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GREEN CHROMATOGRAPHY: THE ECO-FRIENDLY AND SAFER CONCEPT OF GREEN ANALYTICAL CHEMISTRY

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ABSTRACT: Green analytical chemistry is an attempt to reduce the environmental hazards caused by chemicals and chemical processes. To avoid the use or formation of dangerous materials, the best way is to prevent pollution rather than cleaning up the process. Therefore, it is important to choose a method with the least harmful effects on the environment. The main focus or aim of green chromatography is to make a method greener at each and every step of analysis from sample collection to its determination. The present review includes the goals to achieve green chromatography using environmentally benign solvents and reagents, most recent contribution in the development of greener sample preparation since it has effect on whole analytical methodology, chromatographic separation techniques, advantages of green chromatography, green microextraction techniques (solid-phase microextraction, still bar sorptive, liquid-phase microextraction) are included. The aim is to make chromatographic separations greener, depending on the type of chromatography which includes the solventless extraction technique.

INTRODUCTION: Green chemistry is the use of various analytical techniques and methods which eliminate or decrease the generation of feedstocks, products, by-products, solvents, reagents, *etc.* that are hazardous to human health and environment. Or in short, we can say that it is the use of chemistry for prevention or control of pollution ¹. Different synonyms like sustainable chemistry, clean chemistry, benign by design chemistry, and environmentally benign synthesis are also used for Green chemistry. In 1991, the term green chemistry was founded by Anastas and then the concept was further developed by Badami, Nemeroff, and Kletz ².

Green science is huge ideas that have the degree for economic advancement generally utilized for the improvement of the analytical method with less ecological effect and minimum analyst occupational exposure. Various advances comprise the development of microextraction, ultrasound-assisted extraction (UAE) and microwave-assisted extraction (MAE) techniques. Techniques used for separation in research like HPLC or GC should be improved so that one could focus to eliminate the use of harmful solvent and decreases the time for detection.

The word green analytical chemistry (GAC) is defined as clean, environment-friendly chemistry. Green analytical chemistry comprises the analysis or detection of an organic compound with the use of quality assurance/quality control (QA/QC) and further reducing harmful environmental impacts resulting from the analysis. Green chromatography comes to mind first whenever we think of

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chromatographic procedures meeting the standards of green analytical chemistry principles. The chromatographic procedures for any analyte start from sample collection to its preparation and then the separation, finally quantification of the analyte. Similarly, green chromatography also relates to all the stages of analysis. But it focuses more at some steps with environmental impact like preparation of sample and chromatographic separation and therefore have a lot of potential for "Greening" ³ therefore we can say that green chemistry is the utilization of sets of different principle dealing with decreasing the environmental impact by reducing use of generation of risky substances in the design, production, and application of chemical products.

Principles of Green Chemistry: The green chemistry approach is a perfect method to ease the expenses to industry and society. It moves the prospects of accepting the waste and disposal so that no toxic or harmful substances produced from the sources producing chemicals. "Twelve Principles of Green Chemistry" were given by Anastas and Warner ³⁻⁴, as shown in **Fig. 1**.

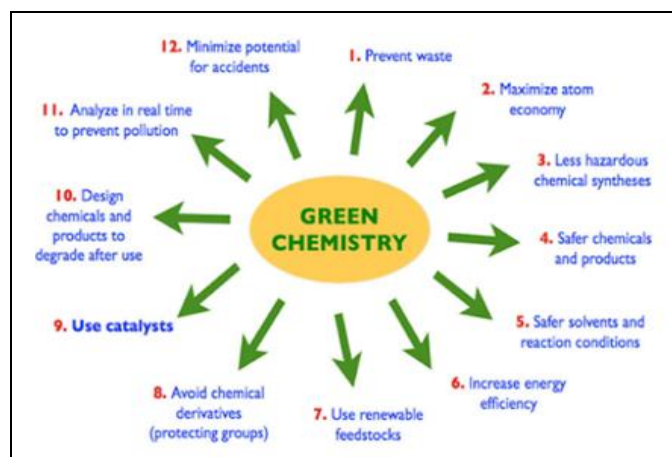


FIG. 1: PRINCIPLES OF GREEN CHEMISTRY

Explanation of each principle;

- 1. Prevent Waste:** Recycling or cleaning the waste is the process which is applied after any research leading to various hazard, therefore prevention of such waste is better than the treatment .these can be achieved by the use of direct determination methodologies, solventless extraction techniques, miniaturization.
- 2. Atomic Economy:** The synthetic method is designed to increase the use of all materials

required in the process to convert into the final product.

- 3. Less Hazardous Chemical Synthesis:** Synthetic method is designed to use and generate substances that minimize toxicity to human health and the environment On-line analytical waste detoxification.
- 4. Designing Safer Chemicals:** Design chemical products to accomplish their desired function while minimizing their toxicity.
- 5. Safer Solvents and Auxiliaries:** Minimize the use of supplementary substances wherever possible; make them completely harmless when used toxic solvents substitution with less-toxic ones, solventless extraction techniques; direct analysis method.
- 6. Energy Efficiency:** Design Energy requirements for chemical processes are reduced and synthetic methods at ambient temperature and pressure must be conducted if the possible application in microwave, ultrasound or pressure-assisted extraction. All these efforts are to minimize energy consumption.
- 7. Renewable Raw Materials Uses:** Use of renewable raw materials whenever required.
- 8. Reduce Derivatives:** Avoid unnecessary derivatization, as it requires additional reagents, and it generates waste derivatization should be avoided wherever possible.
- 9. Catalysis:** Catalytic reagents are super than stoichiometric reagents.
- 10. Design for Degradation:** Design such chemical products so they break down into fewer by-products that do not persist in the environment.
- 11. Real-Time Analysis for Pollution Prevention:** Develop such analytical methodologies that can allow real-time analysis, in-process observation and control before the formation of hazardous substances to develop such procedures that avail to obtain analytical results with short (preferably no) time delay.

12. Inherently Safer Chemistry for Accident Prevention:

Substances and the type of a substance which are used in a chemical process should have the power to minimize the potential for chemical accidents, including releases, explosions, and fires application of no solvent techniques to prevent time period for monitoring, miniaturization, and occupational exposure.

In 2001, Namiesnik suggested that the twelve principles of the green chemistry might be utilized to formulate the “green” character of green analytical chemistry and identified four top priorities as follows:⁴⁻⁵

1. Elimination (or, at least, significant reduction) of consumption of reagents, particularly organic solvents, from analytical procedures.
2. Reduction of emission of vapors and gases, as well as liquid and solid waste, generated in analytical laboratories.
3. Elimination of reagents displaying high toxicity and/or ecotoxicity from analytical procedures (e.g., substituting benzene by other solvents).
4. Reduction of labor and energy consumption of analytical procedures (per single analyte), as shown in **Fig. 2**.

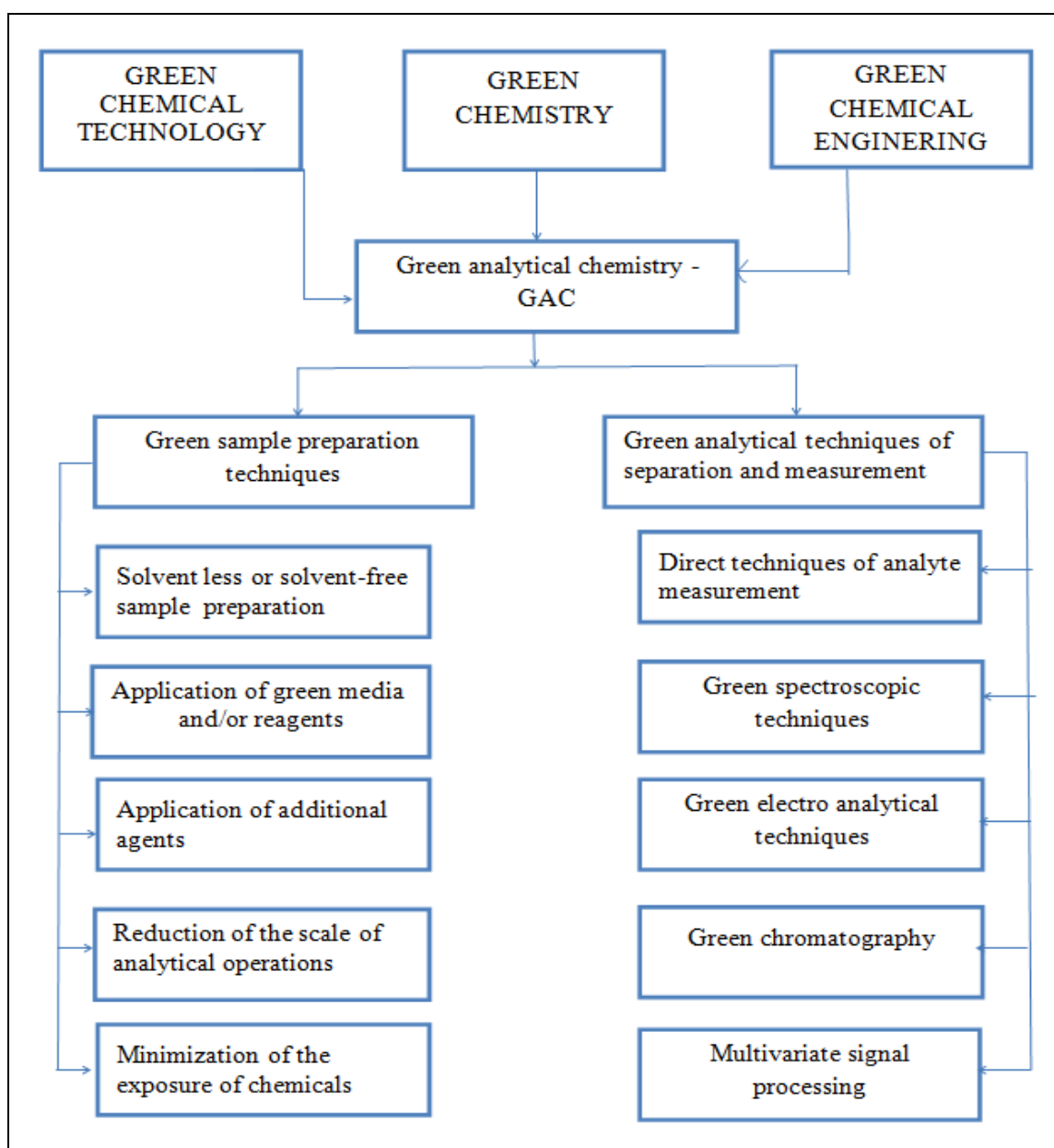


FIG. 2: GREEN ANALYTICAL CHEMISTRY PRINCIPLES APPLIED TO SAMPLE PREPARATION AND THE FINAL DETERMINATION STEP

Green Chromatographic Methodologies without Sample Preparation: The most polluting step in the whole chromatographic analysis procedure is the preparation of the sample, while in green chromatography either there is absence or presence of sample preparation step⁵. It is very useful and advantageous to use direct chromatographic methodologies *i.e.* without sample preparation, whenever possible as occupational exposure to toxic chemicals affects the health of the analyst during the preparation step of the sample. Limitations of such methods are that they are applicable to specific matrices such as water, petroleum³. As compared to liquid chromatography the gas chromatographic methods are more adaptable to the elimination of the sample preparation step.

The method proposed by Grob Grob, work on direct gas chromatographic methods focused on on-column injection development. Detection of halogenated compounds in water samples by direct aqueous injection can be achieved by combining of on-column injection with electron capture detection. Similarly, the detection of hydrocarbons in water samples can be done using combined techniques *i.e.* direct aqueous injection with flame

ionization detection or mass spectrometric detection³. The goals of green analytical chemistry are achieved by the application of direct chromatographic methods in several ways. The utilization of materials used during the preparation of samples (including organic solvents, fibers, sorbents, cartridges *etc.*) is avoided. The overall time for the analysis greatly shortened. The elimination of the sample preparation step allows placing the chromatograph on-line, which may further reduce the analysis time.

Techniques Used for Sample Preparation: The sample preparation step is of fundamental importance for the accuracy and reliability of the final analysis results. In the context of the requirements of green chemistry less time and labor-consuming techniques, especially solvent-less sample preparation techniques, are gaining particular importance. This group of sample pretreatment techniques includes extraction techniques using a carrier gas, solid sorbents combined with thermal desorption of retained analytes and techniques using safe, non-toxic extraction media and green solvents. A brief overview is described in **Table 1**.

TABLE 1: TECHNIQUES USED FOR PREPARATION OF SAMPLE

Techniques	Principle	Advantage
Solid-Phase extraction technique		
Solid-Phase Microextraction (SPME)	Based on the partitioning of analytes between the extraction phase and the sample matrix. A fiber coated with a polymeric stationary phase is placed in the sample (the direct mode – DI-SPME) or its headspace (HS-SPME) Analytes partition into the stationary phase until equilibrium is reached Desorption of the concentrated analytes into an analytical instrument ⁶⁻⁸	Eliminates the need for solvents Combines sampling, analyte isolation and enrichment into one step
Stir-bar Sorptive Extraction (SBSE)	Sorption of analytes onto a thick film polymer (<i>e.g.</i> PDMS) coated on a magnetic stir bar. Can be used in direct or headspace modes ⁹⁻¹⁰	Solventless sample preparation when thermal desorption is applied for analyte desorption
Quick, Easy, Cheap, Effective, Rugged, and Safe Extraction (QuEChERS)	Uses a small amount of organic solvent. Employs a novel, quick dispersive solid-phase extraction cleanup Two main steps: Solvent extraction (intensively shaken). Dispersive SPE (dSPE) ¹¹	Low consumption of solvents and other materials
Liquid extraction technique		
Single Drop Microextraction (SDME)	A micro drop of solvent is suspended from the tip of a conventional microsyringe or PTFE rod. Analytes diffuse into the droplet. The micro drop is retracted into the syringe, then injected into a chromatographic injector Two modes of SDME: – Direct immersion (DI-SDME) – the acceptor organic phase is in direct contact with the aqueous sample, – Headspace SDME (HS-SDME) – the acceptor phase is in the gaseous phase above the sample ¹²	A very small volume of reagents and solvents (1–2 L)
Liquid-Phase Microextraction (LPME)	In dynamic LPME, a microsyringe is used as a microseparating funnel for the extraction of target analytes. An analyte-enriched microdrop is injected into a chromatograph. In two-phase hollow fiber (HF) LPME mode, an organic solvent is immobilized inside a porous polypropylene capillary tube and placed in contact with the water sample. Analytes	Negligible consumption of organic solvent, high potential to pre-concentrate target analytes. Reduced generation of wastes and relatively low

	partition into the solvent through the pores of the capillary. In three-phase HF-LPME mode, analytes cross the organic solvent embedded in the pores of a semi-permeable membrane and concentrate in a third phase inside the lumen of the capillary after modification of their solubility (e.g. through pH change) ¹³	sample consumption
Ionic Liquid Dispersive Liquid-Liquid Microextraction (IL-DLLME)	A three-phase system is applied: sample/extraction solvent/disperser solvent miscible with both. The ionic liquid is used in DLLME instead of a volatile organic solvent as the extraction solvent. An extremely large area of the contact of the solvent and aqueous phase is established (rapid transfer of analytes from the aqueous phase to the extraction phase) ¹¹⁻¹⁴	Eliminates the use of highly toxic chlorinated solvents (ionic liquids are considered green solvents)
Supercritical Fluid Extraction (SFE)	A substance in the supercritical state is applied as the extracting agent (temperature and pressure of the substance above the critical values). The most common supercritical fluids include carbon dioxide, nitrous oxide, ethane, propane, n-pentane, ammonia and sulfur hexafluoride ¹⁵	Minimization or complete elimination of organic solvents
Assisted extraction		
Ultrasonic Extraction (USE)	Ultrasonic energy is used; therefore acoustic cavitation takes place Bubbles of gas are formed, then implode, resulting in local increases in pressure and temperature Two types of ultrasonic devices: ultrasonic probes or baths ¹⁶	Reduced solvent consumption Saving time and energy
Microwave-Assisted Extraction (MAE)	Microwave energy used to enhance the extraction process Sample can be heated, homogenized, digested Two modes: pressurized MAE or atmospheric MAE ¹	Reduction of solvent and sample consumption Saving time and energy
Pressurized Liquid Extraction, or Pressurized Fluid Extraction (PLE or PFE)	Extraction at high pressure and temperature above the atmospheric pressure boiling point. Elevated temperature increases analyte solubility and diffusion rate, and decreases viscosity and surface tension of the solvent. Elevated pressure improves the penetrability of the extractant into the pores of the matrix ¹⁶	Reduced solvent consumption, Possible application of environmentally-friendly solvents (e.g. ethanol, methanol, and Savings in time and energy
Membrane Extraction techniques		
Supported Liquid Membrane Extraction (SLME)	Porous PTFE membrane impregnated with an organic solvent is applied. Analytes are transferred through the membrane due to concentration gradient aq (donor)/org (membrane)/org (acceptor) phase combination is used ¹¹	Reduction in the volume of solvent used
Membrane Assisted Solvent Extraction (MASE)	A three-phase system (aqueous phase/non-porous polymeric membrane/organic phase). Organic solvent receptor phase ¹⁷	Reduced consumption of reagents
Membrane Separated Liquid Extraction (MSLE)	A porous membrane is applied. Analytes are transferred through the membrane due to concentration gradient; aq (donor)/org (membrane)/aq (acceptor) phase combination is used ¹⁷	Low solvent consumption

Application of Green Chemistry: As Green Chemistry is very useful and eco-friendly, some of the advantages are described in **Table 2**.

TABLE 2: APPLICATIONS OF GREEN CHEMISTRY

S. no.	Application	Disadvantages	Innovation	Green advantages
1	Synthesis of nitriles from aldehydes	Increased reaction time, low yield, use of toxic solvents, a requirement of excess reagents, and harsh reaction conditions	The method developed one-step solvent-free conversion of aldehydes into the corresponding nitriles using ZnO as catalyst under microwave irradiation	ZnO is a mild and eco-friendly catalyst, easy to handle and readily available. Also, microwave heating is fast, clean and give high yield ¹⁸
2	Synthesis of 1-amidoalkyl-2-naphthols	High temperature, long reaction time, use of expensive reagents, low yields, high catalyst loading, corrosive reagents, strongly acidic conditions, and the need of additional purification of products	Use of tannic acid as a catalyst for the synthesis of 1-amidoalkyl-2-naphthol derivatives by one-pot multicomponent condensation reactions without solvent	Cost-effective, short reaction time, use of environment-friendly biodegradable cheap catalyst, and good to excellent yields ¹⁹
3	Synthesis of spiro heterobicyclic rings	Use of expensive or not easily available reagents, vigorous reaction conditions, prolonged and tedious steps in the isolation	Using non-toxic and mild Lewis acid molecular iodine catalyst under one-pot synthesis microwave	Simple, environment-friendly, higher yields, reaction simplicity, reduced pollution, and minimum reaction time ²⁰

		of the pure products	irradiation in solvent-free conditions	
4	Synthesis of methacrylate-based hydrogels crosslinked	Coupling agents, catalysts or photoinitiators can affect the biocompatibility of the final material	Through Diels–Alder reaction in aqueous media (Water) which was accomplished without the use of catalysts or initiators	Environmentally friendly, free from side reactions and does not require the participation of any additives ²¹
5	Synthesis of palladium nanoparticles	Need of inert atmosphere because the moisture may oxidize the catalyst or its reactive intermediates in the procedure. Also, the ligands might be sensitive to air which may diminish the efficiency	Synthesize palladium nanoparticles through a facile and green route using nontoxic and renewable natural black tea leaves (<i>Camellia sinensis</i>) extract as the reducing and stabilizing agent, at ambient conditions	Using non-toxic and renewable natural ²⁴ black tea leaves, elimination of expensive, unstable and poisonous ligands, simple methodology, high yields, easy preparation, and handling of the catalyst. The catalyst was recycled several times with no significant loss of catalytic activity ²²
6	Synthesis of 2-amino-4H-pyran derivatives	Using synthetic organic polymers, which may give the risk of toxicity	Using a one-pot three-component protocol for the synthesis in the presence of sodium alginate as a new, renewable, and readily recoverable biofunctional organocatalyst	Eco-friendly, cost-effective, simple procedures, and short reaction time. The catalyst was easily separated from the reaction mixture to obtain desired products with excellent purity, high yields, and mild conditions ²³
7	Synthesis of zinc Selenide nanoparticles	Low purity of the final product, use of high pressure and temperature, hazardous materials/chemicals and use of specific stabilizers as additives	Synthesis of ZnSe–NPs at ambient temperature using ascorbic acid	An easy, green, economical eco-friendly method, fast, reproducible, and cost-effective ²⁴
8	Synthesis of Nanocrystalline cobalt ferrite through soft chemistry methods	Chemical procedures that give the risk of using toxic and hazardous chemicals	Synthesis of cobalt ferrites (CoFe ₂ O ₄) by self-combustion and wet ferritization methods using an aqueous extract of sesame seed	Environmentally friendly and cost-effective methods as they do not use toxic or expensive chemicals ²⁵
9	Synthesis of colloidal silver nanoflowers	Environmental contamination	Biosynthesis of silver nanoflowers using L-cysteine as reducing and capping agent in alkaline solution through 70 °C water bath for 4 h	Eco-friendly mild method without any chemical capping or stabilizing agents, simple and convenient. Results in the preparation of stable metal nanoparticles ²⁶

Green Chromatography Aspects: Gas chromatography (GC) is a choice of technique for the analysis of volatile and semi-volatile compounds. Green chemistry principles can be implemented into gas chromatography in number of ways ¹¹;

- Minimizing the use of solvent use or excluding the use of solvent while preparation of the sample is highly recommended.
- Carrier gas should be chosen to try to make GC analysis greener. Helium (He) and Nitrogen (N₂) are the most commonly used carrier gas in gas chromatography because of their favorable chromatographic properties, being non-toxic, non-flammable, inert and safe to handle.
- Hydrogen, best alternative as a carrier gas in GC. The shortest analysis times are accomplished with hydrogen as the carrier gas. The wide range over high efficiency is obtained makes hydrogen the best carrier gas for samples containing compounds that elute over a wide temperature range when constant pressure is used.
- Helium can be replaced by hydrogen as the carrier gas in methods without sacrificing analysis speed, resolution, and sensitivity. Hydrogen gas generators are available, which overcomes concerns about the safety of hydrogen gas cylinders.

- The other approach that can be used to make GC “greener” is the reduction of the analysis time leading to increased sample throughput. This may be achieved by using columns

shorter than conventional and with smaller internal diameter without sacrificing separation and resolution.

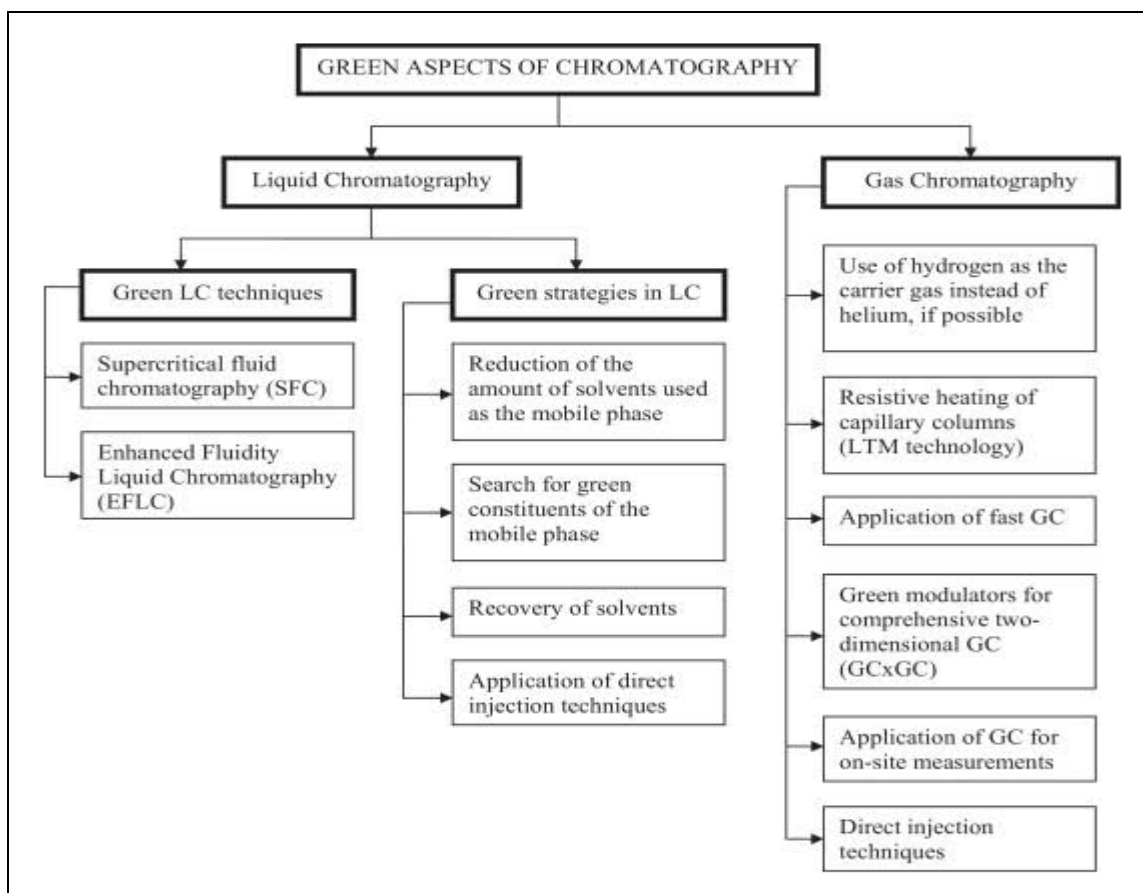


FIG. 3: GIVES AN OVERVIEW ABOUT VARIOUS ASPECT OF GREEN CHROMATOGRAPHY

A. Low Thermal Mass Technology: Temperature programming is considered as the second most important parameter to control after column selectivity, in Gas Chromatography. Increasing column temperature during Gas Chromatography analysis is referred to as temperature-programmed gas chromatography (TPGC). The advantages of TPGC is that it gives better separation for solutes with a wide boiling points range, improved peak symmetry for solutes with high retention factors, and improved detection limits¹¹. It allows the removal of unwanted heavier sample components from the column that could otherwise compromise the integrity of the chromatographic system. In 2001, Low Thermal Mass technology was introduced to achieve ultrafast temperature programming and an unprecedented cooldown time with a power consumption of approximately 1% of conventional gas chromatography¹¹. Fig. 4 and 5 present low thermal mass column module diagram.

LTMGC is considered a green technique because resistive heating of a GC column brings about two main advantages: reduction of power consumption by approximately a factor of 200 and increased speed of column heating (up to 1800 °C/min; achievable rates depend on column mass, configuration and column void times), which can potentially reduce the analysis time.

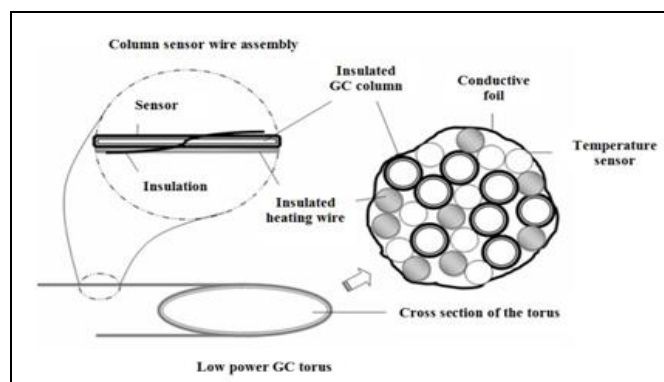


FIG. 4: LOW THERMAL MASS COLUMN MODULE

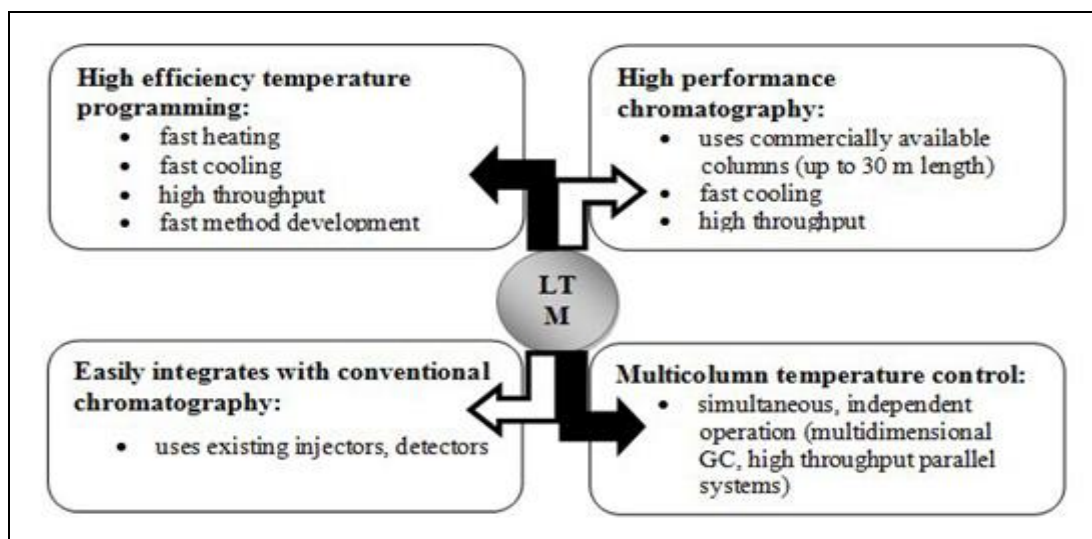


FIG. 5: ADVANTAGES OF LOW THERMAL MASS TECHNOLOGY

B. Comprehensive Two-Dimensional Gas Chromatography (GC×GC): These techniques were introduced in 1991 and known for around 25 years. It is the most powerful separation technique specifically for volatile and semi-volatile analytes when it is combined with time-of-flight mass spectrometry (TOFMS).

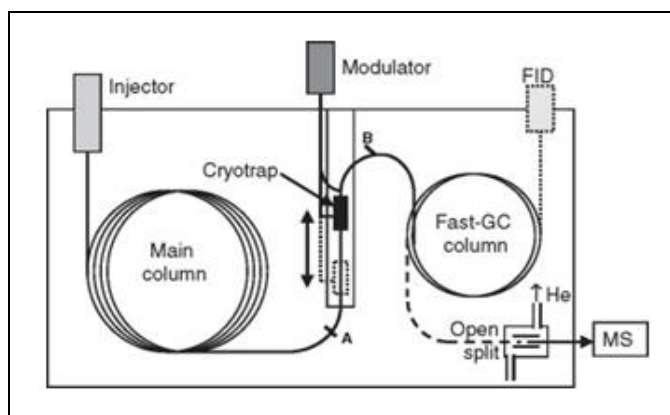


FIG. 6: TWO-DIMENSIONAL GAS CHROMATOGRAPHY (GC×GC)

Some of the features which differentiate the two-dimensional gas chromatography system from conventional one-dimensional GC are

- **Two Different Columns:** one is non-polar and usually 30-60 m long while the other is polar to semi-polar around 0.5-2 m. Reverse configurations and other combinations of the column can also be used.
- **Modulator:** It prevents the loss of separation achieved in the first column and enables two-dimensional separation. Placed between the two chromatographic columns.

- **Detectors:** High-speed data acquisition systems (sampling at least 50 - 100 Hz to obtain 10-20 points per peak) is used, as very narrow peaks eluting from the second column (~50 - 400 ms)¹¹.

Compared to conventional two-dimensional gas chromatography, GC×GC gives better separation of sample components in complex matrices than though both methods require the same time for separation. In principle, this makes GC×GC greener compared to one-dimensional gas chromatography. The great separation power of GC×GC-TOFMS allows the determination of target analytes in complex matrices with little to no sample preparation, which results in significant time and reagent savings. **Fig. 6** illustrates Comprehensive two-dimensional gas chromatography (GC×GC).

Green Liquid Chromatography: Liquid chromatography is considered less green as compared to gas chromatography, as it requires solvents for the separation which may be a source for pollution. On the flip side, this offers more possibilities for “greening”. To achieve environmentally friendly methods, some green HPLC techniques are also used. Nowadays in chemical laboratories all over the world, HPLC and related chromatographic methods are the most widely used analytical techniques. Each working HPLC instrument produces about 1.5–2 L of waste daily which leads to huge consumption of solvent and generation of waste, as in most of the case where HPLC method stationary phase column of

4.6 mm internal diameter and 25 cm length with a mobile-phase flow rate of about 1–1.5 mL min is used ². Based on the 12 principles of green chemistry, three principles were evolved which were applied under the umbrella of the green principle of green chromatography which called three Rs rules (reduce, replace, and recycle). The main focus was kept on the reduction or either replacement of the existing solvents with the greener one ²⁷⁻²⁸.

Solvent Reduction: There are many techniques to reduce the amount of solvent used, which also leads to a decrease in a waste generation; these techniques involve the following:

1. Use of Short Column with Small Particle Size:

It was considered to be the simplest way to reduce the amount of solvent consumption by reducing the analysis time by reducing the run time. By decreasing the column length with decreasing particle size, one can obtain the same separation profile and efficiency of a long column with bigger particle size, but in lesser time of analysis which leads to reduce the solvent amount used. The main drawback of this was it results in an increase in column back pressure ²⁹.

2. Ultra-High Performance Liquid Chromatography (U-HPLC):

U-HPLC gradually replacing the conventional HPLC instruments, as

they were introduced to overcome the high back pressures generated by small particle size. Decreasing the length of the column decrease the run time and solvent consumption and reduce the amount of waste generated. Moreover by using a short length column with small internal diameter gives a shorter run time ³⁰.

3. Reversed Hydrophilic Interaction Liquid Chromatography: In this case, the mobile phase used contains a high percentage of water and stationary phases are reversed to non-polar which results in decreased use of organic solvents ².

4. Microflow and Capillary HPLC: The use of microscale and capillary columns resulted in fewer flow rates that led to solvent savings ².

5. Increased Temperature: This technique has the number of advantages that are represented by providing water with non-polar character at elevated temperatures and reducing the amount of organic modifier needed.

This results in a decrease in the total amount of waste produced, decreasing viscosity leads to decrease backpressure and high flow rate and faster separations. Overall improves peak symmetry with better efficiency ³¹. **Fig. 7** shows the effect of the temperature.

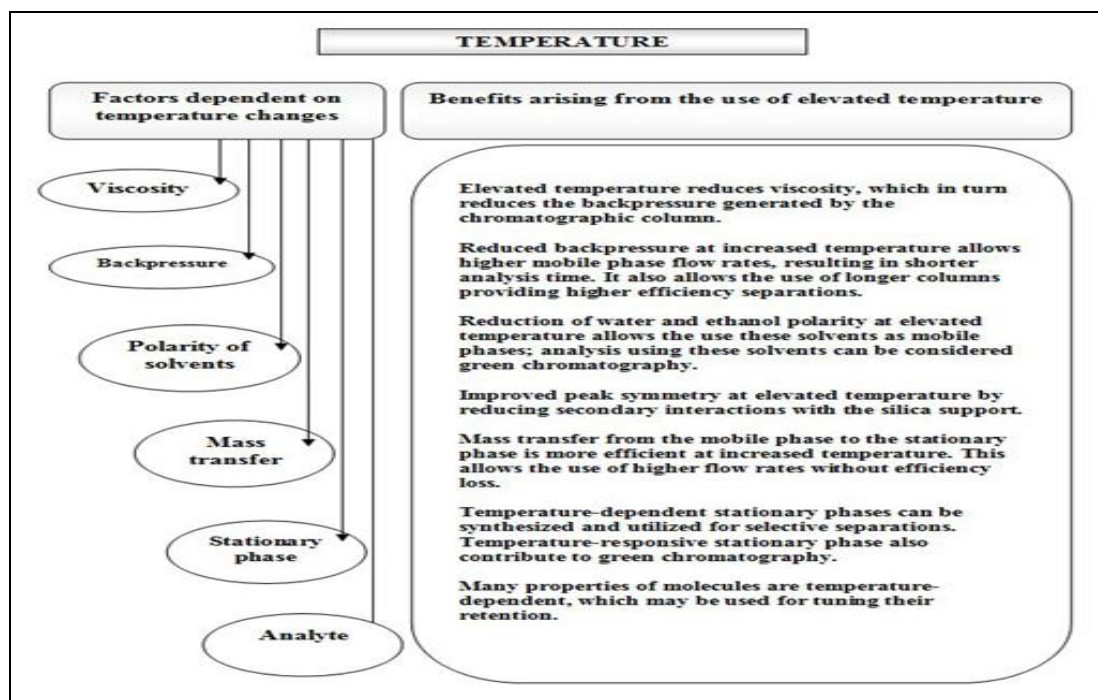


FIG. 7: FACTORS DEPENDENT ON TEMPERATURE CHANGES

Solvent Replacement: In this technique, the toxic and flammable solvents are replaced by greener alternatives. The techniques involved in solvent replacement are as follows:

1. Replacement of Acetonitrile with Ethanol:

From Green analytical chemistry point of view acetonitrile has many disadvantages like volatility, high cost, and flammability. Therefore acetonitrile is replaced by ethanol as it is non-toxic and easily available. However, one of the problems of ethanol is its high viscosity, but this can be solved by increasing the temperature of the mobile phase or using UPLC instrumentation².

2. Superheated Water Chromatography: Water at high temperature (80-250 °C) is used instead of using is combined with organic solvents like water-methanol and water-acetonitrile as eluents. Since the polarity of water decreases by increasing temperature and it can replace organic modifiers. The advantages of using superheated water are as follows: water is available, inexpensive, non-flammable, and environmentally acceptable with low UV cutoff allowing detection at a lower wavelength, in addition to reduced disposal cost.

But there are some of the limitations like a need of high temperature which leads in the degradation of thermally liable compounds, insolubility of lipophilic compounds in water therefore so more temperature-resistant packing materials are required such as polymeric phases³²⁻³³.

3. Supercritical Fluid Chromatography: Carbon dioxide is used in the form of a supercritical fluid that offers a substitute to organic solvent as with supercritical water chromatography. Pressurized carbon dioxide in the supercritical state as eluent gives the advantage of possessing solvent properties similar to petrochemical-derived hydrocarbons, giving a greener choice for commonly used normal-phase solvents (*e.g.*, hexane or heptanes). Moreover, carbon dioxide is having low viscosity results in high flow rates and faster separations.

4. Enhanced Fluidity: In these techniques, polar liquids, such as alcohol, are used to which high proportions of soluble gases have been added. The advantages of this method are low viscosity, increased diffusion coefficients of the solute,

precise control of solvent strength, and high efficiency. Further, this technique liquid chromatography has been used in different separation techniques such as normal- and reversed-phase LC, chiral separations, and size exclusion chromatography.

Ionic liquid: Ionic liquid is a salt in the liquid state. Ionic liquids are formed when salt melts without decomposing or vaporizing. Different ionic liquids are mostly based on quaternary nitrogen cations. Therefore, it is considered a green solvent alternative. The main advantages of ionic solvents are; they have no measurable vapor pressure; thermally robust; generate almost no waste product; excellent solvents for organic, inorganic, and polymeric materials; easy to buy, simple to prepare; a non-flammable.

CONCLUSION: From this review, we can conclude that the amount of waste generated per data point for analytical separation technologies can be decreased dramatically by a number of green analytical chemistry technology alternatives. As these newer, greener analytical separation technologies become more widely utilized, they are having a dramatic, beneficial impact in the workplace, allowing more work to be performed with fewer instruments and greatly reducing the amount of waste solvent associated with the collection of highly-valued analytical HPLC data.

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