The Journal of CPRI,
Vol. 4, No. 2, September 2008 pp. 119–124

Emerging Applications of Polymers to Energy Sector

Dr J Sundara Rajan*

This paper reviews many new and emerging areas of polymer science and its application to power engineering. Electrical and electronic devices make extensive use of polymers in applications ranging from connectors, sockets and switches to bushings, spacers, control panels, supports etc. New areas like electro-active polymers and conductive polymers are finding many applications in everyday use. Conductive polymers unlock the potential to improve a variety of items from electronics to electrical engineering. Hydrogen fuel cells hold promise for the future. This paper highlights the importance of developments in polymer science and its relevance to power engineering.

***Key words**: Polymers, fuel cells, nanocomposites, fibres, conducting polymers*

1.0 INTRODUCTION

Polymers are being increasingly used in power engineering applications because of various advantages like excellent mechanical strength, lightweight, availability in various shapes and sizes. They can also be modified to meet specific requirements for applications in power. This paper reviews recent trends and current research areas in polymers which is of significance to the power sector.

There are many areas of research which are being pursued all over the world. However, this paper will focus on only those areas which are of current interest. These would include (1) Conducting polymers (2) Semi-conducting polymers (3) Polymeric magnets (4) Synthesis, characterisation, processing and fabrication of new polymers (5) Polymer nanocomposites and (6) Hydrogen energy conversion using fuel cells. In addition, use of polymers for electrical insulation and mechanical support offers ample scope for further research and development. Nano fillers are being extensively tried and many applications in electric cables like "fire retardant and low smoke cables", nanocomposites for outdoor insulation, spacer applications in compressed gas insulations, in circuit breakers, development of anti-tracking materials are some of the topics of importance to the power sector. Current research interests in some of these topics and scope for R&D are discussed in this paper.

2.0 CONDUCTING POLYMERS

With rapid advancement in electronics, computer and telecommunication technologies, there has been a constant need for suppression of electromagnetic interferences. The usual shielding techniques have concentrated on the use of standard metals and composites. These have limited mechanical flexibility, are very

*Centre for Collaborative and Advanced Research, Central Power Research Institute, Bengaluru, INDIA

heavy, susceptible to corrosion, and have the difficulty of tuning the shielding efficiency. Therefore conducting polymers have shown promise as materials for shielding electromagnetic radiation and reducing or even eliminating electromagnetic interference (EMI), because of their relatively higher conductivity and dielectric constant and also ease of control of their material characteristics through chemical processing [1].

Another important application of conducting polymers would be polymer magnets. The inherent low density and higher molecular mass of molecule/polymer-based magnets implies that for bulk applications relying on high magnetic moments on mass volume basis is unlikely. In contrast, for other uses like inductors (for example, core material in transformers) which guide the magnetic fields and for magnetic shielding of low-frequency magnetic fields appears to be feasible. The higher permeability to mass ratio makes this group of soft magnetic materials potentially attractive for lightweight transformers, generators and/or motors as well as for DC and low frequency shielding applications [2].

It is also reported that higher shielding efficiency (SE) of largely conducting doped polyaniline, polypyrrole and polyacetylene are comparable to copper, but very thin conductive polymer samples have weak temperature dependent shielding efficiencies. Easy tuning of intrinsic properties by chemical processing suggests that such polymers, especially polyaniline, are good candidates for low frequency shielding applications.

Research in the area of room temperature polymeric magnet for electromagnetic shielding has been established [3] and these magnets have low power loss and flexible low temperature processing.

3.0 CONDUCTING POLYMERS FOR METALLIC APPLICATIONS

The electrical conductivities of the intrinsically conducting polymer range from those of typical insulators to typical semiconductors such as silicon and to those above close to that of copper. Use of these polymers, mainly polyanilines, has increased in recent years. Applications include coatings and blends for electrostatic dissipation and electromagnetic interference (EMI) shielding, electromagnetic radiation absorbers for welding of plastics, conductive layers for light-emitting polymer devices and anti-corrosion coatings for iron and steel.

The conductivities of electronic polymers are transformed from insulating to conducting state by the process of doping, with the conductivity increasing as the doping level increases. Both *n*-type and *p*-type dopants have been utilised to induce an insulator-to-conductor transition in electronic polymers. The doping procedures differ from conventional ion implantation for three-dimensional semiconductors, typically being carried out by exposing the polymer films or powders to vapours or solutions of the dopant, or by electrochemical means. The polymer backbone and dopant ions form a new three-dimensional structure. There are a variety of structures, each differing for different dopant levels and variations in the processing routes. For an isolated, one-dimensional metallic chain, localisation of charge carriers arises for even weak disorder because of quantum interference due to backscattering of electrons. Localisation effects in inhomogeneously disordered (partially crystalline) conducting polymers originate from one-dimensional localisation in the disordered regions that connect the relatively ordered regions (or "crystalline islands"). Within this model, conduction electrons are three-dimensionally delocalised in the "crystalline" ordered regions and the conduction electrons diffuse along electronically isolated chains through the disordered regions where the electrons readily become localised. New concepts of mesoscopic physics and fractal behaviour are being applied to understand the anamolous transport and optical properties of these materials.

4.0 SYNTHESIS / CHARACTERISATION AND FABRICATION OF POLYMERS

Polymers have been studied for their possible use in such fields as conduction, light emission and corrosion protection. The scope of applications is constantly being broadened through the use of 'enhanced' polymers. Enhancement is either in the form of doping, derivatisation, stretching, heat treatment or even blending with other polymers such as polyester or polystyrene. Each of these modifications has differing effects on the physical properties of the materials.

Derivatisation is utilised in the synthesis of sulphonated polyaniline (SPAN). The synthesised SPAN is then characterised by Electron Paramagnetic Resonance (EPR), Fourier Transform Infrared (FTIR) and ultraviolet/visible spectroscopy. The resultant material has shown increased conductivity over underivatised EB (emeraldine base).

Present research in polymers can be broadly classified as materials, processes, geometry and tools. Under the category of materials, the topics would include: rheology, characterisation, alternative polymers, microcellular plastics, controllable materials, polymer composites and reinforced thermosets. Under processes we have extrusion, pultrusion, blow moulding, injection moulding, co-injection moulding, microcellular injection moulding. Some highly specialised tools have been developed for use in polymer technology. The present trend is towards: modelling by computer simulation, process optimisation, use of next generation sensors and web-based system. Since geometry plays an important role, research should also focus on complex, consolidated, micro and nano scales, conventional and non-conventional methods.

5.0 POLYMER NANOCOMPOSITES

Nanoscience and Nanotechnology have been identified worldwide as the key to unlocking a new generation of materials and devices with revolutionary properties and functionalities. The technology has already seen commercial success in industries like electronics and information storage industry, petroleum and chemical industry and healthcare industry amongst others. The interest in nanotechnology lies in the potential associated with designing structures with dimensions right down to the fundamental building blocks of materials—atoms and molecules. The nanotechnology is at an infancy state and this is a strong motivation for many institutes and organisations to launch research on nanotechnology. Current applications of nanotechnology represent only a small fraction of its actual capabilities. Hence there is a big challenge in nurturing research in this field.

The present approach is to develop and promote nanotechnology research and to optimise resources in creating strategic high impact research while retaining diversity in research areas. Several core areas of nanotechnology research have been identified for the near future.

Over the last few years, worldwide research has led to the development of unique capabilities for synthesising polymer nanocomposites containing custom-made synthetic materials. There is a broad array of characterisation tools, including X-ray scattering, atomic force microscopy, X-ray photoelectron spectroscopy and high-resolution transmission electron microscopy for characterising the microstructure of materials. Some of the sophisticated instruments for evaluating material end-use performance include dynamic mechanical analysis (mechanical properties), electrochemical impedance analysis (capacitance and energy storage), and a system for measuring gas permeation rates through polymer films. To name a few areas of key research which is pursued are—

1. Development of PET nanocomposites
2. Polystyrene-based nanocomposites for energy storage
3. Development of other polymer nano-composites for specific power engineering applications.

The global approach towards research in nanotechnology has the following objectives:

- To develop R&D human capital and long-term research capabilities in the strategic field of nanoscience and nanotechnology.
- To galvanise and coordinate multidisciplinary Research and Developmental work in nanoscience and nanotechnology.
- To help set research priorities and directions for high impact nanoscience and nanotechnology research.

6.0 APPLICATIONS OF CONDUCTING POLYMERS

Some of the feasibility studies have assessed the potential applications of conducting polymers in the manufacturing of power equipments. Ten areas were studied namely solid and liquid dielectrics, cables, capacitors, rotating machinery, transformers, bushings, surge suppressors, vacuum interrupters, gas insulated equipment, and others. Each application was rated according to technical importance, probability of its success, economic considerations and time frame for implementation. Of the many potential applications proposed, the top ranking areas were: coating of dielectric films for capacitors, conducting compounds to cover conductors in rotating machines, surface coatings to dissipate charges in bushings, coatings for controlled surface conductivity in gas insulated equipment and thermal history monitors.

Light-emitting coatings powered by electro-active polymers have a wide range of applications, including flexible tent lighting and identification. Some manufacturers have specialised in novel materials and processes under laboratory conditions and turned them into reality by making improvements for everyday activities and commercial applications.

These light-emitting coatings are durable, flexible and can be used on a variety of materials including plastics, metals and fabrics. The coatings create zero heat emissions and will stay lit in abusive environments withstanding piercing, abrasion or compression. Light can also be emitted in both the visible and non-visible spectrum. Visible light emission on fabric enables integration of light-emitting coatings into the fabric itself while eliminating standard light fixtures. Non-visible light emission, also known as near infrared (NIR), helps in identification. This technology allows personnel to observe unknown persons, vehicles etc. Thus, conductive polymers unlock the potential to improve a variety of items from high-end electronics to protection.

7.0 HYDROGEN ENERGY CONVERSION USING FUEL CELLS

Fuel cells are one of the keyenabling technologies for a future hydrogen economy. They have the potential to replace the internal combustion engine in vehicles and to provide power in stationary and portable power applications because of their energy-efficiency, in addition to being clean and fuel-flexible. For transportation applications, there is focusing on direct hydrogen fuel cells, in which on-board storage of hydrogen is supplied by hydrogen generation, delivery and fueling infrastructure. For distributed generation fuel cell applications, application focuses on near-term fuel cell systems running on natural gas or liquid petroleum gas and recognises the longer term potential for systems running on renewable/ alternate fuels. In addition to transportation, fuel cell application focuses (i.e., direct hydrogen fuel cell vehicles) to reduce dependence on petroleum and supports stationary, portable power and auxiliary power applications in a limited fashion where earlier market entry would assist the development of a fuel cell manufacturing base.

Hydrogen program activity is generally focused on the conversion of hydrogen to electrical or thermal power and the use of hydrogen to power vehicles via Polymer Electrolyte Membrane (PEM) fuel cells, for auxiliary power units on vehicles or for stationary applications.

7.1 Polymer Electrolyte Membrane (PEM)

The present research aims at lowering the cost and improving the durability of PEM fuel cells. Current R&D activities focus on improving electro-catalysts, membranes (both for ambient and high-temperature applications) and bipolar plate materials.

7.2 Basic hydrogen fuel cell research programs

In this area of research, the work defines knowledge that enables new and novel materials to transcend the barriers for low-cost and high efficiency energy conversion applications. New and improved materials are to be developed for electrodes, electrolytes, membranes and catalysts, to enable new and novel fuel cell components and operating concepts.

8.0 HIGH VOLTAGE APPLICATIONS

Polymers can contribute significantly to improvements in high voltage insulation. The key areas of research would encompass polymer insulators, non-tracking outdoor polymers, polymers for FRLS cables, high dielectric constant materials for capacitors, nano fillers for improving dielectric and mechanical characteristics and materials for sensor applications. There is vast scope for development or modification of existing polymers for many new areas of applications in high voltage engineering. These materials are to be specifically applied to each area of specialisation like spacer application in GIS, materials for use in current interrupters, vacuum applications, liquid dielectrics and many more. One of the new and emerging areas of significant importance to power engineering is cryogenics. Concepts like High Temperature Super conductors (HTS) are being tried for design of transformers and current limiters. Other areas include motors and generators. Development of polymers for cryogenic applications will be very useful for further developments in HTS.

9.0 CONCLUSIONS

A revolution has taken place over the last 50 years in the field of synthetic polymers and their applications have rapidly penetrated all major fields of engineering. The scientific and technical advances achieved have ensured that investment in R&D on polymers is of benefit to our society and economy. However, for future investments, one has to review many more factors like global markets and competitiveness, substance of the technology and flexibility to adapt to the fast changing technologies all round the world.

The comprehensive understanding of international and national developments and planning for constructive change involving government, industry and academia are therefore of prime importance to derive many benefits of polymer science and engineering research. Polymers have broadly penetrated the materials market at the commodity engineering and high-technology specialty levels. These include power components, automobile and airframe components, fibres/ fabrics and rubber products, interdisciplinary investigations of polymer surfaces and interfaces, synthesis of new polymers and polymeric materials, methods to precisely control the structure of polymers, biosynthesis, catalysis and environmentally benign synthesis; new methods for processing and manufacturing materials, including computer-assisted design of processing and on-line process control. Characterisation of polymers and development of new methods are topics that are currently being studied. It is also very important to study environmental issues related to materials.

Hence, the need of the hour is establishment of corporate research groups with a viable nucleus of highly qualified specialists to enable corporations to take advantage of continuing advances and breakthroughs in polymers. Since the field of polymer engineering and the problems they are addressing are growing bigger, larger and more complex, there is a need for an integrated approach to achieving improvements in key areas like manufacturing, energy, information and communication.

Scientific and technological progress during the last few decades has created huge opportunities for research in polymer science and engineering. There is a large potential for future developments that will strongly contribute to areas of national concern.

REFERENCES

[1] Lee C Y, Song H G, Jang K S, Oh E J, Epstein A J and Joo J, "Electromagnetic Interference Shielding Efficiency of Polyaniline Mixtures and Multilayer Films", Synthetic Metals, 102, pp. 1346–1349, 1999.

[2] Joo J, Lee C Y, Song H G, Kim J W, Jang K S, Oh E J, and Epstein A J, "Enhancement of Electromagnetic Interference Shielding Efficiency of Polyaniline Through Mixture and Chemical Doping", Molecular Crystals, Liquid Crystals, 316, pp. 367–370, 1998.

[3] National Research Council (NRC), 1989 "Materials Science and Engineering for the 1990s: Maintaining Competitiveness in the Age of Materials". Washington, D.C.: National Academy Press.

[4] National Science Foundation (NSF), 1992 National Patterns of R&D Resources: 1992. NSF 92-330. Washington, D.C.: U.S. Government Printing Office.

[5J. Joo, Oh E J, and Epstein A J, "Electromagnetic Interference Shielding Capability of Conducting Polymers in Far-Field and Near-Field Regions", Molecular Electronics and Devices, pp. 107–118, 1995.

[6] Joo J, Long S M, Pouget J P, Oh E J, MacDiarmid A G and Epstein A J, "Charge Transport of the Mesoscopic Metallic State in Partially Crystalline Polyanilines", Physical Review, B 57, pp. 9567–9580, 1998.

[7] Kohlman R S and Epstein A J, "Insulator-Metal Transition and Metallic State of Conducting Polymers", in Handbook of Conducting Polymers, Second Edition, edited by T.A. Skotheim, Elsenbaumer R L, and Reynolds J R (Marcel Dekker, Inc.), 3, pp. 85–121, 1997.

[8] Kohlman R S, Zibold A, Tanner D B, Ihas G G, Ishiguro T, Min Y G, MacDiarmid A G and Epstein A J, "Limits for Metallic Conductivity in Conducting Polymers", Physical Review Letters 78, pp. 3915–3918, 1997.

[9] Feng J, Zhang W, MacDiarmid A G and Epstein A J, "Synthesis and Characterisation of Oligomeric Anilines", Proc. Soc. of Plastics Engineers Annual Technical Conference (ANTEC 1997), Toronto, Ontario, April 27–May 2, pp. 1373–1377, 1997.

[10] Zhang W J, Feng J, MacDiarmid A G and Epstein A J, "Synthesis of Oligomeric Anilines", Synthetic Metals, 84, pp. 119–120, 1997.

[11] Wei X L, Wang Y Z, Long S M, Bobeczko C and Epstein A J, "Synthesis and Physical Properties of Highly Sulfonated Polyaniline", Journal of the American Chemical Society, 118, pp. 2545–2555, 1996.