

GREEN SOLVENTS: AN APPROACH TOWARDS SUSTAINABLE DEVELOPMENT

Abstract

Presently, organic synthetic chemistry is the one major part of science which is using various solvents among which few are toxic and carcinogenic. In synthetic reactions, the use of protective equipment such as goggles, breathing apparatus, face-guard masks can reduce the exposure to harmful chemicals in daily life. The biggest threat is organic solvents which are used in all chemical reactions and mostly released in environment as volatile organic compounds (VOCs) due to leakage. This is because the VOC's are more in any reaction than reagents and side products. So the main problem lies to either remove solvents completely or by substituting VOCs with cheap technological medium which is not harmful for the health of humans and the environment. Also, the main industrial waste is solvents only but, if we choose carefully, the usage and type of solvent, then we can eliminate waste production and can increase reaction output. As indicated by green chemistry principles, use of safer raw material and eco-friendly solvents can eliminate the risk of a production process. So, the present topic is mainly on the use of such carefully selected solvents which are eco-friendly so better known as green solvents: an approach towards green chemistry.

Keywords: Sustainable development, Green Chemistry, Green solvents, Water OIL's

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I. INTRODUCTION

1. Green Chemistry: Green chemistry is an approach to designing, producing, and using chemical products and processes that minimize their effect on the environment and human health. It is sometimes referred to as sustainable chemistry or environmentally friendly chemistry. Green chemistry is a discipline that is constantly developing, with continuing study and innovation aimed at finding long-lasting answers to chemical problems. Creating a more ecologically responsible and sustainable chemical industry depends on adopting green chemistry concepts by businesses and academic organizations.

- **Principles of Green Chemistry:** Green chemistry is based on twelve principles (Anastas, 1998) which comprises of instructions for professional chemists to implement new chemical compounds, new synthesis and new technological processes. These principles include:

- Prevention of waste
- Atom Economy
- Less hazardous chemical synthesis
- Designing safer chemicals
- Use of safe solvents and auxiliary substances
- Energy efficient designing
- Renewable Feedstock or raw materials
- Reduction of unnecessary derivatizations
- Preference to catalytic reagents
- Efficient design for degradation
- Optimum analysis for pollution prevention
- Prevention of accidents and explosions.

The principles of green chemistry focus on the following areas:

- **Atom Economy:** maximizing the use of all starting materials while reducing waste to increase the efficiency of chemical processes.
- **Pollution Prevention:** designing chemical processes to prevent or reduce the production of potentially dangerous materials rather than just dealing with them after they are created.
- **Safer Chemicals:** designing and using less harmful chemicals for people and the environment. Finding safer reaction conditions and substituting dangerous compounds are part of this.
- **Energy Efficiency:** Encourage energy-efficient practices by reducing energy use and, if feasible, turning to renewable energy sources.
- **Renewable Feedstock's:** using sustainable raw materials instead of non-renewable resources as feedstocks. This increases sustainability and lessens reliance on fossil fuels.
- **Design for Degradation:** creating chemical goods that, after usage, decompose into harmless compounds to lessen their harmful effects on the environment and the chance of build-up.
- **Real-Time Analysis:** the creation of analytical techniques that allow for real-time monitoring of chemical reactions and quick optimization and correction to stop the development of dangerous chemicals.

- **Inherently Safer Chemistry:** creating chemical products and processes that are naturally safer, decreasing the need for extra safety precautions, and lowering the likelihood of accidents.
- **Objectives of Green Chemistry:** The objectives of green chemistry are to stop pollution, lessen waste, and encourage resource efficiency across the whole lifespan of chemical goods. The overall objective of green chemistry is to build a more socially and ecologically responsible chemical industry. It provides a proactive and sustainable chemical research, development, and manufacturing approach. The current condition of green chemistry is defined by ongoing expansion, increased awareness, and considerable improvements in sustainable chemical procedures as of my knowledge cutoff in September 2021. The following are some salient features of current green chemistry:
 - **Industry Adoption:** Numerous sectors have actively embraced sustainable methods after realizing the value of green chemistry concepts. Businesses invest in research and development to develop environmentally friendly goods and procedures. This covers the creation of risk-free chemicals, the adoption of effective production processes, and the decrease in waste and emissions.
 - **Innovation in Materials:** Sustainable material innovation is being driven by green chemistry. Alternative materials from renewable resources are being researched, including bioplastics, bio-based polymers, and sustainable composites. These materials provide equivalent or better performance while using fewer fossil fuels and having a more negligible negative effect on the environment.
 - **Renewable Energy Integration:** Green chemistry and renewable energy sources are increasingly combined—sustainable energy sources like solar and wind power chemical reactions and industrial operations. The overall sustainability is improved, and the carbon footprint of chemical manufacturing is decreased because of this integration.
 - **Life Cycle Assessment (LCA):** An essential technique in green chemistry, life cycle assessment assesses a chemical's environmental effect over its entire life cycle. LCA assists in finding improvement opportunities, maximizing resource efficiency, and minimizing ecological burdens.
 - **Policy Support and Regulations:** Governments and regulatory organizations are advocating for green chemistry as they become more aware of its significance. Many nations have put in place laws, rewards, and voluntary initiatives to promote the adoption of sustainable chemical techniques. This entails the creation of green chemical regulations, eco-labeling initiatives, and financial assistance for related research and development.
 - **Education and Research:** Green chemistry is a recognized academic field, and educational programs' curriculum is updated to include green chemistry concepts. The main research subjects are new techniques, technologies, and materials that adhere to sustainability and green chemistry.
 - **Global Collaboration:** Cooperation between academics, businesses, and governments is essential for promoting green chemistry. International conferences, collaborations, and knowledge-sharing initiatives encourage the interchange of concepts, best practices, and research results to hasten the adoption of sustainable chemical practices worldwide.

- **Public Awareness:** Sustainable goods and practices are increasingly in demand from consumers. People are searching for safer, more sustainable, and less hazardous alternatives to human health and the environment as they become more aware of the environmental effect of the chemicals they use. Green chemistry techniques are becoming more critical due to this rising awareness among businesses and industries.

- **Benefits of Green Chemistry**

Green chemistry has numerous benefits, including:

- **Environmental Protection:** Green chemistry helps safeguard ecosystems, air quality, and water resources by avoiding the usage of harmful compounds and waste creation.
- **Human Health:** Reducing the exposure of employees and the public to harmful substances via the use of safer chemicals and procedures improves health outcomes.
- **Resource Efficiency:** To prevent resource depletion and preserve natural resources, green chemistry encourages the effective use of energy, water, and raw materials.
- **Economic Advantages:** Through better energy efficiency, decreased waste disposal and treatment costs, and the creation of new markets for sustainable goods, green chemistry may result in cost savings.
- **Innovation and Sustainability:** Green chemistry principles encourage creativity in creating more ecologically responsible and sustainable new substances.

2. Green Solvents: Green solvents are compounds that dissolve, suspend, or extract other substances without significantly harming human health or the environment. They are sometimes referred to as ecologically friendly solvents or sustainable solvents. These solvents are made to reduce the usage of potentially dangerous or toxic compounds often employed in various industrial and laboratory procedures. They play a significant role in green chemistry methods and help lessen chemical processes' harmful environmental effects.

- **Selection of Green Solvent:** The choice of a green solvent is based on the application, the qualities needed, and compatibility with the treated materials. Green solvents lessen toxicity, flammability, and waste production, which helps decrease chemical operations' environmental effects. Additionally, they provide advantages for end users' and employees' health and safety. Green solvents should still be evaluated based on unique conditions and application needs to guarantee correct handling, proper disposal, and overall sustainability even if they are usually considered safer and more ecologically friendly than regular solvents. Table 1 shows various green solvents that can be replaced easily with already existing toxic solvents.

Table 1: Preferred Green Solvents

Selection of Green Solvents		
High Recommended	Usable	Non Recommended
Water	DMSO	N-Methylpyrrolidone
Methanol	Acetic acid	Dimethylformamide
Acetone	Acetonitrile	Pyridine
Dimethyl carbonate	Tetrahydrofuran	1,4-Dioxane
Ethyl acetate	Ethylene glycol2	Chloroform
Propyl acetate	2-Methyl THF	Dichloromethane
1-Propanol	Methylcyclohexane	Dichloroethane
1-Butanol	Xylene	Benzene
2-Propanol	Cyclohexane	Hexane
t-Butanol	Heptane	Pentane
Toluene	Isoctane	Carbon tetrachloride

The particular application, the solutes' compatibility, and the intended effects on the environment and human health all play a role in solvent selection. Based on each application's unique needs and factors, evaluating and choosing the best green solvent is critical. Selecting green solvents for chemical reactions involves considering several factors related to their environmental impact, health and safety considerations, and overall sustainability. Here are some steps to guide you in the selection of a green solvent:

- **Understand Green Solvent Principles:** Green solvents aim to minimize environmental influence by reducing or eliminating the use of harmful chemicals. These are characterized by low toxicity, low volatility, and a low environmental footprint.
- **Identify Relevant Criteria:** Prediction of the specific criteria to consider when evaluating green solvents which includes factors such as toxicity, flammability, biodegradability, renewability, energy consumption during production, and potential for recycling or reuse.
- **Evaluate Solvent Properties:** Examine the properties of potential green solvents to ensure non-toxicity or have low toxicity, low volatility (to minimize emissions), non-flammable or low flammability, and readily biodegradable. Consideration for the solvents' boiling points, melting points, and solubility parameters compatibility with reaction conditions are also required to fulfilled.
- **Consider Renewable And Sustainable Sources:** Look for solvents derived from renewable resources such as biomass, vegetable oils, or waste streams. Renewable solvents often have a lower environmental impact compared to petroleum-based solvents. Additionally, consider solvents that can be easily recovered, recycled, or reused, reducing waste and minimizing consumption.
- **Consult Green Solvent Databases and Resources:** Utilize online resources and databases that provide information on green solvents, such as the U.S. Environmental Protection Agency's (EPA) Green Chemistry Program or the ACS Green Chemistry Institute. These platforms often provide guidance and information on the environmental properties of various solvents.

- **Prioritize Solvent Substitution:** Whenever possible, consider substituting hazardous solvents with greener alternatives. Solvent substitution involves replacing toxic or environmentally harmful solvents with safer alternatives that achieve similar reaction outcomes. This approach can significantly reduce the environmental impact of chemical processes.
 - **Assess Process Compatibility:** Estimate the compatibility of the green solvent with specific chemical reaction and other process conditions adequately like dissolve reactants, facilitate desired reaction kinetics, and maintain product purity.
 - **Perform Cost-Benefit Analysis:** Consider the cost factors of using green solvents as some of green solvents are expensive. long-term benefits such as improved health and safety, reduced waste disposal costs, and enhanced sustainability credentials, which can outweigh the initial costs.
 - **Seek Expert Advice:** If user still unsure about selecting green solvents or need guidance on specific applications, consult with experts in the field, such as chemists experienced in green chemistry or professionals from academic or industrial green chemistry centers.
- **Types of Green Solvents:** A Green Solvent is mainly a list of solvents composed by American Chemical Society and it encloses information on solvents safety profile and the problems due to safe disposal and use of solvents.

The commonly used organic solvents such as Benzene, Toluene, Xylene and Methanol which are highly toxic and are a concern issue these days. Here are a few instances of green solvents that are often utilized in different applications and can easily replace organic solvents:

- **Water:** The most plentiful and eco-friendly solvent is water. It is a reaction medium used in various procedures, including extraction and dissolution. Water is an excellent green solvent since it is non-toxic, inflammable, and widely available.
- **Ethanol:** A popular green solvent is ethanol, produced from renewable sources like biomass or fermentation. It is often used in cleaning solutions, extraction procedures, and as a solvent for natural materials. Ethanol has minimal environmental effects, is biodegradable, and has minimal toxicity.
- **Limonene:** Citrus fruits are the source of the naturally occurring solvent limonene. It is often used in cleaning goods, as a paint and coating solvent, and in several industrial uses. Limonene has a pleasant citrus fragrance and is non-toxic and biodegradable.
- **Terpenes:** A group of naturally occurring substances found in plants is called terpenes. They are used as environmentally friendly solvents in various goods, such as adhesives, coatings, and cleaning agents. Terpenes such as d-limonene, -pinene, and -pinene are biodegradable, non-toxic, and do not affect the environment.
- **Supercritical Carbon Dioxide (SCCO₂):** A green solvent for particle production, purification, and extraction is SCCO₂. It is non-toxic, inflammable, and has little effect on the environment. SCCO₂ may replace conventional organic solvents in several applications, reducing toxicity and waste production.
- **Ionic Liquids:** Salts that are liquid at or close to room temperature are called ionic liquids. Due to their low volatility, low toxicity, and capacity to dissolve various compounds, they are used as green solvents. Ionic liquids are used in

multiple processes, such as synthesis, separation, and catalysis, and they have unique solvation characteristics.

- **Green Chemistry Solvents:** Several solvent substitutes have been developed within the context of green chemistry. Examples include substituting acetone for toxic solvents, ethyl acetate for chlorinated solvents, and other safe solvents that pose less risk to human health and the environment.

II. GREEN SOLVENTS IN ORGANIC SYNTHESIS

- 1. Water as Green Solvent:** Kumar. D *et. al.* synthesized and evaluate various diarylthiazoles and diarylimidazoles derivatives using water as a solvent. In which they reported the facile method of synthesis of azole derivatives such as imidazole & thiazole by using water, as using Hantzsch synthesis method is having harsh reaction conditions, and longer duration for reaction. Initially reactions were started at room temperature which were not successful but reaction product was there at 80° C and their yield and time duration of reaction was compared by proceeding same reaction with organic solvents (Figure. 1 and 2).

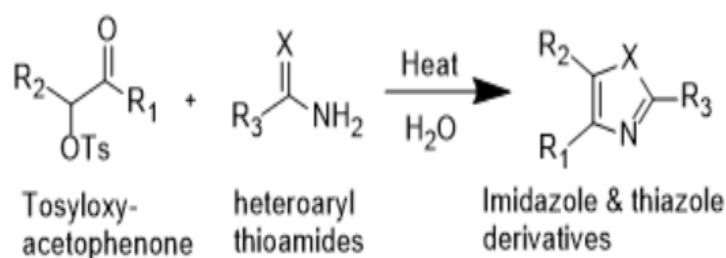


Figure 1: Use of Water as solvent to synthesize Imidazole and Thiazole derivatives

Various Alkyl- or aryl-14H-dibenzo[a,j] xanthene derivatives were prepared by M. Dabrio *et. al.* by reacting beta naphthol with few aliphatic and aromatic aldehydes in the presence of Alum ($\text{KAl(SO}_4\text{)}_2 \cdot 12\text{H}_2\text{O}$) & water at 100° C. and after comparing with organic solvents percentage yield and time of duration of reaction was found to be up to mark.

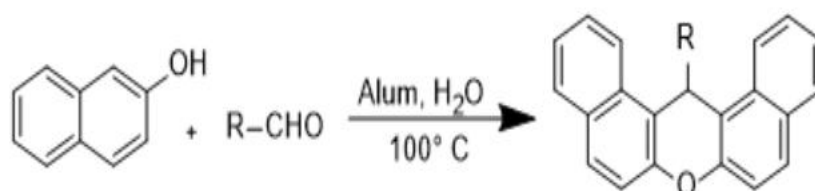
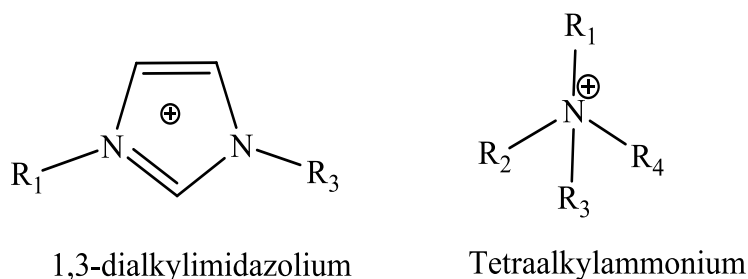


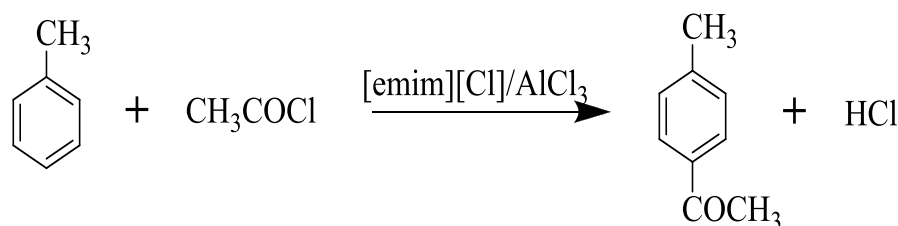
Figure 2: Water as Green Solvent in Organic Synthesis

- 2. Ionic Liquids as Green Solvents:** Green chemistry aims at searching the solvents mainly organic ionic liquids (OILs) which are made up of ions having low melting point and no vapour pressure.

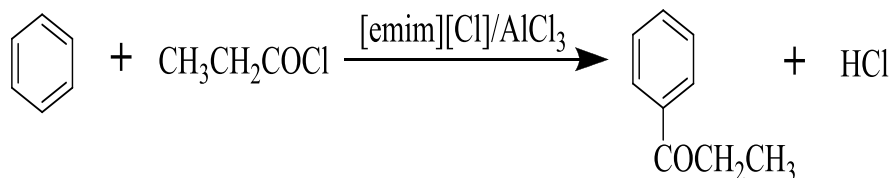
The OILs' are either cations or anions. These cations are of different nature depending on their properties and different synthetic pathways. The most common ionic liquid cations are 1,3-dialkylimidazolium and tetraalkylammonium. Other typical cations are tetraalkylphosphonium, trialkylsulphonium, and N-alkylpyridinium while anions are usually halides such as Cl^- , Br^- , BF_4^- , CF_3CO_2^- , NO_3^- , PF_6^- etc.



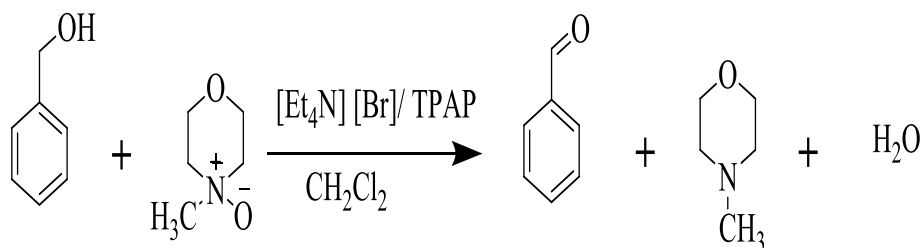
Boschetti et al., studied following four reactions by making use of the Organic Ionic Liquids



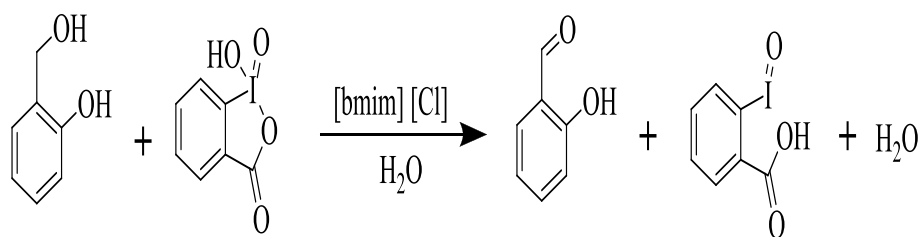
- **Toluene Acetylation by Acetyl Chloride**



- **Benzene Acetylation by Propionyl Chloride**



- **Benzyl Alcohol Oxidation by N-methylmorpholine N-oxide**



- **Salicylic Alcohol Oxidation by *o*-iodoxybenzoic acid.**

- 3. Green Solvent in Poly-Condensation Reactions:** Using two different methods of interfacial poly-condensation—method I: gas-liquid interfacial poly-condensation without an organic solvent and a catalyst, and method II: solid-liquid interfacial poly-condensation using green solvents and without a catalyst—new structures of polymers with phosphorus in the main chain were made by I. Smaranda. *I et.al.* Successful preparations of high molecular weight polymers have been made. The polymers self-extinguish and start to degrade at a temperature of around 300 °C.
- 4. Solvent Free Solid State Reaction:** The mechanism of dry co-grinding in a vibratory ball mill to produce solvent-free solid-state dibenzophenazine has been carried out by C. Leslie *et.al*, in which 9,10- phenanthrenequinone condensed with 1,2 *o*-phenylenediamine to get the dibenzo[*a,c*]phenazine (Figure 3).

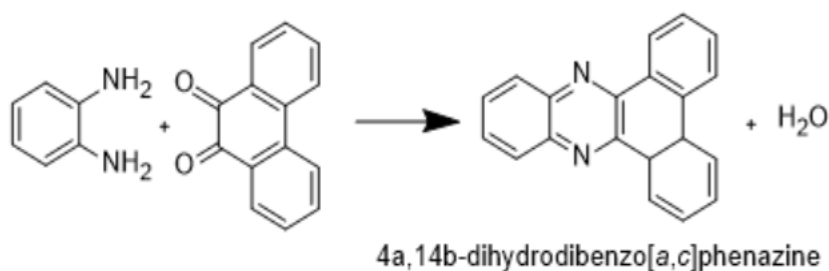


Figure 3: Solvent Free Green Synthesis

Above are few examples towards sustainable development to achieve green chemistry approach by using green solvents. The researchers are already working on this yet opening newer opportunity for upcoming researchers to work in this direction. Oils are a new emerging field of green solvents which is gaining a lot of attention of researchers these days.

III. OILS AS GREEN SOLVENTS

The selection of oils as solvents in pharmaceutical formulations involves careful consideration of factors such as drug compatibility, stability, safety, and regulatory guidelines, on the specific requirements of the drug and the desired route of administration. Here are some commonly used oils in pharmaceutical formulations:

- **Mineral Oil:** Mineral oil, also known as liquid paraffin or white oil, is highly refined petroleum-derived oil. It is often used in topical formulations, such as creams, ointments, and lotions, as a moisturizing agent or as a vehicle for drug delivery.
- **Vegetable Oils:** Certain vegetable oils, such as soybean oil, peanut oil, and corn oil, are used in pharmaceutical preparations. These oils can serve as solvents, carriers, or excipients in various formulations. They are commonly used in oral medications, such as soft gelatin capsules, where the oil acts as a vehicle for drug dissolution and absorption.
- **Castor Oil:** Castor oil is a vegetable oil derived from the castor bean (*Ricinus communis*). It has unique properties that make it suitable for pharmaceutical applications. Castor oil is often used as a laxative in oral preparations and as a component of ophthalmic formulations due to its lubricating properties.
- **Cottonseed Oil:** Cottonseed oil is obtained from the seeds of the cotton plant (*Gossypium*). It is commonly used in oral pharmaceutical formulations, such as capsules and suspensions, as a solvent or vehicle for drug delivery.
- **Medium-Chain Triglycerides (MCTs):** MCTs are a type of fatty acids commonly derived from coconut oil or palm kernel oil. They are often used in oral formulations, especially in liquid and solid dosage forms, as they are easily digestible and can enhance the bioavailability of certain drugs.
- **Olive Oil:** Olive oil, particularly extra virgin olive oil, is sometimes used in pharmaceutical preparations. It can be used as a solvent or carrier for lipophilic drugs in oral formulations.
- **Sesame Oil:** Sesame oil is an edible vegetable oil derived from sesame seeds (*Sesamum indicum*). It is occasionally used in pharmaceutical formulations, particularly in traditional medicine or topical preparations, due to its antioxidant and emollient properties.

It is important to note that the choice of oil in pharmaceutical preparations depends on factors such as drug solubility, stability, compatibility, route of administration, and regulatory considerations. The selection and use of oils in pharmaceutical formulations should comply with applicable regulations and be performed under the guidance of trained professionals. In synthesizing many different compounds, oils may be utilized as starting materials or solvents. Several examples of compounds that may be created using oils are shown below.:

- **Biodiesel:** Transesterification, a technique used to create biodiesel from animal or vegetable fats, is a sustainable energy source. This procedure produces biodiesel and glycerol by reacting oil with an alcohol (often methanol) in the presence of a catalyst.
- **Soap:** Soap is traditionally created by saponifying fats or oils with an alkali, such as sodium hydroxide (NaOH) or potassium hydroxide (KOH). Glycerol and soap molecules are the products of the process. Several oils may be employed to produce soaps with specific qualities and traits.
- **Essential Oils:** Volatile substances are taken from plants to make essential oils. When plant-derived oils are gathered, they are often produced using procedures like cold-press extraction or steam distillation. These oils have aromatic constituents used in various personal care products, aromatherapy, and fragrances.
- **Pharmaceutical Compounds:** Oils may act as transporters or solvents for various medicinal substances. For instance, many medications are created in oil-based liquids or

suspensions to increase solubility or stability. Oils may also be employed as excipients in capsule formulations or as carriers for transdermal medication administration.

- **Lubricants:** Oils often decrease wear and friction between moving components in machinery and motors. These lubricating oils often include additives in their formulation to enhance their functionality and provide protection from oxidation and corrosion.
- **Polymers and Resins:** Some oils, including vegetable oils, are renewable feedstocks that may be utilized to create biodegradable resins and polymers. To make soy-based polyols, which are used to make polyurethane foams and coatings, for instance, soybean oil may be polymerized.

Oils come in various chemical forms, and because of their unique qualities, they may be used in multiple applications across sectors. It may be employed in the formulation of medicinal substances as a solvent. Here are a few applications for oils in the pharmaceutical sector.

- **Oil-based Formulations:** Some medicinal substances are only partially soluble in water or other common solvents. Oils may be used in certain situations to increase the solubility and bioavailability of active therapeutic components as solvents or co-solvents (API). Oil-based compositions may be used topically, intravenously, or orally (via injection).
- **Emulsions:** Oils are often used as the oil phase to create emulsions. Emulsions are combinations of immiscible liquids, such as oil and water, that an emulsifying substance has stabilized. Depending on the exact use, pharmaceutical emulsions may be created for oral, topical, or injectable usage.
- **Topical Preparations:** In topical pharmacological preparations, including creams, ointments, and lotions, oils are often used. They facilitate the transport of the medication to the skin and provide a suitable basis for including active components. Oils may enhance a formulation's spreadability, moisturizing effect, and absorption.
- **Transdermal Drug Delivery:** Several medications may be packaged in oil-based systems for transdermal distribution. The oil helps the medicine bypass the epidermal barrier and serves as a reservoir. Transdermal patches or gels with oils are utilized to achieve regulated and sustained medication release over a long time.
- **Injectable Solutions:** In injectable formulations, oils may be employed as solvents, especially for lipophilic medicines or with limited water solubility. Oil-based injections may provide a gradual medication release, prolonging the therapeutic impact. Examples include microemulsions or suspensions based on oil administered intramuscularly or subcutaneously.

It's crucial to remember that using oils as solvents in pharmaceutical formulations requires careful consideration of elements such as drug compatibility, stability, safety, and regulatory requirements. The drug's particular needs and the preferred mode of administration will determine the kind of oil to use. Oils may also be used as reaction media or solvents in different synthetic procedures in pharmaceutical operations. Here are a few instances:

- **Organic Synthesis:** Oils may be employed as reaction media in synthesizing organic compounds, such as silicone or mineral oil. They can function as non-polar solvents, offering an ideal setting for hydrophobic or lipophilic chemical reactions. For moisture- or temperature-sensitive reactions, oils might be beneficial.

- **High-Pressure Reactions:** High pressure is necessary for several pharmaceutical synthesis processes, such as hydrogenations and the creation of carbon-carbon bonds. Oils may be employed as a pressure-transfer medium in these reactions to maintain a homogenous reaction mixture and convey pressure to the reaction vessel.
- **Reactions with Sensitive or Air-Sensitive Compounds:** Oils may shield air- or temperature-sensitive chemicals from reactions. The reactive components may be protected from oxygen and moisture by employing oil as a solvent or reaction media, reducing deterioration or adverse reactions.
- **Microwave-Assisted Reactions:** Microwave-assisted reactions have grown in favor of the pharmaceutical synthesis industry due to their effectiveness and quick reaction times. In microwave-assisted organic transformations, oils with suitable dielectric characteristics may serve as reaction solvents, promoting rapid and precise reactions.
- **Biocatalytic Reactions:** Vegetable oils have been employed as solvents in biocatalytic processes. To catalyze different transformations, such as hydrolysis, esterification, or oxidation, in pharmaceutical production, enzymes or entire cells may be immobilized or dissolved in oils.
- **Continuous Flow Chemistry:** Control, efficiency, and scalability are benefits of continuous flow chemistry, which includes the constant flow of reactants through a reaction system. Oils may be used in ongoing flow operations as solvents or carrier phases, facilitating the effective production of medicinal molecules.

It is important to remember that the decision to use oil as a reaction medium is influenced by the needs of the reaction, the characteristics of the reactants and products, and the safety issues at play. The chosen oil must also be compatible with the necessary reaction conditions and must not interfere with the purification or formulation processes that follow.

IV. CONCLUSION AND FUTURE PROSPECTS

Within the context of the sustainable development, the primary benefit of using eco-friendly chemical solvents is their positive impact on the environment. However, when companies consider purchasing eco-friendly solvents, there has to be more than reducing one's carbon footprint involved in the equation; that is, switching to an environmentally friendly chemical solvent has to be financially beneficial. Although many companies project the image that their environmental measures are informed by environmental awareness, the main reason that companies begin "going green" is that it is more profitable in some way than not going green.

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