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Review Article

Development of Some Eco-Efficient and Selective Chemical Processes and Products Using Sustainable and Green Chemistry Approaches

Isak R Shaikh[1-4]* and Alamgir A Shaikh[2]

[1]*School of Chemical Sciences, Swami Ramanand Teerth Marathwada University, Nanded, Maharashtra, India*

[2]*Poona College of Arts, Science and Commerce, Camp, Pune, Maharashtra, India*

[3]*Shri Jagdishprasad Jhabarmal Tibrewala University, Jhunjhunu district, Rajasthan, India*

[4]*Razak Institution of Skills, Education and Research (RISER), Shrinagar, Nanded, Maharashtra, India*

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***Corresponding author:** Isak R Shaikh, School of Chemical Sciences, SRTM University, Nanded, India, Email: isak@india.com

Introduction

Historical records show that scientific advancements accounted for substantial changes in our life-style and wellbeing. The Industrial Revolution took place in the western countries in the 1700s when people first appreciated the terms 'science' and 'technology' and valued the applications of 'technological innovations' for their commercialization. During the World Wars, people experienced use of science and technology for destructive purposes. The 20th century science revolutionized the living standard of mankind and offered solutions to great socio-economic or strategic challenges of the time. Though industrialization is considered as an essential feature of economic growth, it at times is infamous due to the adverse environmental health consequences caused by the release of pollutants. Policies are being placed to create a course of action, followed by enactment (of a law), and then rules & regulations that are designed to carry out that law successfully. Today, the environmental policymaking process in most of the developed nations relies heavily on the transition to sustainable production and consumption patterns. Public support is being generated through organized ways to educate all about the environmental issues and research. In the spirit of that, recent science has seen major advances in the ongoing endeavors directed towards diminishing the impact of anthropogenic and industrial activities on the environment.

Sustainable Development

Sustainability has emerged as the broadest and all-encompassing concept of all and it is one of the few significant words that will be carried over broadly outside the scientific language. Brundtland Commission (1987) - the United Nations' Commission on Environment and Development defined sustainable development as "the development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [1]. The Earth Summit (1992): United Nations' Conference on Environment and Development held in Rio de Janeiro (Brazil) highlighted the urgent need to find a more sustainable way of life; reduce environmental emissions and use resources carefully [2]. It also advocated to move towards a model in which environmental enhancement is fully integrated with economic development. There is a need to understand sustainable development as a global responsibility. The members of the World Business Council for Sustainable Development (WBCSD), a consortium first established in 1990 and based in Geneva, have signified the business value of sustainable development and pinpointed responsibility and liability on the part of corporate enterprises that use hazardous materials in their processes or products [3]. The WBCSD coined the term "eco-efficiency" in its 1992 publication "Changing Course" and this new business concept is meant for implementing the "Agenda- 21" in the private sector [2]. Pollution reduction in natural as well as synthetic industrial chemical processes and development of more renewable forms of energy are key aspects of sustainable development from chemical and energy perspectives.

Chemistry is the study of matter; it is the branch of science concerned with the substances of which matter is composed, the investigation of their properties and reactions, and the use of such reactions to form new substances. Among the greatest achievements of chemistry are petrochemical and pharmaceutical industries. Some of the greatest benefits to public from pharmaceutical industry include the painkillers, antibiotics, anti-malarial, anticancer drugs, etc. Fine chemicals, polymeric and other advanced materials too have lots of applications in day-today-life and industries. And, most of these many useful chemical technologies are available at significant environmental cost. Though the 20th century chemistry revolutionized the living standard of mankind, the major disadvantages of this progress are now being identified as significant pollution through greenhouse gases, heavy metal toxicity, eutrophication, persistent organic pollutants, etc. In India, for example, the measures adopted in the "Green Revolution" increased agricultural production and made India self-sufficient in food grains but unfortunately the excessive usage of chemical pesticides and fertilizers are now found to cause negative effects on the soil, land, water and our body & its metabolism. Nowadays, pollution due to chemical industries has become a major issue worldwide. Policy makers, environmentalists and the public in general assume that the chemical industry disregard the environmental consequences. And in view of un-avoidable pollution, a recent challenge is to understand and make the chemical processes occurring in Nature (ecology/environment) sustainable. There is no excuse for the ignorance or the lack of knowledge of the short-term as well as long-term effects of chemical products or processes produced in industries. The challenge for the present-day chemical industry is to continue providing applications and socio-economic benefits in an environmentally friendly manner. Eco-efficiency has been recognized as an important tool in transforming unsustainable development to sustainable development. The concept of green chemistry can certainly help achieve sustainability in chemistry point of view or rather stand as a component of sustainable development (Figure 1). Having said that, sustainability not only offers the choice to conserve or consume resources sensibly, but it also encompasses the societal attitude towards the environmental change.

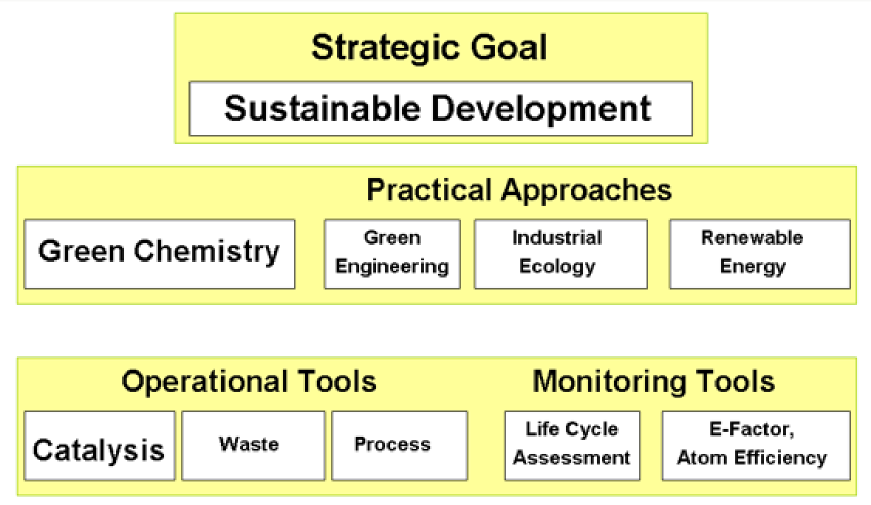

Figure 1: The big picture of sustainable development in chemistry point of view.

Green and Sustainable Chemistry

The Environmental Protection Agency (EPA) of the United States of America is credited for coining and defining the concept of Green Chemistry. Paul T. Anastas firstly proposed this term. "Green Chemistry is the use of chemical principles and methodologies for source reduction. Green Chemistry incorporates pollution prevention in the manufacturing of chemicals and promotes pollution prevention and industrial ecology" [4]. The International Union of Pure and Applied Chemistry (IUPAC) defined Green Chemistry as the invention, design and application of chemical products and processes to reduce or to eliminate the use and generation of hazardous substances [4-5]. For Prof. Roger Sheldon, "green chemistry efficiently utilizes (preferably renewable) raw materials, eliminates waste, and avoids the use of toxic and/or hazardous reagents and solvents in the manufacture and application of chemical products" [6]. All member countries of the Organization for Economic Cooperation and Development (OECD) – an intergovernmental organization endorsed an initiative called "Sustainable Chemistry" which would advocate the development of environmentally benign chemicals [7]. Sustainable chemistry, as defined by the OECD, seeks to improve the efficiency with which natural resources are used to meet human needs for chemical products and services. Sustainable chemistry encompasses the design, manufacture and use of efficient, effective, safe and more environmentally benign chemical products and processes. Essentially sustainable chemistry is about doing more with less: making most of the finite resources and minimizing waste, reducing the environmental impact of chemical processes and products. Lancaster (2002) in his book entitled, "Green Chemistry: An Introductory Text" successfully brought in together all the concepts and relevant examples for students and researchers [8]. Over the last few decades, green chemistry has been recognized as a culture and methodology for achieving sustainable development. Broadly speaking, green chemistry practices environmentally benign aspects of basic chemistry and applied engineering [9].

The concepts of "sustainable chemistry" and "green chemistry" are written above separately to avoid any confusion in understanding motivation in nut-shell of the principal author's research endeavors. The terms of green chemistry and sustainable chemistry have been almost fully conceptualized and grown into a multidisciplinary area today. The future of this field is, at least in part, due to society's global awareness of long-term industrial growth going hand-in-hand with pollution-free or relatively safer chemistry practices.

Green chemistry addresses source reduction [10]. In this context, 'green' processes can be described as chemical conversions that consume a minimal amount of energy and produce the least waste. In addition to chemistry, chemical engineering is required to achieve true source reduction. "Green Engineering is the design, commercialization, and use of processes and products that are feasible and economical, while minimizing both risk to human health and the environment, and generation of pollution at the source" [10]. "Green chemistry and engineering" include the production of chemicals and development of processes by avoiding pollution and are inherently safe for humans. This multidisciplinary chemistry strategy aims to conserve ecology and environment for the present and future generations. Public assumes that pollution is inevitable and also that the Government is obliged to monitor industries and control emissions. Governmental agencies usually put legislative framework in place for the pollution prevention and can demand the treatment of pollutants or cleaning-up contaminated sites including the air, water, and soil. This has led to at least some law-abiding chemical manufacturers investing substantial capital on environmental matters. Allen and Rosselot [9] presented the following hierarchy for pollution prevention and waste management, in decreasing order of preference:

I. Source reduction

II. In-process recycling

III. On-site recycling

IV. Off-site recycling

V. Waste treatment to render it (the waste) less hazardous

VI. Secure disposal

VII. Direct release to the environment

Usually due to the plurality and complexity of chemical synthesis pathways, design and development of completely environmentally friendly chemical products and processes is an enormous challenge. On a bright side, it is definitely practical to confirm whether a potential chemical manufacturing process is "greener" than the existing ones.

The Twelve Principles of Green Chemistry

Important principles that govern and guide today's green chemistry [4] are formulated by Anastas and Warner. The author (of this paper) enlists herein, as he understands, the famous twelve principles:

A. Prevention is better than (waste) treatment

B. Atom economy referring to the design for maximizing the incorporation of all starting materials utilized to get the desired chemical product.

C. Use and produce chemical substances that has little or no toxicity to human health and the environment.

D. Designing Chemicals only having the desired effect or function and not their side- effects or toxicity

E. Avoid using volatile solvents and auxiliaries

F. It is preferred to carry out synthetic methodologies at ambient temperature and pressure by avoiding economic and environmental impact due to energy usage

G. Use of Renewable Feedstocks

H. Reduce derivatizations, protecting groups, and temporary chemical modifications, etc.

I. Use of catalysts for selective synthetic methodologies

J. Chemical products should be degradable and they or their degradation product shall not pollute the environment

K. Application of real-time, on-site analytical methodologies for in-process monitoring and control of hazardous substances

L. Chemical process should be devoid of any accidental threats, such as corrosion, explosion, fire, etc.

There is a need to achieve these twelve principles of green chemistry. The author recommends herein that a new concept of elemental sustainability should also be added to such chemistry by which one may conserve the rare metals and or their supply by way of encouraging the careful resource utilization and recycling. Utilization of a single metal atom as functional entity or catalyst instead of its nanoparticles or bulk usage could also save precious elements or rare chemical matter.

Concepts Related to Green Chemistry

In addition to green chemistry, following are the related concepts and industrial initiatives that are required to be defined and understood appropriately:

a) Pollution Control or Prevention: This reflects elimination or at least reduction of emissions and chemical pollutants.

b) Waste Minimization: This includes minimization of side-products or wastes generated by chemical process.

c) Waste Treatment: As the term implies, the practice of waste treatment incorporates in- process recycling, cleaning-up of waste contaminated system and or its secure disposal.

d) Waste Utilization: This concept describes the treatment of waste and its conversion to useful and safe resource.

e) Benign Design: This concept of 'benign design' refers to the designing and manufacturing of chemical products and processes in a way that exert no or minimal negative environmental impact. The concept of green chemistry intersects with the concept of 'benign design' wherein these approaches will lead to the discovery and production of less hazardous and less toxic materials, or molecules based upon renewable feedstocks.

f) Industrial Ecology (IE): It describes the energy and material flow through an industrial system. The purpose of study is to find balance between environmental and economic performance within global ecological constraints. The IE, sometimes known as the science of sustainability, is an interdisciplinary framework that seeks to design and operate industrial systems as living systems interdependent with natural systems. Graedel and Allenby [11] described IE as the science of consumption and reusability of natural resources in production, rather than the traditional practice of extracting and using resources, then discarding and disposing.

g) Sustainability: Generally speaking, sustainability is the term describing endurance of systems and processes. This concept is studied and managed in many contexts of environmental, social and economic organization. There is a relationship among green chemistry, benign design, industrial ecology and sustainable development [12]. Off late, increasing research endeavors on green and sustainable chemistry are evident by a continually growing number of publications in this field. This covers a wide spectrum of research approaches from basic chemistry to industrial process development [13].

Financial Analysis of Green Chemistry

Implementing the concepts of green chemistry and engineering usually demands basic to applied research on synthesis, catalysis, reactor design, and improved unit operations. Reduced utilization of raw materials or energy, reduced waste management along with safety, reduced environmental damage or relatively reduced future liabilities are amongst the long- term benefits offered by greening chemistry and chemical engineering. And, there is a need to develop financial tools needed to quantify these benefits or at least to meet the so-called triple bottom line [14]. Apart from the traditional economic analysis, justification and implementation of green chemistry projects will require the following tools evaluating the benefits of green chemistry:

a. Life Cycle Assessment or Life Cycle Analysis,

b. Toxicology and Long-term Risk Assessment

c. Total Cost Assessment (Figure 2)

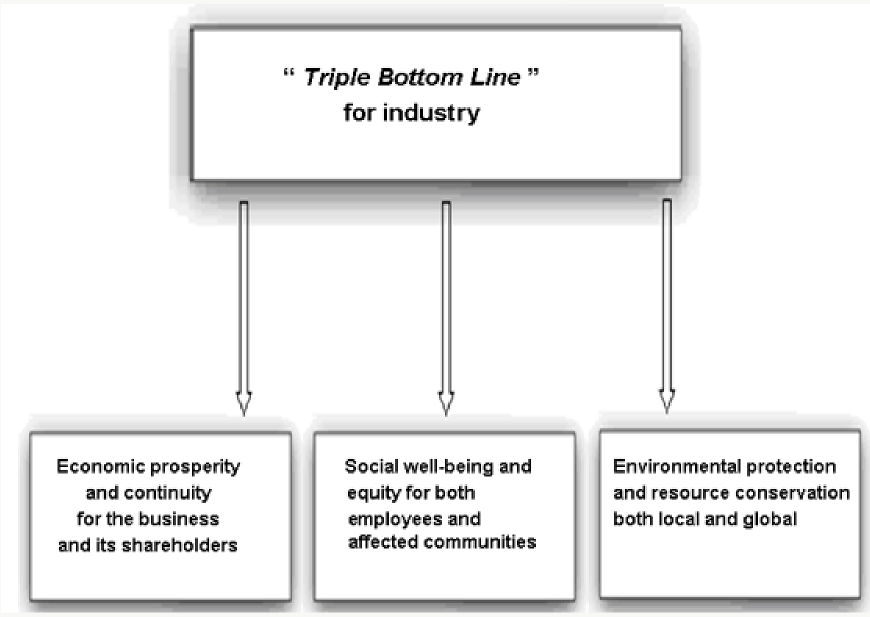

Figure 2: The "triple bottom line" for industry.

a. Life Cycle Assessment (LCA): LCA methodology, originated in the early 1970s, is an active research area. The material and energy flows of a process are taken into account starting from the point where raw materials are extracted from the environment, through transportation, processing, production/manufacturing, distribution, and use, and finally closing at the point where the product is disposed, recycled, or re-manufactured. Herrchen and Klein reviewed [15] the LCA and its application in assessing environmentally benign chemical technology alternatives. Though LCA does not suffice to assess the economic and social impact of a given green technology, it is a method for predicting quantitative environmental impacts of the production, including by-products formation and use of solvents and auxiliaries. Following is the list of impact categories (human health, ecosystem health and resources) [16] addressed in a Life Cycle Assessment:

i. Depletion of resources (abiotic or biotic)

ii. Desiccation

iii. Impacts of land use (sub-divided into land competition, loss of life support functions, and loss of biodiversity)

iv. Climate change

v. Stratospheric ozone depletion

vi. Human toxicity

vii. Eco-toxicity (sometimes subdivided into freshwater aquatic, marine aquatic, terrestrial)

viii. Photo-oxidant formation

ix. Acidification

x. Eutrophication

xi. Impacts of ionizing radiation

xii. Odor

xiii. Noise

xiv. Waste heat

b. Toxicology: This issue is of prime importance and covers socially important challenges of our time: protecting public health and the environment. Anthropogenic activities that cause pollution pose significant threat to the environment. Oceanic currents and atmospheric transport processes can spread organic and inorganic toxicants throughout the world. The main focus of the studies shall be to evaluate the exposure to and effects of chemicals in air, water, soil and food chains, etc. and consequently confirms the adverse effects within life forms (including humans). It mainly covers the study of interaction between toxicants and ecosystems including organisms. The unique combination of environmental chemistry and toxicology promotes science and research for the well-being of current and future generations. Environmental toxicology in itself is a multidisciplinary field encompassing various aspects of biology, ecology and risk assessment.

c. Long-Term Risk Assessment: Risk assessment is very important for good health and safety management. It is necessary to evaluate scientifically a potential or known hazard and its adverse health effects. For example, risk may be defined as the probability of harm that an individual might come across from exposure to a given hazard. Risk assessment identifies hazard towards both the safety of chemical plant and the process. Risk assessments foresee and quantify a variety of human and environmental risks based on the structure and function or property of a recognized hazardous chemical product.

d. Total Cost Assessment (TCA): TCA is fundamental to accounting and assigning all costs of production to the entity within the organization that generates those costs. The American Institute of Chemical Engineers (www.aiche.org/cwrt) provides a guide to TCA, [17] and a spreadsheet tool for performing TCA. The term 'green chemistry and engineering' we learnt by now not only covers the traditional educational and research disciplines related to chemistry and chemical engineering but also includes safety, risk assessment, hazard, health, life-cycle assessment, financial analysis, and their intersection with public policies. The introductory part so far detailed the concepts, terminology, and other relevant aspects for understanding big picture of sustainable development in chemistry and environment point of view [18].

Green Chemistry in Classroom and Laboratories

The academic and research institutions worldwide have already started adopting the Green Chemistry track in the Chemical Sciences PhD Programme. In addition to conventional chemistry, the research scholars obtaining a Ph.D. degree from such programme are trained in multi-disciplinary science, technology, engineering and mathematics (or statistics, for that matter) and providing with the methodologies or techniques and approaches or experiences to assess chemistry's impact on environment, ecology and more particularly the human health. Chemistry is the study of matter. Green (and sustainable) chemistry offers an ecologically and environmentally benign view of chemistry research and development for relevant products and services. Pollution, toxicity, and ecological and or environmental consequences are necessary components to understanding the entire "life cycle" of any chemistry related industrial or commercial endeavour. It is therefore need of our times to develop human resource with the appropriate green chemistry & engineering skills and also the facilities or infrastructure to pursue chemistry for sustainable development. Chemistry lies at the very heart of everything within us and around us. Its knowledge and the methods steadily increased over the centuries. The core principles of chemistry are:

A. The act of creation, combining, or synthesis, and

B. The act of analysis, characterization, destruction or separation. Today, the growing need for the atom efficiency, energy efficiency and environmental concerns stemming from the increase in chemical products demand necessitate the development of the 'sustainable or environmentally benign' production methods.

There are a variety of challenges in making chemistry 'green.' Research in chemistry for sustainable development demands the co-operation of chemists, biochemists, engineers, statisticians, health scientists, etc. In present-day chemical industries, it is hard to find an obsolete "green" product or process. The greening of a chemical product or process may be achieved through a number of means, including improved syntheses, recyclable and selective catalysts, innovative process design, utilization of renewable raw materials, production of less toxic products, use of non-volatile and environmentally friendly solvents, etc. In other words, the concept of green chemistry can primarily be solicited in any aspect of chemistry, chemical engineering, risk assessment and toxicology. In addition to the fundamental scientific data, the financial metrics must also be taken into consideration while making environmentally optimized or greener chemical products and processes a profitable business ethic. In order for us to create and establish a more neutral chemical industry by minimizing industrial impact on human, eco-system health and resources, the goal of green chemistry, as the first step, shall be to discover and develop environmentally friendly, non-toxic and sustainable alternatives for chemical products, materials, solvents, catalysts, systems and feedstocks. The researchers in this field see it not just as an area of chemical science, but as a philosophy, a "way of life."

Motivation

"Green and Sustainable Chemistry" or the "Chemistry for Sustainable Development" is understood here as the contribution of chemistry in the implementation of the Johannesburg Declaration, [19] (World Summit of Sustainable Development, 2002), the Rio Declaration (Earth Summit, 1992) [2] and Our Common Future: Report of the World Commission on Environment and Development (Brundtland Commission, 1987) [1]. This article offers a kind-of primer or the perspective including the importance of the research line taken and its justification in the present era. The various researches highlight mainly introduce sustainable development, chemistry – the science of matter and also details the conceptualization of green / sustainable chemistry or the importance of chemistry for sustainable development. The text details readers the purpose of this research in minimizing or eliminating the environmental, economic and ecological cost of some chemical processes by keeping in mind the term "sustainability" and the famous 12 principles of green chemistry. The research scholar identifies (i). studies involving preparation and characterization of some nanoporous materials and their applications as heterogeneous catalysts in synthetic/industrial chemistry, and (ii) understanding sustainability of chemical processes in environment to be at the heart of greening of chemistry. That is why there is this moral obligation of the academicians and chemistry researchers to engage in communicating and developing the solutions to pollution issues due to chemical sciences and allied disciplines. These research activities surely contribute to the entrepreneurial sustainable development. This mainly features selected principles of the green chemistry from the famous 12 principles of green chemistry, focusing on environmentally friendly chemical technology and tactics to minimize the occurrence and effects of pollution, including the utilization of the agricultural waste. The approaches herein should offer solutions to some crucial problems associated with ecology, environment and synthetic chemistry applications.

Objectives of the present review

The key aspect of these researches (from a Ph.D. thesis submitted to the JJTU Rajasthan in July 2014) is to contribute to sustainable development from chemical science perspective by developing more environmentally friendly chemical products & processes.

The objectives were:

a) To develop green chemistry approaches in synthesis, modification/fabrication, characterization of some zeolites and related nanoporous materials for their possible catalytic applications in making synthetic chemical processes or methodologies eco-efficient and selective.

b) Based on various different research schemes, there may include specific or sub-objectives from the aforementioned main objective.

c) To understand and develop chemical processes in Nature Some of specific or sub-objectives from this main objective include

i. The valorization of agricultural residue such as the wheat husk ashes for extracting or recovering some chemical products and for converting them into useful functional or value-added products and thereby achieve sustainability.

ii. The study, in chemistry point of view, of the possible effects of some heavy metals (for example, Cd, Cr, Mn, Zn, etc.) present in soil and or irrigation waters on seed germination and seedling growth of wheat and also the discussion on the plausible sustainability in this (i.e. phytotoxicity) chemical process in Nature;

iii. The investigation into eutrophication due to phosphate and some other chemicals and nutrients supplied in excess to an aquatic body by physico-chemical analyses

Practicality and the perspective of the research works

Following is the various contributions of the author who argues on how the objectives originally sought for are achieved. This describes the multi-disciplinary approach and attitude with which the topic of sustainability is understood and addressed in chemistry point of view. Particularly the former has had a very positive influence in summarizing the many nice research results presented in this perspective.

I. Firstly, the author provides a general introduction to sustainable development, chemistry – the science of matter and the conceptualization and importance of sustainable and green chemistry in the present era. The contents on sustainability in chemistry point of view form the basis for research reviewed in this aspect. Following on from the introductory part, there is a kind of Strategic Goal for sustainable development. This displays the big picture of sustainable development in chemistry point of view and includes practical approaches and the operational as well as monitoring tools. The concepts of green chemistry, catalysis and life-cycle assessment are interesting, and there is an urgent need to find industrial applications thereof. The author's secondary research entitled, "Organocatalysis: Key Trends in Green Synthetic Chemistry, Challenges, Scope towards Heterogenization and Importance from Research and Industrial Point of View" accounts the chemistry behind the "catalytic magic" of small organic molecules [20]. Many topics in chemistry and catalysis are treated in this review, with relevant references giving the brief on research and development of the underlying science and relating it to catalytic practice and industrial point of view. The general scope of this literature is thus to bring many outstanding researches together and show the vitality of the catalysis (including organocatalysis) through several aspects and also to offer suggestions for new and innovative directions of research as well as scope for incorporating "organocatalysis" to heterogeneous catalysis. This may form the basis for research embodied in various other academic and industrial researches.

II. In view of the potential green chemistry applications of immobilized organocatalysts, a scheme of research involved the successful heterogenization of a basic ionic liquid, bearing NTf2- (Hünig base) – the non-nucleophilic anion - on mesoporous SBA-16 silica [21]. It is found that this recyclable catalytic system is highly active towards the C-C bond forming Knoevenagel condensation between benzaldehyde and ethyl cyanoacetate. The solvent-free reaction at room temperature utilizing an ionic liquid lead to almost 100% conversion and selectivity and thus exemplifies the principles of green chemistry.

III. In another project of research, mordenite zeolite was modified and employed in the carbonylation of methanol minimizing by-products by ensuring a high yield and selectivity of acetic acid / acetyls. The reaction conditions, atmospheric reactor and the use of copper promoted H-mordenite (Cu-H-MOR) catalysts are all meant to inhibit the methanol-to- gasoline (MTG) chemistry and focus on the selectivity towards the acetyl products [22]. This led the best results and also the oxalic acid washed mordenite performed better than the neat H- MOR catalyst. It would not be arrogant to say that this new catalytic method is economically advantages over the well-established Cativa process which involves an iodide co-catalyst. There is no need of a halide promoter and thus the reaction medium is devoid of corrosive HI which would permit industries use reactors made of less exotic and cheaper material. This point brings economic advantage to this process. Such a heterogeneous catalytic process would separate products and catalyst easily. The use of syngas as a feedstock over a hydrogen tolerant catalyst provides a cheaper alternative than purified CO. The increase in selectivity to acetyls is directly proportional to the increase in Cu loading onto mordenite. The use of 75 mol% Cu modified H-MOR catalyst for optimized industrial carbonylation is identified at mild reaction temperature and atmospheric pressure. This is an interdisciplinary approach employing knowledge from chemistry and chemical engineering to develop new process by researching in the area of heterogeneous catalysis through a combination of bench scale laboratory work ranging through to pilot plant.

IV. In an attempt to develop material wealth from wastes, the mesoporous MCM-41 and titanium incorporated MCM-41 type silica materials are synthesized from the wheat husk ash [23-24]. The result is very interesting because it valorizes a significant agricultural waste stream. MCM-41 and Ti-incorporated MCM-41 thus prepared are tested for their catalytic applications in synthetic organic reactions. Sourcing silica from the wheat husk ashes for the syntheses of such catalytic materials has a potential cost-effective application and therefore could be adopted as a new industrial methodology. Neat MCM-41 represented acid catalysis and the Ti incorporated within gave redox catalytic property to the siliceous materials. In yet another research project, the hydrothermal synthesis of ZSM-5 zeolite, a microporous aluminosilicate, by sourcing silica from wheat husk ash is carried out and is followed by its modification to the various protonated forms i.e. H-ZSM-5. This result is important because ZSM-5 / H-ZSM-5 are working catalytic materials at industrial level and are considered as a well-known commodity, The samples are found to have characteristic crystallinity as evident by XRD peaks, good thermal as well as chemical stability, and catalytic character. The efficacy of H-ZSM-5 (with Si/Al ratio 30) for various organic reactions suggests the availability of catalytic active sites associated with the MFI-structured zeolite framework Al and or Si atoms. Our results mainly demonstrate [i] an attractive and potential scalable and industrially viable methodology for the wheat husk ash based high-purity and useful zeolite H-ZSM-5 synthesis; [ii]. the principles of green chemistry such as mild reaction conditions, recyclability of the solid acid catalyst, and selectivity of desired product from organic reactions, including cyclocondensation and multi-component reactions [25]. The novel catalytic applications of H-ZSM-5 are interesting because these organic transformations over this neat zeolite sample are achieved without having to introduce isomorphously substituted or extra- framework or impregnated metal ions or clusters. The results with regards to the application of H-ZSM-5 showed the catalytic behavior in various types of organic reactions, such as three / four-component reactions that have not so far been proved possible to achieve using a zeolite catalyst such as this. These interesting research schemes describe how the silica extraction methodology valorizes the wheat husk ashes and attempts to establish them as a novel (re)source of silica instead of an agricultural waste stream.

V. There could be some more researches meant for understanding sustainability in some ecological and environmental chemical processes. Apart from the elemental sustainability type of work and or the waste-to-wealth chemical processes of sourcing silica from the wheat husk ash, various other research schemes can appreciate sustainability.

VI. In one of the schemes of research, an age-old problem of heavy metal phytotoxicity is researched and discussed in sustainable chemistry point of view. To examine the effect of heavy metals on wheat seed germination, aqueous concentrations of chromium (Cr), cadmium (Cd), manganese (Mn) and zinc (Zn) metal ions are fed over the period of eight consecutive days. The (phytotoxic) effects mainly on (i) the germination of seed, (ii) the seedling vigor index, (iii) the root, shoot, seedling growth, and also (iv) the tolerance indices of wheat are discussed. In this study, the germination and root length (in emergence) are adversely affected by aqueous concentrations of heavy metals fed to wheat seeds in Black Cotton soil (of Nanded city, Maharashtra State, Republic of India). All results, when compared to control, show gradual reduction in seed germination and the decrease in growth of root and shoot with increasing concentrations of these heavy metals. The inhibition is stronger in root than in shoot. The toxic effects of selected metals to seed germination can be arranged in the rank order of inhibition as: Zn>Cd>Mn>Cr. The increasing heavy metal concentrations increase the phytotoxicity of shoot and root and decrease the tolerance indices and the seedling vigor indices. These methods and results thus provide a model system for developing sustainability in chemistry point of view and screening of various concentrations of heavy metals for their useful micro-nutritional properties or harmful phytotoxic effects. This shall also screen for the seeds able to counteract the deleterious effects of such heavy metals in various types of irrigation waters and agricultural soils. In other words, the studies of soil contents and irrigation water systems can help us achieve sustainable chemical process in ecological and environmental perspectives [26].

VII. Another research project embodied an investigation on eutorphication of a water body due to phosphate and other nutritious chemicals fed in excess to the aquatic environment. This studied chemical and physical quality parameters of water and also the composition of phytoplankton and zooplankton community as related to eutrophication or related chemistry [27]. Total hardness, calcium and magnesium hardness, increased dissolved solids and chloride & magnesium ions show deterioration of water quality. From the biological study of plankton diversity of this water body, it is concluded that about twenty-eight genera of phytoplankton and thirteen different genera of zooplankton are found in this water body. The reasons behind finding such dynamics are zero availability of oxygen and free carbon dioxide.

Conclusion

This section is meant for drawing conclusions and highlighting the importance of hands-on chemistry researches towards sustainable development. Particularly the latter has had a very positive influence in achieving and reviewing the many nice contributions or results presented herein. The scholar puts together dedicated efforts to achieve important advances in diminishing the impact of chemistry and related activities on the environment. The sustainable and green chemistry offers effective approaches to some crucial environmental problems associated with chemistry. It addresses some of the issues facing in employing economically viable chemical technologies / processes while simultaneously protecting the environmental health and safety. This will therefore be of particular interest to researchers in academia, industry, and government policies applying chemistry for sustainable development, and also to chemistry students, other professionals and consultants dealing with chemistry and relevant environmental concerns. The author believes that his various researches shall stand as a reliable reference to future researchers in the field of green chemistry for sustainable development [28]. To summarize, the various contributions of the researcher are reviewed and argued on how far the underlying goal of these researches is achieved by developing practical chemical production and application greener than the existing ones. The success of the scholar lies in bringing-in together the principles of "green chemistry" and "sustainability" in his research endeavors to show the vitality of the subject through several relevant applications. While advocating the need for interdisciplinary and integrative efforts, these approaches might offer clues on new and innovative directions of research in the cause of "greening chemistry."

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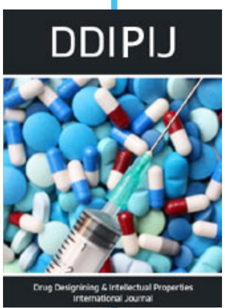

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