Innovative Analytical Solutions for Sustainable Polymer Production: Magnetic Resonance

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Introduction

The matter is comprised of chemical building blocks organized in various arrangements to create a multitude of materials. A type of matter known as polymers (which means "many parts") is a repeating chain of such chemical building blocks found all around us.

Polymers include naturally occurring biological molecules such as proteins (chain of connected amino acid) and genetic material DNA (connected nucleic acids). Examples of natural polymers include rubber and cellulosa or stack. Polymers can also be artificial or engineered with identical links that prove invaluable to everyday objects in life. Materials such as plastics or fabric like polyester in clothing are composed of polymers. Polymers are an integral part of our modern life, heavily used in research with various applications in industrial laboratories to various products in everyday life.

German organic chemistry professor Hermann Staudinger taught at ETH Zurich and is the pioneer of modern polymer engineering. He also conducted research at various famous universities, including LMU Munich and the University of Karlsruhe. Staudinger coined the terms "polymerization" and "macromolecules," which are crucial to understanding and manipulating polymers.

Awarded the Nobel Prize in Chemistry in 1953, Staudinger propelled forward research in macromolecular chemistry. His contributions led to further discoveries that transformed materials science into a widely applicable and innovative field.

As a long repetitive chain of molecules, polymers possess specific characteristics that make them useful in various applications. Different properties of polymers arise from intramolecular composition and intermolecular interaction. For example, some polymers are more flexible and can be stretched, such as rubber, while others, like acrylic glass, are rigid and toughened against outside forces.

Some polymers can reversibly be molded and solidified, whereas others are irreversibly hardened. The polymeric material is designed to match turn-key properties in various applications, and therefore, molecular interactions and compositions must be well understood.

Polymerization is defined as the process of creating polymers by linking smaller molecules into long chains known as macromolecules that underpins the creation of polymers today.

The everyday application of such analytical techniques has enabled us a range of functionalities from research and product innovation development to manufacturing and quality control.

Leading scientific technology companies like Bruker develop a range of diverse advanced polymer solutions to serve the entire polymer value chain. Starting from basic academic research, innovations are transferred into more applicable and industrial environmentsand finally find their way into our daily. This eBook will delve into the uses of polymers in everyday life and highlight innovations in polymer applications.

Furthermore, it will explain how magnetic resonance spectroscopy provides advanced solutionsfor the polymer industry particularly how Bruker addresses challenges in polymer synthesis.

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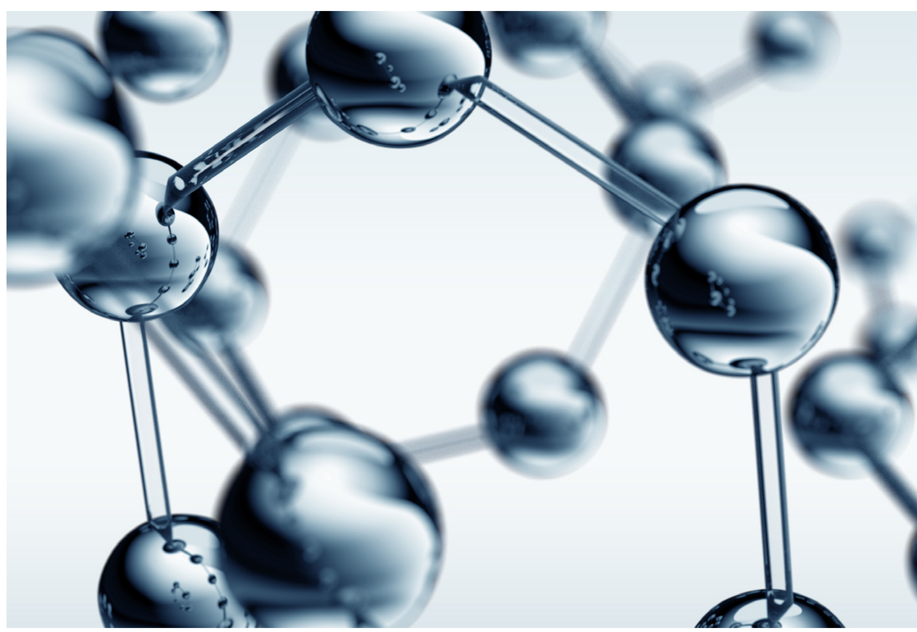

01. Polymers in Everyday Life

Polymers are omnipresent in everyday life and play a crucial role in almost every aspect of it. Synthetic polymeric materials are purposefully designed, diverse and versatile with massive potential in every aspect, used almost without any limit.

Examples of such industrial applications include packaging, electronic devices, mobility, construction, energy conversion, and storage to healthcare sectors. From clothing and cookware to architecture and transportation, polymers make a lot of human functions possible. Especially in a rapidly advancing scientific community, polymers provide technological solutions to facilitate everyday living.

Global polymer supply chains are constantly confronted by competition and, more increasingly, by new regulations. The ability to adapt rapidly to these external triggers throughout the whole value chain leads to a reduced time-to-market for novel products. Therefore, such capabilities and the ability to be adopted give a company a significant advantage, helping them get ahead of the competition curve. The concept of rapid adoption includes the application of novel technologies, testing methods, and formulations at any stage, from raw material to functional products and from product innovation via manufacturing to quality control.

As manufacturing needs rise in an increasingly industrialized world, the need for different materials that could be effective in various situations becomes more and more apparent. This chapter will describe a few specific examples of polymers in everyday life to depict the wide-ranging capabilities of these repetitive macromolecules.

Polymers and Packaging

The leading everyday application of polymers is in plastics and packaging material. About 45% of plastics manufactured are used for packaging or to contain goods, making this the most significant polymer application area.

Plastic can be flexible or rigid and often very durable, hygienic, and manufactured cost-effectively; many types of plastic containers are used to preserve products like foods, pharmaceuticals, or any other traded goods. Plastic packaging protects goods while being manufactured, stored, transported, and even displayed in retail.

The polymeric composition defines the characteristics of plastic materials. Plastics need to meet a demanding condition in which many packaging materials are subject to regulatory requirements.

Plastics have a high temperature resilience, can be suitable for heating food in ovensand microwaves and can last while frozen or kept in coolers. Furthermore, these materials have high durability, strong sealing properties and the ability to be shaped and maintain a unique but versatile form.

Alongside chemical resistance, the potential to be transparent for viewing the content and at the same time providing insulation is imperative. Polymers used to manufacture plastic are typically extracted from non-renewable oil or coal sources; however, movements toward renewable, biodegradable plastics from plants and trees are becoming more prominent.

These more environmentally friendly options widen the potential for plastics to be used even more widely in the future. These advances are discussed further in the chapter covering innovations in the polymer industry.

Polymers and Transportation

The transportation industry also relies heavily on polymers. Most notable are polymers used in car tires and other wheel components of the vehicles, including but not limited to trucks, motorbikes, and airplanes. Specifically, manufatctures employ a mixture of natural and synthetic forms of rubber to design tires on special requirements. Natural rubber is intrinsically tough and durable against wear and tear, a requirement from the manufacturer to become acceptable in vehicles and safe driving.

Synthetic rubber polymers such as butadiene rubber are known to resist rolling, wear and tear and bolster traction. Furthermore, synthetic rubber polymers like halobutyl rubber provide an impermeable ring layer that holds the air inside, preventing it from leaking keeping the tire inflated.

Synthetic rubbers are combined with natural rubber to bolster the natural polymer’s inherent strengths and add physical and chemical properties to make the tire more efficient and reliable.

Synthetic rubber polymers such as butadiene rubber are known to resist rolling, wear and tear and bolster traction. Furthermore, synthetic rubber polymers like halobutyl rubber provide an impermeable ring layer that holds the air inside, preventing it from leaking keeping the tire inflated.

There are several important pillars in designing functional material based on the purpose it is formulated. Various ratios of base constituents, including trace levels of additives, lead to various properties. The other important pillar is processing polymers.

The molecular structure of polymeric material can be intentionally modified via well-understood additive interactions in the presence of defined thermodynamic parameters or electromagnetic radiation. One example is the vulcanization process of tires where inter-molecular bridges are formed: a higher density of crosslinks leads to more rigid materials suitable for tires durability.

Polymers and Health

The powers of polymers further extend to the health industry. For example, polymers are used in medical sutures and implants.

Medical sutures are usually synthetic materials used to stitch open wounds to prevent further injury and infection and facilitate tissue healing.

The sutures need to be flexible, with threading strong enough to withstand physical motions of the body that could affect the wound area and durable enough to stay securely knotted throughout the entire healing process.

Furthermore, sutures are required to be biologically compatible with patients and sterile to reduce discomfort and inflammation around the wound area. Polymers possess different tensile strengths suited to various suturing cases and can be synthesized to biodegrade and absorbed by the body after healing.

Polymers can be created in various fiber architectures like monofilament structures to reduce bodily inflammation, minimize tissue reaction, and promote healing.

Polymers are used for medical implants because they can be easily manipulated biologically, chemically, and physically. The ability of polymers to degrade in particular underpins the function of medical implants and drug delivery systems.

Additionally, due to its carbon-based structure, polymers are more alike to biological tissue than other inorganic engineered materials, making polymers a suitable choice for implants. The uses of polymers are not limited to packaging, tires, sutures and implants. However, these are a few common examples that depict the wide-ranging applications of polymers in daily life.

Several industries rely upon polymers, and people interact with polymers daily, depending on them for day-to-day living. That is why continued innovation within the polymer industry is vital, including seeking solutions for polymer applications and addressing challenges that arise from creating polymers.

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02. Sustainability in Polymers - Summary of New Trends

With over 370 million tons of plastics produced globally every year — and 50% of this number representing single-use plastics — the last few decades have seen an exponential increase in the production of plastics (projected to reach 1.1 billion tons by 2050) [1, 2, 3]. However, since synthetic polymers and plastics are typically derived from fossil feedstocks, they are hardly degradable.

While recycling can be part of the solution in the fight against plastic pollution, it does not provide a long-term solution to the ongoing demand for plastics (only 10% of these are recycled)[3]. Linear low-density polyethylene (LLDPE) plastics, for instance, are commonly used in packaging. While demand in the developed world is expected to rise by 142% over the next 20 years, it is eclipsed by the developing world, expecting to see a rise of 306%[4].

The solution seems to be to reduce reliance on fossil fuel-derived plastics while also providing better pathways to degradation and recycling. Biodegradable polymers are a promising technology, the production of which is projected to double between 2021 and 2026, reaching just under 2,000 kilotons per year by 2026[5].

The contribution of these biodegradable polymers to environmental sustainability will require a concerted effort between academia, industry and government.

What are sustainable polymers?

Sustainable polymers are macromolecules derived from renewable feedstocks, such as lignin, carbohydrates, renewable acids, lactones, and terpenes. The production of these polymers consumes less energy and water, produces less waste and carbon, and results in easily degradable compounds.

Challenges of Sustainable Polymer Production

Currently, the production of sustainable polymers relies heavily on food crops such as soybean, corn, sugarcane, and vegetable oils. There are ongoing efforts to find ways of using non-food stock such as switchgrass, plant lignin, and agricultural waste.Furthermore, producing sustainable polymers that exhibit the toughness, elasticity, and thermal conductivity of traditional polymers is also a challenge.

Future Trends in Sustainable Polymers

Schemes such as the Circular Plastics Alliance illustrate governments' commitment to sustainable plastics production[6]. Even the banks responsible for funding new projects are expressing concerns over the environmental impact of plastics[4].

As sustainable polymers are a new technology, there will need to be a concerted effort between industry and government to instigate policies and programs that bring their full benefits to market. In fact, over 100 countries would like to see a treaty setting targets for plastic waste reduction[7]; 70 leading businesses have also lent their voice to these proposals[8].

Moreover, regulating the advertising of environmentally friendly products will increase the public's awareness of plastic pollution and enhance their confidence in governments and industry.

Key Takeaways

Bringing the full benefits of sustainable polymers to market will require the involvement of government, industry, academia, and the wider public. Forward-looking polymer producers will support environmental clean-up schemes and develop greener methods for polymer synthesis.

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03. New Innovations in Polymer Applications

With polymers possessing advantages which are beneficial to a multitude of industries, researchers are consistently developing innovations in polymer applications. In expanding the potential of polymers, these macromolecules could facilitate efficient human processes even further. This chapter highlights selected novel polymer applications regarding environmental impact and medicine that broadly impact science and technology industries.

Lowering the Environmental Impact of Polymer Products

Lowering the environmental impact of products that are composed of polymers, such as plastics that do not degrade and instead infiltrate and pollute ecosystems, is a significant priority for many polymer developers. The quality of biodegradability in polymers requires innovative solutions to reduce polymer waste.

Biodegradable polymers can reduce the environmental risk by safely degrading after disposal, avoiding polluting the environment, and posing a threat to wildlife and humans alike. Polymer engineers are also designing macromolecules for recycling with this priority in mind. As previously mentioned, plastics play a significant role in our everyday lives. But many plastic products are made of different base materials. Due to the need for separation, these composite materials are difficult to recycle.

However, researchers have begun investing in the potential of biobased recyclable polymers by improving the decomposition ability of individual polymer components and designing various chemical properties of polymers to improve their recyclability.

For example, researchers are investigating the invention of plastics from renewable feedstock, which allows for carbon-neutral products. Renewable plastics possess new chemical structures with thermal and barrier advantages that fit packaging needs, especially with goods that need to be contained at specific temperatures.

Along a similar vein, innovations in using biopolymers, organic polymers naturally produced by organisms, have shown to be a promising sustainable solution that does not adversely affect the natural environment.

For example, biopolymers can enhance soil strength for construction purposes which holds great potential for sustainable engineering activities. Like biopolymers, another emerging form of macromolecule that shows environmental benefit is geopolymers. Geopolymers are inorganic polymers linked by strong covalent bonds, making them very useful for industrial uses.

Specifically, the use of geopolymers in the production of green cement is a notable new development. The production of geopolymers for green cement utilizes waste and by-products of other manufacturing processes such as fly-ash to manufacture the concrete.

Architectural projects built using green concrete can reduce carbon footprint by repurposing waste into productive material. Commercial companies are also striving to innovate the environmental impact of polymers. For example, Adidas created the first fully recyclable performance shoe line titled Futurecraft.Loop.

This running shoe can be returned to Adidas to be recycled and reused as it is wholly composed of fibers from plastic pollution and waste found in the ocean and other marine environments. In tackling plastic waste problems, this innovation in polymers contributes to a circular economy. Producing goods with only a single material type can be repurposed in a "closed loop" manufacturing model related to the sustainable circular economy. This model is intended for the long-term production of reusable goods and emphasizes a reduced carbon footprint.

Advancing Polymers in Biomedicine and Health

Novel, innovative advancements in the polymer industry are also taking place in health and biomedicine. Controlled and reliable delivery of targeted drugs and therapeutics is essential when considering drug release. Polymers are suitable for such drug delivery devices if used via biological implantation placed in the body.

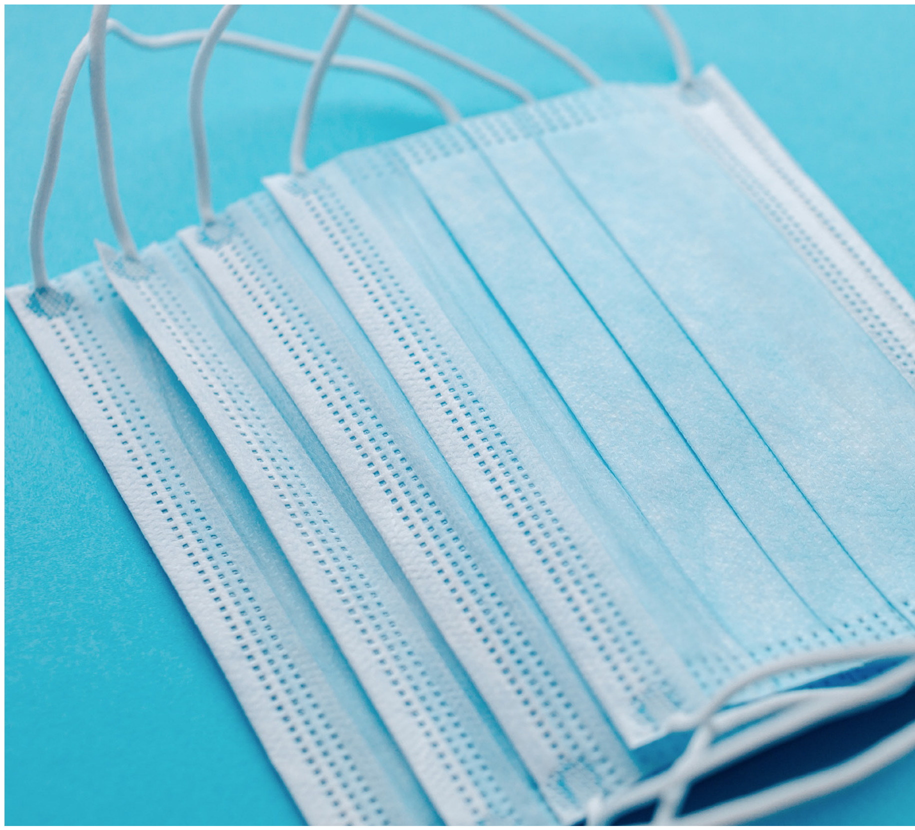
For example, a biodegradable polymer microchip possessed containers filled with various drugs for staggered release into the body at the proper dosage and timing prescribed by health care physicians.

Furthermore, "smart" magnetic polymer coated with drug delivery implants is another example of a vital innovation in advancing individualized therapeutic medicine. This invention ensures the drug is preserved and protected at a similar temperature to the human body, only to be released at the right moment through a non-invasive method while at the same time, it can be "remotely controlled" using a magnetic field.

This approach ensures that the safety and comfort of the patient are prioritized. With the ability to address the wide variety of diseases that require tailored treatments, polymers enable personalized drug delivery to patients and boost the efficacy of biomedical therapeutics.

Perhaps the most recognizable and obvious need for advanced polymers today also regards the medical community, mainly concerning personal protective equipment. In particular, the protective face mask has become ubiquitous during the COVID-19 pandemic and is valuable in protecting people from disease transmission via bacteria or viruses.

Polymers have contributed to developing a protective mask filter capable of inactivating SARS-Cov-2 and multi-resistance bacteria particles.



The first of its kind, the filter is a nonwoven product made of synthetic polymers with antiviral and antibacterial properties, displaying the expansive extent to which polymers can be applied. This innovation can profoundly impact the medical community and, more comprehensively, positively impact public health.

The polymer industry is rapidly progressing with new inventions and developments. Thus, advanced solutions are necessary to keep pace.

Leading laboratory technology companies such as Bruker support innovations in polymer applications by providing tailored analytical testing solutions. In the next chapter, particular solutions employed by the polymer industry to keep the field inventive and progressive in addressing society's needs are discussed.

Enhancing the New Plastic Upcycling Approach

The most common type of plastic is polyethylene, which derives from crude oil. This material can be easily recycled into new plastic, making it valuable in plastic upcycling approaches.

There are two types of polyethylene: low-density and high-density. The former is made from petroleum and possesses flexibility and high tensile strength, making it resistant to scratches and impacts.

The latter was invented decades later than low-density polyethylene and is made from tightly packed polymer chains from petroleum, boasting an impressively high tensile. High-density polyethylene also has a low absorption ability for moisture. Both types of polyethylene are recyclable, which can cut energy usage and costs for plastic disposal and manufacturing processes.

We often donwcycle polymers recycling, such as reusing food packaging for lower quality packaging purposes. While recycling is a common way to repurpose plastic, upcycling is an emerging approach with various advantages.

Instead of recycled plastic losing value in the cycle, upcycling is producing plastic products with high value. For example, researchers at RMIT University in Australia created nanotubes and fuel using plastic.

A manufacturer may want to produce – or upcycle - a plastic polymer applicable for higher quality packaging because it produces sustainable, cost-efficient alternatives for plastic. Plastic can be upcycled into valuable chemicals via catalytic methods like depolymerization and hydrogenolysis.

Plastic can also be upcycled into fuels and other materials. Plastic can be upcycled into a higher purity of hydrogen and high-value carbon materials regarding food packaging.

When embracing this new plastic upcycling approach, scientists have performed experiments that convert what would have been single-use polyethylene into high-value and high-quality liquid end products, which helps combat plastic pollution.

This metamorphosis of polyethylene conserves and applies the intrinsic chemical and energy value the polymer possesses that would have been otherwise wasted. To produce this, advanced physical and chemical manipulations are required. Upcycling relies on complex catalytic transformations to alter the molecular weight, conformation, and strength properties of plastic discussed in the following chapter.

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04. How Magnetic Resonance Provides Solutions for Polymer Industry

The polymer industry is advancing rapidly to keep up with the needs of a world that is increasingly dependent on technology and industrialization. This progress presents a need for sophisticated analytical testing solutions that can help polymer scientists to innovate and invent.

One such technique commonly relied upon in polymer-focused research and industry processes is magnetic resonance.

Magnetic resonance splits into 2 major segments, Nuclear Magnetic Resonance (NMR), observing nuclear spins, and Electron Paramagnetic Resonance (EPR or ESR), observing spins of unpaired electrons. Both technologies allow for non-destructive analytical testing on an atomic level and come in various applications, from push-button operated benchtop systems to highly sophisticated floor-standing systems. Bruker has been the global leader in magnetic resonance technology development and has pushed the boundaries of what is possible for more than 60 years.

NMR is the single most important key technology to dynamically investigate intra-molecular characteristics and inter-molecular interactions in the native state of macromolecules. NMR gives detailed insight into the composition and structure of polymers. NMR application cover purity, identity, and structure of additives, catalysts, and monomers to polymer tacticity and sequence isomerization.

Details on the composition and arrangement of co-polymers, branching positions and frequency, crosslinking positions and density, nature, and quantitation of end groups, as well as chain lengths, can be determined. Bulk material characteristics like crystallinity versus amorphous fractions, crosslink density, xylene soluble, oil, and hydrogen content, and melting and crystallization kinetics can be understood by NMR push-button solutions.

EPR offers valuable insights in detecting and evaluating degradation induced by photo, thermal, and chemical processes. This range also includes potential irradiation-induced defects in sterilization processes in a quality control environment. So EPR adds stability optimization and self-life determination features to the analytical portfolio, including reaction monitoring and paramagnetic impurity profiling on a trace level of toxic by-products.

Advancing Polymers in Biomedicine and Health

Magnetic resonance is a valuable technique that provides insight into catalysis, particularly when studying polymers that are omnipresent in our lives and are found in most products that people use daily. By helping to obtain data on molecular chemical reactions and interactions in various processing steps, magnetic resonance enables researchers and manufacturers to understand better polymers and their ability to be upcycled into various high-value products.

NMR has been a robust analytical tool employed in polymer analysis since the 1960s. As a non-destructive method, NMR is used to characterize biopolymers like proteins and nucleic acids and polymer-based products such as tires, pharmaceuticals, packaging, and technological devices.

When conducting NMR measurements, the amount of molecules in a sample is directly proportional to the signal area. Consistent, linear responses are provided by NMR from all compounds in a sample, ensuring high precision. Therefore, users can achieve quantifications over several orders of magnitude, a useful quality when characterizing polymers.

As an ideal instrument in investigating polymer-based materials, NMR can reveal detailed structural knowledge of polymers and a deeper understanding of polymer properties like identity and purity. It can facilitate product development through reverse engineering and provide insight into the composition of polymer products via sophisticated quantitative analysis.

The information provided by NMR is also crucial in the beginning stages of a polymers value chain e.g. during catalysis.

Catalysis can be considered an initial step in a supply chain. Catalysis refers to improving the rate of a chemical reaction by presenting a particular substance that induces a speedier or a less-energy-consuming process. This substance is called a catalyst.

Catalysis is an essential part of the polymer value chain, specifically during polymerization reactions that transform monomers into polymers. This speed-and-energy-focused step is necessary to build polymers with different physical and chemical characteristics – a valued ability in the polymer industry.

Magnetic resonance can help with catalysis from a research and development perspective and in production and quality control environments. Nuclear magnetic resonance is particularly useful for monitoring the catalytic process itself and for rapid purity and identity control of the catalyst used. For example, to improve the efficiency of polymerization processes, experts can apply NMR to characterize reactions of dissolved gases to identify effective catalysts.

NMR can also be used to investigate the interactions between a catalyst and monomers, as well as the stereochemistry of a product of catalytic polymerization. Thus, NMR enables users to study the structure of a polymer product and any intermediate materials formed during the process. Furthermore, NMR can also gather more information on the effects of by-products on the performance of different catalysts, which can inform researchers and developers as they work towards improving the catalysis.

From Raw Material to Quality Control

Though polyethylene is the most common plastic, other types, such as polypropylene (a thermoplastic polymer), have various real-world applications. Polypropylene manufacturing facilities employ the chemical

xylene, a traditional quality tool, and a conventional wet-chemical method to process and control quality. Xylene acts as a solvent that dissolves molecules of polypropylene samples, leading to a key-measures like amorphous content and tacticity parameters like stiffness and hardness.

However, using xylene requires technical expertise to control plastics' quality during production. State-of-the-art benchtop NMR technology allows obtaining the same accepted and known value for Xylene Soluble Content without actually using the chemical xylene. In this way, a cumbersome wet-chemical process can efficiently be removed from the manufacturing processes of polypropylene. Similar principles apply for ethylene content, density, and crystallinity, as well as the crosslink density, molecular weights, and rubber content of polymers.

Most modern applications of benchtop Time-Domain-NMR (TD-NMR) enable quality engineers to obtain the necessary reading at the push of a button. This method strongly supports harmonized means throughout supply chains as the product quality control of one stakeholder has to correlate with the incoming control goods of the next one.

Case Study 1: Ensuring Quality Control in Car Tire Manufacturing

We have established that polymers are an integral part of the manufacturing of car tires. Automobile parts like tires are held to a high safety standard. To ensure they meet this standard, tire manufacturers must conduct quality control testing of their rubber products to confirm high-performing goods. Rubber is composed of entangled macromolecules organized in layers, with each layer possessing different chemical and physical properties.

As nuclear magnetic resonance can effectively image the molecular structure of soft tissues, polymer engineers can extend this concept to the flexible layers of rubber polymers of car tires, improving the final product quality.

TD NMR has a unique ability to visualize the internal layers of rubber and the crosslink density distributions within it. Crosslink density is the density of inter-chain bonds connecting different parts of the polymer structure. In rubber, the crosslink density influences mechanical properties like tensile strength. Thus, analyzing this property of polymers is very valuable in polymer production, specifically tire rubber that needs to be strong and at the same time durable for road use.

Furthermore, NMR can help researchers identify solutions to the negative environmental impact of used rubber tires. The Bruker NMR method has been used to help develop a recycling method for organic polymers found in rubber tires to address the environmental challenge.

TD NMR is a reliable and accurate analysis method, and it has been used as a reference technique of comparison against alternative ways of determining crosslink densities, This is TD NMR such as organic solvent swelling, dynamic mechanical analysis, and stress vs. strain procedures.

NMR is a well-accepted technology across the tire value chain, with high-resolution

NMR applications in the R&D environment helping to design new materials. During the production roll-out of these new materials, benchtop-based derivates of the same NMR technology have helped quality and production engineers to meet and maintain the desired product quality.

With its ability to easily characterize crosslink density, NMR is a powerful tool in ensuring quality control for car tire manufacturing, allowing them to test a rubber tire and see whether its physical characteristics meet performance and safety.

standards.NMR is a non-destructive and sample pre-serving method, enabling researchers to perform other analysis techniques on the rubber samples and garner more robust data, reducing the amount of sample material needed for research analysis. Bruker offers advanced NMR technology catered towards NMR analysis of tire rubber quality.

Case Study 2: Developing Thermoreversible Polymers by Assessing Crosslink Density

The use of NMR to assess crosslink density, which acts on various polymer properties, can also be applied to the development of more dynamic and reactive forms of polymers.

The crosslink density of polymer networks can also determine melting points and resistance to extremely high or low temperatures. This is why NMR is valuable in synthesizing thermoreversible polymers, materials that can be broken down at high temperatures and reformed at cooler temperatures.

Stimuli-responsive polymers made of covalently adaptable networks (CANs) are useful for specialty applications such as those requiring recyclability or even physical shape changes. Covalently adaptable networks hold much potential for expanding how polymers are adapted to various purposes. Recent polymer engineering research employed nuclear magnetic resonance spectroscopy equipment by Bruker to obtain spectra of polymers to synthesize thermo-reversible polymer networks.

Case Study 3: Performing Biosafety Analysis for Resorbable Spinal Fixation Implants

The last case study of this chapter will highlight the use of NMR in performing biosafety analysis for biomedical applications such as implants. Spinal fixation implants are a common surgery performed to heal spinal injuries.

Biodegradable, resorbable implants are favored over old-fashioned metal implants because they eliminate the need for a second surgery, lower implant rejection risk by the body, and are potentially less painful for the patient (especially the elderly).

Therefore, performing chemical analysis of these implants is of utmost importance for the safety and efficacy of implantation surgeries and the facilitation of healing. The Bruker floor-standing NMR instrument was utilized by researchers to characterize synthesized polymer spinal implants, which were found to have strong biocompatibility and caused no adverse reactions in the tissue samples.

Magnetic resonance is a sophisticated laboratory technique valuable to polymer studies, as depicted in the examples above. It is one way that laboratory equipment companies such as Bruker can meet the needs of the research community and industry.

Please see our next chapter for further discussion on providing solutions to polymer challenges.

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05. Addressing Challenges to Polymer Synthesis

For polymer engineers to keep innovating materials for everyday use and beyond, certain challenges to polymer synthesis need to be addressed. This chapter will highlight various difficulties developers face when producing polymers and what technological solutions there are to overcome these difficulties, with special attention given to the products by Bruker.

Challenges Using Biodegradable Polymers for Sustainable Packaging

While biodegradable polymers and sustainability are notable innovations toward efforts to be more environmentally considerate, these materials do not come without their own challenges. In particular, biodegradable plastics have poor gas and moisture barrier characteristics.

This current disadvantage significantly limits biodegradable polymers from being used in a lot of different food packaging applications as leaks or damage to packages are a risk. Thus, tailoring these polymer characteristics is needed to boost the barrier abilities of these polymers to better serve packaging requirements.

In order to solve this, research into the structure and chemical properties of biodegradable polymers is required as it is currently lacking. Presently, there is a knowledge gap regarding maximizing barrier protection using layers and chemical interactions of polymers with foods. Advanced techniques can address this lack in the literature. For further information on the advances of these decomposable materials, please see the chapter covering new innovations in polymer applications.

Determining Physical and Chemical Properties of Polymers: The Minispec Time-Domain-NMR Benchtop System

Determining the physical and chemical properties of polymers underpins much of the research and development that goes into polymers. Extracting this valuable information regarding polymer properties previously relied on conventional wet-chemical or physical testing methods with long labor times. However, Bruker offers a product designed to replace this technology and reduce labor times associated with polymer analysis. This product, titled the Minispec, relies on time-domain NMR to accomplish its purpose.

Time-domain NMR (or TD-NMR) maximizes ease of use and time to result of a variety of polymer samples.

From powders and pellets to liquids and films, the Minispec can produce results in seconds. Furthermore, analysis can be conducted over a wide range of extreme temperatures, between -100 °C to +200 °C, which is crucial to observe the structural behaviors of polymers under different conditions they will be subject to as final products. TD-NMR can be used to study crosslink density, mentioned previously as a significant measurement to automobile tire quality testing. TD-NMR can also be applied to failure analysis and examining the kinetics of polymers.

The Minispec possesses key advantages that further streamline polymer synthesis and harmonize analytical testing methods throughout the value chain, from product innovation to quality control. Harmonized analytical testing methods allow for increased result comparability and so for enhanced failure root cause analysis. Overall, harmonized methods lead to shorter time to market for new products and therefore to significant competitive advantages.

A full analysis cycle is typically completed within half an hour with a compact arrangement that allows the equipment to be available near production. The Minispec also performs analysis that is easily repeated with advanced temperature control. Furthermore, the process is non-invasive and non-destructive, which reduces waste and cost. Coupled with advanced software, the Minispec is sophisticated, flexible, and customizable to specific client needs.

Polymers Synthesis with Magnetic Resonance

The complete range of magnetic resonance technologies are applicable to streamline all stages of the polymer synthesis research and development process.From quality control and process monitoring to material research and failure analysis, an advanced solution is available to address unique circumstances and individualized needs.

As diverse as the applications for polymers are, challenges that arise when synthesizing them are equally so. Fortunately, there are sophisticated solutions provided by leading companies like Bruker that overcome these obstacles and improve the efficiency of polymer synthesis.

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Conclusion

Polymers make up the fabric of life. These chains of repeating molecules possess a range of valuable characteristics that can be physically and chemically manipulated to unique applications. This eBook provided an overview of polymers in everyday life and the recent developments which continue to improve living today.

We saw polymers in plastics packaging protecting goods through shipping and transport as well as preserving foodstuffs. As aforementioned, polymers are essential to transportation, such as in the construction of vehicle parts like tires, and also heavily impact the health industry by playing a valuable role in surgeries requiring sutures and implants. Presently, innovations in the polymer industry are focusing on addressing environmental concerns by synthesizing biodegradable and recyclable polymer products. Public health is also a primary focus of polymer research. The development of materials suited to personalized medicine and therapy, and personal protection are at the forefront of polymer innovation.

This eBook also delved into specific scientific solutions that enable the useability of polymers and increase their potential for applications beyond their current roles. It was previously summarized how nuclear magnetic resonance provides a non-invasive, non-destructive, and streamlined technique for the analysis of polymers. Whether it be performing quality control in car tire manufacturing, developing dynamic reactive polymers, or performing biosafety analysis, NMR is a sophisticated tool that ensures high quality polymer products are produced.

Together we discover

The application specialists at Bruker have collaborated with scientists in the field of polymer research all along the years to newly develop and further improve experiments and measurement techniques to lead to better and more insightful results. Valuable tools developed by Bruker that aid in this type of blended material analysis include high performance floor standing NMR with their high temperature probes, and large volume, cryogenically cooled probes. The latter being important as polymer samples are often highly viscous and hard to get into small diameter tubes. Additionally, the large amounts of sample will allow more easily the detection of small amounts of impurities.

A heated sample changer allows that polymer samples can be kept at elevated temperatures and thus a liquid state from preparation to measurement. Bruker has also developed a series of probes that are optimal for the analysis of fluorinated materials. These include conventional and cryogenically cooled probes that allow the simultaneous observation and decoupling of protons, carbon and fluorine.

Easy Analysis from Sample to Result

The new advanced range of push button benchtop instruments enable a fully automated analysis, data interpretation and report generation for mixtures of small molecules being used in the production process. These solutions are designed for users with no NMR knowledge delivering an end-to-end solution offer to meet the need of the modern polymer companies. In addition,a software-based workflow allows labs to easily share NMR results and reports.

As a global leader in providing cutting-edge solutions for work on polymers in research and industry, Bruker Magnetic Resonance technology facilitates scientists and polymer engineers in continuous innovation.

Magnetic Resonance and Polymer industry: joining for a better future

The lifecycle of polymers will likely undergo significant changes in the coming years as more applications shift toward recyclable, degradable, and plant-based materials and exciting new applications arise. Magnetic Resonance will remain an essential set of technologies to improve, evolve, and meet the challenge of the polymer industry.

Improving products and production processes at manufacturing sites, but also strengthening analytical testing landscapes for retailers, consumers, regulatory bodies, and recycling companies is the common goal of Bruker and its partners. If you would like to learn more about customized solutions in polymer synthesis or recent innovations in the polymer industry, you can contact an MR expert at Bruker.

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