

Annexure 1: Details of Research Experience and accomplishments

Research Experience

Involved in basic and applied research in the areas of Homogeneous & Heterogeneous Catalysis, C-1 Chemistry and Chemical Reaction Engineering, the most significant ones being in Kinetic Modeling, Multiphase Reactor Engineering and Catalysis for reactions such as Carbonylation, Hydroformylation, Oxidative Carbonylation, Hydrogenation and Oxidation. Research work was always focused on selecting basic science problems for Ph. D. programmes with relevance to current and future industrial processes. Established a school in Homogeneous Catalysis Research at NCL, which has provided a base for developing new generation technologies via Carbonylation and hydroformylation. This expertise has also led to major contract research projects at NCL under my leadership from multinational as well as Indian industries. I have supervised **31 Ph D students**, who worked in **Chemical Reaction Engineering and Catalysis**. Research activities can be summarized as follows:

- **Kinetic Modeling of Catalytic Reactions**
Experimental studies on homogeneous & heterogeneous catalytic reactions were undertaken with the goal of developing rate equations representing intrinsic kinetics, model discrimination, and molecular approach to kinetic modeling for simple as well as complex multi-step reactions. Several case studies involving hydrogenation, carbonylation, hydroformylation, reductive alkylation and oxidation reactions using supported metal catalysts as well as homogeneous Rh, Pd and Ru complex catalysts investigated.
- **Multiphase Reactor Engineering**
Approaches for analysis of rate processes in gas-liquid, gas-liquid-solid, gas-liquid-liquid and gas-liquid-liquid-solid catalytic reactions have been developed to understand the significance of interphase and intraparticle mass transfer steps and experimental verification studied for homogeneous, heterogeneous as well as biphasic catalytic reactions. Theoretical models for the performance of batch and continuous slurry reactors and trickle bed reactors were developed and extensive experimental verification studied for hydrogenation reactions of industrial relevance.
- **Homogeneous Catalysis by Metal Complexes**
Synthesis of metal complex catalysts, their catalytic activity/selectivity and stability studies as well as characterization of catalytic species for carbonylation and hydroformylation reactions have been investigated.
- **'Heterogenized' Homogeneous Catalysts**
Methodologies for Heterogenization of homogeneous catalysts using anchoring, encapsulation, tethering and ossification techniques developed and detailed characterization studied using solid state NMR, XRD, XPS and other techniques. Some of the catalysts have shown promising applications for carbonylation and hydroformylation reactions. Also, biphasic catalysis using water soluble metal complexes studied to demonstrate importance of interfacial catalysis in rate enhancement.

Industrial Research & Development

Involved in development of several innovative processes on a laboratory and pilot plant scales. Completed contract research projects sponsored by DuPont, USA, GE, USA, ICI Polyurethanes, Huntsman Polyurethanes, Belgium, Invista, UK and projects financed by EEC, IFCPAR, KFA (Germany) and Volkswagen Foundation (Germany). Collaborated with Rhone Poulenc, France; ENSIGC, Toulouse; LGPC, Lyon; University of Venice, Italy; University of Erlangen, Germany etc. Worked as Consultant on R & D & Process Improvement for several companies. Completed the following industrial sponsored projects at NCL.

- Butenediol/Butanediol sponsored by HOC –Lab/Pilot/Semi-commercial Scale
- Methyl Ethyl Ketone by oxidation of butanes, Sponsored by NOCIL – Lab/Pilot Scale
- Propionic Acid: Sponsored by Deccan Sugar Institute, Pune & GAAC, Ahmedabad
- Acetic Acid by Carbonylation of Methanol: Sponsored by GAAC, Ahmedabad
- Carbamates: A non-phosgene, non-MIC route, Sponsored by Excel Industries, Mumbai.
- Non-Phosgene Route for Aryl Carbonate Intermediates, Sponsored by IPCL, Baroda
- A process for Maleic anhydride to THF Sponsored by Adarsh Chemicals & Fertilizers Ltd, Surat –Lab/Pilot Scale
- Acetic Acid by Carbonylation of Methanol, Collaborative Project with GNFC, Bharuch
- P-Aminophenol by single step hydrogenation of nitrobenzene, Collaborative project with Vinati Organic Ltd—Lab/Pilot Scale
- A process for racemization of L-2-aminobutanol : A collaborative project with Lupin Laboratories, Mumbai (2003-2004)

International Collaborations

- NCL-University of Erlangen (Prof. H. Hoffmann) collaboration on “Modelling of Slurry Reactors” financed by Volkswagen Stifting, Germany
- NCL-University of Erlangen (Prof. H. Hoffmann) collaboration on “ High pressure chemical reaction engineering” financed by CSIR-KFA programme
- Indo-USSR collaborative project with Institute of Organic Chemistry, Moscow (Prof. Lapidus)
- Indo-French collaborative project (IFCPAR) between NCL, ENSIGC Toulouse (Prof. H. Delmas) and Rhone Poulenc –CNRS Laboratory,Lyon (Dr. Jean JENCK) on “Reaction Engineering of Biphasic Catalysis” and “Non-isothermal Fix Bed Reactors for Hydrogenations”
- NCL-LGPC-Rhone Poulenc (Lyon, France) collaborative project on “Non-isothermal multiphase catalytic reactors”, supported by European Commission, Brussels
- NCL-DuPont (USA) collaborative project on” Reaction Engineering of Slurry & Fixed bed Hydrogenation Reactors for Dicarboxylic Acids’(1995).
- NCL-DuPont (USA) project on “Hydrogenation of aq Maleic acid to THF using bimetallic catalysts” (1996).
- NCL-DuPont (USA & UK) on “ Development of Breakthrough Reaction-Separation Techniques for Liquid Phase Oxidation” Part I – Digestion Technology (1999-2000)
- NCL-DuPont (USA & UK) on “ Development of Breakthrough Reaction-Separation Techniques for Liquid Phase Oxidation” Part II – Modelling & Experimental Validation” (2000-2001)
- NCL-DuPont (USA & UK) on “ Development of Breakthrough Reaction-Separation Techniques for Liquid Phase Oxidation” Part III – Scale up Implications”(2001-2002)
- NCL-General Electric (USA) collaborative projects on “ DPC by Carbonylation of Phenols and Bis-phenol A” –Part I : Catalyst Development (1996-2001)

A series of 6 project completed during 1996 to 2001 focused on various aspects of developing non-phosgene routes for monomers of polycarbonates and also for direct synthesis of oligomers of polycarbonates.

- NCL-ICI Polyurethanes Project on “ Oxidative Carbonylation of DADPM and Polymeric DADPM” (1997-1998)
- NCL-Huntsmann Polyurethane Collaborative Project on “Non-phosgene Routes for Isocyanates” Part I (2000-2001)
- NCL-Huntsmann Polyurethane Collaborative Project on “Non-phosgene Routes for Isocyanates” Part I (2001-2002)
- Indo-Italian collaborative project between NCL and Universita Delgi studi Venezia, Italy (Prof. Toniolo) on “Carbonylation by homogeneous catalysis”
- NCL-Invista (UK) Ltd collaborative project on “ Hydrogenation of trace impurities in ethylene glycol and oligomers : Catalyst selection and performance evaluation” (2003-

- 2004)
- NCL-Invista (UK) Ltd collaborative project on “Reactions in Supercritical water “ (2004-2005)
- NCL-Schenectady International Inc, USA project on ‘Catalytic Hydrogenation of Isophorone Nitrile) (2006)

Awards & honours

- Prof S K Bhattacharya award of the Eminent scientist of the Catalysis Society of India (2005)
- Professor G V Bakore Memorial Award of Indian Chemical Society, (2003).
- FICCI Award in Physical Sciences including Mathematics (2000-2001).VASVIK Award of Vividhlaxi Audyogik Samshodan Vikas Kendra (1989).
- ”SHRI HARI OM ASHRAM PRERIT S. S. BHATNAGAR” Research Endowment Award for CATALYSIS (1988)
- Recognition by DuPont Textiles & Interiors for creative contributions to a liquid phase oxidation process (2002)
- K. G. Naik Gold Medal of M. S. University of Baroda (1993).
- Golden Jubilee Visiting Fellow of BUDCT, Bombay (1992).
- Best Scientist of the Year Award of NCL Research Foundation (1996).
- Distinguished Speaker Award of IChE for Hetero Drugs G S Ladha Lecture (Dec 2002)
- *Highest Industrial Earning Trophy of NCL Research Foundation for 1998/1999,1999/2000, and 2005/2006 for Homogeneous Catalysis Division under my leadership.*
- Member Expert Group-Catalysis to ICS-UNIDO, Trieste, Italy.
- Acted as a member of Expert Committee for technical evaluation of acetic acid and carbamate technologies for DGTD, Government of India (1987-88)
- Member, selection committee for professors at IITs and Scientists in CSIR labs
- Expert Member, Indian Chemical Manufacturers Association (ICMA)’s Expert Committee on Energy & Technology, 2000 onwards.
- *Member, Board of Directors of Bilcare Limited, Pune*
- *Member, Board of Directors of Praj Industries Ltd, Pune*
- Member, High Power Committee for NMITLI Projects-CSIR, India
- Chairman of several internal committees of NCL including IPR (Patents related matters)
- Reviewed papers for International journals in Chemistry and Chemical Engineering (JACS, Chem. Mater., Langmuir, J. Catalysis, AIChEJ, Chem. Eng. Sci., Ind. Eng. Chem. Research, Applied Catalysis, Cat. Comm., Cata. Letters etc) and proposals for Petroleum Research Funds (PRF)
- Recognised Research Guide for Ph. D. degree of Mumbai, Pune and Shivaji University
- Member, International Advisory Committee for CAMURE (Catalysis in Multiphase Reactors: International symposium series) & CHEMREACTOR-17 conferences. Chaired organisation of CAMURE-6 at NCL, Pune, India in January 2007

Fellowship of National Academies / Societies

2005	Indian National Science Academy (INSA)
1989	Indian Academy of Sciences
1993	National Academy of Engineering
1992	Maharashtra Academy of Sciences
1990	Catalysis Society of India
1992	Honorary Fellow of Indian Institution of Chemical Engineers
2000	Chemical Research Society of India