

APPLICATION, PRINCIPLES AND SYNTHESIS OF ORGANIC COMPOUNDS BY USING GREEN CHEMISTRY APPROACHES

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Abstract:

The aims of the review are to prepare organic compounds from the materials available in the local market in order to gain access to products in cost-effective, rapid, high yield and environment friendly procedures. The review focus on environment friendly synthetic, various green chemistry approaches and Microwave procedures which could be utilized in the synthesis of various organic compounds and their comparison of conventional synthetic methods. These methods avoid the usage of hazardous substances and are environmental friendly.

Keywords: *Conventional, atom economy, green chemistry.*

1. Introduction

Green chemistry is “the utilization of a set of principle that reduces or eliminates the use or generation of hazardous substances in the design, manufacture, and application of chemical products.” Now a lot of approaches are being made in the laboratories particularly at the undergraduate level to make students understand the meaning of green and safe chemistry. Also various harmful by products could be reduced by utilizing alternative approaches to synthesize common synthetic products [1,2].

2. Green chemistry set of principles:

Green chemistry is based on various principles are as follows [3,4]

Checking the waste generation: This principle aims at reducing unwanted material by developing approaches which reduces the number of reaction steps and materials like (solvents, handling aids).

Atom and molecular approach: Products made through bottom-up nanotechnology are more efficient which is built up by using atom –by-atom and molecule-by-molecule approach. It also reduces waste. Synthesis involving less material should be designed.

Safer chemical productions: This aims at enhancing process safety by reducing use of dangerous solvents and finding their alternatives.

Scheming safer resources: This deals with minimizing adverse effects.

Solvents and other materials: The use of other ingredients (e.g. solvents, separation agents, etc.) should be reduced and be safe.

Designing products for energy efficiency: The energy required for synthesizing should be assessed for environmental and economical effects and their use should be reduced. Ambient temperature and pressure should be used for synthetic methods.

Use of renewable raw material: Raw material which could be utilized further should be used instead of diminishing ones which are technically and economically feasible.

Minimising the use of derivatives: The derivatives of compounds should be reduced or avoided which include group blockage, protection/deprotection, brief modification.

Catalysis: Catalyst could fasten the reaction where higher temperature is the necessity. In the processes energy factor should be considered very important from the environmental and economic point of view.

Design according to degradation: Nanoparticles are metabolized within the body so the need of the hour is to produce harmless products. Also when nanomaterials are exposed to the environment must decompose into non-reactive products.

Real-time monitoring and process control: Analytical methods should be established further which would ensure that dangerous substances are not formed. This also takes into consideration that extra energy is reduced and that by products are avoided.

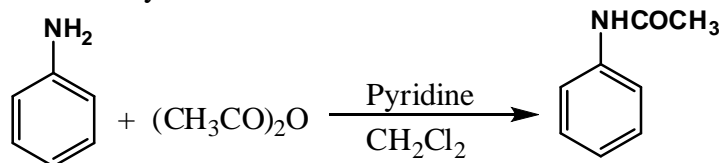
Inherently safer chemistry: Substances involved in chemical procedures should be selected which could reduce accidents which involves release, blast and fires [5].

3. Application of green chemistry in organic synthesis:

A few examples of common preparations are given below and how these could be made safer and environment friendly is also described.

3.1. Acetylation of primary amine (Preparation of acetanilide) [6]:

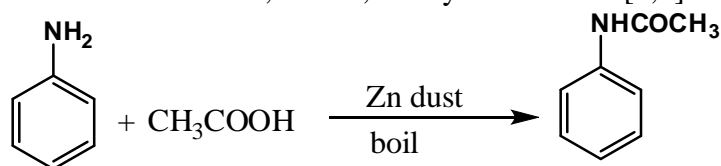
Conventional method: Non green solvent dichloromethane is used; Pyridine is toxic and is not eco-friendly. Acetic anhydride leaves one molecule of acetic acid unused which devoid the rule of atom-economy.



Non-green Components: Use of chlorinated solvent like CH_2Cl_2 , pyridine is also not eco-friendly and acetic anhydride leaves one molecule of acetic acid unused (not atom-economic)

Greener approach: A mixture of aniline and zinc dust in acetic acid in a round bottom flask was heated over a gentle flame using water condenser. Heating was continued for about 2 hrs. The reaction mixture was then carefully poured in cold water in a beaker with cooling and vigorous stirring. The shining crystals of acetanilide were separated slowly. After 15 min. the acetanilide crystals were collected by filtration. The solid crystals were washed over the Buchner funnel with water and the product was dried. It was crystallized in boiling water. If necessary, decolorizing charcoal may be used, m.p. 114°C and yield: about 91%. This method does not involve

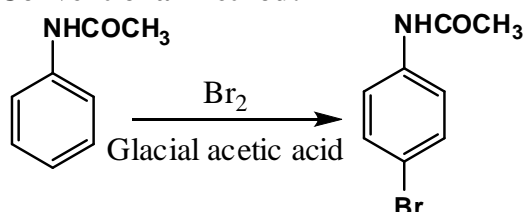
acetic anhydride, hazardous solvent, less waste products. Same procedure could be carried out with substituted aniline to form nitro, chloro, methyl derivatives [6,7].



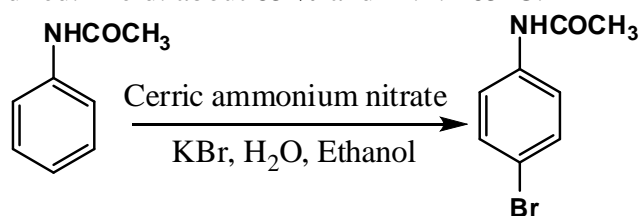
Green Context: Avoids use of acetic anhydride (usage banned in some states, due to its utility in narcotic business), minimizes waste by-products and avoids hazardous solvent

3.2. Electrophilic aromatic substitution reaction-II (Bromination of acetanilide) [8,9].

Conventional method:



Green Procedure: In a conical flask acetanilide was dissolved in ethanol. Then potassium bromide and ceric ammonium nitrate were dissolved in water. This solution was transferred into an addition funnel. This solution was added drop wise to the conical flask containing acetanilide solution. After the addition was over, the reaction mixture was stirred for 10 minutes in room temperature, white crystals appeared. Then this solution was poured into ice-cold water. The white crystals were filtered through Buchner funnel and the solid was dried. Yield: about 85 % and M.P. 165°C.

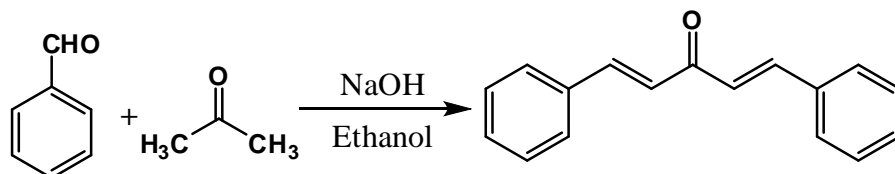


Green Context: Corrosive molecular bromine is replaced with a novel brominating agent, bromination is carried out in aqueous medium, chlorinated solvents are avoided, use of acetic acid as solvent is avoided and reaction is considerably fast [10].

Note: This reaction can be used for making bromo-derivative of acetanilide in identification of organic compounds.

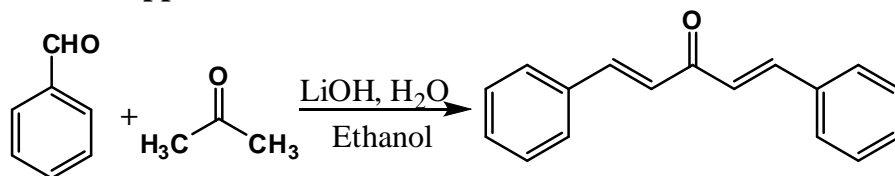
3.3. Base catalyzed aldol condensation (Synthesis of dibenzalpropanone) [11,12]:

Conventional method:



In a conical flask fitted with a cork, benzaldehyde, acetone and methylated spirit or alcohol were shaken together for 2 minutes. To it was added 10% sodium hydroxide solution and shaken vigorously for 10 minutes with simultaneous pressure release. The reaction mixture was cooled in ice and the pale yellow solid was filtered, washed with water, dried, collected, weighed and recrystallized from ethanol. The reaction mixture is cooled solid is filtered. Here hazardous organic solvents are added and reagents are toxic in nature.

Greener approach:

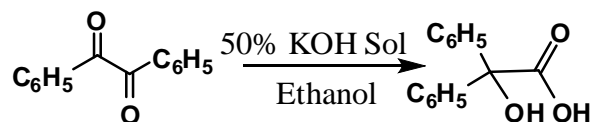


In a round bottom flask containing a small magnetic bar, the aldehyde and ketone were taken with ethyl alcohol and lithium hydroxide monohydrate was added into it. The reaction mixture was magnetically stirred vigorously for 8-10 minutes. The pale yellow solid precipitated out, crushed ice was added and the solid was allowed to settle down. The precipitated pale yellow solid was filtered, washed with water, air dried and recrystallized with ethanol. Yield is about 90 %, M.P. 120-121°C. **Precaution:** The aldehyde should be free from acid.

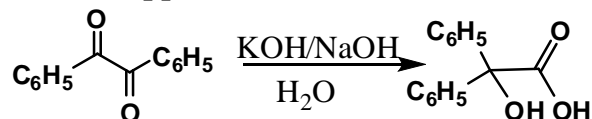
Green Context: Hazardous organic solvents are avoided and reagents are non-toxic. Lithium hydroxide is easy to handle as it is comparatively less hygroscopic than other alkali metal hydroxide. Use of catalytic amount of the base.

3.4. Rearrangement reaction-III (Benzil Benzilic acid rearrangement) [6,9]:

Conventional method: Benzil reaction with KOH and ethanol gives Benzilic acid. Not atom efficient, solvents are used.



Greener approach:

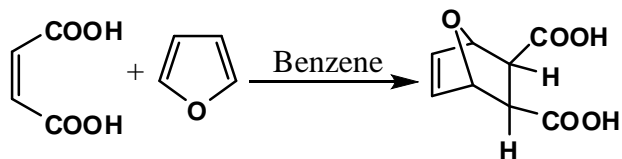


Preparation of Benzilic Acid in Solid State under Solvent-free Condition: Benzil was thoroughly grounded with solid NaOH or KOH in a dry mortar with the help of a pestle to make an easy flowing powder. This material was subsequently taken in a dry conical flask fitted with a piece of cotton at its mouth and heated on a boiling water-bath for 20 minutes. Then it was cooled to room temperature, dissolved in minimum amount of water (unreacted benzil, if any, was removed simply by filtration) and the aqueous solution was acidified with conc. HCl with thorough cooling in ice. The precipitated benzilic acid was filtered, washed with cold water and crystallized from hot water, if needed. M.P. 149-151°C and yield is about 80% [13].

Green Context: Solvent-free procedure and atom efficient.

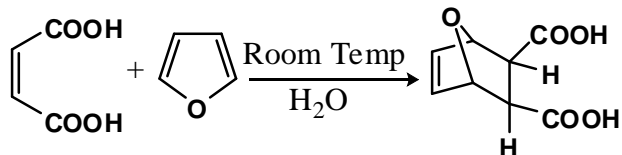
3.5. [4+2] Cycloaddition reaction (Diels-Alder reaction between furan and maleic acid) [14,15]:

Conventional method: Benzene is used.



Non-green Component: Use of benzene which is one of the most toxic solvents

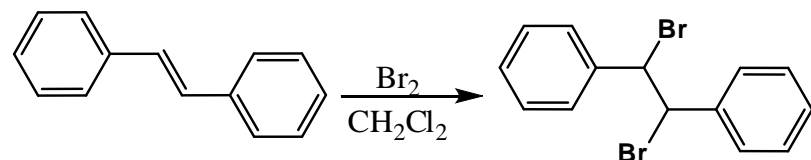
Green approach: A mixture of furan, maleic acid, in water is shaken or stirred for 2-3 hrs at room temperature. The product formed, is filtered, washed with water, dried and recrystallized from aqueous ethanol, M.P. 138-140°C and yield is about 80%. Reaction avoids benzene, works at room temperature, atom efficient.



Green Context: Reaction carried out in aqueous medium avoiding benzene, efficient at room temperature itself and 100% atom efficient [16,17].

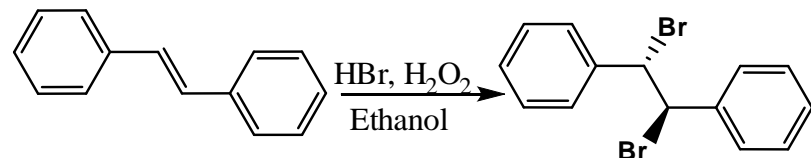
3.6. Halogen addition to C=C bond: Bromination of *trans*-stilbene [18,19]:

Conventional method:



Non-green Component: Use of liquid bromine and Chlorinated solvents

Green approach: *Trans*-stilbene in ethanol was refluxed. The aqueous solution of HBr (33%) and hydrogen peroxide (H₂O₂, 30%) were added from a dropping funnel sequentially to this refluxing solution of stilbene. The colourless solution became deep orange in colour. Within 15 minutes, the orange colour disappeared. This indicates the bromination of stilbene. The solution was allowed to cool down. During this the precipitate due to stilbene dibromide separated out. The precipitate was filtered, recrystallized and dried. M.P. 237°C and yield is about 70%.



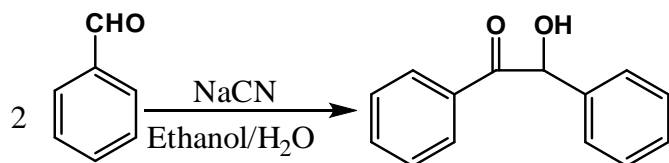
Other methods involve use of pyridiniumtribromide as the bromine source

Alternative Procedure: To a solution of *trans*-stilbene in acetic acid was added a mixture of sodium bromide and sodium bromate at room temperature with stirring by a glass rod. The reaction mixture was then stirred occasionally with a glass rod for 1 hour. The developed light brown colour disappeared. The acetic acid in the reaction mixture was then neutralized by sodium hydroxide solution. The precipitate of stilbene dibromide separated out. This was filtered and dried. Yield is about 80%.

Green Context: Corrosive liquid bromine is avoided and atom efficient. Water is the only byproduct in HBr-H₂O₂ method and in NaBr-NaBrO₃ method sodium acetate is formed along with water. HBr-H₂O₂ mixture and bromide-bromate couple offer *in situ* oxidation of Br⁻ to molecular bromine. **Caution:** Care must be taken while handling the solution of hydrogen bromide and hydrogen peroxide [20].

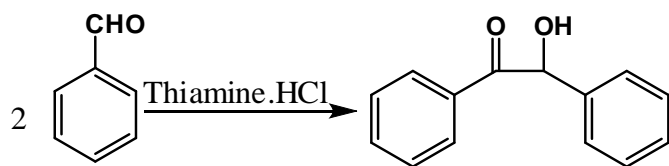
3.7. Coenzyme catalyzed benzoin condensation (Thiamine hydrochloride catalyzed synthesis of benzoin) [6,21]:

Conventional method:



Non-green Component: Involves the use of highly poisonous sodium cyanide

Greener approach: The thiamine hydrochloride was dissolved in water (about 5 ml) in a round bottom flask. Ethanol (95%) was added and the solution was cooled by swirling the flask in an ice water bath. Meanwhile, sodium hydroxide solution was cooled in a small conical flask in an ice bath. Then over a period of about 10 min the sodium hydroxide solution was added dropwise to the thiamine solution. Fresh benzaldehyde was added to the reaction mixture. The mixture was heated gently on a water bath for about 90 min. The mixture was cooled to room temperature and then in ice bath to induce crystallization of the benzoin. If product separated as oil, the mixture was reheated until it was once again homogeneous. Then it was allowed to cool more slowly than before. Scratching of the flask with a glass rod may induce crystallization. Yield is about 30%, and M.P. 135°C



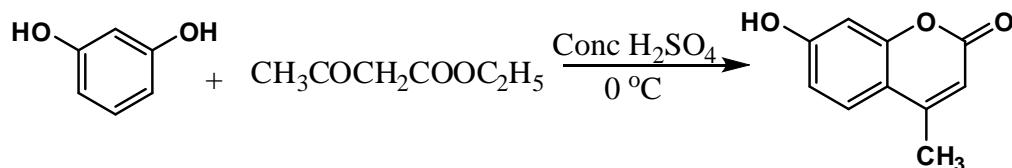
Alternate Green Procedure:

Caution: Benzaldehyde used in the experiment should be free of benzoic acid, Thiamine hydrochloride should be kept in refrigerator when it is not in use.

Green Context: Hazardous and poisonous cyanide ion is replaced by thiamine hydrochloride and reaction is effected at a lower temperature.

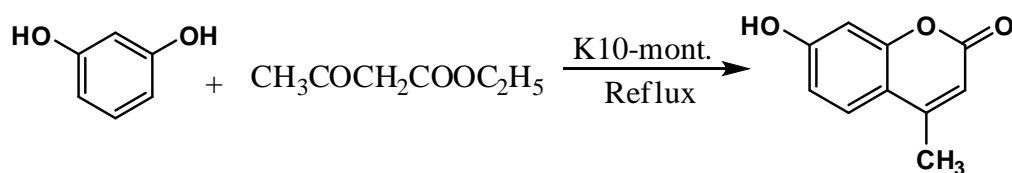
3.8. Pechmann condensation for coumarin synthesis (Clay catalyzed solid state synthesis of 7-hydroxy-4-methylcoumarin) [22].

Conventional method:



Non-green Component: Use of corrosive conc. Sulfuric acid.

Greener approach:

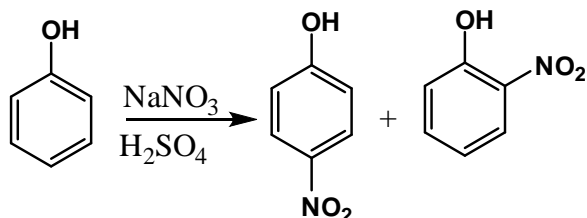


Resorcinol was dissolved completely in ethyl acetoacetate in a 50 ml dry round bottom flask. K10 montmorillonite clay was added to this homogeneous mixture and mixed thoroughly using a glass rod. The reaction mixture finally appeared as a paste. It was placed on a hot water bath and heated gently for 3-4 h. After completion of the reaction, mixture was cooled to room temperature and 7-hydroxy-4-methylcoumarin was extracted with ether by vigorous shaking. The clay was separated by filtration. Separation with ether was repeated for 2 times. Finally the filtrate was evaporated and the product is obtained as a white solid. Yield is about 85%, M.P. 180°C.

Green Context: Strong and corrosive H_2SO_4 is avoided, a solid acid catalyst K10 montmorillonite is employed, reaction is carried out in solid state avoiding use of solvents, catalyst can be reused, largely reduced reaction time and ice-bath conditions during addition is avoided. **Note:** When refluxed on a heating mantle, the yield increases significantly.

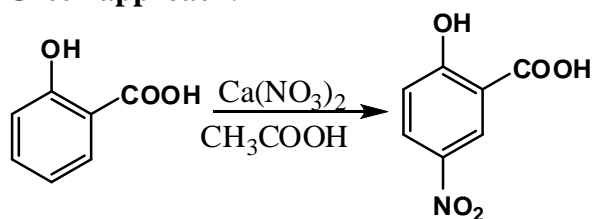
3.9. Electrophilic aromatic substitution reaction-I (Nitration of phenol) [23]:

Conventional method:



Non-green Component: Involves use of Con. Sulfuric acid

Green approach:



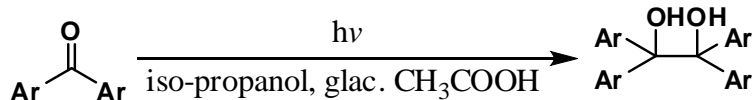
Calcium nitrate was dissolved in warm acetic acid and salicylic acid was added to it. Then the mixture was heated in a boiling water bath (maintained at $> 80^\circ\text{C}$) for 1 min. Salicylic acid was dissolved completely and the solution became dark red. It was immediately poured into a 10 ml of ice cold water. The resultant turbid dark red solution was placed in a refrigerator. After four hours, the yellow crystals that separated were washed free of acid with minimum amount of ice cold water and then dried. Yield is about 50 %, M.P. 234 °C

Green context: Nitration is rapid, ecofriendly nitration of phenols and its derivatives without nitric acid, reagents and byproducts (calcium acetate) in this reaction are useful agrochemicals, environmentally benign and thus eco-friendly and regioselective nitration is achieved.

Caution: The yield of the reaction mainly depends on temperature of the reaction and solubility (since products are soluble in water). Very minimum amount of water should be used for washing of acetic acid as well as the byproducts like calcium acetate and calcium nitrate.

Note: This nitration procedure is very efficient with salicylic acid and thus may be used for making derivative of salicylic acid in identification of organic compounds. However, it may not give equally good results for nitration of all aromatic compounds and thus should not be treated as a general method of nitration.

3.10. Green photochemical reaction (Photoreduction of benzophenone to benzopinacol) [24].

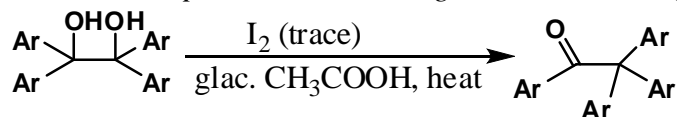


Benzopinacol can be prepared from benzophenone in presence of sun light (photochemically) using isopropanol as the reducing agent in presence of acetic acid. Acetic acid is added to prevent the cleavage of benzopinacol to benzophenone and benzhydrol by the alkali derived from the glass container used for the reaction.

Procedure: Benzophenone was placed in a test tube and dissolved in isopropanol. The test tube was then filled with isopropanol and to it was added a drop of glacial acetic acid. The test tube was stoppered and the reaction mixture was exposed to bright sun light. Colourless crystals of benzopinacol started appearing along the sides of the test tube after 5-6 hrs. The reaction mixture was allowed to stand in bright sun light for 4-5 days for the completion of the reaction. The solid was dried, M.P. 182°C.

Green Context: Use of safe chemicals and safer reaction conditions and use of renewable source of energy (solar energy). The product obtained above will be used in the next experiment (conversion of benzopinacol to benzopinacolone is pinacol-pinacolone rearrangement).

3.11. Pinacol pinacolone rearrangement reaction-I (Preparation of benzopinacolone) [25]:

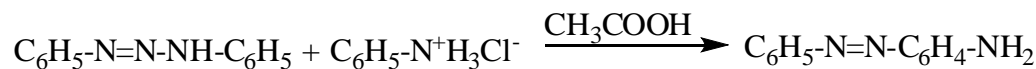


Benzopinacol obtained in the first experiment is converted to benzopinacolone by heating under reflux (5 minutes) with glacial acetic acid containing trace amount of iodine dissolved in it. This reaction is known as pinacol-pinacolone rearrangement.

Procedure: Benzopinacol was placed in a round bottomed flask and to it was added a solution of iodine (trace) in glacial acetic acid and the reaction mixture was refluxed on a wire gauze by Bunsen burner for 5-7 minutes. The reaction mixture was allowed to cool down to room temperature and then kept in the refrigerator overnight. The crystals of benzopinacolone were filtered, dried in air, M.P. 182°C.

3.12. Rearrangement reaction-II (Rearrangement of diazoaminobenzene to p-aminoazobenzene)

Conventional Procedure:



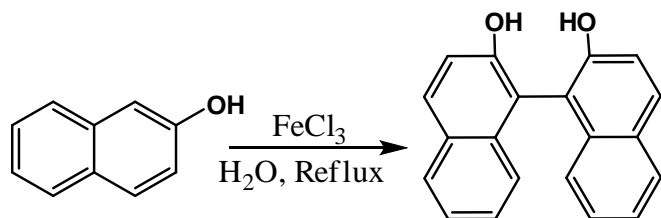
Green Procedure:

$\text{C}_6\text{H}_5\text{-N=N-NH-C}_6\text{H}_5 + \text{C}_6\text{H}_5\text{-N}^+\text{H}_3\text{Cl}^- \xrightarrow{\text{K10 mont.}} \text{C}_6\text{H}_5\text{-N=N-C}_6\text{H}_4\text{-NH}_2$ Diazoaminobenzene was thoroughly mixed with K10 montmorillonite clay. The mixture was taken in a round bottom flask and heated in a water bath for 3 hours with periodical shaking after every 15 min. The mixture was then extracted with ether. The ether layer was evaporated and the residue was recrystallized from aqueous ethanol, M.P. 127-128°C and yield is about 85 % [26].

Green Context: Eco-friendly method, simple reaction procedure and no need for excess aniline and acetic acid.

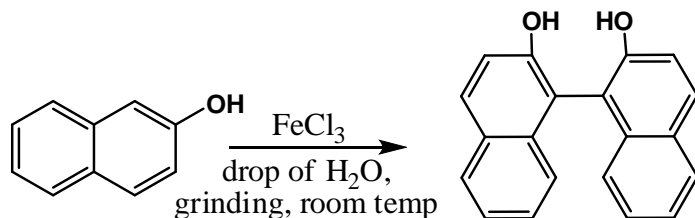
3.13. Radical coupling reaction (Preparation of 1, 1-bis-2-naphthol) [27]:

Conventional Procedure:



Non-green Component: Use of more energy (reflux)

Green Procedure:

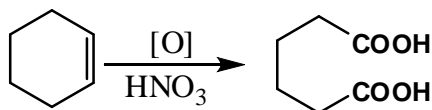


A mixture of 2-naphthol and iron (III) chloride with 2 drops of water in an agate (or porcelain) mortar pestle was grinded for about 20 minutes. The mixture was allowed to stand for about 2 hrs with a little grinding now and then. The mixture was transferred with water into a beaker and boiled for 10-15 minutes. The mixture was cooled and the solid was filtered, washed with boiling water (10 ml), dried and recrystallized from toluene, M.P. 214-217°C and yield is about 90% [].

Green Context: Efficient method, easily available catalyst, reaction is performed with simple grinding at room temperature without any solvent and work up of the reaction involves aqueous medium. This demonstrates the concepts of oxidative coupling, free radical and C-C bond formations.

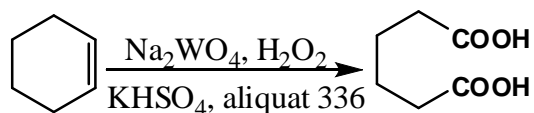
3.14. Green oxidation reaction (Synthesis of adipic acid)

Conventional Procedure:



Non-green Component: This procedure involves corrosive conc. nitric acid. This causes evolution of oxides of nitrogen. The reaction has to be carried out in fume cupboard and oxides of nitrogen need to be absorbed in water.

Green Procedure:

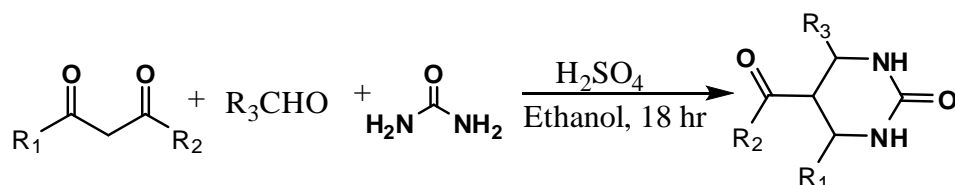


To a 50 ml round- bottom flask fitted with a condenser sodium tungstate dihydrate was added. This was followed by addition of aliquat 336, 30% hydrogen peroxide and potassium hydrogen sulphate. The mixture was shaken and then cyclohexene was added. The reaction mixture was heated on a sand bath to reflux for 2 hrs. The progress of the reaction was monitored by observing whether the layers are separated. As the liquid cyclohexene was converted to the water soluble adipic acid, the organic layer will eventually disappear. After two hours of reflux, the round-bottom flask was removed from the sand bath. Upon cooling, the crude adipic acid was precipitated. The crude sample was recrystallized from water to get pure adipic acid, M.P.151-153°C, yield is about is 70% [28].

Green Context: Eliminates the use of nitric acid, atom economy: Waste by-products are minimized, better yield, use of hydrogen peroxide as oxidizing agent in place of KMnO_4 or HNO_3 and phase transfer catalysis.

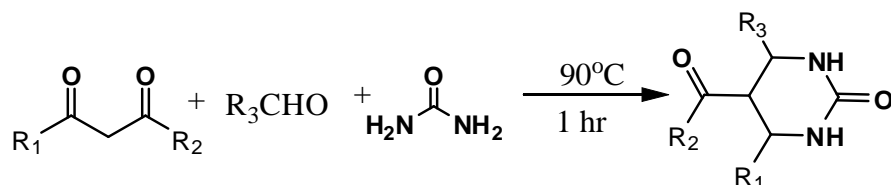
3.15. Three component coupling (Synthesis of dihydropyrimidinone)

Conventional Procedure:



Non-green component: Use of sulphuric acid, solvent workup and long reaction time

Green Procedure:



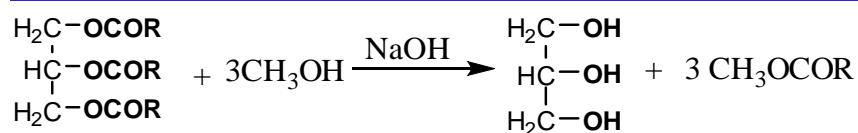
Procedure: A mixture of benzaldehyde, ethyl acetoacetate and urea, taken in a round bottom flask was shaken by hand for 2 minutes. The reaction mixture was then heated in a water bath at 90°C for one hour. With progress of the reaction a solid started to deposit and after one hour the flask is full of solid. The solid was taken out carefully with a spatula or spoon in a conical flask. The yellow solid was washed with cold water (1 ml) and then recrystallized from rectified spirit to give a colourless solid, mp 201-202°C and yield is about 79% [29].

Green context: Use of no hazardous organic solvents, no requirement of catalyst and faster reaction.

3.16. Transesterification reaction (Synthesis of biodiesel)

This experiment focuses on synthesis of diesel fuel from vegetable oil. The mechanism involves a transesterification reaction, the process of transforming one type of ester into another type of ester.

Green Reaction:

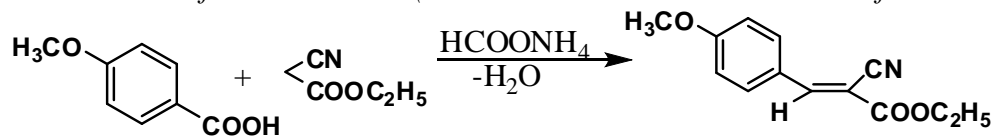


Green Procedure: The finely ground anhydrous NaOH was added into pure (99% or higher purity) methanol in a Erlenmeyer flask and stirred vigorously until all the NaOH was dissolved. The pure vegetable oil was warmed to about 40°C in a beaker. The warmed up oil was poured into the methoxide solution with continuous stirring. At first the mixture would become cloudy, but should soon two layers would separate. This was stirred for 15-20 minutes. The contents of the flask were transferred into a separatory funnel. The mixture will separate into two different layers. The glycerol will fall to the bottom, and the methyl ester (biodiesel) will float to the top. Allow the experiment to sit for an hour. The stopcock of the separatory funnel was opened and the glycerol was allowed to drain into a small beaker [30].

Green Context: This lab experiment demonstrates three key green principles: the use of renewable feedstock, catalysis and design for degradation. Vegetable oil is a renewable starting material as it is derived from growing plants, rather than irreplaceable material like the earth's petroleum and natural gas supplies. The reaction is catalyzed by NaOH making this process economically viable for the industrial scale production of biodiesel. Biodiesel is an excellent product as it is environmentally friendly.

Safety: Methanol is a flammable and poisonous. Dispose excess by allowing it to evaporate in the fume hood. NaOH is a very corrosive, causes severe burns may cause permanent eye damage and very harmful by ingestion.

3.17. Solvent-free reaction (Microwave-assisted ammonium formate-mediated Knoevenagel reaction)



Procedure: *p*-Anisaldehyde, ethyl cyanoacetate and ammonium formate were intimately mixed in a round bottomed flask fitted with CaCl₂ drying tube and placed on a bed of alumina taken in a beaker. This was then subjected to microwave irradiation for 90 seconds (with an installment of 30 sec each at a power level of 300 watts followed by intermittent cooling). After completion of reaction it was taken out, cooled to room temperature and crushed ice was added to the reaction mixture and shaken well. The solid product, precipitated in a granular form, was filtered, washed well with water and dried to furnish ethyl 2-cyano-3-(4'-methoxyphenyl)-propenoate in pure form. The product can be further purified by recrystallization from ethyl acetate-petroleum ether (60-80 °C), M.P. 88 °C and yield is about 80 % [6].

Green Context: Solvent-free reaction procedure, simple workup and rapid conversion (within 90 sec) and use of microwave energy for activation.

4. Discussion:

In order to reduce the environmental impact there is a need for clean chemical processes including synthetic procedures and reaction conditions. To achieve these goals, green chemistry is being developed based on innovative and unconventional synthetic procedures including reactions carried out in water, in supercritical

fluids, in ionic liquids, in micro emulsions, in solvent free conditions, by ultrasounds and microwaves that must allow regio and stereo selectively products to be prepared with high yields. The concept of green chemistry not only involves the planning of new procedures and the synthesis of new environmentally benign materials, but also requires a new chemical mentality along with new energetic and research development policy [31-36]. Today in the modern world scientists are worried and trying to develop and discover new environment friendly synthetic methodologies for organic compounds.

Microwave irradiation, as an unconventional energy source, has been used for a variety of applications including organic synthesis wherein chemical reactions are accelerated because of selective absorption of microwave energy by polar molecules, non-polar molecules being inert to the microwave dielectric loss. The application of microwave irradiation in conjunction with the use of catalysts (ionic liquids and inorganic oxides) and in solvent free conditions enables organic reactions to occur expeditiously at ambient pressure thus providing unique chemical processes with special attributes such as enhanced reaction rates, higher yields and the associated ease of manipulation. These less cumbersome solvent free methods conducted at ambient pressure have become very popular wherein the neat reactants undergo facile reactions often on the surfaces of inorganic oxides such as alumina, silica and clay or 'doped' supports thus minimizing the use of organic solvents. From a practical standpoint, these reactions can be performed in open glass containers under solvent less conditions and simply involve mixing of neat reactants with the catalyst/promoter or their adsorption on mineral and exposing the reaction mixture briefly to microwaves [37-42].

5. Conclusion:

There is a need to change or modify the conventional methods which are not eco-friendly, utilize hazardous solvents, not atom specific in the sense that does not matches green chemistry principles. This could be useful for the safe being of students and is also environment friendly. New strategy has recently been developed for non conventional methods in organic synthesis. Microwave irradiation takes a particular place as it induces specific interaction between materials and wave of electromagnetic nature assimilated to dielectric heating. Heating of products submitted to microwaves exposure can result from material-wave interaction. It is brought about by the transformation into heat of the part of energy in the electromagnetic waves. Heating by microwaves is therefore an original procedure to bring the advantages of speed, no inertia, quick energy transfer and no superficial overheating. Microwaves can be used to promote many organic synthesis; the material-wave interactions produce uniform heating of the reaction medium.

References

- [1]. Ahluwalia V. K., Kidwai M., New Trends In Green Chemistry, Anamaya publisher New Delhi, 2nd edition, 2007: 5-18, 250.
- [2]. Ahluwalia V.K., Green Chemistry Environmentally Benign Reactions, published by India books, 2nd edition, 2006, 1-10.
- [3]. Urmila JJ, Gokhale KM , Kanitkar AP; Green Chemistry: Need of the Hour. Ind J Pharm Edu Res. 2011; 45(2):168-174.
- [4]. Verma R, Kumar L, Kurba VB. Sch. Acad. J. Pharm., 2014; 3(1): 79-81.
- [5]. Verma R, Kumar L, Kurba VB. *Inter J Pharmacol Res*, 2014, 4(1), 1-3.

- [6]. Monograph on Green Chemistry Laboratory Experiments, edited and published by Green Chemistry Task Force Committee, DST, 1-79.
- [7]. Meshram H, IICT, Hyderabad, Private Communication
- [8]. Redasani VK, Kumawat VS, Kabra RP, Kansagara P, Surana SJ. *Inter J ChemTech Res*, 2010; 2(3): 1856-1859.
- [9]. Tanaka K, Toda F. *Chem. Rev.*, 2000; 100: 1045.
- [10]. Schatz PF. *J Chem Edu*, 1996, 173, 267.
- [11]. Hathaway BA. *J Chem Edu*, 1987; 64: 367.
- [12]. Bhagat S, Sharma R, Chakraborti AK. *J. Mol. Cat. A: Chemical* 2006; 260: 235-240.
- [13]. Tanaka K, Toda F. *Chem. Rev.*, 2000, 100, 1045.
- [14]. Woodward RB, Baer H. *J. Am. Chem. Soc.* 1948, 70, 1161.
- [15]. Rideout DC, Breslow R. *J. Am. Chem. Soc.* 1980; 102: 7816.
- [16]. Woodward AB, Baer H. *J. Am. Chem. Soc.* 1948, 70, 1161.
- [17]. Rideout SC, Breslow R. *J. Am. Chem. Soc.* 1980, 102, 7816.
- [18]. McKenzie LC, Huffman LM, Hutchison JE. *J Chem Edu*, 2005, 82, 306.
- [19]. Lallie CM, Lauren MH, James E.H. *J Chem Edu*, 2005; 82 (2): 306-310.
- [20]. McKenzie LC, Huffman LM, Hutchison JE. *J Chem Edu*, 2005, 82, 306.
- [21]. Lampman PDL, Chriz GM; Introduction to organic lab technique; College Publishing, New York, 1982.
- [22]. Greener approach to undergraduate chemistry experiments, ACS publications, 2002; 25.
- [23]. Bose AK, Ganguly SN, Manhas MS, Rao S, Speck J, Pekelny U, Pombo-Villars E, *Tetrahedron Lett.* 2006; 47:1885.
- [24]. Lampman PDL, Chriz GM; Introduction to Organic Lab Technique; College Publishing, New York, 1982 exp. 47.
- [25]. Bachmann WE; β -Benzopinacolone-Organic Syntheses. *J. Am. Chem. Soc.* 1927; 49: 246 (*Org. Synth.*, 1943, *Coll. Vol* 2, p. 73).
- [26]. Pitchumani K, Venkatachalapathi C, Sivasubramanian S. *Indian J. Chem.*, 1997, 36B, 187.
- [27]. Vogel AI. *Textbook of Practical Organic Chemistry*, Fifth Edition, 1989.
- [28]. Reed SM, Hutchison JE. *J Chem Edu*, 2000, 77, 1627.
- [29]. Ranu BC, Hajra A, Dey SS. *Org. Proc. Res. Dev.* 2002, 6, 817.
- [30]. Thompson JE. *Greener Education Material for Chemists* (<http://greenchem.uoregon.edu/gems.html>)
- [31]. James EH. *ACS Nano*, 2008; 3(2): 395-402.
- [32]. Vishnoi NK. Biochemical preparations. In *Advanced practical organic chemistry*. 2nd revised edition. New Delhi: Vikas publishing house Pvt. Ltd. (India); 2003: 450.
- [33]. Fringuelli F., Piermatti O., Pizzo F., Vaccaro L., *Eur. J. Org. Chem.*, 2001, 42, 439.
- [34]. Katritzky A. R., Nichols D. A., Siskin M., Murgan R., Belasubramanian M., *Chem. Rev.*, 2001, 101, 837.
- [35]. Siskin M., Katritzky A. R., *Chem. Rev.*, 2001, 101, 825.
- [36]. Bailker A., *Chem. Rev.*, 1999, 99, 453.
- [37]. Jessop P. G., Ikariya T., Noyori R., *Chem. Rev.*, 1999, 99, 475.
- [38]. Earle M. J., McCormac P. B., Seddon K. R., *Green Chem.*, 1999, 1, 23.
- [39]. Krister H., *Adv. Colloid Interface Sci.*, 1994, 51, 137.
- [40]. Fini A., Breccia A., *Pure. Appl. Chem.*, 1999, 71, 573.
- [41]. Verma R. S., *Green Chem.*, 1999, 1, 43.
- [42]. Bougrin K., Soufiaoui M., Loupy A., Jacqualt P, *New J. Chem.*, 1994, 19, 213.