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APPLICATION OF GREEN CHEMISTRY IN ENGINEERING FIELD

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ABSTRACT

Green chemistry for chemical synthesis addresses our future challenges in working with chemical processes and products by inventing novel reactions that can maximize the desired products and minimize by-products, designing new synthetic schemes and apparatus that can simplify operations in chemical productions, The beginning of green chemistry is frequently considered as a response to the need to reduce the damage of the environment by man-made materials and the processes used to produce them. A quick view of green chemistry issues in the past decade demonstrates many methodologies that protect human health and the environment in an economically beneficial manner. This paper involves the main themes of the implementation of green chemistry principles in everyday life in industry, the laboratory and in education. A brief history of green chemistry and future challenges are also mentioned.

Keywords: green chemistry, green analytical chemistry, novel reactions, atom economy, sustainable environment

I. INTRODUCTION

Green chemistry is a pro-active approach to pollution prevention. It targets pollution at the design stage, before it even begins. If chemists are taught to develop products and materials in a manner that does not use hazardous substances, then much waste, hazards and cost can be avoided. Green Chemistry is designing chemical products and processes that reduce or eliminate the use and/or the generation of hazardous substances

Traditional approaches to pollution prevention focus on mitigating the hazard or end-of-pipe pollution prevention controls. These traditional technologies focus on limiting the exposure of a hazardous material. Unfortunately, exposure precautions can and will fail (i.e., gloves can tear, goggles can break, chemical releases can occur). Green chemistry goes to the root of the problem and aims to eliminate the hazard itself.

Green Chemistry is the only science that focuses on the intrinsic hazard of a chemical or chemical process.

II. DEFINITION

Green chemistry is also known as environmentally benign chemistry, or sustainable chemistry. Perhaps the most widely accepted definition of green chemistry is the one offered by chemists Paul Anastas and John Warner, who defined green chemistry as the design of chemical products and processes that reduce or eliminate the use and generation of hazardous substances.

Green chemistry applies to organic chemistry, inorganic chemistry, biochemistry, analytical chemistry, and even physical chemistry. While green chemistry seems to focus on industrial applications, it does apply to any chemistry choice

III. GREEN CHEMISTRY TECHNOLOGIES PROVIDE A NUMBER OF BENEFITS, INCLUDING

* Reduced waste, eliminating costly end-of-the-pipe treatments
* Safer products
* Reduced use of energy and resources
* Improved competitiveness of chemical manufacturers and their customers

IV. DIFFERENCE BETWEEN ENVIRONMENTAL SCIENCE AND GREEN CHEMISTRY

Both areas of study seek to make the world a better place. The two are complimentary to each other. Environmental Science identifies sources, elucidates mechanisms and quantifies problems in the earth's environment. Green Chemistry seeks to solve these problems by creating alternative, safe technologies. Green Chemistry is not Environmental Chemistry. Green Chemistry targets pollution prevention at the source, during the design stage of a chemical product or process, and thus prevents pollution before it begins.

V. CONCEPTS OF GREEN CHEMISTRY

Green Chemistry Concepts Green Chemistry is not a new branch of chemistry, it is more of a thought process, using the existing tools of chemistry in a manner which will continue to provide the societal and economic wealth we have come to expect whilst protecting the environment. The following are three of the more important concepts that hopefully chemists of the future will think of daily.

- Sustainable development. With oil production due to decline within the next 30 years, production methods to get chemicals from renewable resources such as crops will need to be developed.
- Atom Efficiency. It is an obvious statement but every atom that goes into a chemical reaction must come out somewhere. Be developing synthetic methods that maximize the number of atoms going into the reaction that end up in the product waste will be minimized.

Solvent selection. When preparing organic chemical most chemists will automatically carry out the reaction in an organic solvent such as toluene or dichloromethane. These solvents are often difficult to recover and purify and often form the major part of the chemical industry's waste. In fact many reactions can be carried out without solvent, in water or in environmentally friendly supercritical fluids such as carbon dioxide. It is sound economic and environmental practice not to use solvents unless absolutely essential.

The remainder of this article will illustrate how these concepts are being put in practice. Sustainable Development In terms of providing a mix of chemical raw materials plants can be viewed as non-toxic, biodegradable and CO_2 neutral alternatives to oil. One common chemical derived from plants, which is non-toxic and much under used, as a chemical feedstock is glucose. A good example where this could be used is in the manufacture of adipic acid, which is used in the manufacture of nylon 6.6.

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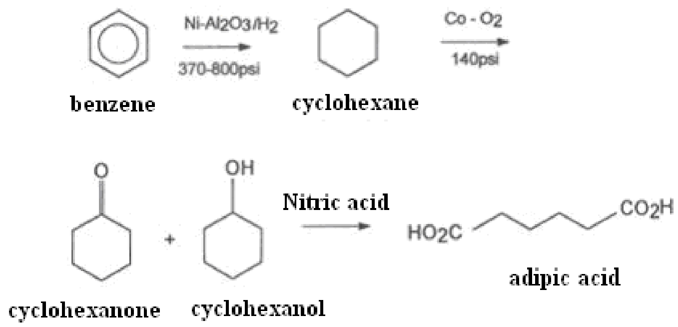
The conventional route for making adipic acid is shown in the following figure. Benzene, a carcinogenic chemical coming from the refinery process, is catalytically hydrogenated under high pressure to cyclohexane, which in turn is oxidised to give adipic acid.

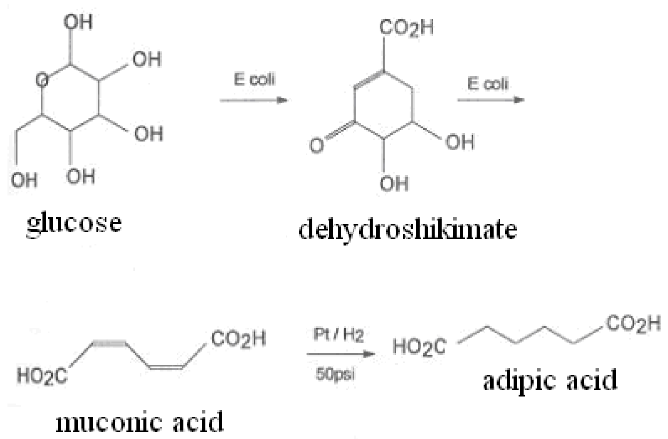
Conventional route to adipic acid



An alternative Route developed by John Ford at Michigan State University starts from glucose and uses bacteria to convert it to muconic acid that is easily reduced to the product. Advantages of this route include:

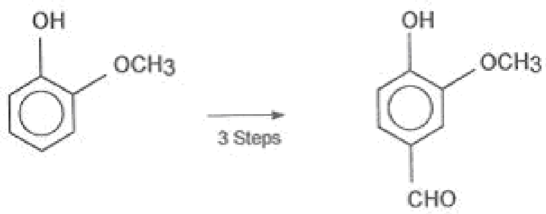
- Sustainable feedstock
- Avoids use of carcinogenic benzene
- Avoids requirement for costly high pressure equipment
- Uses water as solvent
- Avoids production of waste N_2O, from use of nitric acid, which contributes to global warming

Alternative route to adipic acid from glucose



Vanillin, which is widely used in flavoring and fragrances as well as a raw material for pharmaceuticals, is currently made by two routes, one from biomass the other from oil. The biomass route involves a series of extraction and distillation steps from waste produced during pulp manufacture. The non-sustainable route involves a series of fairly complex steps staring from 2-methoxyphenol but is used because of the currently cheaper process economics.

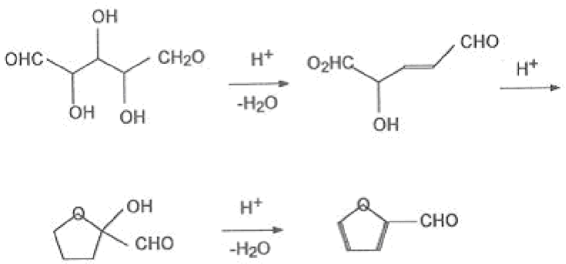
Vanillin prdocution



2Methoxyphenol Vanillin

Furfural is an excellent example of production of a major chemical from biomass. The Quaker Chemical Company have been producing furfural from pentosans (5 carbon sugars for many years through a series of acidic dehydration and rearrangement steps This is by far the major process for furfural production, which is used as a solvent in petroleum refining and as a pharmaceutical intermediate.

Production of furfural from pentose



Atom Efficiency Too often when chemical process has been developed in the past chemists has not considered by-product generation or the fate of so called 'catalysts' which have been used in near stoichiometric amounts. With increasing costs of waste disposal and tighter control of effluent industry is becoming increasingly concerned that what goes into a reactor should come out as a useable product. A classic example of this is the industrial manufacture of phenol.

For many years phenol was made by sulphonation of benzene with oleum to give benzene sulphonic acid. This was reacted with sodium hydroxide, first to give the sodium salt and then at high temperature to eliminate sodium sulphite, which was, disposed of as a waste product.

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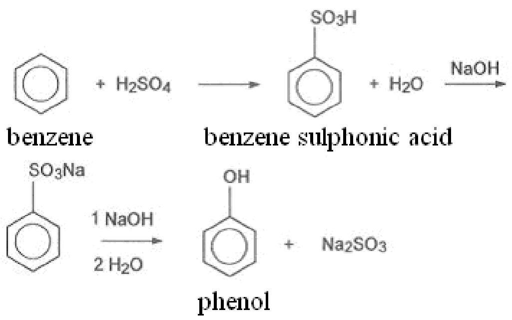
Old phenol manufacturing process



The overall equation for the manufacture of phenol is then:

$C_6H_6 + H_2SO_4 + 2NaOH \rightarrow C_6H_5OH + Na_2SO_4 + 2H_2O$

Assuming that a 100% yield is obtained i.e. all the benzene is converted to phenol then the atom efficiencies are:

Atom	% Efficiency
Carbon	100
Hydrogen	50
Oxygen	20
Sodium	0
Sulphur	0

What is even worse if we look at the relative molecular masses is that for every tonne of phenol produced can produce over 1.5 tonnes of waste.

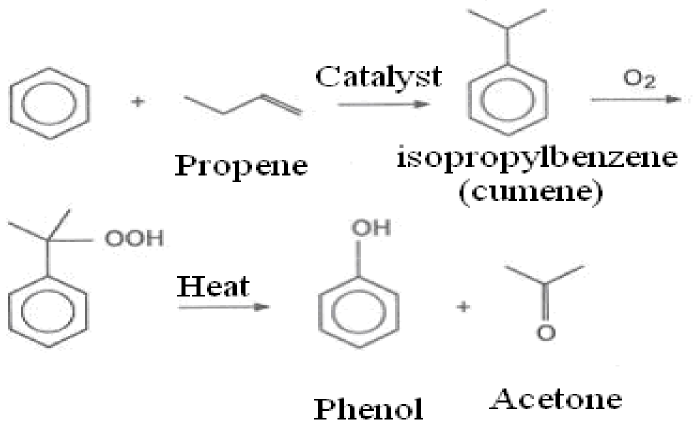
We can compare this with the modern process for production of phenol shown in the following figure. This involves reaction of benzene with propene with a reusable heterogeneous catalyst to form isopropyl benzene. This is reacted with oxygen to give hydro peroxide, which decomposes to phenol and acetone. Unlike sodium sulphite the acetone is a valuable chemical produced in high purity.

The overall equation for this reaction is:

$C_6H_6 + C_3H_8 + O_2 \rightarrow C_6H_5OH + C_3H_6O$

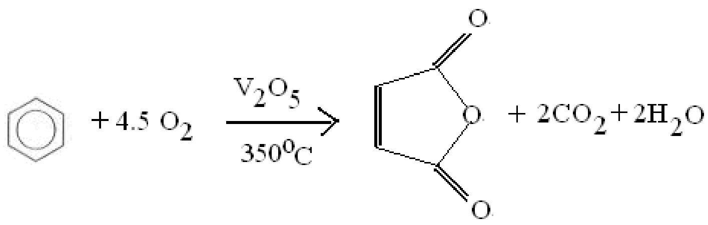
Again if we assume 100% yield, then the atom efficiencies are 100% in each case.

Modern phenol manufacturing process



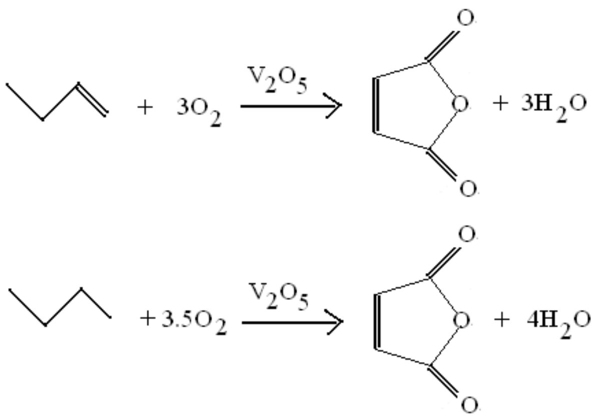
Another example of where the chemical industry has developed a more atom efficient process in recent years is in the production of maleic anhydride (used in the manufacture of polyester resins). Historically the process-involved oxidation of benzene to maleic anhydride using a vanadium pentoxide catalyst doped with molybdenum or tungsten as shown in the following figure. Although this process worked well it is readily seen that only four of the six carbon atoms in benzene are required to produced the product, the other two carbons form end up as carbon dioxide. Not only is this process bad from the point of view of atom efficiency, it produces significant amounts of CO_2 which lead to global warming.

Maleic anhydride production from benzene



maleic anhydride

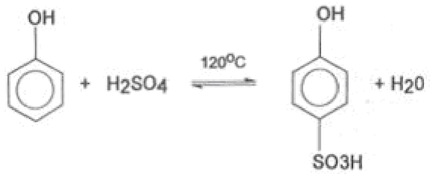
The current process, which has dominated maleic anhydride production for the last 15 years, uses either butene or butane as feedstock. The benefit here is that all the carbon atoms of these C4 feedstocks end up in the product.



Solvent Selection: The choice of solvent in a reaction or process should be given as much thought as the choice of reagent. Solvents are often used in large quantities and either end up as waste or need purification before recycling which is both inefficient in terms of energy and time. Solvents are, however, sometimes essential and frequently careful choice will have beneficial effects both in terms reaction rate and selectivity.

A simple illustration of a process where a solvent is not required is in the manufacture of phenol sulphonic acid, used extensively as a plating electrolyte in tin can manufacture. The process involves reaction of phenol (a solid) with concentrated sulphuric acid.

Manufacture of phenol sulphuric acid



Phenol is preheated to a temperature above its melting point (42^{o}C) and charged to a reactor. Sulphuric acid is added and the reaction temperature increased, as this happens the phenol and acid become miscible without the need for solvent and reaction takes place. Water is removed by distillation to drive the reaction forward. When the reaction is complete the product is cooled to about 50^{o}C before water is added and the final product - a 60% solution of phenol sulphonic acid in water - discharged from the reactor.

VI. THE TWELVE PRINCIPLES OF GREEN CHEMISTRY

Anastas and Warner have developed the Twelve Principles of Green Chemistry to aid one in assessing how green a chemical, a reaction or a process is.

1. It is better to prevent waste than to treat or clean up waste after it is formed.
2. Synthetic methods should be designed to maximize the incorporation of all materials used in the process into the final product.
3. Wherever practicable, synthetic methodologies should be designed to use and generate substances that possess little or no toxicity to human health and the environment.
4. Chemical products should be designed to preserve efficacy of function while reducing toxicity.
5. The use of auxiliary substances (e.g. solvents, separation agents, etc.) should be made unnecessary whenever possible and, innocuous when used.
6. Energy requirements should be recognized for their environmental and economic impacts and should be minimized. Synthetic methods should be conducted at ambient temperature and pressure.
7. A raw material feedstock should be renewable rather than depleting whenever technically and economically practical.
8. Unnecessary derivatization (blocking group, protection/deprotection, and temporary modification of physical/chemical processes) should be avoided whenever possible.
9. Catalytic reagents (as selective as possible) are superior to stoichiometric reagents.
10. Chemical products should be designed so that at the end of their function they do not persist in the environment and break down into innocuous degradation products.
11. Analytical methodologies need to be further developed to allow for real-time in-process monitoring and control prior to the formation of hazardous substances.
12. Substances and the form of a substance used in a chemical process should chosen so as to minimize the potential for chemical accidents, including releases, explosions, and fires.

VII. THE NEED FOR GREEN CHEMISTRY

Chemistry has played a vital role in improving our life but all these development are responsible for various environmental problems. Some examples can be mentioned here for chemical, which were synthesized for the benefit of human beings, has other detrimental effects like pesticides, chlorofluorocarbons (CFC as refrigerants), Dioxins, Thalidomide drug. Some diseases, which became famous by the discharge of poisonous pollutants from the industries, were Minamata disease (mercury poisoning), Itai-Itai Disease (cadmium poisoning), Methaemoglobinaemia (excessive amount of nitrogen fertilizers) etc. On the basis of what has been stated, it is clear that most of the environmental and health problems would not have been there, had the various industries followed the basic norms. It is in this context that green chemistry plays a vital role in keeping the environment clean. The concept of green chemist addresses environmental issues in an economic profitable manner. Green chemistry must permeate not only to the chemical industries, but it is necessary to bring about changes at the grass root level.

VIII. FUTURE CHALLENGES OF GREEN CHEMISTRY

The future challenges facing green chemistry are as diverse as the scientific imagination and address the broadest issues of sustainability. Because of this breadth, it should be no surprise that a number of these challenges are being pursued for reasons ranging from economic to scientific.

1. Transformations utilizing energy rather than material.
2. Efficient spitting of water by visible light.
3. Solvent systems that effect efficient heat and mass transfer while catalyzing reactions and intrinsically adding in product separation.
4. Development of a synthetic methodologies “toolbox” that is both atom economical and benign to human health and the environment.
5. Plastic and polymers designed for innocuous degradation through the use of additives free design.
6. Materials design for recycle/reuse decisions based on embedded entropy.
7. Development of “preventative toxicology” where increasing knowledge of biological and environmental mechanism of action are continuously incorporated into design of Chemical products.
8. Less energy-intensive manufacture of photovoltaic cells that are more efficient.
9. Development of non-combustion, non-material-intensive energy sources.
10. Value-added consumptive/fixation use of CO_2 and other greenhouse gases at high Volume.
11. Transformation preserving sensitive functionally without the use of protecting groups.
12. Development of surfaces and materials that are durable and do not require coating and cleaners.

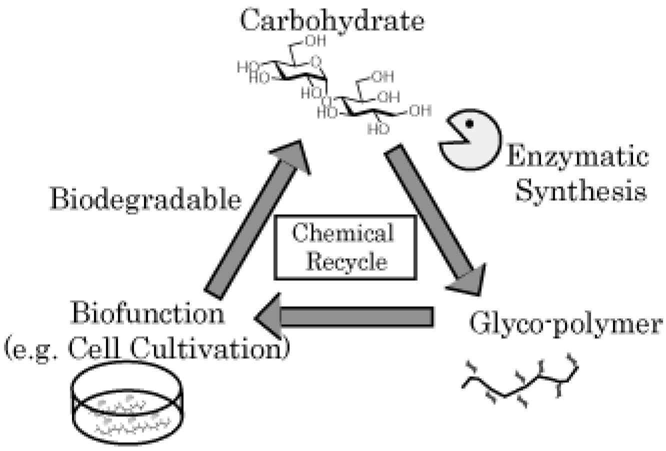
IX. GREEN CHEMISTRY HAS ITS APPLICATIONS IN THE INDUSTRIAL SECTOR

1. Green starting materials: Commodity chemicals from glucose. Glucose is an excellent feed-stock to synthesis a variety of commodity chemicals using the biochemical pathway. This route helps to minimize the use of carcinogenic starting materials such as benzene. Moreover the synthesis is performed with water instead of organic solvents.

E.g. conversion of glucose to adipic acid- a raw material in the manufacture of nylon66 fibre.

2. Green solvents: use of supercritical carbon dioxide. The traditional solvents used in organic synthesis such as chlorinated hydrocarbons have a number of environmental problems due to which benign solvents, which are eco-friendly, have been developed. One such solvent is super critical carbon dioxide, which is liquid CO_2 (at 31degrees, 73 atm) and is used in a wide variety of organic reactions. The solvent is non-toxic, non-flammable, renewable and inexpensive.
3. Green chemical products: synthesis of thermal polyaspartates. Thermal polyaspartate is an economically vi able, effective and biodegradable alternative to polyacrylic acid used in many industrial applications. TPA is produced by first converting aspartic acid to polysuccinimide in presence of a catalyst at low temperature followed by a base hydrolysis. The catalyst can be recovered from the process and waste is minimized.

Syntheses of Biomaterial by Green Chemistry Since bioactive compounds of peptide and saccharides are multifunctional compounds; these compounds are synthesized by the complicated multi-step reactions. Development of facile synthesis of bioactive compounds and biomaterials with the concept of "Green Chemistry". The biodegradable glycoconjugate polymers by enzymatic syntheses, and the bioactive saccharide by simple mimic compounds are investigated.



X. CONCLUSION

Green chemistry is the design of chemical manufacturing systems to minimize their adverse affects on the environment. Thus, a primary goal of green chemistry and engineering is to reduce the environmental impact of chemical processes and chemical manufacturing while simultaneously enhancing the overall process performance. Although it is beneficial to simply reduce the use of organic solvents in chemical processes, green chemistry and engineering goes further, in that it evaluates the entire manufacturing operation to identify techniques that can be applied to minimize the overall process hazard, while maintaining economic practicality. Evaluation of the environmental impacts of the manufacturing process requires a systems approach and appropriate metrics that permit quantitative assessment of environmental hazards. Thus, this chapter begins with a discussion of the drivers for green engineering and the metrics through which processes can be evaluated.

Then, the hydro formylation process is used as a case study to illustrate the way in which green chemistry principles can be applied to real processes.

Two elements are specifically highlighted:

(a) The use of catalysts to facilitate active and selective chemistry and the immobilization of said catalysts within the reactor system, and

(b) The development of processes based on benign reaction solvents, and the benefits that can accrue from simplified separations operations.

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