



Polymer Laboratory: Teaching Polymer Chemistry

O. Ferreira¹, P.M. Plasencia², M.J. Afonso², A. Silva³ and M.F. Barreiro¹

¹Polytechnic Institute of Bragança and Laboratory of Separation and Reaction Engineering, ²School of Technology and Management, ³Secondary School S/3 Abade de Baçal (Portugal)
oferreira@ipb.pt, marina@ipb.pt, mjafonso@ipb.pt, adiliatsilva@gmail.com, barreiro@ipb.pt

Abstract

This work aims to present the results achieved within the science communication project CV/PVI/1386-Laboratório de Polímeros (Polymer Laboratory), financed by Ciência Viva - Agência Nacional para a Cultura Científica e Tecnológica (2006-2008). Several demonstration/experimental kits were developed concerning three main thematic: (1) Polymer concepts; (2) Polymer synthesis and (3) Polymer properties. Additionally, a fourth module entitled "Technological aspects" was also put into practice by taking advantage from the LSRE-IPB installed capacity in the area of Polymer Chemistry. The various modules were designed to reach a wide target public, including students from primary and secondary schools to undergraduate levels, and general society. Polymer architecture (linear, branched and crosslinked) and polymer synthesis procedures (step versus chain growth polymerization) can be demonstrated by using the "Kit-models" to construct simplified molecular models that illustrate those concepts. Synthesis examples include the preparation of linear polymers and networks. In the first case, Nylon 6,6 synthesis is proposed and, in the second one, a polyurethane foam and a PVA polymer slime can be experienced. Among polymer properties, several demonstrations can be mentioned: (1) Dissolution versus swelling, (2) Swelling volume versus crosslinking degree and (3) Hydrophobic versus hydrophilic polymers.

1. Introduction

Polymers are part of our everyday lives. Its prevalence in modern society and impact on several industrial sectors is well recognized. Polymer chemistry embraces many scientific disciplines and supports the development of a huge number of products such as plastics and synthetic fibers, agricultural and pharmaceutical chemicals, healthcare products, paints and adhesives, and biomedical applications such as artificial skin and drug delivery systems. According to the American Chemical Society (ACS), it is estimated that as many as 50% of all chemists will work in polymer science in some capacity during their careers [1]. Considering that many teachers have little or no in-depth knowledge of polymers and the importance of teaching these subjects, developing new tools or systemizing the existing ones is a key issue to enhance the presence and attractiveness of polymer chemistry subjects in school from the early educational levels.

In the past few years, and following the former project CV/PVI/1386 (Laboratório de Polímeros - Polymer Laboratory) financed by Ciência Viva - Agência Nacional para a Cultura Científica e Tecnológica (2006-2008), we have been working on the collection and development of experiments whose primary objective is to provide a resource to support polymer chemistry teaching. The developed modules were designed to reach a wide target public including students from primary and secondary schools to undergraduate levels. Moreover, its use to motivate scientific culture in general society was also depicted. Several experiments/demonstrations were developed concerning three main areas: (1) Polymer concepts; (2) Polymer synthesis and (3) Polymer properties. Additionally, a fourth module entitled "Technological aspects" was also put in practice taking advantage from the installed capacity in Polymer Chemistry of the Laboratory of Separation and Reaction Engineering



node, at the Polytechnic Institute of Bragança (LSRE-IPB). This last module corresponds to polymer study tours to the R&D polymer related projects, some of them in cooperation with industry.

The principles of polymer chemistry are very often hard to rationalize and experimental demonstration of concepts is always preferable over a lecture format. This concern is well recognized by the scientific society and several good examples of online teaching resources can be found. A survey of international websites dedicated to the teaching of polymers can be found at the IUPAC Polymer Education Website [2]. Among others we can refer Macrogalleria [3] and PolyEd [4] from US. Other interesting materials can be found at the Carnegie Mellon educational site [5].

In this work, a survey of experiments/demonstration modules will be presented putting in evidence the key concepts and the level of complexity, having in view different target publics.

2. Experiments and demonstrations

2.1. Kit models

Concepts such as the polymer definition itself (monomer *versus* polymer), homopolymer *versus* copolymer, polymer molecular weight and molecular weight distribution, polymer architecture (linear, branched and crosslinked), and synthesis procedures (step versus chain growth polymerization) can be illustrated by using the “Kit-models”. This kit is composed of colored magnetic rod like pieces (white, red, yellow and blue) representing the monomers and metallic beads representing reticulation points or multifunctional monomers. Figure 1 illustrates the demonstration of the concept “polymer architecture”. This tool is mostly useful for undergraduate levels. Nevertheless, the polymer concept could be easily presented to children and general society.

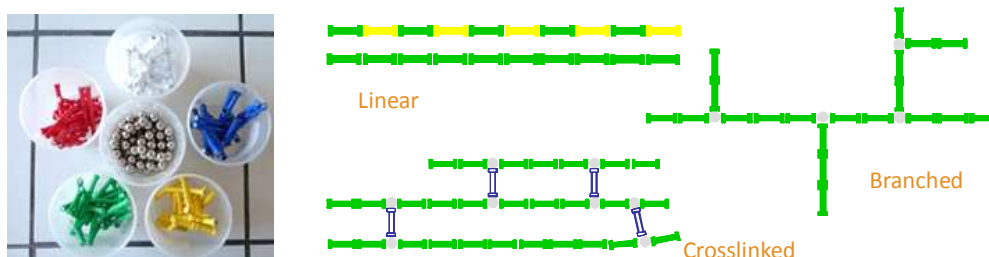
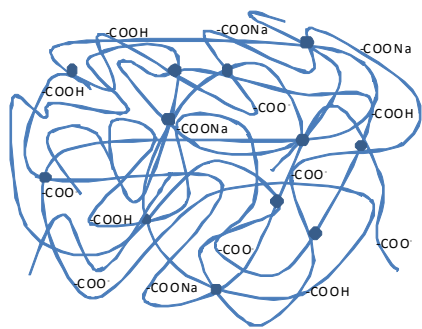


Figure 1. Kit models and its use to illustrate linear, branched and crosslinked polymers.

2.2. Hydrophobic versus hydrophilic polymers

Polymers can be either hydrophilic or hydrophobic. Hydrophilic polymers contain polar or charged functional groups, rendering them soluble in water. Superabsorbent polymers are crosslinked polyelectrolytes. Because of their ionic nature and interconnected structure, they can absorb large quantities of water (up to 500 times their own weight in liquid) and find a wide range of applications (e.g. baby diapers, hygiene products and agriculture water storage). With this demonstration the concept of hydrophilic, hydrophobic and superabsorbent polymers can be explained. At an undergraduate level, the concept of polymeric networks can be introduced as well as the concept of crosslinking degree. Especially devoted to children, this demonstration can be adapted by using superabsorbent-based toys (Figure 2).



A



B



C

Figure 2. Activity with a superabsorbent-based dinosaur: A. Superabsorbent polymer structure, B. Putting the dinosaur in contact with water, and C. Monitoring the results (before and after swelling).

2.3. The gelation of PVA with sodium borate – polymer slime

Polymer slime is a crosslinked polymer that can be made by combining polyvinyl alcohol (PVA) solutions with borate ions. Crosslinking is achieved by weak hydrogen bonds. Slime is very flexible if containing enough water, but becomes rigid at rest due to hydrogen bonding intensification. However, this network of hydrogen bonding is easily destroyed by deformation through handling and squeezing. Apart from the consensual entertainment value, this experiment is extremely useful for science education due to the many interesting concepts of polymer chemistry involved. With this experiment, and depending on the background knowledge of the audience, several concepts can be illustrated (hydrophilic polymers, polymeric networks, physical crosslinking, crosslinking degree, etc.). The effects of crosslinking degree on the polymer properties can be demonstrated by using different amounts of sodium borate, as shown in Figure 3. The use of more sodium borate imparts to the network a high level of crosslinking.

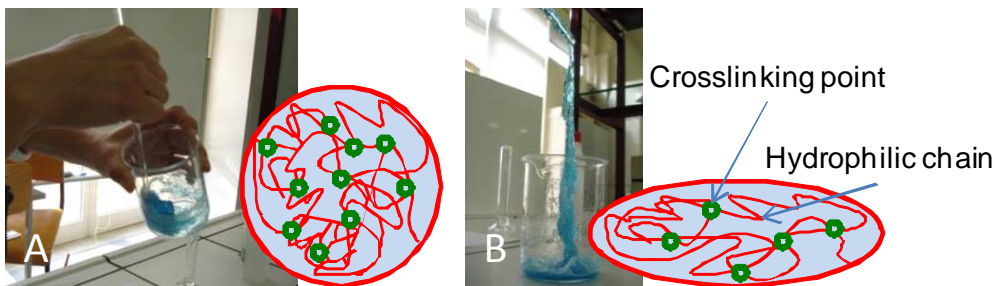


Figure 3. Polymer slime with different crosslinking degrees (High (A) and Low (B)).

2.4. Synthesis of Nylon 6,6

Nylon is a synthetic thermoplastic polymer invented in the late 1930s by Wallace Carothers at E.I. du Pont de Nemours and constitutes one of the most important commercially produced fibres. Chemically, they are linear polyamides and their properties are strongly associated with the ability of these polymers to form extensive hydrogen bonding. The two most common versions are Nylon 6,6 (derived from two monomers, adipoyl chloride and hexanediamine) and Nylon 6 (derived from a cyclic monomer, caprolactam). Comparatively to Nylon 6, Nylon 6,6 has a molecular structure that potentiates a higher degree of internal hydrogen bonding resulting in a maximum alignment of molecular chains. At laboratory level, the synthesis of Nylon 6,6 can be demonstrated by using a solution of adipoyl chloride in chloroform and hexanediamine in water. The aqueous solution (containing the diamine monomers) floats on the top of the organic solution (containing the diacid



chloride monomers). The reactive groups upon contact at the interface form the polymer by a technique called interfacial polymerization. As the interfacial reaction continues, a nylon "rope" can be pulled continuously as it is formed at the water-chloroform interface. This experiment dealing with the synthesis of a polymeric material offers various possibilities, including the introduction of some historical facts of polymer science, which is highly recommendable and motivating. Additionally, the concepts associated with step growth polymerization can be introduced with the help of the "kit models", preceding the synthesis demonstration by using a specific polymerization technique (interfacial polymerization). Moreover, interfacial polymerization can introduce students to microencapsulation technologies, where this technique could be easily extrapolated, i.e., instead of a planar interface, microcapsules can be envisaged as microreactors with circular interfaces. The material formed at the interface will serve as the shell microcapsule protecting a core containing an active agent. Figure 4 shows schematically the preparation of Nylon 6,6 by the interfacial polymerization, to produce a "rope" and hypothesises the production of microcapsules by using a similar chemical system. Other examples include the concept of thermoplastic polymers (melt processable polymers), hydrogen bonding *versus* crystallinity and molecular structure versus degree of hydrogen bonding (Nylon 6,6 *versus* Nylon 6).

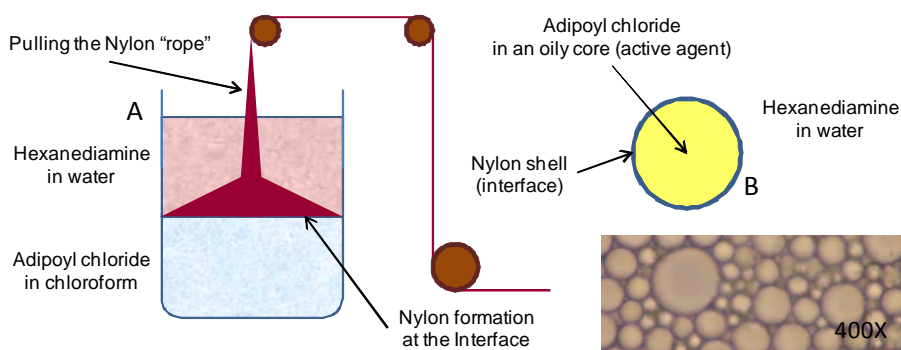


Figure 4. Examples of interfacial polymerization: A. the synthesis of a Nylon 6,6 "rope", and B. the production of microcapsules.

2.5. Synthesis of polyurethane foam

Polyurethanes are considered as one of the most versatile polymeric materials offering a wide range of products with applications in diverse sectors (e.g. coatings, foams, fibres, and elastomers). Polyurethane chemistry was discovered and patented by Otto Bayer and co-workers in 1937. It is based on the isocyanate group's reaction with active hydrogen containing compounds. It involves the primary reaction of the isocyanate group (-NCO) with a hydroxyl group (-OH) to produce the urethane (-COONH-), but also several secondary reactions that might occur depending on the used synthesis conditions, namely temperature and NCO/OH ratio. In general terms, we can ascribe the secondary reactions to the ones that promote chemical crosslinking and the ones that produce chemical blowing agents (carbon dioxide). Figure 5 shows the preparation of rigid polyurethane foams using a commercial system provided by Bayer MaterialScience AG. These polymeric materials have extensive chemical crosslinking thus becoming thermosetting materials (they can't be heated and remoulded as the thermoplastics). Additionally to the concept of thermosetting polymers and chemical crosslinking, this demonstration can also be used to introduce expanding materials, polymer formulation, chemical and physical blowing agents, as well as the importance of using catalysis in polymer synthesis. Due to the complementary concepts, the use of this demonstration combined with the one previously described (Nylon synthesis), is recommended for a deeper approach to polymer synthesis and is especially valuable for undergraduate students.

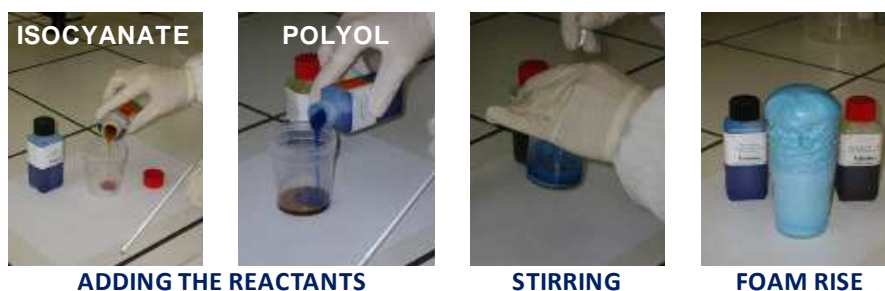


Figure 5. Synthesis of a polyurethane foam using a two component chemical system provided by Bayer MaterialScience AG.

2.6. Technological aspects – Polymer study tours

This module corresponds to polymer study tours where teachers and students, mostly from secondary schools, are guided into the R&D polymer related projects in course at LSRE-IPB. They intend to highlight concepts such as, product development, polymer chemistry, processes and applications. Figure 6 shows some of the possibilities. Projects dealing with microencapsulation, synthesis of bio-based polymers, water compatible polymers and fire-retardant formulations can be visited.



Figure 6. Some R&D areas concerning Polymer Chemistry.

3. Conclusions

A survey of experiments/demonstration modules intended to support polymer chemistry teaching and promote scientific culture dissemination was presented. This work highlights the concepts to be explained and puts in evidence different educational approaches designed to reach specific publics, rather than providing a thorough explanation of the experimental protocols. Hopefully, a contribution is given to further explore some existing and widely used polymer experiments. Future tasks include the development of new modules with special emphasis on green processes, biobased and biodegradable polymers.



Acknowledgments

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References

- [1] American Chemical Society (<http://portal.acs.org/portal/acs/corg/content>, see careers in chemistry)
- [2] IUPAC Polymer Education Website (<http://iupac.org/polyedu/index.html>)
- [3] Macrogalleria (<http://pslc.ws/macrog/index.htm>)
- [4] POLYED (<http://www.uwsp.edu/chemistry/polyed/>)
- [5] Carnegie Mellon Education Website - Macromolecular products
<http://gelfand.web.cmu.edu/scimodules/>)