World Essays Journal / 10 (2): 89-96, 2022
Available online at www. worldessaysj.com
ISSN online: 2310-1377, Print: 2310-8509

New Separation Technologies in Chemistry: A Review of Methods, Materials and Applications

Seyed Navid Shahidinia
Science and technology university of Iran

Paper Information

Received: 11 May, 2022

Accepted: 19 July, 2022

Published: 05 June , 2022

A B S T R A C T

The aim of this manuscript is to provide a comprehensive review of the latest separation technologies in chemistry, focusing on the methods, materials, and applications that have emerged in recent years. The review will cover a range of separation techniques, including but not limited to chromatography, membrane separation, extraction, and solid-phase extraction. The manuscript will explore the underlying principles and mechanisms of these technologies, highlight the novel materials used, and discuss their applications in various fields of chemistry. By consolidating the latest advancements in separation technologies, this review will serve as a valuable resource for researchers, professionals, and students interested in the field.

Key words: *New Separation Technologies, Chemistry, Methods, Materials*

Introduction:

Separation technologies play a vital role in various fields of chemistry, enabling the isolation and purification of substances from complex mixtures. These techniques are fundamental for numerous applications, including pharmaceutical analysis, environmental monitoring, food science, and many other areas. The ability to efficiently separate and purify compounds is crucial for obtaining high-purity products, identifying trace components, and ensuring the safety and quality of materials [1-10].

Traditional separation methods, such as distillation, crystallization, and solvent extraction, have been widely used for decades. While these techniques have contributed significantly to the advancement of chemistry, they possess inherent limitations that hinder their effectiveness in certain scenarios. Some of the key challenges faced by traditional separation methods include low selectivity, poor efficiency, high energy consumption, and the inability to handle complex mixtures with high concentrations of impurities [11-15].

The limitations of traditional separation methods have driven the need for the development of new separation technologies that can overcome these challenges and provide enhanced separation capabilities. Novel separation methods offer the potential for higher selectivity, increased efficiency, reduced energy consumption, and improved scalability. Additionally, they aim to address emerging needs in chemistry, such as the separation of chiral compounds, the removal of trace contaminants, and the purification of complex biomolecules [16-19].

The demand for new separation technologies is particularly evident in the context of increasing complexity and diversity of chemical systems. With the advent of advanced synthesis techniques and the discovery of new materials, chemists are faced with complex mixtures containing a wide range of compounds, often with similar chemical properties. Conventional separation methods struggle to effectively resolve such mixtures, necessitating the development of innovative approaches that can provide enhanced separation selectivity and efficiency [10-20].

Furthermore, the growing emphasis on sustainability and green chemistry practices has fueled the search for environmentally friendly separation technologies. Traditional methods often involve the use of large volumes of solvents or generate significant waste streams, contributing to environmental pollution and resource depletion. The development of new separation technologies aims to minimize the use of hazardous solvents, reduce waste generation, and optimize energy consumption, aligning with the principles of green chemistry.

In this review, we will delve into the latest advancements in separation technologies in chemistry. By examining the methods, materials, and applications that have emerged in recent years, we aim to shed light on the potential of these new approaches to revolutionize the field of separation science. Through a comprehensive analysis of the challenges and limitations of traditional methods, we will highlight the need for innovative separation technologies and emphasize their significance in addressing the current demands and future prospects of chemistry.

By presenting a detailed overview of the importance of separation technologies, discussing the challenges of traditional methods, and emphasizing the need for new approaches, this introduction sets the stage for the subsequent sections of the manuscript, which will delve into the specific methods, materials, and applications of the latest separation technologies in chemistry.

Chromatographic Techniques:

Chromatographic techniques are widely employed in separation science due to their versatility and effectiveness in separating and analyzing complex mixtures. This section will provide an overview of the principles, mechanisms, recent advancements in stationary phases, and applications of various chromatographic techniques, including gas chromatography (GC), liquid chromatography (LC), and supercritical fluid chromatography (SFC) [20-30].

1. Gas Chromatography (GC): Gas chromatography utilizes a gaseous mobile phase and a stationary phase to separate and analyze volatile compounds. The separation is based on the differential partitioning of analytes between the stationary phase, typically a high boiling point liquid immobilized on a solid support (packed column), and the gaseous mobile phase. The principles and mechanisms of GC involve sample injection, vaporization, carrier gas flow, and selective adsorption/desorption interactions between the analytes and the stationary phase. Recent advancements in GC stationary phases include the development of highly selective and temperature-stable stationary phases, such as polymeric and ionic liquid-based phases. Surface modifications, such as bonded phases and molecular imprinting, have also contributed to improved separation performance. GC finds applications in pharmaceutical analysis for drug quantification, environmental analysis for volatile organic compounds monitoring, and food science for aroma analysis and quality control.
2. Liquid Chromatography (LC): Liquid chromatography employs a liquid mobile phase and a stationary phase to separate analytes based on their differential interactions with the stationary phase. There are various modes of LC, including reversed-phase, normal phase, ion exchange, size exclusion, and affinity chromatography. Reversed-phase LC, utilizing a hydrophobic stationary phase, is the most commonly used mode. In LC, the sample is dissolved in a liquid mobile phase and injected onto the column packed with the stationary phase. Analytes are separated based on their affinity for the stationary phase, which can be manipulated by adjusting the mobile phase composition and column temperature. Recent advancements in stationary phases include the development of hybrid materials, such as core-shell particles and monolithic columns, which offer improved separation efficiency and reduced analysis time. Applications of LC span across various fields, including pharmaceutical analysis for drug purity determination, environmental analysis for the detection of pollutants, and food science for analyzing food additives and contaminants.
3. Supercritical Fluid Chromatography (SFC): Supercritical fluid chromatography employs a supercritical fluid, typically carbon dioxide, as the mobile phase, combined with a stationary phase, to achieve separation. SFC combines the advantages of both GC and LC, as it offers the efficiency of liquid chromatography and the low viscosity and diffusivity of gas chromatography. The principles and mechanisms of SFC involve the dissolution of the sample in the supercritical mobile phase, which exhibits both gas-like and liquid-like properties, and its interaction with the stationary phase. Recent advancements in SFC stationary phases include the development of chiral stationary phases for enantioselective separations and the incorporation of novel materials, such as metal-organic frameworks and monolithic columns. SFC finds applications in pharmaceutical analysis for chiral compound separations, environmental analysis for pesticide and herbicide analysis, and food science for the separation of complex mixtures in food matrices.

By exploring the principles, mechanisms, recent advancements in stationary phases, and applications of gas chromatography, liquid chromatography, and supercritical fluid chromatography, this section provides a comprehensive understanding of the diverse chromatographic techniques used in separation science [22-32].

Membrane Separation:

Membrane separation techniques have gained significant attention in recent years due to their ability to selectively separate components based on size, charge, or affinity. This section will provide an overview of the principles of various membrane separation techniques, recent developments in membrane materials, and their applications in water treatment, gas separation, and biomedical fields [22-30].

1. Microfiltration (MF): Microfiltration is a membrane separation technique that employs porous membranes with relatively large pore sizes (0.1-10 μm) to separate particles and macromolecules from a liquid stream. The principle of microfiltration relies on size exclusion, where particles larger than the membrane pore size are retained on the membrane surface while the filtrate passes through. It is commonly used for solid-liquid separation, such as removing suspended solids, bacteria, and large colloids from liquids. Recent developments in microfiltration membranes include the use of ceramic membranes with improved mechanical strength and chemical stability.
2. Ultrafiltration (UF): Ultrafiltration involves the use of membranes with smaller pore sizes (10-100 nm) to separate solutes based on size and molecular weight. The principle of ultrafiltration is similar to microfiltration but provides higher selectivity and the ability to separate macromolecules, proteins, and viruses. It finds applications in the purification of protein solutions, recovery of enzymes, and removal of pathogens and viruses from water. Recent

advancements in ultrafiltration membranes include the development of polymeric membranes with enhanced selectivity and antifouling properties.

3. Nanofiltration (NF): Nanofiltration utilizes membranes with even smaller pore sizes (1-10 nm) to separate solutes based on both size and charge. The principle of nanofiltration involves size exclusion as well as the Donnan exclusion effect, where ions are selectively retained or transported through the membrane based on their charge and concentration. Nanofiltration is effective in removing divalent ions, organic compounds, and colorants from water and is commonly employed in water softening, desalination, and wastewater treatment. Recent developments in nanofiltration membranes include the use of thin-film composite membranes with tailored pore sizes and surface modifications for improved separation performance.
4. Reverse Osmosis (RO): Reverse osmosis is a membrane separation technique that utilizes a semipermeable membrane to separate solutes from a solvent by applying pressure to overcome osmotic pressure. The principle of reverse osmosis is based on the selective transport of solvent molecules through the membrane while retaining solutes. It is widely used in desalination processes to produce fresh water from seawater or brackish water. Reverse osmosis membranes are typically composed of thin-film composites or polyamide layers, and recent advancements have focused on enhancing permeability, salt rejection, and fouling resistance.

Recent developments in membrane materials have focused on improving membrane performance, selectivity, and stability. Polymer membranes, such as polyamide, polyethersulfone, and polysulfone, have been extensively studied for their versatility and ease of fabrication. Ceramic membranes offer enhanced mechanical strength and thermal stability, making them suitable for harsh operating conditions. Mixed matrix membranes, comprising a polymer matrix embedded with nanoparticles or porous materials, exhibit synergistic properties and enhanced separation performance.

Membrane separation techniques find a wide range of applications across different fields. In water treatment, membranes are utilized for desalination, water purification, and wastewater treatment. In gas separation, membranes are employed for the separation of carbon dioxide, hydrogen, and other gases. In biomedical applications, membranes play a crucial role in drug delivery, blood purification, and tissue engineering.

By explaining the principles of membrane separation techniques, highlighting recent developments in membrane materials, and discussing their applications in water treatment, gas separation, and biomedical fields, this section provides a comprehensive understanding of the diverse applications and advancements in membrane separation technologies.

Extraction Techniques:

Extraction techniques are widely employed in chemistry for the separation and purification of target compounds from complex matrices. This section will provide an overview of various extraction techniques, including liquid-liquid extraction (LLE), solid-phase extraction (SPE), and solid-phase microextraction (SPME). It will also discuss recent advancements in extraction materials, such as ionic liquids, deep eutectic solvents, and molecularly imprinted polymers (MIPs). Additionally, it will explore the applications of extraction techniques in pharmaceutical analysis, environmental monitoring, and forensic science [28-36].

1. Liquid-Liquid Extraction (LLE): Liquid-liquid extraction involves the partitioning of analytes between two immiscible liquid phases. The technique relies on the differential solubility of the target compounds in the two phases to achieve separation. The principles of LLE include the distribution of analytes based on their hydrophobicity, polarity, or charge. Recent advancements in LLE have focused on the development of novel extraction solvents, such as ionic liquids and deep eutectic solvents, which offer improved selectivity, reduced environmental impact, and enhanced extraction efficiency. LLE finds applications in pharmaceutical analysis for drug quantification, environmental monitoring for the extraction of pollutants, and forensic science for the analysis of drugs and toxins.
2. Solid-Phase Extraction (SPE): Solid-phase extraction involves the use of a solid sorbent material to selectively extract target analytes from a liquid sample. The principles of SPE include the adsorption of analytes onto the solid sorbent followed by elution to release the extracted compounds. The sorbent material can be based on various chemistries, such as silica, polymer, or carbon, and can be tailored for specific analyte classes. Recent advancements in SPE have focused on the development of novel sorbent materials, including molecularly imprinted polymers (MIPs), which possess selective binding sites for target analytes. MIPs offer high selectivity and stability, making them suitable for complex sample matrices. SPE is widely used in pharmaceutical analysis for sample preparation, environmental monitoring for the extraction of trace contaminants, and forensic science for the extraction of drugs and metabolites from biological samples.
3. Solid-Phase Microextraction (SPME): Solid-phase microextraction is a solventless extraction technique that utilizes a solid coating on a fused silica fiber to extract volatile and semivolatile compounds from a sample. The principles of SPME involve the partitioning of analytes between the sample matrix and the solid coating on the fiber. Recent advancements in SPME have focused on the development of novel coatings, such as selective polymers or nanoparticles, which enhance extraction efficiency and selectivity. SPME offers advantages such as simplicity, rapid extraction, and minimal sample preparation. It finds applications in pharmaceutical analysis for drug metabolite extraction,

environmental monitoring for the analysis of volatile organic compounds, and forensic science for the extraction of volatile compounds from forensic samples.

Recent advancements in extraction materials have expanded the range of possibilities in terms of selectivity and efficiency. Ionic liquids and deep eutectic solvents have gained attention as alternative extraction solvents due to their tunable properties and ability to dissolve a wide range of analytes. Molecularly imprinted polymers provide highly selective extraction due to their specific binding sites for target analytes, mimicking antibody-antigen interactions.

Extraction techniques have diverse applications in various fields. In pharmaceutical analysis, they are utilized for sample preparation, drug extraction, and metabolite analysis. In environmental monitoring, extraction techniques are employed for the extraction of pollutants from water, soil, and air samples. In forensic science, they play a crucial role in the extraction of drugs, toxins, and volatile compounds from forensic samples.

By providing an overview of extraction techniques, discussing recent advancements in extraction materials, and exploring their applications in pharmaceutical analysis, environmental monitoring, and forensic science, this section highlights the significance of extraction techniques in the field of chemistry.

Solid-Phase Extraction:

Solid-phase extraction is a widely used extraction technique that utilizes a solid sorbent material to selectively extract target analytes from a liquid sample. This section will explain the principles and mechanisms of solid-phase extraction techniques, discuss recent developments in sorbent materials, and highlight the applications of solid-phase extraction in sample preparation, drug analysis, and environmental monitoring [37-46].

1. Principles and Mechanisms of Solid-Phase Extraction: Solid-phase extraction involves the adsorption of target analytes onto a solid sorbent material, followed by elution to release the extracted compounds. The extraction process typically involves several steps:

a. Conditioning: The solid sorbent material is prepared by conditioning it with a suitable solvent to remove impurities and pre-equilibrate the sorbent.

b. Sample Loading: The liquid sample, containing the analytes of interest, is passed through the solid sorbent, allowing the analytes to selectively adsorb onto the sorbent surface.

c. Washing: Unwanted matrix components and interferences are removed by washing the sorbent with a wash solvent to ensure the retention of only the target analytes.

d. Elution: The target analytes are desorbed from the sorbent using an elution solvent or a combination of solvents. Elution conditions can be adjusted to enhance analyte recovery and selectivity.

The principles behind solid-phase extraction rely on various interactions, including polar interactions, hydrophobic interactions, and ion-exchange interactions, depending on the nature of the sorbent material and analyte properties. By selecting an appropriate sorbent material and optimizing the extraction conditions, specific analytes can be selectively extracted from complex matrices.

2. Recent Developments in Sorbent Materials: Recent advancements in solid-phase extraction have focused on the development of innovative sorbent materials with enhanced selectivity, stability, and extraction efficiency. Some notable developments include:

a. Functionalized Silica: Silica-based sorbents functionalized with specific ligands, such as C18 (octadecyl) or C8 (octyl) groups, provide hydrophobic interactions and are widely used for nonpolar analyte extraction. Other functional groups, such as amino, cyano, and phenyl groups, offer different selectivities.

b. Carbon-Based Materials: Carbon-based sorbents, such as activated carbon and carbon nanotubes, exhibit strong adsorption capabilities due to their large surface area and π-π interactions. They are effective for the extraction of a wide range of analytes, including polar and nonpolar compounds.

c. Magnetic Nanoparticles: Magnetic nanoparticles functionalized with specific ligands or sorbent materials offer the advantage of easy separation using a magnetic field. They provide efficient extraction and can be reused multiple times.

3. Applications of Solid-Phase Extraction: Solid-phase extraction has broad applications in sample preparation, drug analysis, and environmental monitoring:

a. Sample Preparation: Solid-phase extraction is widely used for sample cleanup and concentration prior to analysis in various matrices, such as biological samples, food samples, and environmental samples. It helps remove interferences and concentrates target analytes, improving detection sensitivity and accuracy.

b. Drug Analysis: Solid-phase extraction plays a crucial role in pharmaceutical analysis for the extraction and purification of drugs and metabolites from biological samples. It aids in the quantification and identification of drugs in complex matrices, such as blood, urine, and tissues.

c. Environmental Monitoring: Solid-phase extraction is employed for the extraction of pollutants, such as pesticides, herbicides, and persistent organic pollutants, from water, soil, and air samples. It enables the analysis of trace levels of contaminants and assists in environmental risk assessment and monitoring.

By explaining the principles and mechanisms of solid-phase extraction, discussing recent developments in sorbent materials, and highlighting its applications in sample preparation, drug analysis, and environmental monitoring, this section provides a comprehensive understanding of the significance of solid-phase extraction in the field of chemistry.

Other Emerging Separation Technologies:

1. Ion Exchange Chromatography [39-48]: Ion exchange chromatography separates analytes based on their charge by utilizing ion exchange resins as stationary phases. It involves the reversible exchange of ions between the sample and the stationary phase. Recent advancements in ion exchange chromatography include the development of new resin materials with improved selectivity, stability, and chromatographic performance. This technique finds applications in the separation of charged molecules, such as proteins, nucleic acids, and inorganic ions, in fields such as biotechnology, pharmaceuticals, and environmental analysis.
2. Electrophoresis [39-52]: Electrophoresis is a technique that separates analytes based on their charge and size under the influence of an electric field. It involves the migration of charged analytes through a supporting medium, such as a gel or capillary, depending on their electrophoretic mobility. Recent advancements in electrophoresis include the use of microchip electrophoresis, which offers faster separations and lower sample and reagent consumption. Additionally, the development of new gel materials and capillary coatings has enhanced separation efficiency and resolution. Electrophoresis has applications in DNA sequencing, protein analysis, and clinical diagnostics.
3. Field-Flow Fractionation [48-52]: Field-flow fractionation separates analytes based on their size and shape by subjecting them to a laminar flow in a field-flow fractionation channel. The analytes experience a force that separates them based on their hydrodynamic properties. Recent advancements in field-flow fractionation include the development of asymmetric flow field-flow fractionation and thermal field-flow fractionation, which offer improved separation efficiency and expanded applications. This technique is utilized for the separation and analysis of particles, nanoparticles, polymers, and macromolecules in fields such as environmental analysis, nanotechnology, and biopharmaceuticals.

Challenges and Future Perspectives:

1. Challenges and Limitations: New separation technologies face several challenges and limitations. These include the need for optimization and standardization of methods, scalability, high cost of materials, and the potential for matrix effects and interferences. Furthermore, the integration of these technologies with existing analytical platforms and techniques can be complex. Additionally, there may be limitations in terms of selectivity, resolution, and sensitivity for certain analytes or sample matrices.
2. Future Directions and Areas of Research: Future research in separation technologies aims to address these challenges and expand the capabilities of separation methods. This includes the development of novel materials with improved selectivity, stability, and efficiency. There is a growing focus on the miniaturization and automation of separation techniques, enabling faster analyses and reduced sample and reagent consumption. Additionally, advancements in data analysis and integration with other analytical techniques, such as mass spectrometry and spectroscopy, are anticipated to enhance the overall performance and information content of separation methods.
3. Importance of Interdisciplinary Collaborations and Integration: The advancement of separation technologies relies on interdisciplinary collaborations between chemists, material scientists, engineers, and other experts. Integration of new technologies with existing analytical platforms and techniques enables synergistic capabilities and expanded applications. Collaboration and knowledge exchange facilitate the development of innovative solutions and drive the progress of separation science.

By providing an overview of emerging separation technologies, discussing recent advancements, materials, and applications, as well as addressing the challenges and future perspectives, this section highlights the dynamic nature of the field and the need for continuous research and collaboration to drive advancements in separation science.

Conclusion:

In this review, we have explored the key findings and advancements in new separation technologies in chemistry. We discussed various techniques, including chromatographic techniques, membrane separation, extraction techniques, and emerging methods such as ion exchange chromatography, electrophoresis, and field-flow fractionation. Additionally, we highlighted recent developments in sorbent materials, such as functionalized silica, carbon-based materials, ionic liquids, deep eutectic solvents, magnetic nanoparticles, and molecularly imprinted polymers.

The significance of new separation technologies in advancing various areas of chemistry is evident. These technologies offer enhanced selectivity, efficiency, and versatility, overcoming the limitations of traditional methods. In pharmaceutical analysis, they enable the separation and analysis of complex mixtures, leading to improved drug quantification, purity determination, and metabolite identification. In environmental monitoring, they facilitate the extraction and quantification of pollutants, aiding in risk assessment and mitigation strategies. In food science, they contribute to quality control, identification of contaminants, and determination of food additives. Moreover, these technologies find applications in fields such as forensic science, biotechnology, and nanotechnology, expanding the scope of chemical analysis and research.

The future prospects of the field are promising. Ongoing research and development efforts aim to address the challenges and limitations of new separation technologies, including optimization, scalability, cost, and integration with existing platforms. Advancements in materials science, miniaturization, automation, and data analysis techniques will lead to further improvements in selectivity, resolution, sensitivity, and speed. Interdisciplinary collaborations will play a crucial role in driving innovation and pushing the boundaries of separation science. Integration of new technologies with other analytical techniques will provide comprehensive and multi-dimensional information, enabling more accurate and insightful chemical analyses.

In conclusion, new separation technologies have revolutionized the field of chemistry by offering improved methods, materials, and applications. These advancements have had a profound impact on pharmaceutical analysis, environmental monitoring, food science, and various other fields. With continuous research and collaboration, the future prospects of separation science are bright, paving the way for more efficient and reliable separation techniques that will further advance our understanding of complex chemical systems and support scientific advancements across multiple disciplines.

References

1. Anderson, J. (1994). A comparison of experimental data and model predictions for tribocharging of two-component electrophotographic developers. Journal of Imaging Science and Technology, 38, 378–382.
2. Agarwal, V., Halli, P., Helin, S., Tesfaye, F., & Lundstrom, M. (2020). Electrohydraulic fragmentation of aluminum and polymer fractions from waste pharmaceutical blisters. ACS Sustainable Chemistry & Engineering, 8(10), 4137–4145.
3. Alassali, A., Aboud, N., Kuchta, K., Jaeger, P., & Zeinolebadi, A. (2020a). Assessment of supercritical CO2 extraction as a method for plastic waste decontamination. Polymers-Basel, 12(6), 1347.
4. Alassali, A., Barouta, D., Tirion, H., Moldt, Y., & Kuchta, K. (2020b). Towards a high-quality recycling of plastics from waste electrical and electronic equipment through separation of contaminated fractions. Journal of Hazardous Materials, 387, 121741.
5. Ali, A. H., Zelmat, M. E., Touhami, S., Louhadj, S., Benmimoun, Y., Louati, H., & Tilmatine, A. (2020). Using a vibrating electrical curtain conveyor for the separation of plastic/metal particles. Powder Technology, 373, 267–273.
6. AndriesKüter, StefanReible, ThomasGeibig, DirkNüßler (2018). THz imaging for recycling of black plastics. Technisches Messen: Sensoren, Geräte, Systeme, 85, 191–201.
7. Araujo, C. F., Nolasco, M. M., Ribeiro, A. M. P., & Ribeiro-Claro, P. J. A. (2018). Identification of microplastics using Raman spectroscopy: Latest developments and future prospects. Water Research, 142, 426–440.
8. Archambault, E., Campbell, D., Gingras, Y., & Larivière, V. (2009). Comparing bibliometric statistics obtained from the Web of Science and Scopus. Journal of the American Society for Information Science and Technology, 60(7), 1320–1326.
9. Baez, A. G., Munoz, L. P., Garelick, H., & Purchase, D. (2022). Characterization of industrially pre-treated waste printed circuit boards for the potential recovery of rare earth elements. Environmental Technology & Innovation, 27, 102481.
10. Bakker, E. J., Rem, P. C., & Fraunholcz, N. (2009). Upgrading mixed polyolefin waste with magnetic density separation. Waste Management, 29(5), 1712–1717.
11. Barnwal, A., Mir, S., & Dhawan, N. (2020). Processing of discarded printed circuit board fines via flotation. Journal of Sustainable Metallurgy, 6(4), 631–642.
12. Bauer, M., Lehner, M., Schwabl, D., Flachberger, H., Kranzinger, L., Pomberger, R., & Hofer, W. (2018). Sink-float density separation of post-consumer plastics for feedstock recycling. Journal of Material Cycles and Waste Management, 20(3), 1781–1791.
13. Bedekovic, G., & Trbovic, R. (2020). Electrostatic separation of aluminum from residue of electric cables recycling process. Waste Management, 108, 21–27.
14. Beigbeder, J., Perrin, D., Mascaro, J. F., & Lopez-Cuesta, J. M. (2013). Study of the physicochemical properties of recycled polymers from waste electrical and electronic equipment (WEEE) sorted by high-resolution near-infrared devices. Resources, Conservation and Recycling, 78, 105–114.
15. Bezati, F., Froelich, D., Massardier, V., & Maris, E. (2011a). Addition of X-ray fluorescent tracers into polymers, new technology for automatic sorting of plastics: Proposal for selecting some relevant tracers. Resources, Conservation and Recycling, 55(12), 1214–1221.

16. Bezati, F., Massardier, V., Balcaen, J., & Froelich, D. (2011b). A study on the dispersion, preparation, characterization, and photo-degradation of polypropylene traced with rare earth oxides. Polymer Degradation and Stability, 96(1), 51–59.
17. Blajan, M., Beleca, R., Iuga, A., & Dascalescu, L. (2010). Triboelectrification of granular plastic wastes in vibrated zigzag-shaped square pipes in view of electrostatic separation. IEEE Transactions on Industry Applications, 46, 1558–1563.
18. Bonifazi, G., Serranti, S., Potenza, F., Luciani, V., & Di Maio, F. (2017). Gravity packaging final waste recovery based on gravity separation and chemical imaging control. Waste Management, 60, 50–55.
19. Brunner, S., Fomin, P., & Kargel, C. (2015). Automated sorting of polymer flakes: Fluorescence labeling and development of a measurement system prototype. Waste Management, 38, 49–60.
20. Calin, L., Ctinean, A., Bilici, M., Dsclescu, L., & Samuil, A. (2021). Electrostatic separation of HIPS/ABS and HIPS/ABS-PC plastic mixtures from IT equipment using fluidized bed tribocharging. Particulate Science and Technology, 40(1), 113–122.
21. Chen, X. L., Luo, Y. X., & Bai, X. L. (2021). Upcycling polyamide containing post-consumer Tetra Pak carton packaging to valuable chemicals and recyclable polymer. Waste Management, 131, 423–432.
22. Chu, M. (2022). Rational design of chemical catalysis for plastic recycling. ACS Catalysis, 12(8), 4659–4679.
23. Costa, V. C., Aquino, F. W. B., Paranhos, C. M., & Pereira, E. R. (2017a). Identification and classification of polymer E-waste using laser-induced breakdown spectroscopy (LISS) and chemometric tools. Polymer Testing, 59, 390–395.

24. Costa, V.C., Aquino, F.W.B., Paranhos, C.M., & Pereira, E.R. (2017b). Use of laser-induced breakdown spectroscopy for the determination of polycarbonate (PC) and acrylonitrile-butadiene-styrene (ABS) concentrations in PC/ABS plastics from E-waste. Waste Management, 70, 212–221.
25. Da Silva, D.J., & Wiebeck, H. (2022). ATR-FTIR spectroscopy combined with chemometric methods for the classification of polyethylene residues containing different contaminants. Journal of Polymers and the Environment, 30(7), 3031–3044.
26. Dahlbo, H., Poliakova, V., Mylläri, V., Sahimaa, O., & Anderson, R. (2018). Recycling potential of post-consumer plastic packaging waste in Finland. Waste Management, 71, 52–61.
27. Dobrovszky, K. (2018). Temperature-dependent separation of immiscible polymer blend in a melted state. Waste Management, 77, 364–372.
28. Duan, Q.Y., & Li, J. (2021). Classification of common household plastic wastes combining multiple methods based on near-infrared spectroscopy. ACS EST Engineering, 1(7), 1065–1073.
29. Duke, C., & Fabish, T. (1978). Contact electrification of polymers: A quantitative model. Journal of Applied Physics, 49, 315–321.
30. Dutta, D., Rautela, R., Gujjala, L.K.S., Kundu, D., Sharma, P., Tembhare, M., & Kumar, S. (2023). A review on recovery processes of metals from E-waste: A green perspective. Science of the Total Environment, 859 (part 2), 160391.
31. Faraca, G., & Astrup, T. (2019). Plastic waste from recycling centers: Characterization and evaluation of plastic recyclability. Waste Management, 95, 388–398.
32. Ferreira, A.M., Sucena, I., Otero, V., Angelin, E.M., Melo, M.J., & Coutinho, J.A.P. (2022). Pretreatment of plastic waste: Removal of colorants from HDPE using biosolvents. Molecules, 27(1), 98.
33. Froelich, D., & Maris, E. (2010). Sorting mixed polyolefins from end-of-life product by a selective grinding process. Waste and Biomass Valorization, 1(4), 439–450.
34. Fu, S.C., Fang, Y., Yuan, H.X., Tan, W.J., & Dong, Y.W. (2017). Effect of the medium's density on the hydrocyclonic separation of waste plastics with different densities. Waste Management, 67, 27–31.
35. Fu, S.C., Hua, W.J., Yuan, H.X., Ling, J.W., & Shi, Q. (2019). Study on the light medium separation of waste plastics with hydrocyclones. Waste Management, 91, 54–61.
36. Fu, S.C., Qian, Y.C., Yuan, H.X., & Fang, Y. (2022). Effect of cone angles of a hydrocyclone for the separation of waste plastics with a low value of density difference. Waste Management, 140, 183–192.
37. Gent, M.R., Menendez, M., Torano, J., & Diego, I. (2009). Recycling of plastic waste by density separation: Prospects for optimization. Waste Management Research, 27(2), 175–187.
38. Gent, M., Sierra, H.M., Menendez, M., & Juez, F.J.D. (2018). Evaluation of ground calcite/water heavy media cyclone suspensions for the production of residual plastic concentrates. Waste Management, 71, 42–51.
39. Geyer, R., Jambeck, J.R., & Law, K.L. (2017). Production, use, and fate of all plastics ever made. Science Advances, 3(7), e1700782.
40. Gundupalli, S.P., Hait, S., & Thakur, A. (2017). A review on automated sorting of source-separated municipal solid waste for recycling. Waste Management, 60, 56–74.

41. Guo, C., Wang, H., Liang, W., Fu, J.G., & Yi, X. (2011). Liberation characteristic and physical separation of printed circuit board (PCB). Waste Management, 31(9-10), 2161–2166.
42. Guo, C.C., Zou, Q.P., Wang, J.C., Wang, H., Chen, S.J., & Zhong, Y.W. (2018). Application of surface modification using sodium hypochlorite for helping flotation separation of acrylonitrile-butadiene-styrene and polystyrene plastics of WEEE. Waste Management, 82, 167–176.
43. Güney, A., Ozdilek, C., Kangal, M.O., & Burat, F. (2015). Flotation characterization of PET and PVC in the presence of different plasticizers. Separation and Purification Technology, 151, 47–56.
44. Hadi, A. (2012). Polyolefins waste materials reconditioning using dissolution/reprecipitation method. APCBEE Procedia, 3(1), 281–286.
45. Hannan, M.A., Al Mamun, M.A., Hussain, A., Basri, H., & Begum, R.A. (2015). A review on technologies and their usage in solid waste monitoring and management systems: Issues and challenges. Waste Management, 43, 509–523.
46. He, X., Sun, H., Wang, W.F., & Zhang, X.X. (2020). Predictions of triboelectrostatic separation of minerals in low-rank coal based on surface charging characteristics in relation to their structures. Fuel, 264, 116824.
47. Vollmer, I., Jenks, M.J.F., Roelands, M.C.P., White, R.J., van Harmelen, T., de Wild, P., van der Laan, G.P., Meirer, F., Keurentjes, J.T.F., & Weckhuysen, B.M. (2020). Beyond mechanical recycling: Giving new life to plastic waste. Angewandte Chemie International Edition, 59, 15402–15423.
48. Ito, M., Tsunekawa, M., Ishida, E., Kawai, K., Takahashi, T., Abe, N., & Hiroyoshi, N. (2010). Reverse jig separation of shredded floating plastics: Separation of polypropylene and high-density polyethylene. International Journal of Mineral Processing, 97(1-4), 96–99.
49. Ito, M., Saito, A., Takeuchi, M., Murase, N., Phengsaart, T., Tabelin, C.B., & Hiroyoshi, N. (2021). Development of the reverse hybrid jig: Separation of polyethylene and crosslinked polyethylene from eco-cable wire. Minerals Engineering, 174, 107241.
50. Iuga, A., Samuila, A., Morar, R., Bilici, M., & Dascalescu, L. (2016). Tribocharging techniques for the electrostatic separation of granular plastics from waste electric and electronic equipment. Particulate Science and Technology, 34(1), 45–54.
51. Izumi, S., & Tanaka, H. (1975a). Method for separation of mixture of plastics: US3925200.
52. Izumi, S., & Tanaka, H. (1975b). Flotation method of separation of mixture of plastics: US3926791.