

Lignocellulosic Precursors Used in the Elaboration of Activated Carbon

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1. Introduction

Many authors have defined activated carbon taking into account its most outstanding properties and characteristics. In this chapter, activated carbon will be defined stating that it is an excellent adsorbent which is produced in such a way that it exhibits high specific surface area and porosity. These characteristics, along with the surface's chemical nature (which depends on the raw materials and the activation used in its preparation process), allow it to attract and retain certain compounds in a preferential way, either in liquid or gaseous phase. Activated carbon is one of the most commonly used adsorbents in the removal process of industrial pollutants, organic compounds, heavy metals, herbicides, and dyes, among many others toxic and hazardous compounds.

The world's activated carbon production and consumption in the year 2000 was estimated to be 4×10^8 kg (Marsh, 2001). By 2005, it had doubled (Elizalde-González, 2006) with a production yield of 40%. In the industry, activated carbon is prepared by means of oxidative pyrolysis starting off soft and hardwoods, peat, lignite, mineral carbon, bones, coconut shell, and wastes of vegetable origin (Girgis et al., 2002; Marsh, 2001).

There are two types of carbon activation procedures: Physical (also known as thermal) and chemical. During physical activation, the lignocellulosic material as such or the previously carbonized materials can undergo gasification with water vapor, carbon dioxide, or the same combustion gases produced during the carbonization. Ammonium persulfate, nitric acid, and hydrogen peroxide have also been used as oxidizing agents (Salame & Bandoz, 2001). Chemical activation consists of impregnating the lignocellulosic or carbonaceous raw materials with chemicals such as $ZnCl_2$, H_3PO_4 , HNO_3 , H_2SO_4 , NaOH, or KOH (Elizalde-González & Hernández-Montoya, 2007; Girgis et al., 2002). Then, they are carbonized (a process now called "pyrolysis") and, finally, washed to eliminate the activating agent. The application of a gaseous stream such as air, nitrogen, or argon is a common practice during pyrolysis which generates a better development of the material's porosity. Although not commonly, compounds such as potassium carbonate, a cleaner chemical agent (Tsai et al., 2001b; 2001c) or formamide (Cossarutto et al., 2001) have been also used as activating agents.

Commercial activated carbon is produced as powder (PAC), fibers (FAC), or granules (GAC) depending on its application. It regularly exhibits BET specific surface magnitudes between 500 and 2000 m²g⁻¹. However, the so-called "super-activated carbons" exhibit surfaces areas above 3000 m²g⁻¹. Activated carbon's macro, meso, and micropore volumes may range from 0.5 to 2.5 cm³g⁻¹ (Marsh, 2001).

The adsorption capabilities of activated carbon are very high because of its high specific surface, originated by porosity. Also, depending on what type of activation was used, the carbon's surface may exhibit numerous functional groups, which favor the specific interactions that allow it to act as an ionic interchanger with the different kinds of pollutants.

The activated carbon is commonly considered an expensive material because of the chemical and physical treatments used in its synthesis, its low yield, its production's high energy consumption, or the thermal treatments used for its regeneration and the losses generated meanwhile. However, if its high removal capacity compared to other adsorbents is considered, the cost of production does not turn out to be very high. The search for the appropriate mechanism for its pyrolysis process is an important factor for tackling production costs.

The exhausted material's thermal regeneration (Robinson et al., 2001) consists of drying the wet carbon, pyrolysis of the adsorbed organic compounds, and reactivating the carbon, which generates mass losses up to 15 %. The carbon's regeneration can also be accomplished by using water vapor or solvents to desorb the absorbed substances, which, in turn, leads to a new problem regarding pollution. Because of these environmental inconveniences as well as the loss in adsorption capacity and the increase in costs which the regeneration process implies, using new carbon once the old one's surface has been saturated is often preferred.

With the goal of diminishing the cost of producing activated carbon, contemporary research is taking a turn towards industrial or vegetable (lignocellulosic) wastes to be used as raw material, and, then, lessen the cost of production (Konstantinou & Pashalidis, 2010). Besides, the use of these precursors reduces residue generation in both rural and urban areas.

This chapter presents a twenty-year (1992 - 2011) worldwide research review regarding a large amount of lignocellulosic materials proposed as potential precursors in the production of activated carbon. The most common characteristics that lignocellulosic wastes used in carbon production and the parameters that control porosity development and, hence, the increase in specific surface during carbonization are also mentioned. A comparison between countries whose scientists are interested in carbon preparation from alternative waste lignocellulosic materials by continent is made. The most commonly used agents for chemical, physical, or a combination of both activations methods which precursors undergo are shown.

2. Characteristics of the selected raw materials for activated carbon production

The materials selected nowadays to be potential precursors of activated carbons must fulfill the following demands:

1) They must be materials with high carbon contents and low inorganic compound levels (Tsai et al., 1998) in order to obtain a better yield during the carbonization processes. This is valid for practically every lignocellulosic wastes. They must be plentiful in the region or country where they will be used to solve any specific environmental issue. For example, corncob has been used to produce activated carbon and, according to Tsai et al. (1997), corn grain is a very important agricultural product in Taiwan. The same condition applies for the avocado, mango, orange, and guava seeds in Mexico (Elizalde-González et al., 2007; Elizalde-González & Hernández-Montoya, 2007, 2008, 2009a, 2009b, 2009c; Dávila-Jiménez et al., 2009). Specifically, Mexico has ranked number one in the world for avocado production, number two for mango, and number four for orange (Salunkhe & Kadam, 1995). On the other hand, jute stick is abundantly available in Bangladesh and India (Asadullah et al., 2007), from which bio-oil is obtained, and the process's residue has been used to produce activated carbon. Bamboo, an abundant and inexpensive natural resource in Malaysia, was also used to prepare activated carbon (Hameed et al., 2007). Cherry pits are an industrial byproduct abundantly generated in the Jerte valley at Spain's Caceres province (Olivares-Marín et al., 2006). Other important wastes generated in Spain that have also been proposed with satisfying results in the production of activated carbon with high porosity and specific surface area are: olive-mill waste generated in large amounts during the manufacture of olive oil (Moreno-Castilla et al., 2001) and olive-tree wood generated during the trimming process of olive trees done to make their development adequate (Ould-Idriss et al., 2011).

2) The residue generated during consumption or industrial use of lignocellulosic materials regularly represents a high percentage of the source from which it is obtained. For example, mango seed is around 15 to 20 % of manila mango from which it is obtained (Salunkhe & Kadam, 1995). In the case of avocado, 10 to 13 % of the fruit weight corresponds to the kernel seed and it is garbage after consumption (Elizalde-González et al., 2007). Corn cob is approximately 18 % of corn grain (Tsai et al., 2001b). Orange seeds constitute only about 0.3 % of the fresh mature fruit (Elizalde-González & Hernández-Montoya, 2009c), but orange is the most produced and most consumed fruit worldwide (Salunkhe & Kadam, 1995). Sawdust does not constitute a net percentage of tree residue, rather, it is a waste obtained from wood applications conditioning. However, it has proven to be a good precursor when it is obtained from mahogany (Malik, 2003).

3) They must be an effective and economic material to be used as an adsorbent for the removal of pollutants from both gaseous and liquid systems. Specifically, carbons produced from lignocellulosic precursors have been used to eliminate basic dyes (Elizalde-González et al., 2007; Elizalde-González & Hernández-Montoya, 2007; Girgis et al., 2002; Hameed et al., 2007; Rajeshwarisivaraj et al., 2001), acid dyes (Elizalde-González et al., 2007; Elizalde-González & Hernández-Montoya, 2008, 2009a, 2009b, 2009c; Malik, 2003; Rajeshwarisivaraj et al., 2001; Tsai et al., 2001a), reactive dyes (Elizalde-González et al., 2007; Senthilkumaara et al., 2006), direct dyes (Kamal, 2009; Namasivayam & Kavitha, 2002; Rajeshwarisivaraj et al., 2001), metallic ions such as Cr^{4+} , Hg^{2+} and Fe^{2+} (Rajeshwarisivaraj et al., 2001), Eu^{3+}

(Konstantinou & Pashalidis, 2010), Cu^{2+} (Dastgheib & Rockstraw, 2001; Konstantinou & Pashalidis, 2010; Toles et al., 1997) or Pb^{2+} (Giraldo & Moreno-Piraján, 2008), and low molecular mass organic compounds such as phenol (Giraldo & Moreno-Piraján, 2007; Wu et al., 1999, 2001), chlorophenol (Wu et al., 2001), and nitro phenol (Giraldo & Moreno-Piraján, 2008). For example, bamboo powder charcoal has demonstrated being an attractive option for treatment of superficial and subterranean water polluted by nitrate-nitrogen (Mizuta et al., 2004). Carbon produced from bamboo waste (Ahmad & Hamed, 2010) as well as the one obtained from avocado peel (Singh & Kumar, 2008) have proven effective in diminishing COD during the treatment of cotton textile mill wastewater and wastewater from coffee processing plant, respectively. Carbon molecular sieves for separating gaseous mixtures are another application of activated carbons prepared from lignocellulosic precursors (Ahmad et al., 2007; Bello et al., 2002).

3. Parameters for activated carbon preparation

Research has shown that carbons's properties such as specific surface area, porosity, density and mechanical resistance depend greatly on the raw material used. However, it may be possible to modify these parameters changing the conditions in the pyrolysis process of the lignocellulosic materials.

In particular, the most important parameters to be considered while preparing activated carbons from lignocellulosic materials are described below.

3.1 Activating agent

H_3PO_4 is the most commonly used chemical agent for synthesis of activated carbon. The use of ZnCl_2 has declined because of the environmental pollution problems with zinc disposal (Girgis et al., 2002). In the case of physical activation, the use of water vapor and carbon dioxide is preferred to promote the partial oxidation of the surface instead of oxygen, which is too reactive.

3.2 Mass ratio of precursor and activating agent

The complete saturation of lignocellulosic precursor must be ensured to develop the adsorbent porosity with the minimum activating agent consumption. This leads a minor consumption of chemical compounds and a better elimination of the excess during the carbon washing process. The effect of the increase in proportion of the impregnation over the carbon porous structure is greater than the one obtained with the increase of carbonizing temperature (Olivares-Marín et al., 2006a).

3.3 Heating speed

Regularly, heating ramps with a low speed are used for preparation of activated carbon. This approach allows the complete combustion of material precursor and favors a better porosity development. Rapid heating during pyrolysis produces macroporous residue (Heschel & Klose, 1995).

3.4 Carbonizing temperature

It has the most influence over the activated carbon's quality during the activating process. It must be at least 400 °C to ensure the complete transformation of organic compounds (present in lignocellulosic precursors) into graphene structures. The degree of specific surface area development and porosity is incremented on par with the carbonizing temperature (Olivares-Marín et al., 2006b). During physical activation, carbonization temperatures are greater than those needed for chemical activation (Lussier et al., 1994). However, carbonization temperatures used in activated carbon production are generally greater than 400 °C and temperatures ranging from 120 to 1000 °C have been used. (Elizalde et al., 2007; Elizalde-González & Hernández-Montoya, 2008; Rajeshwarisivaraj et al., 2001; Salame & Bandosz, 2001). It has been reported that carbon obtained from peach pits with temperatures below 700 °C still have a high content of hydrogen and oxygen (MacDonald & Quinn, 1996).

3.5 Carbonizing time

This parameter must be optimized to obtain the maximum porosity development while still minimizing the material's loss due to an excessive combustion. Bouchelta et al. (2008) have shown that the yield percentage decreases with increase of activation temperature and hold time. Carbonization times ranging from 1 h (Rajeshwarisivaraj et al., 2001; Wu et al., 1999) up to 14 h (Rajeshwarisivaraj et al., 2001) have been used in charcoal production.

3.6 Gas flow speed

It has been observed that during pyrolysis, the passing on an inert gas, such as N₂ or Ar, favors the development in the carbon's porosity. In this case, the flow and the gas type may affect the final properties of the activated carbon. CO₂ flow-rate had a significant influence on the development of the surface area of oil palm stones (Lua & Guo, 2000).

3.7 Effect of washing process

During the lignocellulosic residue's pyrolysis, the presence of chemical activating agents generates carbons with a more orderly structure. The later elimination of chemical activating agents, by means of successive washings, will allow a better development of porosity.

4. Worldwide studied precursors

Numerous lignocellulosic residues have been selected as potential activated carbon precursors. Among them, there is the wood obtained from several kinds of tree species such as *Eucalyptus* (Bello et al., 2002; Ngernyen et al., 2006; Rodríguez-Mirasol et al., 1993), pine (Giraldo & Moreno-Piraján, 2007; Sun et al., 2008), *Quercus agrifolia* (Robau-Sánchez et al., 2001), wattle (Ngernyen et al., 2006), china fir (Zuo et al., 2010), acacia (Kumar et al., 1992), olive tree (Ould-Idriss et al., 2011), softwood bark (Cao et al., 2002), mahogany sawdust (Malik, 2003), sawdust flash ash (Aworn et al., 2008), and sawdust (Giraldo & Moreno-Piraján, 2008; Zhang et al., 2010), coconut shell (Cossarutto et al., 2001; Giraldo & Moreno-Piraján, 2007; Hayashi et al., 2002; Heschel & Klose, 1995; Hu et al., 2001; Kannan & Sundaram, 2001), coconut fiber (Namasivayam & Kavitha, 2002; Phan et al., 2006; Senthilkumaara et al., 2006), corn cob (Aworn et al., 2008; Tsai et al., 1997; 1998; 2001a;

2001b; Tseng & Tseng, 2005; Wu et al., 2001), cherry stones (Gergova et al., 1993; 1994; Heschel & Klose, 1995; Lussier et al., 1994; Olivares-Marín et al., 2006a; 2006b), apricot stones (Gergova et al., 1993; 1994), peach stones (Heschel & Klose, 1995; MacDonald & Quinn, 1996; Molina-Sabio et al., 1995; 1996; Rodríguez-Reinoso & Molina-Sabio, 1992) and peach seed (Giraldo & Moreno-Piraján, 2007), mixture of apricot and peach stones (Puziy et al., 2005), wheat straw (Kannan & Sundaram, 2001), rice straw (Ahmedna et al., 2000) and rice husks (Ahmedna et al., 2000; Aworn et al., 2008; Kalderis et al., 2008; Kannan & Sundaram, 2001; Malik, 2003; Swarnalatha et al., 2009), sugarcane bagasse (Ahmedna et al., 2000; Aworn et al., 2008; Giraldo & Moreno-Piraján, 2007; Juang et al., 2002; 2008; Kalderis et al., 2008; Tsai et al., 2001;), palm fiber (Guo et al., 2008), palm pit (Giraldo & Moreno-Piraján, 2007; 2008), palm shell (Ahmad et al., 2007; Arami-Niya et al., 2010; Hayashi et al., 2002), stem of date palm (Jibril et al., 2008), and palm seeds (Gou et al., 2008; Hu et al., 2001), palm stones (Luo & Guo, 2000), pecan shells (Ahmedna et al., 2000; Dastgheib & Rockstraw, 2001; Toles et al., 1997), almond shells (Gergova et al., 1994; Hayashi et al., 2002; Iniesta et al., 2001; Mourao et al., 2011; Nabais et al., 2011; Rodríguez-Reinoso & Molina-Sabio, 1992; Toles et al., 1997), macadamia shells (Aworn et al., 2008; Evans et al., 1999), cedar nut shells (Baklanova et al., 2003), hazelnut shells (Heschel & Klose, 1995), pistachio shell (Hayashi et al., 2002), and walnut shells (Hayashi et al., 2002; Heschel & Klose, 1995), bamboo powder (Ahmad & Hameed, 2010; Hamed et al., 2007; Kannan & Sundaram, 2001; Mizuta et al., 2004), jute fibers (Asadullah et al., 2007; Phan et al., 2006; Senthilkumaara et al., 2006), plum kernels (Heschel & Klose, 1995; Wu et al., 1999), avocado kernel seeds (Elizalde-González et al., 2007) and avocado peel (Devi et al., 2008), coffee bean husks (Baquero et al., 2003), coffee residue (Boudrahem et al., 2009), and coffee ground (Evans et al., 1999), date stones (Bouchelta et al., 2008; Hazourli et al., 2009), grape seeds (Gergova et al., 1993, 1994), vine shoot (Mourao et al., 2011), orange seeds (Elizalde-González & Hernández-Montoya, 2008, 2009c) and guava seeds (Elizalde-González & Hernández-Montoya, 2008, 2009a, 2009b), mango pit (husk and seed) (Dávila-Jimenez et al., 2009; Elizalde-González & Hernández-Montoya, 2007; 2008), olive stones (Rodríguez-Reinoso & Molina-Sabio, 1992; Yavuz et al., 2010) and olive cake (Konstantinou & Pashalidis, 2010; Moreno-Castilla et al., 2001), peanut hull (Girgis et al., 2002; Kannan & Sundaram, 2001), cassava peel (Rajeshwarisivaraj et al., 2001), pomegranate peel (Amin, 2009), cotton stalks (Girgis & Ishak, 1999), kenaf (Valente-Nabais et al., 2009), cork waste (Carvalho et al., 2004), flamboyant pods (A.M.M. Vargas et al., 2011), rapeseed (Valente-Nabais et al., 2009), *Macuna musitana* (Vargas et al., 2010), and seed husks of *Moringa Oleifera* (Warhurst et al., 1997). Table 1 shows clearly the lignocellulosic precursors used in activated carbon production classified according to the source they were obtained from.

Figure 1 shows the great variety of lignocellulosic residues used in worldwide production of activated carbon. It can be observed that wood from several tree species, several kinds of nuts, or different coconut parts are among the most commonly used along with the traditional raw materials used for the preparation of activated carbon. This figure shows that from a single vegetable, different parts have been tested as precursors. For example, the seed and peel of avocado have been studied (Elizalde et al., 2007; Singh & Kumar, 2008). The same condition applies for the rice straw (Ahmedna et al., 2000) and the rice husk (Kalderis et al., 2008; Swarnalatha et al., 2009). Note that when carbons are prepared with lignocellulosic precursors, they are called charcoal. If they are of mineral origin, then they

are called coal. Both kinds are susceptible to chemical, physical, or a combination of both activation types to produce the outstanding activated carbons.

It has been found that the activated carbon's properties depend greatly on the composition of their raw materials (Gergova et al., 1993; Girgis et al., 2002). Development of porosity and active sites with a specific character is aided by physical activation because a partial oxidation occurs, and the carbon's surface is enriched with several functional groups (Salame & Bandoz, 2001). Chemical activation further develops these characteristics. Additionally, chemical activation has several advantages over physical activation. Besides, it is done at lower temperatures. Some authors have chosen a combination of both methods to produce their activated carbons for fitting specific applications. For example, it can be cited the activated carbon obtained from coconut peel activated with water vapor and then treated with formamide to accomplish the adsorption of the vapor (Cossarutto et al., 2001). On the other hand, there are wood carbons chemically activated with H_3PO_4 and KOH , and then treated with ammonia persulfate, nitric acid, or hydrogen peroxide (as oxidating agents) with the objective of obtaining carbons either with the nitro- group with positive charges on the nitrogen atom or with negative charges on the oxygen atoms, making them better adsorbents for ionic species (Salame & Bandoz, 2001).

Wood	<i>Eucalyptus</i>	Nuts Shells	Pecan	Palm	Fiber
	Pine		Almond		Pit
	<i>Quercus agrifolia</i>		Macadamia		Shell
	Wattle		Cedar		Stem of date
	China fir		Hazelnut		Seeds
	Acacia		Pistachio		Stones
	Olive tree	Walnut	Coconut	Shell	
	Softwood bark	Cherry		Fiber	
	Mahogany sawdust	Apricot	Straw	Rice	
	Sawdust flash ash	Peach		Wheat	
Sawdust	Plum	Peel	Avocado		
Seeds	Peach		Date	Cassava	
	Plum		Olive	Pomegranate	
	Avocado	Rice	Jute	Fibers	
	Grape	Coffee bean		Stick	
	Orange	Mango	Coffee	Ground	
	Guava	<i>Moringa Oleifera</i>		Residue	
	Mango	Corn cob	Peanut hull	Rapeseed	Cork waste
<i>Macuna musitana</i>	Kenaf	Cotton stalks	Flamboyant pods		
Sugarcane bagasse	Vine shoot	Olive cake	Bamboo powder		

Table 1. Waste materials used in activated carbon production grouped according to their source.

Although some carbons obtained from corn cob with a BET specific surface up to $2595 \text{ m}^2\text{g}^{-1}$ have been prepared via chemical activation with KOH (Tseng & Tseng, 2005), high surface areas can be obtained by means of physical activation. These carbons reach values of $1400 \text{ m}^2\text{g}^{-1}$ or more using *Eucalyptus* as the precursor and CO_2 as an oxydating agent (Ngernyen et

al., 2006; Rodríguez-Mirasol et al., 1993). Figure 2 shows that the worldwide tendency in relationship with the activation type indicates that activated carbons are physically prepared in greater amounts. This tendency may be due to the fact that the best activated carbons for adsorbing of species with positive charges are those oxidized with acid functional groups. The development of these acid groups can be done via oxidation with oxygen present in the air or using some other oxidating materials such as water vapor or carbon dioxide (Dastgheib & Rockstraw, 2001). Besides, with physical activation, there is no consumption of chemical activating agents. This simplifies the preparation of activated carbons in terms of avoiding the washing procedure involved in the chemical activation and the pollution caused by this procedure.

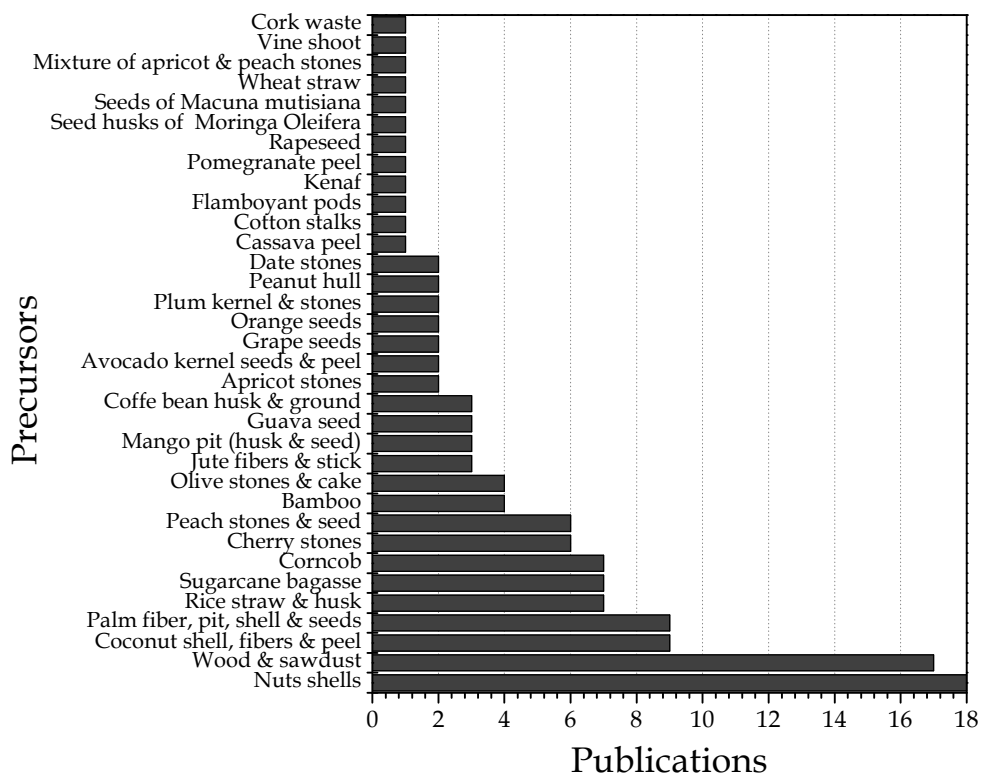


Figure 1. Lignocellulosic raw materials used in the production of activated carbon. Wood includes several varieties such as *Acacia*, *Eucalyptus*, fir, mahogany, olive, pine, and wattle. Almond, cedar, hazelnut, macadamia, pecan, pistachio, and, walnut are included in the nuts shells class.

Figure 2 also shows that some authors have also opted for combining activation methods. They use some of the most common chemical agents and then employ streams of diverse oxidating agents in place of inert gases.

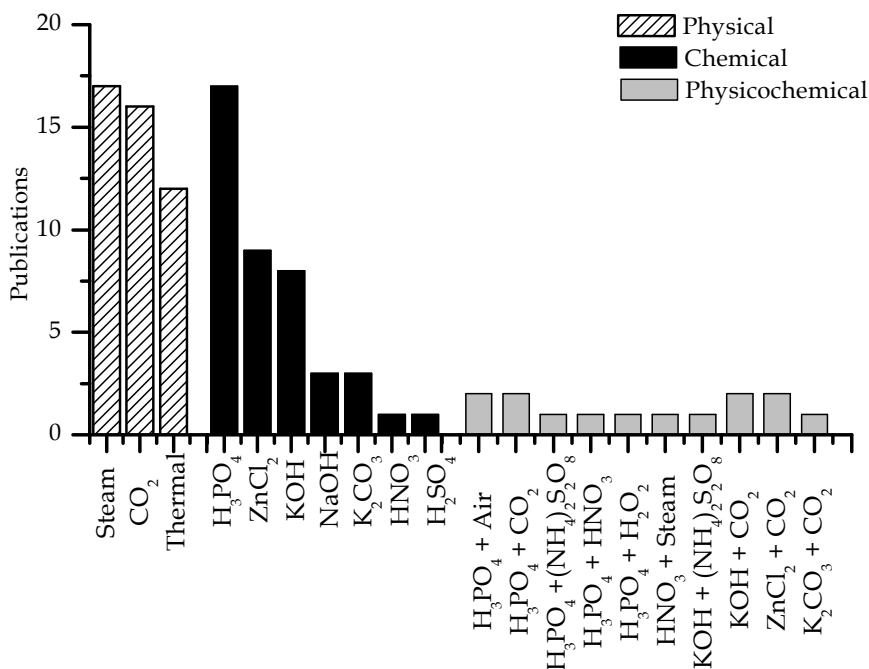


Figure 2. Comparison between the different types of activation and activating agents used in the preparation of activated carbons from lignocellulosic residues.

As a result of the review done, see Figure 3, the different countries' participation in the production of activated carbon was established for this chapter. Asia is the continent with the most research done for the reduction of costs in the production of activated carbon, followed by Europe and America. In Asia, with the exception of Japan, all the countries that participated in the research can be considered underdeveloped, same as America, with the exception of the USA and Canada. It could be thought that the USA has a high degree of research because it is a leading country in terms of technological development in many areas of knowledge. Regarding Europe, it is clear its low participation in this research field. Only Spanish researchers seem to be interested in the activated carbon production problem and they have reported the use of the diverse residues generated in their country for activated carbon preparation. In Africa, because of its underdeveloped economies, only Egypt, Algeria and Morocco participate in this research topic.

Even though the generalized tendency regarding the production of activated carbon leads towards the use of lignocellulosic materials, these can be produced from any carbon-based material (Girgis et al., 2002). Other non-conventional materials that have also been tested are the following: waste slurry of fertilizer plants and blast furnace waste (Gupta et al., 1997), bituminous coal (H. Teng et al., 1997, 1998), paper mill sludge (Khalili et al., 2000), bagasse fly ash (Gupta et al., 2000), waste tires (H. Teng et al., 2000), anthracite (Lillo-Ródenas et al., 2001; Lozano-Castelló et al., 2001), sewage sludge plus coconut husk (Graham et al., 2001;

Tay et al., 2001), sewage sludge (Graham et al., 2001), sewage sludge plus peanut shell (Graham et al., 2001), sewage sludge of derived fertilizer (Bagreev et al., 2001), viscose rayon (Ko et al., 2002), corrugated paper plus silica (Okada et al., 2005), resorcinol-formaldehyde resin (Elsayed et al., 2007), cattle manure compost (Kian et al., 2008), among others.

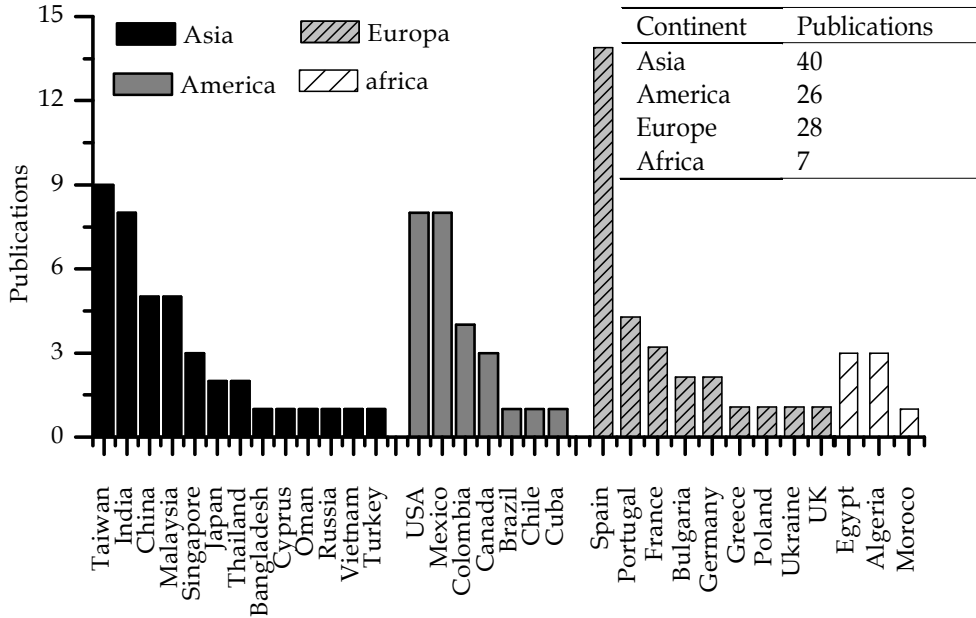


Figure 3. Worldwide distribution and production of activated carbon obtained from lignocellulosic wastes.

5. Conclusion

The literature review (1992 – 2011) indicates that worldwide researchers try to propose new sources to obtain raw materials for the production of activated carbon. They have in mind not only to lessen its cost of production, but also to diminish environmental impact of agricultural and industrial wastes. The way to enhance the adsorptive qualities of the carbons produced is also being studied to make its production more profitable, and, hence, solve specific environmental issues.

6. References

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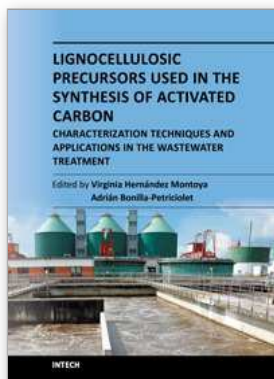
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The present book discusses the principal lignocellulosic precursors used in the elaboration of activated carbons in different countries such as Asia, America, Europe and Africa; the different methods and experimental conditions employed in the synthesis of activated carbons, including one analysis of the principal stages of the preparation such as carbonization and activation (i.e., chemical or physical activation). Also, the recent and more specialized techniques used in the characterization of activated carbons are discussed in this book. For example, the techniques employed to determine textural parameters (mercury porosimetry and gas adsorption isotherms at 77 K) and different spectroscopies to determine chemical functionality (Raman, FT-IR, etc.) and other X-Ray techniques. Additionally, an overview of the application of activated carbons obtained from lignocellulosic precursors for wastewater treatment. Specifically, the analysis and discussion are focused on the advantages and capabilities of activated carbons for the removal of relevant toxic compounds and pollutants from water such as heavy metals, dyes, phenol, etc. Finally, the use of pyrolysis method for the valorization of two Mexican typical agricultural wastes (orange peel and pecan nut shell) for energy and carbon production is considered in this book.

How to reference

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