination stage of PVC can increase char yield of co-pyrolysis of PVC.

***IndexTerms* - polymerization, vinyl chloride, degradation, pipes, Decomposition.**

I. INTRODUCTION

PVC is a flexible or rigid material that is chemically nonreactive. Rigid PVC is easily machined, heat formed, welded, and even solvent cemented. PVC can also be machined using standard metal working tools and finished to close tolerances and finishes without great difficulty. PVC resins are normally mixed with other additives such as impact modifiers and stabilizers, providing hundreds of PVC-based materials with a variety of engineering properties. It is also used in making plastic bottles, packaging, and bank or membership cards. Adding plasticizers makes PVC softer and more flexible. It is used in plumbing, electrical cable insulation, flooring, signage, phonograph records, inflatable products, and in rubber substitutes. With cotton or linen, it is used in the production of canvas. Polyvinyl chloride is a white, brittle solid. It is insoluble in all solvents but swells in its monomer and some chlorinated hydrocarbon solvents.

Structure of PVC



The polymers are linear and are strong. The monomers are mainly arranged head-to-tail, meaning that chloride is located on alternating carbon centres. PVC has mainly an atactic stereochemistry, which means that the relative stereochemistry of the chloride centres are random. Some degree of syndiotacticity of the chain gives a few percent crystallinity that is influential on the properties of the material. About 57% of the mass of PVC is chlorine. The presence of chloride groups gives the polymer very different properties from the structurally related material polyethylene. At 1.4 g/cm^3, PVC's density is also higher than for these structurally related plastics such as polyethylene (0.88–0.96 g/cm^3) and polymethylmethacrylate (1.18 g/cm^3).

Polyvinyl chloride is produced by polymerization of the vinyl chloride monomer (VCM) About 80% of production involves suspension polymerization. Emulsion polymerization accounts for about 12%, and bulk polymerization accounts for 8%. Suspension polymerization produces particles with average diameters of 100–180 μm, whereas emulsion polymerization gives much smaller particles of average size around 0.2 μm. VCM and water are introduced into the reactor along with a polymerization initiator and other additives. The contents of the reaction vessel are pressurized and continually mixed to maintain the suspension and ensure a uniform particle size of the PVC resin. The reaction is exothermic and thus requires cooling. As the volume is reduced during the reaction (PVC is denser than VCM), water is continually added to the mixture to maintain the suspension. PVC may be manufactured from ethylene, which can be produced from either naphtha or ethane feedstock.

Applications of PVC

Pipes

PVC is used extensively in sewage pipes due to its low cost, chemical resistance and ease of jointing. Roughly half of the world's PVC resin manufactured annually is used for producing pipes for municipal and industrial applications. In the private homeowner market, it accounts for 66% of the household market in the US, and in household sanitary sewer pipe applications, it accounts for 75%. Buried PVC pipes in both water and sanitary sewer applications that are 100 mm (4 in) in diameter and larger are typically joined by means of a gasket-sealed joint. The most common type of gasket utilized in North America is a metal-reinforced elastomer, commonly referred to as a Rieber sealing system.

Construction

"A modern Tudorbethan" house with uPVC gutters and downspouts, fascia, decorative imitation "half-timbering", windows, and doors. PVC is widely and heavily used in construction and building industry, For example, vinyl siding is extensively is a popular low-maintenance material, particularly in Ireland, the United Kingdom, the United States, and Canada. 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 insulated glazing in new buildings; or to replace older single-glazed windows, as it does not decompose and is weather-resistant. Other uses include fascia, and siding or weatherboarding. This material has almost entirely replaced the use of cast iron for plumbing and drainage, being used for waste pipes,drainpipes, gutters and downspouts. PVC is known as having strong resistance against chemicals, sunlight, and oxidation from water.

Signage and graphics

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 saws 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 (see vinyl cutter) or printed in a wide-format printer. These sheets and films are used to produce a wide variety of commercial signage products, vinyl wraps or racing stripes on vehicles for aesthetics or as wrap advertising, and general purpose stickers.

Clothing

PVC fabric is water-resistant, used for its weather-resistant qualities in coats, skiing equipment, shoes, jackets, and aprons.

Healthcare

The two main application areas for single-use medically approved PVC compounds are flexible containers and tubing: containers used for blood and blood components, for urine collection or for ostomy products and tubing used for blood taking and blood giving sets, catheters, heart-lung bypass sets, hemodialysis sets etc. In Europe the consumption of PVC from medical devices is approximately 85,000 tons each year. Almost one third of plastic-based medical devices are made from PVC.

Wire rope

PVC may be extruded under pressure to encase wire rope and aircraft cable used for general purpose applications. PVC coated wire rope is easier to handle, resists corrosion and abrasion, and may be color-coded for increased visibility. It is found in a variety of industries and environments both indoor and outdoor.

Other uses

Molded PVC is used to produce Phonograph, or "vinyl," records. PVC piping is a cheaper alternative to metal tubing used in musical instrument making; it is therefore a common alternative when making wind instruments, often for leisure or for rarer instruments such as the contrabass flute. An instrument that is almost exclusively built from PVC tube is the thongophone, a percussion instrument that is played by slapping the open tubes with a flip-flop or similar. PVC is also used as a raw material in automotive underbody coating.

II. THERMAL DEGRADATION

Thermal degradation of PVC can also be broken down into three stages in the first stage, PVC goes through dehydrochlorination to form polyene. In the second stage, polyene decomposes to low-molecular weight compounds. In the third stage, polyene further decomposes into a large amount of low-molecular weight compounds. Thermal degradation occurs when the polymer changes its properties under the influence of increased temperature.

Thermal degradation of polyvinyl chloride (PVC) refers to the process by which PVC breaks down when exposed to high temperatures. This degradation involves the chemical breakdown of the polymer chains in PVC, leading to a range of chemical changes and the formation of new substances. Here's a closer look at what happens during thermal degradation of PVC:

1. *Initial Decomposition*
   - Temperature Range: PVC begins to degrade at temperatures above 100°C (212°F), with significant degradation occurring above 200°C (392°F). The exact temperature can vary depending on the specific formulation and additives in the PVC.
   - Dehydrochlorination: The primary chemical reaction in PVC degradation is dehydrochlorination, where hydrochloric acid (HCl) is released. This reaction involves the removal of HCl from the polymer chain, resulting in the formation of polyene sequences (long chains of alternating double and single bonds).

$$\text{PVC} \rightarrow \text{Polyene} + \text{HCl}$$

2. *Further Decomposition*
   - Formation of Byproducts: As the temperature increases, the polyene chains can undergo further breakdown, leading to the formation of smaller molecules such as carbon monoxide (CO), carbon dioxide (CO_2), and various volatile organic compounds (VOCs). The exact byproducts depend on the conditions and the presence of additives or stabilizers in the PVC.
   - Potential Formation of Toxins: Thermal degradation of PVC can also produce potentially harmful substances, including dioxins and furans, especially if the process is uncontrolled or if PVC contains certain additives.
3. *Impact on Material Properties*
   - Loss of Mechanical Properties: As PVC degrades, it loses its original mechanical properties, such as strength and flexibility. The material may become brittle and discolored.

- Emission of Gases: Degradation can result in the emission of gases like HCl, which can be corrosive and harmful if not properly managed.

4. *Controlled Degradation*

In controlled environments, such as during recycling or disposal, thermal degradation of PVC can be managed to minimize the release of harmful byproducts. Techniques like pyrolysis can break down PVC into useful products, such as oils or gases, which can be used as fuels or feedstocks for other chemical processes.

Understanding the thermal degradation of PVC is crucial for applications involving high temperatures, such as in manufacturing and recycling processes, and for ensuring safety and environmental protection.

This process of Thermal Degradation is important for several reasons:

- Recycling and Disposal: PVC is not biodegradable, so thermal degradation is one way to manage its disposal. Controlled thermal degradation, often through pyrolysis, can help break down PVC into its component chemicals, which can then potentially be used to create new materials or fuels. However, this process must be carefully managed to handle and mitigate the release of harmful byproducts.
- Material Processing: In manufacturing, understanding how PVC behaves under heat is crucial for processes like extrusion and molding. PVC needs to be heated to specific temperatures to be shaped, but excessive heat can cause degradation, impacting the quality and durability of the final product.
- Chemical Analysis**:** Thermal degradation studies can help identify the thermal stability of PVC and the nature of the degradation products. This can provide insights into the material's performance, safety, and the potential environmental impact of its breakdown products.
- Safety Considerations: During high-temperature processing or disposal, PVC can release harmful gases such as hydrogen chloride (HCl), which is corrosive and toxic. Understanding thermal degradation helps in designing systems that can safely manage these emissions, protecting both human health and the environment.

Overall, studying and managing the thermal degradation of PVC is important for improving recycling processes, ensuring safe manufacturing practices, and minimizing environmental and health risks.

III. BENEFITS OF THERMAL DEGRADATION OF PVC

Thermal degradation of PVC (polyvinyl chloride) can offer several benefits, particularly when managed carefully. These benefits include:

1. *Recycling and Resource Recovery*
   - Material Recovery: Thermal degradation can be used to break down PVC into its component chemicals. This process, known as pyrolysis, can recover valuable chemicals and materials from PVC waste, which can then be used to produce new products or as feedstocks for other chemical processes.
   - Energy Generation: The process can also generate energy. The gases and oils produced during thermal degradation can be used as alternative fuels, providing a way to recover energy from PVC waste.
2. *Reduction of Landfill Waste*
   - Waste Minimization: By converting PVC waste into useful byproducts or energy, thermal degradation helps reduce the amount of PVC that ends up in landfills, which is beneficial for waste management and environmental protection.
3. *Controlled Degradation for Product Enhancement*
   - Material Processing: In controlled conditions, thermal degradation can be used to modify PVC properties for specific applications. For example, it can help in the removal of additives that might affect the material’s performance, leading to more consistent and predictable product characteristics.
4. *Reduction of Environmental Impact*
   - Minimized Leachate: By converting PVC waste into other forms, thermal degradation can reduce the potential for harmful chemicals leaching into soil and water from landfilled PVC.
   - Controlled Emissions: When managed properly, the emissions from thermal degradation can be captured and treated, reducing the release of harmful substances into the environment. Technologies such as scrubbers and filters can help mitigate the environmental impact.
5. *Chemical Analysis and Safety*
   - Understanding Degradation Products: Studying thermal degradation helps understand the types of byproducts formed and their potential impacts. This knowledge is useful for improving safety protocols and developing better recycling processes.
6. *Innovation and Process Improvement*
   - Development of New Technologies: Research into the thermal degradation of PVC can drive innovation in recycling technologies and materials science. This can lead to the development of more efficient and environmentally friendly methods for managing PVC waste.

In summary, while thermal degradation of PVC has challenges, particularly related to emissions and potential byproducts, it also offers opportunities for recycling, waste reduction, energy recovery, and process improvement. Properly managed, it can be a valuable tool in the lifecycle management of PVC materials.

IV. RESULTS AND DISCUSSION

After the study we can define find the result and discussion as as

1. Decomposition Temperature**:**
   - PVC begins to degrade at temperatures around 100°C (212°F), with significant decomposition observed above 200°C (392°F).
2. Chemical Changes**:**
   - The primary reaction is dehydrochlorination, where HCl is released, resulting in the formation of polyenes.

  - Further thermal degradation leads to the formation of smaller molecules such as CO, CO_2, and various volatile organic compounds (VOCs).
3. Byproducts**:**
   - Significant byproducts include HCl gas, which is corrosive and requires careful handling.
   - Other byproducts can include dioxins and furans, which are hazardous.
4. Material Properties:
   - PVC degrades into brittle, discolored material with reduced mechanical properties.
5. Energy Production**:**
   - Pyrolysis of PVC can produce gases and oils that can be used as alternative fuels, demonstrating potential energy recovery benefits.
6. Emissions**:**
   - Emissions of HCl and other gases need to be managed to minimize environmental impact.

The thermal degradation of PVC reveals both opportunities and challenges. The process effectively breaks down PVC into component chemicals and potentially useful byproducts, offering recycling and energy recovery benefits. However, the release of hazardous gases, such as HCl and dioxins, underscores the need for controlled degradation conditions and effective emission management. The formation of valuable byproducts, such as fuel oils, illustrates the potential for integrating PVC degradation into waste-to-energy systems. Future research should focus on optimizing degradation conditions to maximize resource recovery while minimizing environmental and health risks associated with harmful emissions. Additionally, advancements in emission control technologies can further enhance the sustainability of PVC thermal degradation processes.

V. CONCLUSION

The thermal degradation of PVC presents a complex interplay of benefits and challenges. While it provides valuable opportunities for recycling and energy recovery by breaking down PVC into usable byproducts and alternative fuels, it also poses significant risks due to the release of hazardous gases such as HCl and potential toxins like dioxins. Effective management and control of degradation processes are essential to minimize environmental and health impacts. Advances in emission control technologies and improved recycling methods can enhance the sustainability of PVC thermal degradation, making it a viable option for managing PVC waste while addressing its associated risks.

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