POLYMER SCIENCE: PAST AND PRESENT TRENDS

Commemorating 100 years of the postulation of the Macromolecular Hypothesis by the German Organic Chemist, Hermann Staudinger, the Society of Polymer Science India (SPSI) organized a one-day conference in Somaiya Vidyavihar University, Mumbai on March 2, 2020 touching upon the past and future challenges in the field of polymer science and industry. The conference was inaugurated by Professor M.M. Sharma, FRS. Other speakers in the seminar included Prof. S. Sivaram, Ex-Director of National Chemical Laboratory, Pune; Dr. Prakash Trivedi, Gharda Polymers, Mumbai; Prof. S. Ramakrishnan, Indian Institute of Science, Bangalore; Shri Samir Somaiya, Chairman & Managing Director, Godavari Biorefineries Limited, Mumbai; Prof. Anil Kumar, Chair Professor in Polymer Science, Indian Institute of Technology, Mumbai; Dr. Virendrakumar Gupta, Vice-President, Reliance Polymer Laboratories, Mumbai; and Prof. V. N. Rajasekharan Pillai, Vice-Chancellor and Professor of Polymer Science, Somaiya Vidyavihar University. The conference was hosted by the Dept of Polymer Science of the University.

(Left to Right) 1. Prof. Anilkumar, 2. Dr. Virendrakumar Gupta, 3. Prof. V. N. R. Pillai, 4. Dr. Prakash Trivedi, 5. Prof. M M Sharma, 6. Shri Samir Somaiya, 7. Prof. Sivaram, 8. Prof. S. Ramakrishnan

Polymers have made revolutionary changes in human lives, ever since the pioneering macromolecular hypothesis of Hermann Staudinger in 1920. The " Macromolecular Hypothesis" was proposed by Hermann Staudinger in a lecture on rubber in a Swiss Chemical Society meeting in 1917. In 1920, this was published as a research paper entitled, "Uber Polymerization", in ***Ber. Deutsch. Chem. Ges. 1920, 53, 1073.*** Hermann Staudinger received the 1953 Nobel Prize in Chemistry for this revolutionary hypothesis and further extensive research proving the hypothesis. In fact the word "macromolecule" was coined by him. Innovations in the synthesis, characterization and production of varied classes of polymers have been accompanied by an in-depth understanding of the behaviour of polymers in solution in bulk. The field is vastly growing and numerous scientific and technological developments took place in recent years. Staudinger's hypothesis has impacted the field of materials science and biopolymers. New application areas are being progressively developed and industrial products are continuously improved. There are also daunting challenges now for polymer science. These include issues related to sustainability, recycling and eventual fate of polymer and plastic materials.Renewability. The future requirements of energy storage and conversion, new therapies for diseases and approaches to a circular economy may seek solutions from polymer-based approaches. An overview of the historical developments in the area of basic and industrial polymer science, in the light of Staudinger's Macromolecular Hypothesis was the overall theme of the conference.

In his inaugural address of the conference as well as in the opening function of the Mumbai Chapter of the Society of Polymer Science India in the Somaiya Vidyavihar University Campus, Prof. M. M. Sharma, FRS (Institute of Chemical Technology, Mumbai) focused on the role of innovations in the growth of economy with particular reference to the polymer industry. He illustrated the multifarious and tunable attributes of polymers which make them the most advanced class of materials for a wide range of technology platforms. In energy sustainability, health care, security devices, informatics,defense and protection, polymers play predominant roles. In fact, more than any other class of materials, polymers have the ability to serve in many different capacities, from major structural components to high value-added ingredients in very small scales in applications like lithography and drug delivery. The lecture also touched upon the "Macromolecular Wonders of Nature" like cellulose, natural rubber, shellac, proteins, nucleic acids, shellac, terpene resins and silk. "The broad field of macromolecular science has never been more vibrant, exemplified by the stunning fundamental advances in many fields including polymerization methods, theory, simulation and modelling, understanding of new physical phenomena, advances in characterization techniques, and harnessing of self-assembly and biological strategies for producing complex multifunctional structures". Prof. Sharma illustrated these areas with the cases of innovative processing for nano-structural materials, precision fabrication in three dimensions, processing of complex inorganic and organic systems, low-temperature, environmentally benign processing and *in-situ* real-time process monitoring.

Prof. M.M. Sharma giving the Inaugural address

"One Hundred Years of Macromolecules: Some Vignettes From History" was the tittle of the narrative presentation made by Prof. S. Sivaram, tracing the history of polymer science and technology, as early as from the period 1820-26, During the period, Michael Faraday, identified isoprene as a constituent of natural rubber, now known as poly (isoprene), determined the elemental composition natural rubber, and investigated the reaction of rubber with sulfur. Sivaram highlighted the first general discussion on "Polymerism" by Marcellin Berthelot in 1863 in his historic lecture titled "la polymerie" in the Chemical Society of Paris. Berthelot had a remarkable understanding of the conversion of vinyl compounds into polymeric chain molecules. In 1853 he reported the thermal and catalytic polymerization of pinene and later he published his results in the Polymerization of ethylene, propylene, pentene and pinene. While tracing the origin of the term "Polymer", he observed that it was Carothers in 1929 who gave a general description of the term polymers, as substances whose structures may be represented by R-R-R- where the units -R- are bivalent radicals which in general are not capable of independent existence (***J. Am.Chem.Soc. 51, 2548, 1929).***

Glancing through the early works of Hermann Staudinger, we can see noteworthy contributions in organic synthetic and natural products chemistry during the period 1900-1920 before the postulation of the Macromolecular Hypothesis. Through sheer audacity of intuition and imagination, Staudinger proposed that polymers of natural and synthetic origin were composed

of large number of base units linked together by covalent bonds ***[(Ber. Dtsch. Chem. Ges., 53, 1073 (1020)]***. Staudinger propounded this revolutionary concept without any experimental evidence. Prof. Sivaram shared some of the very interesting anecdotes on the controversies surfaced during that period. Heinrich Wieland, the 1927 Chemistry Nobel Laureate, told Staudinger, ***"Dear Colleague, abandon your idea of large molecules; organic molecules with molecular weights exceeding 5000 do not exist. Purify your products and they will turn out to be low-molecular weight materials".*** Staudinger's ideas met with much resistance and criticism from eminent chemists of the period, notable amongst them, the Nobel Laureate Emil Fischer. People at that time called the chemistry being pursued by Staudinger as "Junk Chemistry". After one of the lectures given by Staudinger in Zurich 1925, one of the speakers termed Staudinger's championship of long chain molecules as akin to some traveler in Africa reporting that he had seen a zebra 400 meters long! Staudinger persevered in spite of being ostracized by the scientific community. From 1926 onwards Staudinger shifted exclusively to the study of macromolecules.

Dr. S. Sivaram, IISER, Pune

Hermann Staudinger published more than 800 papers amounting to more than 10,000 pages. His autobiography, “From Organic Chemistry to Macromolecules” published in 1970 summarizes the trials and tribulations he encountered in teaching and research. His collected works, “The Scientific Contributions of Hermann Staudinger” were published by his wife Martha Staudinger between 1969 and 1976. For many years, Staudinger’s textbook in German “ The High Molecular Weight Organic Compounds, Rubber and Cellulose”, published by Springer in 1932 was the “bible” for many academics and industrial practitioners in polymer science and technology.

ACS International Historical Landmark of Chemistry: University of Freiburg

Both Prof. M. M. Sharma and Prof. Sivaram also covered the pioneering contributions of Herman Mark and W. H. Carothers, which gave the first experimental evidence for the Macromolecular hypothesis of Hermann Staudinger. The solid foundations on which polymer science and technology are established now owe a great deal to these three pioneering chemists. Herman Mark was the first to solve the crystal structure of Cellulose in 1928, the first crystal structure of a polymer which reconciles the X-ray pattern with the chemical composition. Using X-Ray crystallography, Mark established that natural rubber is a polymer of isoprene, and that isoprene is in a *cis* configuration in the polymer chain. Wallace Carothers, through his inventions of nylon and neoprene in 1930, helped demonstrate that principles of organic synthesis can be

extended to the synthesis of macromoleculesand placed the field on a solid foundation of theory and practice.

Dr. Prakash Trivedi, Gharda Chemicals

The lecture by Dr. Prakash Trivedi from the Specialty Polymer Division of Gharda Chemicals, Mumbai, was on the synthesis, structure, extraordinary special properties and applications of Poly Ether Ketone (PEK) family of polymers (Prakash Trivedi & Atul Raja). Polyether Ketone Ketone (PEKK) is a semicrystalline polymer with a high glass transition temperature of 152˚C and melting temperature of 372˚C, which offer solutions to many high temperature and chemically resistant applications. These polymers, developed exclusively by Gharda Chemicals, and their various value-added filled grades have improved strength and high wear resistance in extreme conditions. These class of polymers retain mechanical and physical properties at high temperatures without permanent deformation. Other unique properties of these Polymer includes outstanding resistance to hydrolysis, excellent thermal, mechanical and electrical properties and radiation resistance. Gharda is the First and only producer of this polymer in the world. Dr. Trivedi illustrated the unique characteristics of this class of polymers which are available in powder and pellet forms. The specific flexural modulus of PEKK are in the range of steel A36 and aluminum. Dr. Trivedi also presented the development and patented synthetic processes of high molecular weight Aminobenzoic polybenzimidazole (ABPBI) by Gharda Chemicals. The

versatile industrial applications of these two classes of polymers were also discussed in the lecture.

The growing excitement in the area of Controlled Radical Polymerization was the theme of the lecture by Prof. S. Ramakrishnan. After giving on overview of the current status of the step-growth, chain-growth and living polymerization processes, he described the latest strategies in the design of controlled radical polymerization (CRP). The “active-dormant” equilibrium concept, Stable Free Radical Polymerization (SFRP), the nitroxyl radical mediated CRP, the atom-transfer process, the Atom Transfer Radical Polymerization (ATRP), and the Reversible Addition Fragmentation Chain Transfer (RAFT) were discussed in detail in this context. The advantages of CRP, like the possibility of stopping and restarting at any time during the polymerization, access to polymers with controlled and narrow distribution of molecular weight and low polydispersity index, and above all the ability design polymers with highly complex and pre-determined architecture were highlighted in the lecture with clear illustrations. “Controlled radical polymerization can lead to the facile synthesis of interesting polymer systems with far greater ease and flexibility compared to the conventional radical polymerization. Several interesting applications that rely on ready access to well-defined block copolymers, graft copolymers, three- and four-arm star molecular brushes, core-shell polymer systems, and nano-structured polymers with unique applications will be realized because of these developments”, Ramakrishnan concluded.

Shri Samir Somaiya and Prof. S. Ramakrishnan

Shri Samir Somaiya, the Chancellor of Somaiya Vidyavihar University and the Chairman & Managing Director of the Godavari Biorefineries Limited while welcoming the pioneers of the polymer research in India to the Somaiya University Campus, highlighted the importance of such industry-academia collaboration in a city like Mumbai, which is the business capital of India. He narrated very briefly and succinctly the vision of the Somaiya Group of institutions in education, health care, sustainable development and in Indian tradition and culture. Linking to the theme of the Conference, "Staudinger's Macromolecular Concept and 100 years of Polymer Science", Shri Samir Somaiya, emphasized that his dream of the new Somaiya Vidyavihar University is to create the right kind of ambience to encourage youngsters to come with ideas and hypotheses, work for it incessantly with perseverance and achieve the goals, like the Nobel Laureate Herman Staudinger.

Shri Samir Somaiya

Prof. Anil Kumar, Chair Professor in Polymer Science, Indian Institute of Technology, Mumbai, in his concluding remarks mentioned about the Society of Indian Society of Polymer Science and its activities. The initiatives of Dr. Virendrakumar Gupta, Vice-President, Reliance Industries Ltd, and the Co-Chair of the Industry-Academia Joint Board of the University's Polymer Science Programme we're particularly acknowledged. Prof. V. N. Rajasekharan Pillai, Professor of Chemistry and Vice-Chancellor of the Somaiya Vidyavihar University welcomed the speakers, the office bearers of the Society of Polymer Science, India, participants from the industry and academia and the students from the Somaiya and other educational institutions. The meeting was hosted by the Dept of Polymer Science of the Somaiya Vidyavihar University, ably supported by the teaching faculty of the Dept, Dr. Padma Vankar, Dr. Vandana Jamdar and Dr. Vijayanti Ghase.

The one-day conference on 100 years of Macromolecular Hypothesis gave a platform for academics, industrial practitioners, researchers and post-graduate students to share their insights and experience in the areas of teaching, research and industrial development. It also served on a venue for the inauguration of the Mumbai Chapter of the Society of Polymer Science, India a four-decade old scientific society started in Madras, now head-quartered in Pune. To conclude this report, Prof. Sivaram's statement in the lecture appeared to be most appropriate ***"For over 100 years we have learnt how to stitch monomers together to make polymers; now we must begin to learn how to remove the stitches, how to convert polymers into monomers".***