

We are IntechOpen, the world's leading publisher of Open Access books Built by scientists, for scientists

6,900

Open access books available

186,000

International authors and editors

200M

Downloads

Our authors are among the

154

Countries delivered to

TOP 1%

most cited scientists

12.2%

Contributors from top 500 universities



WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index
in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?
Contact book.department@intechopen.com

Numbers displayed above are based on latest data collected.
For more information visit www.intechopen.com



Applications of Carboxylic Acids in Organic Synthesis, Nanotechnology and Polymers

Aidé Sáenz-Galindo, Lluvia I. López-López,
Fabiola N. de la Cruz-Duran,
Adali O. Castañeda-Facio,
Leticia A. Ramírez-Mendoza,
Karla C. Córdova-Cisneros and
Denisse de Loera-Carrera

Additional information is available at the end of the chapter

<http://dx.doi.org/10.5772/intechopen.74654>

Abstract

Carboxylic acids are versatile organic compounds. In this chapter is presented a current overview of the use of carboxylic acids in a different area as organic synthesis, nanotechnology, and polymers. The application carboxylic acids in these areas are: obtaining of small molecules, macromolecules, synthetic or natural polymers, modification surface of nanoparticles metallic, modification surface of nanostructure such as carbon nanotubes and graphene, nanomaterials, medical field, pharmacy, etc. Carboxylic acids can be natural and synthetic, can be extracted or synthesized, presented chemical structure highly polar, active in organic reactions, as substitution, elimination, oxidation, coupling, etc. In nanotechnology, the use of acid carboxylic as surface modifiers to promote the dispersion and incorporation of metallic nanoparticles or carbon nanostructure, in the area of polymer carboxylic acids present applications such monomers, additives, catalysts, etc. The purpose of this chapter is to emphasize the importance of carboxylic acids in different areas, highlighting the area of organic synthesis, nanotechnology and polymers and its applications.

Keywords: carboxylic acids, organic synthesis, nanotechnology, polymers, application

1. Introduction

Carboxylic acids are compounds with excellent chemical and physical properties, the most particular characteristics of this type of organic compounds, is their high solubility in polar

solvents, as water, or alcohols, methanol, ethanol, etc. Chemical structure contains a carbonyl function (-C=O) and an hydroxyl group (OH), these groups interact easily with polar compounds, forming bridges of H, obtaining high boiling points. The carbonyl group (C=O) is considered a one of the most functional groups involved in many important reactions. The carboxylic acids are the most important functional group that present C=O .

This type of organic compounds can be obtained by different routes, some carboxylic acids, such as citric acid, lactic acid or fumaric acid are produced from by fermentation, most of these type of carboxylic acids are applied in the food industry. Historically, some carboxylic acids were produced by sugar fermentation. Synthetics route, there are different synthesis reactions such as reactions of oxidation from alcohols in the presence of strong oxidants such as KMnO_4 , oxidation of aromatic compounds among other routes.

For example, citric acid is a carboxylic acid, can be obtained by different routes, synthetic, enzymatic and naturally occurring, is considered harmless and cheap, used in the food industry, because is non-toxic, has a thermal stability to the 175°C . Bian *et al.*, in 2017, reported the use of citric acid impregnated in porous material for the synthesis of Ni particles. They showed, that the presence of citric acid, is important in the dispersion of the Ni particles when are incorporate in porous materials, thus inhibiting the agglomeration [1].

Derivatives of carboxylic acid, as alkyl halides, esters, and amides, present different and important application in diverse areas. In the case of esters, these are obtained from the reaction between carboxylic acids and alcohols in presence of an acid catalyst usually H_2SO_4 with heat, this type of reaction is known as esterification. In the case of the amides, it is obtained in the presence of an amine, may be primary and secondary, with a carboxylic acid, in this reaction also can be used a catalyst and heat to accelerate the reaction.

Due to their chemical and physical characteristics, this type of organic compounds presents innumerable applications in the different areas, such as medicine, pharmacy, organometallic, polymer, nanotechnology, food, among others. Exist different reports, where study carboxylic acid, in the area organic synthesis, in 2008 Lazzarato *et al.*, reported the use of a carboxylic acid, salicylic acid type "aspirin-like", molecule obtained through a novel approach, where the phenol reaction to nitrooxy-acyl, this molecule present pharmaceutical properties [2].

In nanotechnology, the carboxyl acid, present in different applications, in 2016, Sáenz *et al.*, reported the use of organic carboxylic acids: tartaric acid, maleic acid, and malic acid, assisted the surface modification of multiple wall carbon nanotubes (MWCNTs) by ultrasonic radiation, with applications in the production of polymer nanomaterials. Finding that the modification with this type of carboxylic acids favors the dispersion of MWCNTs in the polymer matrix [3].

In the polymer area, also the carboxylic acids present important applications, in 2017 Oguz *et al.*, reported the obtain of "green composites" of Poli(lactic acid) and 10 wt % waste cellulose fibers, demonstrating that is easy, economical and sustainable its obtaining, this "green composites" presented improved tensile and impact properties [4]. Yasa *et al.*, reported the synthesis and characterization of polyol esters from iso-undecenoic and iso-undecanoic acids,

using montmorillonite K10 clay as a catalyst, in presence of deionized water at a temperature of 250°C in an autoclave. This type of polymer presented applications like lubricant properties and good oxidation stability [5].

In general, the carboxylic acids presents applications in different areas, the propose of this chapter is to show a general panorama, about the applications of carboxylic in organic synthesis, nanotechnology, and polymer.

2. Use of carboxylic acids

2.1. Organic synthesis

The use of carboxylic acids in organic synthesis is a very wide area and the chemical transformations of this group to another have made it a very versatile functional group. These chemical transformations have seen improvement when they carry out through Green chemistry processes.

One of the methods to aim for energy efficiency (one of the principles of Green Chemistry) is to make reactions under microwave irradiation. The first report by this methodology was an esterification reaction with carboxylic acids and alcohols obtaining high yields in a short reaction time [6].

In addition to the esterification, the amidation reaction by a transformation of the carboxylic acids is also important because of the new covalent bond formed. This bond is of great importance because it can be found in a wide variety of molecules both in natural products and in small molecules with pharmacological activity [7–9]. Therefore, the development of new direct amidation reactions is important [10, 11]. One of those direct methodologies of amide formation is by reacting amines with carboxylic acids using toluene as a solvent [12] or using radiofrequency heating under neat conditions [13]. However this reagent-free pathway has limitations in the substrate scope.

On the other hand, Lanigan *et al.* reported a methodology in which they used simple borate esters that are efficient reagents for the direct synthesis of amides, using a variety of carboxylic acids and amines [14]. This reaction can be carried out openly to the air under acetonitrile reflux. The amidation product can be purified in a very simple way, in most cases, it only needs a simple filtration procedure using commercially available resins giving excellent yields (**Figure 1**). <<http://pubs.acs.org/doi/abs/10.1021%2Fjo400509n>>.

Another methodology in which microwave irradiation was used in the amidation reaction has proven to be an efficient synthesis of amides [15–18]. For example, Ojeda-Porras *et al.* [19] described a green methodology for the direct amidation (**3**) of carboxylic acids (**1**) and amines (**2**) using silica gel as a solid support (**Figure 2**).

In addition to the typical use of carboxylic acids in transformations other carbonyl groups, they can be used as a substrate in multicomponent reactions such as the well-known Ugi [20, 21]

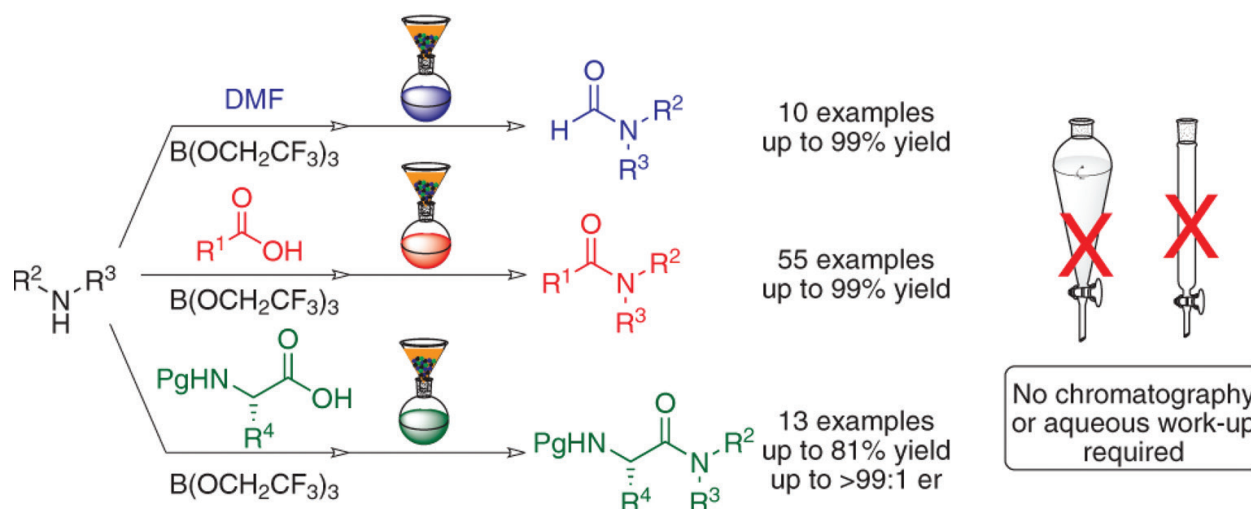


Figure 1. Carboxylic acids were used to obtain a variety of amides [12].

and Passerini [22, 23] reactions. An example is the reaction between an oxazolidine **4**, an isocyanide **5** and a carboxylic acid **6** to provides *N*-acyloxy ethylamino acid derivatives (**7**) (**Figure 3**) [24] so that it can be complemented with those structures that are produced by the well-established Ugi and Passerini reactions and they allow the generation of a chemical libraries.

As well, carboxylic acids can be used in organocatalytic reactions. As is in the case, carboxylic acid **11** can be used directly to obtain the α -hydroxy phosphonates **12**. The reaction was carried out in a simple way with a variety of aldehydes **8** and ketones **9** with trimethylphosphite **10** in the presence of catalytic amounts of pyridine 2,6-dicarboxylic acid **11** in water as a solvent. This generates a low cost and environmentally friendly methodology (**Figure 4**) [25].

Another example of using carboxylic acids as catalysts is by incorporating them into the structure of ionic liquids (IL). Jahani *et al.* described the condensation of 1,8-dioxo-octahydroxanthene **16** with 5,5-dimethyl-1,3-cyclohexanedione (**13**) and aldehyde derivatives **14** using carboxylic acid functionalized IL (**15**) under microwave irradiation (**Figure 5**) [25]. <https://creativecommons.org/licenses/by-nc-nd/4.0/> provides and offers the advantages of using IL and microwave irradiation are making the reaction an efficient and eco-friendly procedure.

Carboxylic acids present important applications in the pharmaceutical area, due to their chemical structure. Different methods have been developed for their detection, in medicines, in cosmetics, in food additives, etc. In 2015, Soham *et al.*, reported a selective chromogenic system, which not only can discriminate maleic acid vs. fumaric acid but can also differentiate



Figure 2. Amidation reaction via carboxylic acids and amines [17].

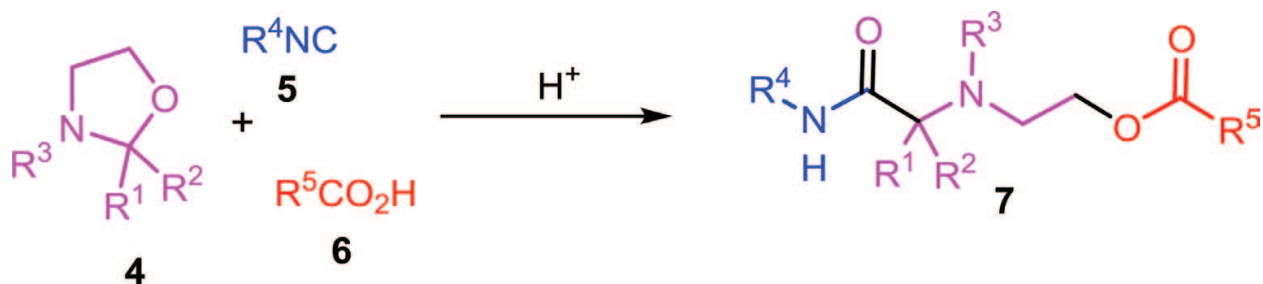


Figure 3. Use of carboxylic acid in a multicomponent reaction [24].

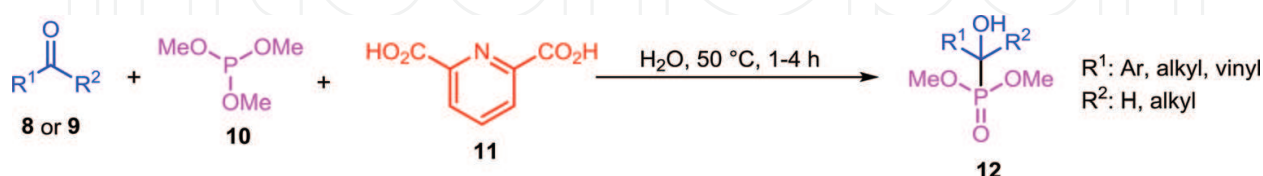


Figure 4. Carboxylic acid as a catalyst [25].

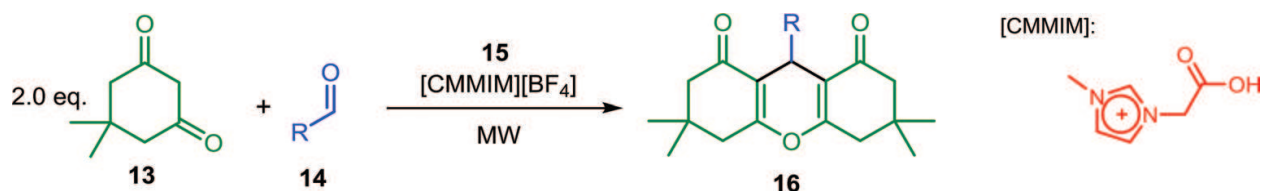


Figure 5. Carboxylic acid in ionic liquid in the multicomponent reaction [26].

maleic acid among diverse carboxylic acids. This method uses sharp colorimetric, as well as fluorogenic responses in both physiological conditions and food additives. The detection of this type of organic acids is very important. For example, maleic acid plays an important role in the organism because it is a Krebs cycle inhibitor whereas, fumarate is produced in the Krebs cycle. Excessive consumption of maleic acid can cause different kidney diseases [27].

2.2. Nanotechnology

Recently carboxylic acids have been studied extensively, due to their important applications in the petrochemical, food industry, dyes, stabilizers and currently in nanotechnology [28]. This type of acid has become very important because it has been considered as a green solvent as part of the Eutectic Deep Solvents (DES), studied in 2003 by Abbott *et al.* [29] which are obtained by a mixture of hydrogen bond acceptor (such as a quaternary ammonium salt) and a hydrogen bond donor species (proton donating species). One of the most common acids is carboxylic acids, belonging to green solvents because they are not highly toxic and inexpensive [30].

One of the most important applications today of the carboxylic acids is the surface modification of the nanoparticles, this because during the synthesis of the nanoparticles by any methodology these tend to agglomerate due to the van der Waals forces and the absence of repulsive forces. In addition, oxidation at the surface of the nanoparticles causes instability

which leads to aggregation [31]. One of the strategies to avoid this problem is to protect the colloidal particles with a passivating or stabilizing agent, which associates with the surface of the nanoparticles to keep them suspended, and therefore to prevent their aggregation [32]. In addition to acting as stabilizers, carboxylic acids also influence the solubility, reactivity, size and shape of nanoparticles [33]. Among other surface modifiers, the most used agents to stabilize the surface of the nanoparticles are polyvinylpyrrolidone (PVP), chitosan, starch, cellulose, and gelatin. Carboxylic acids serve as stabilizers for the preparation of nanoparticles, due to the carboxyl group provides coordination to the nanoparticles surface and therefore they stabilize. An example of this is oleic acid, which is widely used for the stabilization of nanoparticles, as well as for controlling the size and morphology of nanoparticles [34]. In this sense in 2008 Yang *et al.*, obtained nanoparticles of Fe_3O_4 with sizes of 6–30 nm using oleic acid as surfactant or surfactant, this group of researchers functionalized the nanoparticles with carboxylic acids obtaining acid catalysts for the hydrolysis of carbohydrates, being able to observe that the acid functionalization can have large advantages in producing more active catalysts and thus an application in green processes [35]. On the other hand, Cabello *et al.* were able to surface functionalize multiwall carbon nanotubes using acetic acid and aniline, assisted by ultrasound, demonstrating the hydrophilic behavior of carbon nanotubes [36].

Hojjati *et al.*, modified TiO_2 nanoparticles with carboxylic acid followed by polymerization with acrylic acid to obtain a well-dispersed nanoparticle in polyacrylic acid [37]. Armenalo used the carboxylic acid as a solvent to obtain CuS particles, finding several advantages with the use of this solvent because it favors the hydrolysis of the C-S bond thus producing a fast CuS supersaturation and a high speed of nucleation, favoring the growth of the particles and prevents agglomeration of the particles [38]. Qu *et al.* studied the chemical modification of nanoparticles of TiO_2 with carboxylic acids by the solvothermal method finding improvement in the photovoltaic performance of the TiO_2 nanoparticles despite being coated with carboxylic acid [39].

In other studies, it has been shown that the use of carboxylic acid as a surface modifier of nanoparticles can be easily redispersed in diverse matrix or solvents and improves properties as antibacterial activity [40]. In recent years, inorganic nanoparticles have been widely studied due to the excellent properties that they provide, due to their large surface area, emphasizing applications such as optical, catalytic, electrical, sensing, transport, magnetic, thermal conductivity, electromagnetic. These properties are the result of the large surface area that they possess. Metals such as gold, silver, palladium, and copper have been used to make inorganic nanoparticles of various shapes and sizes [41, 42]. The procedure and the conditions of synthesis of the nanoparticles directly influence its shape and size.

A wide variety of methods have been developed to synthesize metallic nanoparticles with different morphologies, as, nanotubes, nanodisks, nanofibers and others. In general, these procedures are classified into three groups: chemical methods, physical and biological methods.

Chemical methods are the most used, due to their ease of climbing [43]. The chemical reduction of metal salts in solution is the most commonly used method [44]. According to Slistan, the chemical reduction allows adequate control of the size, size distribution, and shape of nanoparticles [45].

In aqueous systems, the reducing agent is added or generated in situ, among the most commonly used reducing agents are sodium borohydride, hydrazine, and dimethylformamide, however in recent year's nontoxic and equally effective substances have been used, such as sodium citrate and glucose [46]. On the other hand, in non-aqueous systems, the solvent can also act as a reducing agent [47], such solvents can be alcohols such as polyethylene glycol, glycerol, and ethylene glycol, through which colloidal nanoparticles are obtained [48]. The advantage of these systems is that addition of reducing agents is not required, even synthesizing at room temperature [49]. Physical methods include electrochemical methods, laser ablation, thermolysis, microwave irradiation, and sonochemistry. For example, the thermolysis method involves the decomposition of solids at high temperature; through this process it is possible to obtain particles smaller than 5 nm [43].

Biologicals methods are developed using a metal salt and a reducing agent, which may be microorganisms, enzymes or plant extracts [49].

However, in general, the nanoparticles obtained by any methods tend to agglomerate due to the absence of repulsive forces and the forces of attraction of van der Waals [47]. Another common characteristic of metallic nanoparticles (Ag, Cu, etc.) is the oxidation of the surface causing instability of the nanoparticles and deriving in the aggregation of the same [31]. As a strategy to avoid these two major problems, the nanoparticles are modified superficially, to keep them stable in an aqueous solution and therefore to prevent their aggregation [50]. In addition to acting as stabilizers, surface modifiers also influence the solubility, reactivity, size, and shape of nanoparticles [33]. The surface modification of inorganic nanoparticles has today attracted attention, because they can be incorporated perfectly into some polymer, ceramic or metal matrix, improving the interaction between the two phases (the dispersed phase refers to the inorganic nanoparticles and the continuous phase is referred to the metallic, ceramic or polymer phase) formed nanocomposite or hybrid materials, combining the properties of the two phases [51, 52].

There are several types of surface modification such as chemical treatments, synthetic polymer grafts, the ligand exchange technique, among others; modification by chemical treatments may include reactions with metal alkoxides, carboxylic acid epoxides, silane coupling agents, among others; this being a convenient method to avoid the agglomeration of the nanoparticles and thus improve the dispersion [51], to achieve the surface modification of nanoparticles has been used ultrasonic irradiation as a technique that obeys the principles of green chemistry, because it reduces the use of solvents as well as energy. Another benefit of this technique is that the reaction mixture can be heated rapidly and uniformly, resulting in a shorter reaction time and a complete interaction avoiding the production of by-products [53].

Nanoparticles can be surface modified with adsorption of polymers on the surface, is one of the simplest methods to improve the dispersion of nanoparticles in aqueous systems. Nanoparticles with a hydrophilic behavior can be dispersed in polar solvents by modifying them with anionic or cationic polymeric dispersants. These dispersants generate repulsive forces between the particles and increase the dispersibility of the nanoparticles. In this case, the polycarboxylic acids, trioctylphosphine (TOPO), oleic acid and amines are examples of surfactants that modify nanoparticles of Al_2O_3 , Fe_2O_3 , TiO_2 and that can even be added during the synthesis of the nanoparticles [54].

The nanoparticles can also be functionalized with organic molecules with biological functions, e.g., lipids, vitamins, peptides, and sugars, in addition to other macromolecules such as proteins, enzymes, DNA and RNA. The combination of inorganic nanoparticles and biomolecules allows the use of these in biological systems because they combine unique properties for applications such as molecular recognition [55].

Another very important methodology found within the principles of green chemistry is the use of plasma to modify the surface of nanoparticles. Plasma surface modification is an effective and economical surface treatment technique for many nanoparticles.

This is a relatively simple, fast and dry method which has been used to modify the surface chemistry of different nanoparticles. It has also proved to be a versatile method since it allows the use of gases and/or organic molecules, whereby the surface modification can be adjusted to specific requirements, in other words, a particular functional group can be chosen.

This technique was originally implemented to modify the polymer surfaces, but in recent years has been used for the treatment of different nanoparticles [56]. The principle of the plasma polymerization technique is the creation of ionized and radical molecules by the bombardment of an electromagnetic field. These molecules and radicals can react with the surface of the substrate by erosion, removal, and deposition. As a result, the surface properties of the substrate will be modified.

Several organic molecules such as acrylic acid, pyrrole and styrene have been used in plasma to modify nanoparticles of zinc oxide, alumina and carbon nanofibers, respectively [57]. By this process it is possible to form a thin layer ranging from 1 to 3 nm in thickness.

The analytical methods used for characterizing the obtained nanoparticles are transmission electron microscopy (TEM) for size and shape determination, dynamic light scattering, fluorescence spectroscopy. Furthermore, binding of ligand molecules to metal nanoparticles can be probed by surface-enhanced Raman scattering.

Silver nanoparticles are recognized with antifungal and antibacterial properties and have applications in biosensing, antivirals against HIV-I, in water purification systems and paint products. In case of Au nanoparticles, these are used in cancer diagnosis and therapy, antiviral and antibacterial, MRI, biosensing applications. Magnetic nanoparticles have antimicrobial properties and are used in biomedicine such as drug delivery, magnetic resonance, and cancer treatment. The uses of TiO_2 nanoparticles that are also antimicrobial are in skin care products, nanomedicine, photocatalysis, gas sensor, wastewater to eliminate organic and inorganic pollutants. ZnO nanoparticles also have antimicrobial and anticancer properties, used in cosmetics, medical fillers, electronic and optoelectronic devices and gas sensors. The main applications of the nanoparticles of Al_2O_3 are in drug delivery, in membranes to eliminate pathogenic microorganisms, antimicrobial applications, removal of heavy metals from wastewater, in catalysis and in gas separation processes. On the other hand, the applications of SiO_2 nanoparticles are in biosensing, also serve as a carrier for antimicrobial applications, drug delivery, and tissue engineering [53].

Carboxylic acids are currently used as surface modifiers in carbon-based nanostructure: carbon nanotubes, single wall and multiple walls, graphene, nanofibers, etc., with the purpose of

improving the dispersion in polar solvents such water, ethanol, methanol, ethyl acetate, etc. This type of superficial modifications can be carried out through different alternatives making use of green chemistry, which recommend the use of sustainable activation energies such as ultrasound, microwaves, plasma, that helps to reduce energy consumption and decrease the time of reaction in the surface modification.

2.3. Polymer

The carboxylic acids present applications in the obtaining of polymers, acting as monomers, additives, initiators, catalysts, dopants, etc. Currently, an area of great interest is the production of acidic polymers, with different applications, for example in electronic area required that present characteristics such as electron donors, high solubility in aqueous solvents, etc. [58].

As additive the carboxylic acids have been studied. In 2017, it was reported the study of a series of linear carboxylic acids whit different chain lengths of 6 trans-2-hexanoic acid carbon atoms (CA-6), trans-2-decanoic acid (CA-10), 9-tetradecanoic acid (CA-14), used as halogen-free additives-solvent, considered a sustainable and viable process useful for the production of polymeric films whit optical properties, whit potential application in solar cells. The conclusion of the study showed that increasing the length of the carboxylic acid chain changes the topology of the polymeric film [59].

Recent studies reported the use of acids polymers as dopants, to access and stabilize the electrically conducting states of conducting. The acids polymers are used for replace small-molecules acids as: poly(acrylic acid), poly(styrenesulfonate) (PSS), and poly(2-acrylamido-2-methyl-1-propanesulfonic acid), (2-acrylamido-2-methyl-1-propanesulfonic acid) (PAAMPSA), because its chemical nature, helps to stabilize the conduction of the polymers, in conclusion, the presence of an excess of carboxylic acid in the chemical structure promotes good dispersion, thus stabilizing the electric nature of the doped polymers [60].

In 2012 Shi *et al.*, reported the obtaining of two new blue transmissive donor-acceptor electrochromic polymers: a polymeric material synthesized by alternating copolymerization route and another random copolymerization, demonstrating that this type of polymeric materials having characteristic as higher water solubility. The results of this study, show that these polymeric acids, present electrochromic properties [61].

Recently Mohammadifar *et al.*, reported the reaction of cationic polymerization at room temperature and solvent free to obtain polyglycerol, the polymerization is classified as green polymerization, in this type of polymerization, citric acid participates as a donor of proton, promoting polymerization, it was reported that this type of polymerization does not require a purification process which indicates that the process is very sustainable, these types of polymers may be potential candidates for biomedical applications [62].

There are different types of polymer acids, natural or synthetic, for example, polylactic acid presents applications as polymeric acid antibacterial, due to its physical and chemical characteristics, the polylactic acid can be modified or incorporated whit other polymer matrices and form composites, it also presents high biodegradability and biocompatibility, which makes it a sustainable material [63–65].

Poly (methacrylic acid), is a peculiar material, its chemical structure consists of a polar backbone where the carboxylic acid is and rest of the structure is non polar. In 2017, Robin *et al.*, reported the study of behavior rheological of concentration of the poly (methacrylic acid) in aqueous solutions and influence in viscosity [66], the purpose of this study is know the physic-chemical of the polymeric material and to be able to formulate different composites, concluding that the poly (methacrylic acid) in aqueous solutions present a rheological behavior controlled by the balance between in the different interactions intramolecular as hydrogen-bonding [66]. Also the poly (methacrylic acid) is considered a biodegradable and sustainable polymeric material, used for the obtaining of biomaterials. Poly (methacrylic acid) brushes are highly susceptible to swelling in aqueous solution due to ionization of carboxylic groups presents in their chemical structure [67].

In general, the applications of carboxylic acid in the polymer are due to the presence of a polar group that helps solvate in aqueous systems, facilitating its processing.

3. Conclusion

In conclusion, the carboxylic acids have been widely applied in different areas, highlighting organic synthesis, nanotechnology and polymers, have been used in basic applications until relevant application. In organic synthesis, carboxylic acids can act as an organic substrate, reagents in reactions “one step” which are considered “green reactions” in some cases, also are used as catalysts, presents activity in substitution, addition, condensation, polymerizations and copolymerization reactions. Actually, the research in organic synthesis is directed toward green reactions, easy, fast, economical, sustainable processes, the carboxylic acids are reagents that present a high reactivity, due to the chemical nature of the carbonyl group. In nanotechnology, the carboxylic acids are used as modifiers substrate in surface modifications of the nanostructure of carbon: CNT's or graphene, the proposal to obtain a polar surface thus improving the dispersion of the nanostructure of carbon in different polar matrices. The chemical nature of the carboxylic acids allows to carry out this type of application. Currently, in the area of polymeric materials, the carboxylic acids have been demonstrated that present important application as soluble polymer, degradation polymeric processes, obtain of composites and hybrid, a hydrophilic polymer, etc. It is considered that the application of the carboxylic acids is due to natural chemical, specifically by hydrophilic characteristic provided by the functional group. The research on the use of carboxylic acids, is very interesting, in this chapter were described some recent report. However, there are still vast challenges within this field that remain to be explored.

Acknowledgements

The authors acknowledge the financial support from project Modification of Carbon Nanotubes with Nitrogen Organic compounds obtained by Green Methodologies in the Thematic Collaboration Network: Green Organic Synthesis with Application in Nanotechnology, funded by PRODEP-México.

Author details

Aidé Sáenz-Galindo^{1*}, Lluvia I. López-López¹, Fabiola N. de la Cruz-Duran¹, Adali O. Castañeda-Facio², Leticia A. Ramírez-Mendoza¹, Karla C. Córdova-Cisneros² and Denisse de Loera-Carrera³

*Address all correspondence to: aidesaenz@uadec.edu.mx

1 Department of Organic Chemistry, Autonomous University of Coahuila, Saltillo, México

2 Department of Science and Technology of Polymer, Autonomous University of Coahuila, Saltillo, México

3 Autonomous University of San Luis Potosí, San Luis Potosí, México

References

- [1] Bian Z, Xin Z, Meng X, Tao M, Lv Y, Gu J. Effect of citric acid on the synthesis of CO methanation catalysts with high activity and excellent stability. *Industrial and Engineering Chemistry Research*. 2017;**56**:2383-2392. DOI: 10.1021/ac.iecr.6b04027
- [2] Lazzarato L, Donnola M, Rolando B, Marini E, Cena C, Coruzzi G, Guaita E, Morini G, Fruttero G, Gasco A, Biondi S, Ongini E. Searching for new NO-donor aspirin-like molecules: A new class of nitrooxy-acyl derivatives of salicylic acid. *Journal of Medicinal Chemistry*. 2008;**51**:1894-1903. DOI: 10.1021/jm701104f
- [3] Sáenz A, Rodríguez K, Rubio M, Bermúdez L, Ramírez L, Avila C, Jiménez R. Assisted surface modification with ultrasonic energy of carbon nanotubes with malic acid, malonic acid and tartaric acid. *Chemistry Advance*. 2016;**11**:47-52
- [4] Oguz O, Bilge K, Simsek E, Citak MK, Wis AA, Ozkoc G, Menciloglu YZ. High-performance green composites of poly(lactic acid) and waste cellulose fibers prepared by high-shear thermokinetic mixing. *Industrial and Engineering Chemistry Research*. 2017;**56**:8568-8579
- [5] Yasa SR, Krishnasamy S, Singh KR, Penumarthi V. Synthesis and characterization of iso-undecenoic and isoundecanoic acids based polyol esters. *Industrial and Engineering Chemistry Research*. 2017;**56**:7423-7433
- [6] Gedye R, Smith F, Westaway K, Ali H, Baldisera L, Laberge L, Rousell J. The use of microwave ovens for rapid organic synthesis. *Tetrahedron Letters*. 1986;**27**:279-282. DOI: 10.1016/S0040-4039(00)83996-9
- [7] Roughley SD, Jordan AM. The medicinal chemist's toolbox: An analysis of reactions used pursuit of drug candidates. *Journal of Medicinal Chemistry*. 2011;**54**:3451-3479. DOI: 10.1021/jm200187y
- [8] Carey JS, Laffan D, Thomson C, Williams MT. Analysis of the reactions used for the preparation of drug candidate molecules. *Organic & Biomolecular Chemistry*. 2006;**4**:2337-2347. DOI: 10.1039/B602413K

- [9] Constable DJC, Dunn PJ, Hayler JD, Humphrey GR, Leazer JJJ, Linderman RJ, Lorenz K, Manley J, Pearlman BA, Wells A, Zaks A, Zhang TY. Key green chemistry research areas-a perspective from pharmaceutical manufacturers. *Green Chemistry*. 2007;**9**:411-420. DOI: 10.1039/B703488C
- [10] Ghose AK, Viswanadhan VN, Wendoloski JJJ. A knowledge-based approach in designing combinatorial or medicinal chemistry libraries for drug discovery. 1. A qualitative and quantitative characterization of known drug databases. *Journal of Combinatorial Chemistry*. 1999;**1**:55-68. DOI: 10.1021/cc9800071
- [11] Amarnath L, Andrews I, Bandichhor R, Bhattacharya A, Dunn P, Hayler J, Hinkley W, Holub N, Hughes D, Humphreys L, Kaptein B, Krishnen H, Lorenz K, Mathew S, Nagaraju G, Rammeloo T, Richardson P, Wang L, Wells A, White T. Green chemistry articles of interest to the pharmaceutical industry. *Organic Process Research and Development*. 2012;**16**:535-544. DOI: 10.1021/op300068d
- [12] Allen CL, Chhatwal AR, Williams JM. Direct amide formation from unactivated carboxylic acids and amines. *Journal of Chemical Communications*. 2012;**48**:666-668. DOI: 10.1039/C1CC15210F
- [13] Houlding TK, Tchabanenko K, Rahman Md. T, Rebrov EV. Direct amide formation using radiofrequency heating. *Organic and Biomolecular Chemistry*. 2013;**11**:4171-4177. DOI: 10.1039/C2OB26930A
- [14] Lanigan RM, Starkov P, Sheppard TD. Direct synthesis of amides from carboxylic acids and amines using $B(OCH_2CF_3)_3$. *The Journal of Organic Chemistry*. 2013;**78**:4512-4523. DOI: 10.1021/jo400509n. <http://pubs.acs.org/doi/abs/10.1021%2Fjo400509n> (Notice: for further permissions related to the material should be directed to the ACS)
- [15] Lukasik N, Wagner-Wysiecka E. A review of amide bond formation in microwave organic synthesis. *Current Organic Synthesis*. 2014;**11**:592-604. DOI: 10.2174/1570179411666140321180857
- [16] Varma RS, Naicker KP. Solvent-free synthesis of amides from non-enolizable esters and amines using microwave irradiation. *Tetrahedron Letters*. 1999;**40**:6177-6180. DOI: 10.1016/S0040-4039(99)01209-5
- [17] Yaragorla S, Singh G, Lal Saini P, Reddy MK. Microwave assisted, Ca (II)-catalyzed Ritter reaction for the green synthesis of amides. *Tetrahedron Letters*. 2014;**55**:4657-4660. DOI: 10.1016/j.tetlet.2014.06.068
- [18] Perreux L, Loupy A, Volatron F. Solvent-free preparation of amides from acids and primary amines under microwave irradiation. *Tetrahedron*. 2002;**58**:2155-2162. DOI: 10.1016/S0040-4020(02)00085-6
- [19] Ojeda-Porras A, Hernández-Santana A, Gamba-Sánchez D. Direct amidation of carboxylic acids with amines under microwave irradiation using silica gel as a solid support. *Green Chemistry*. 2015;**17**:3157-3163. DOI: 10.1039/C5GC00189G

- [20] Ugi I, Meyr R, Fetzer U, Steinbruckner C. UGI. München: Versuche mit Isonitrilen. *Angewandte Chemie*. 1959;**71**:386. DOI: 10.1002/ange.19590711110
- [21] Ugi I. The α -addition of immonium ions and anions to isonitriles accompanied by secondary reactions. *Angewandte Chemie International Edition*. England. 1962;**1**:8-21. DOI: 10.1002/anie.196200081
- [22] Passerini M. Sopra gli Isonitrili (I). Composto del p-Isonitrilazobenzolo con Acetone ed Acido Acetico. *Gazzetta Chimica Italiana*. 1921;**51**:126-129
- [23] Passerini M. Sopra gli Isonitrili (II). Composti con Aldeidi o con Chetoni ed Acidi Organici Monobasici. *Gazzetta Chimica Italiana*. 1921;**51**:181-188
- [24] Diorazio LJ, Motherwell WB, Sheppard TD, Waller RW. Observations on the reaction of N-alkyloxazolidines, isocyanides and carboxylic acids: A novel three-component reaction leading to N-acyloxyethylamino acid amides. *Synlett*. 2006;**14**:2281-2283. DOI: 10.1055/s-2006-950413
- [25] Jahani F, Zamenian B, Khaksar S, Taibakhsh M. Pyridine 2,6-dicarboxylic acid as a bifunctional organocatalyst for hydrophosphonylation of aldehydes and ketones in water. *Synthesis*. 2010;**19**:3315-3318. DOI: 10.1055/s-0030-1257866
- [26] Dadhania AN, Patel VK, Raval DK. Ionic liquid promoted facile and green synthesis of 1,8-dioxo-octahydroxanthene derivatives under microwave irradiation. *Journal of Saudi Chemical Society*. 2014;**S163-S168**. DOI: 10.1016/j.jscs.2013.12.003. <https://creativecommons.org/licenses/by-nc-nd/4.0/>
- [27] Soham S, Chirantan K, Gopal D. Colorimetric and fluorometric discrimination of geometrical isomers maleic acid vs fumaric acid) with real-time detection of maleic acid in solution and food additives. *Analytical Chemistry*. 2015;**87**:9002-9008. DOI: 10.1021/acs.analchem.5b02202
- [28] Pai Z, Selivanova N, Oleneva P, Berdnikova P, Beskopyl'nyi A. Catalytic oxidation of alkenes with hydrogen peroxide to carboxylic acids in the presence of peroxopolyoxotungstate complexes. *Catalysis Communications*. 2017;**88**:45-49. DOI: 10.1016/j.catcom.2016.09.019
- [29] Abbott A, Capper G, Davies D, Rasheed R, Tambyrajah V. Novel solvent properties of choline chloride/urea mixtures. *Chemical Communications*. 2003;**0**:70-71. DOI: 10.1039/B210714G
- [30] Teles A, Capela E, Carmo R, Coutinho J, Sivestre A, Freire M. Solvatochromic parameters of deep eutectic solvents formed by ammonium-based salts and carboxylic acids. *Fluid Phase Equilibria*. 2017;**448**:15-21. DOI: 10.1016/j.fluid.2017.04.020
- [31] Panigrahi S, Praharaj S, Basu S, Ghosh SK, Jana S, Pande S, Vo-Dinh T, Jiang H, Pal T. Self-assembly of silver nanoparticles: Synthesis, stabilization, optical properties, and application in surface-enhanced Raman scattering. *The Journal of Physical Chemistry. B*. 2006;**110**:13436-13444. DOI: 10.1021/jp062119l

- [32] Xuping S, Yonglan L. Preparation and size control of silver nanoparticles by a thermal method. *Materials Letters*. 2005;**59**:3847-3850. DOI: 10.1016/j.matlet.2005.07.021
- [33] Sarkar A, Kapoor S, Mukherjee T. Synthesis of silver nanoprisms in formamide. *Journal of Colloid and Interface Science*. 2005;**287**:496-500. DOI: 10.1016/j.jcis.2005.02.017
- [34] Hosseini M, Parchegani F, Alavi S. Carboxylic acid effects on the size and catalytic activity of magnetite nanoparticles. *Journal of Colloid and Interface Science*. 2015;**437**:1-9. DOI: 10.1016/j.jcis.2014.08.056
- [35] Yang H, Ogawa T, Hasegawa D, Takahashi M. Synthesis and magnetic properties of monodisperse magnetite nanocubes. *Journal of Applied Physics*. 2008;**103**:7-10. DOI: 10.1063/1.2833820
- [36] Cabello C, Sáenz A, Pérez C, López L, Barajas L, Cantú L, Ávila C. Modification of multi-wall carbon nanotubes (MWNTC's) using acetic acid and aniline by ultrasonic radiation. *Revista Latinoamericana de Metalurgia y Materiales*. 2015;**35**:27-33
- [37] Hojjati B, Sui R, Charpentier. Synthesis of TiO₂/PAA nanocomposite by RAFT polymerization. *Polymer*. 2007;**48**:5850-5858
- [38] Armelao L, Camozzo D, Gross S, Tondello E. Synthesis of copper sulphide nanoparticles in carboxylic acids as solvent. *Journal of Nanoscience and Nanotechnology*. 2006;**6**:401-408
- [39] Qiyun Q, Hongwei G, Ruixiang P, Qi C, Xiaohong G, Fanqing L, Mingtai W. Chemically binding carboxylic acids onto TiO₂ nanoparticles with adjustable coverage by solvothermal strategy. *Langmuir*. 2010;**26**:9539-9546. DOI: 10.1021/la100121n
- [40] Cash BM, Wang L, Benicewicz BC. The preparation and characterization of carboxylic acid-coated silica nanoparticles. *Journal of Polymer Science part a: Polymer Chemistry*. 2012;**50**:2533-2540. DOI: 10.1002/pola.26029
- [41] Sárkány A, Papp Z, Sajó I, Sachay Z. Unsupported Pd nanoparticles prepared by γ -radiolysis of PdCl₂. *Solid State Ionics*. 2005;**176**:209-215. DOI: 10.1016/j.ssi.2004.06.008
- [42] Narayanan K, Sakthivel N. Coriander leaf mediated biosynthesis of gold nanoparticles. *Material Letters*. 2008;**62**:4588-4590. DOI: 10.1016/j.matlet.2008.08.044
- [43] Poole C, Owens F. *Introduction to Nanotechnology*. Hoboken ed. John Wiley & Sons Inc; 2003. p. 402. DOI: 10.1557/mrs2005.114
- [44] Masala O, Seshadri R. Synthesis routes for large volumes of nanoparticles. *Annual Review of Materials Research*. 2004;**34**:41-48. DOI: 10.1146/annurev.matsci.34.052803.090949
- [45] Slistan A, Herrera R, Rivas J, Avalos M, Castillon F, Posadas A. Synthesis of silver nanoparticles in a polyvinylpyrrolidone (PVP) paste, and their optical properties in a film and in ethylene glycol. *Material Research Bulletin*. 2008;**43**:90-96. DOI: 10.1016/j.materresbull.2007.02.013
- [46] Raveendran P, Fu J, Wallen S. A simple and "green" method for the synthesis of Au, Ag, and Au-Ag alloy nanoparticles. *Green Chemistry*. 2006;**8**:34-38. DOI: 10.1039/B512540E

- [47] Bradley JS, Schmid G.. Conclusions and perspectives. In: Gunter Schmid, editor. Nanoparticles: From Theory to Applications. EUA: Wiley-VCH Verlag GmbH & Co. KGaA; 2004. DOI: 10.1002/3527602399.ch7
- [48] Luo C, Zhang Y, Zeng X, Zeng Y, Wang Y. The role of poly(ethylene glycol) in the formation of silver nanoparticles. *Journal of Colloid and Interface Science*. 2005;**288**:444-448. DOI: 10.1016/j.jcis.2005.03.005
- [49] Mohamed A, Mohamed S, Aziza E, Mosaad A. Antioxidant and antibacterial activity of silver nanoparticles biosynthesized using *Chenopodium murale* leaf extract. *Journal of Saudi Chemical Society*. 2014;**18**:356-363. DOI: 10.1016/j.jscs.2013.09.011
- [50] Sun X, Luo Y. Preparation and size control of silver nanoparticles by a thermal method. *Materials Letters*. 2005;**59**:3847-3850. DOI: 10.1016/j.matlet.2005.07.021
- [51] Kango S, Kalia S, Celli A, Njuguna J, Habibi Y, Kumar R. Surface modification of inorganic nanoparticles for development of organic-inorganic nanocomposites — A review. *Progress in Polymer Science*. 2013;**(8)**:1232-1261. DOI: 10.1016/j.progpolymsci.2013.02.003
- [52] Hethnawi A, Nassar N, Vitale G. Preparation and characterization of polyethylenimine-functionalized pyroxene nanoparticles and its application in wastewater treatment. *Colloids and Surfaces, A: Physicochemical and Engineering Aspects*. 2017;**525**:20-30. DOI: 10.1016/j.colsurfa.2017.04.067
- [53] He J, Zhou L, Yang L, Zou L, Xiang J, Dong S, Xiaochao Y. Modulation of the surface structure and catalytic properties of cerium oxide nanoparticles by thermal and microwave synthesis techniques. *Applied Surface Science*. 2017;**402**:469-477. DOI: 10.1016/j.apsusc.2017.01.149
- [54] Sato K, Kondo S, Tsukada M, Ishigaki T, Kamiya H. Influence of solid fraction on the optimum molecular weight of polymer dispersants in aqueous TiO₂ nanoparticle suspensions. *Journal of the American Ceramic Society*. 2007;**90**:3401-3406
- [55] Sperling RA, Parak WJ. Surface modification, functionalization and bioconjugation of colloidal inorganic nanoparticles. *Philosophical Transactions of the Royal Society A*. 2010;**368**:1333-1383. DOI: 10.1098/rsta.2009.0273
- [56] Shi D, Wang SX, Van Ooij WJ, Wang LM, Zhao J, Yu Z Uniform deposition of ultrathin polymer films on the surfaces of Al₂O₃ nanoparticles by a plasma treatment. *Applied Physics Letters*. 2010;**78**:1243-1245. DOI: <http://dx.doi.org/10.1063/1.1352700>
- [57] Shi D, Lian J, He P, Wang LM, Xiao F, Yang L, Schulz MJ, Mast DB. Plasma coating of carbon nanofibers for enhanced dispersion and interfacial bonding in polymer composites. *Applied Physics Letters*. 2003;**83**:5301-5303. DOI: <http://dx.doi.org/10.1063/1.1636521>
- [58] Schneiderman DK, Hillmyer MA. 50th anniversary perspective: There is a great future in sustainable polymers. *Macromolecules*. 2017;**50**:3733-3749. DOI: 10.1021/acs.macromol.7b00293
- [59] Sezen-Edmonds M, Loo Y. Beyond doping and charge balancing: How polymer acid templates impact the properties of conducting polymer complexes. *Journal of Physical Chemistry Letters*. 2017;**8**:4530-4539. DOI: 10.1021/acs.jpclett.7b01785

- [60] Zhang Y, Yuan J, Sun J, Ding G, Han L, Ling X, Ma W. Alkenyl carboxylic acid: Engineering the nanomorphology in polymer-polymer solar cells as solvent additive. *ACS Applied Materials & Interfaces*. 2017;**9**:13396-13405. DOI: 10.1021/acsami.7b02075
- [61] Shi P, Amb CHA, Dyer AL, Reynolds JR. Fast switching water processable electrochromic polymers. *ACS Applied Materials and Interfaces*. 2012;**4**:6512-6521. DOI: 10.1021/am3015394
- [62] Mohammadifar E, Bodaghi A, Dadkhahtehrani A, Nemati Kharat A, Adeli M, Haag R. Green synthesis of hyperbranched polyglycerol at room temperature. *ACS Macro Letters*. 2017;**6**:35-40. DOI: 10.1021/acsmacrolett.6b00804
- [63] Laaziz SA, Raji M, Hilali E, Essabir H, Rodrigue D, Bouhfid R, Qaiss A. Bio-composites based on polylactic acid and argan nut shell: Production and properties. *International Journal of Biological Macromolecules*. 2017;**104**:30-42. DOI: 10.1016/j.ijbiomac.2017.05.184
- [64] Laadila MA, Hegde K, Rouissi T, Brar SK, Galvez R, Sorelli L, Cheikh RB, Paiva M, Abokitse K. Green synthesis of novel biocomposites from treated cellulosic fibers and recycled bio-plastic polylactic acid. *Journal of Cleaner Production*. 2017;**164**:575-586. DOI: <http://dx.doi.org/10.1016/j.jclepro.2017.06.235>
- [65] Jaso V, Glenn G, Klamczynski A, Petrovic ZS. Biodegradability study of polylactic acid/ thermoplastic polyurethane blends. *Polymer Testing*. 2015;**47**:1-3. DOI: 10.1016/j.polymertesting.2015.07.011
- [66] Robin C, Cédric Lorthioir C, Amiel C, Fall A, Ovarlez G, Le Coeur C. Unexpected rheological behavior of concentrated poly(methacrylic acid) aqueous solutions. *Macromolecules*. 2017;**50**:700-710. DOI: 10.1021/acs.macromol.6b01552
- [67] Wu Y, Nizam NM, Ding X, Xu FJ. Rational design of peptide-functionalized poly(methacrylic acid). *ACS Biomaterials Science & Engineering*. 2017. DOI: 10.1021/acs.biomaterials.7b00584

IntechOpen