"Energy Applications of Biomass: Dissemination Proposal for Universal Access to Knowledge." This work is the result of collaboration between prominent researchers and specialists in various areas of bioenergy and sustainability, from leading institutions in the academic field. The multidisciplinary team that has contributed to this initiative is made up of members of the Facultad de Ingeniería en Tecnología de la Madera de la Universidad Michoacana de San Nicolás de Hidalgo, la Universidad Juárez del Estado de Durango, el Instituto de Investigaciones en Ecosistemas y Sustentabilidad, la Escuela Nacional de Estudios Superiores Unidad Morelia, y el Centro de Investigación en Geografía Ambiental de la Universidad Nacional Autónoma de México. Guiados por académicos de la Universidad Intercultural Indígena de Michoacán, we have created this basic and introductory reference material on the energy use of biomass. Aimed at a broad audience that includes students, teachers, producers, members of rural and indigenous communities, local authorities, researchers, technologists and entrepreneurs, this document covers everything from basic science and the characterization of biomass resources to the estimation of energy potential, considering theoretical, geographical aspects and impact analysis. Our objective is to promote the energy and technological transition, promoting alternative, fair and sustainable scenarios that allow the democratization of energy from a local approach. We hope that this work will be a valuable tool for those seeking to understand and contribute to the development of more inclusive and responsible energy solutions.

intérprete: Arturo Aguilera Mandujano

Universidad Intercultural Indígena de Michoacán

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ENERGY APPLICATIONS OF BIOMASS

Informative proposal for universal access to knowledge

Mario Morales Máximo y Luis Bernardo López Sosa
Coordinadores

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PROLOGUE

One of the tasks that must be daily in the contemporary work of the academic sector is the dissemination and dissemination of knowledge. Faced with the problems that have worsened in recent years such as drought, change in land use, deforestation, loss of biodiversity, loss of heritage, and social transformations, it is necessary to make humanistic, scientific, technological, and innovation, at the service of society and the environment. In this sense, one of the current challenges lies in establishing dialogic knowledge processes in an inter-community, multisectoral, multidisciplinary way, everywhere and with all people. This is not an easy task, since it represents a paradigm shift in the daily lives of researchers, the technological community, and the entire academic community in general. It is not easy to leave a comfort zone and much less establish interpersonal relationships when the language, culture, and tradition are different, and that in many cases represents a barrier that makes the dialogue of knowledge and the joint construction of knowledge impossible. Therefore, strategies for dissemination, dissemination, dissemination and construction of knowledge today require articulated forms, founded and motivated by participatory, consensual processes, with community ties and close interaction with the most territorially distant populations; because it is not only necessary to reach distant places, but once arriving, learn and share, understand and build different ways of perceiving and comprehending the world, as well as co-generating knowledge. With the previous considerations, this work represents a valuable exercise, which interweaves the research work of a group of people from different universities in Mexico, who prepared 14 informative chapters on the energy use of biomass, and who, with the support of interpreters, speakers of native languages from different communities, have jointly built an unpublished multilingual editorial work that aims, on the one hand, to be a reference as dissemination material in native languages as part of a strategy for universal access to knowledge; and on the other hand, promote the rescue, preservation and revitalization of the native languages of Mexico.

This work is an example of the sum of wills to show a way to democratize knowledge and look for alternatives to overcome some of the communication challenges, looking for the most assertive channels, but mainly towards the construction of new dynamics of dissemination and dissemination of knowledge. knowledge inclusively.

Luis Bernardo López Sosa

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CHAPTER 1

GENERALITIES OF SOLID BIOFUELS

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Summary

Renewable energies include hydro, wind, geothermal, solar and biomass. The latter is an important and promising source for the generation of alternative energy to energy from fossil fuels, and is available from forestry and timber residues, in addition to different agro-industrial residues and of course from energy crops. This type of biomass and the densified solid biofuels (pellets and briquettes) that could be made from it, are an important option to achieve more sustainable and clean energy sources, and with their appropriate and sustainable use, could contribute to mitigating climate change.

Keywords: pellets, briquettes, particle density, proximal analysis, calorific value.

Renewable energy sources are a fundamental component in the search for sustainable solutions to supply the energy needs of the world population and at the same time reduce the environmental impact (Al-Shetwi et al., 2020)the grid integration requirements have become the major concern as renewable energy sources (RESs. These energy sources are characterized by their ability to regenerate naturally and continuously, unlike fossil fuels, which are finite and contribute to climate change (Mandley et al., 2020). Renewable energies can be classified as hydraulic, wind, geothermal, solar and biomass (Velázquez-Martí, 2018).

Lignocellulosic biomass is one of the promising sources for the generation of alternative energy, and is considered a source of renewable energy of great importance in the search for sustainable and clean alternatives that can satisfy energy needs, since it is derived mainly from materials vegetables composed of lignin, cellulose and hemicellulose, which are structural components of plants and can present numerous advantages as a source of renewable energy (Angulo-Mosquera et al., 2021) analyse the pretreatments and thermal treatments required to recover energy, and compare them with traditional fossil fuels. Other areas such as the sustainability and economic feasibility of solid biofuels are likewise addressed by explaining frequently used tools to evaluate the environmental impact as Life Cycle Assessment (LCA. This biomass can be obtained from agricultural, forestry and wood industry waste, as well as energy crops (Velázquez-Martí, 2018).

The use of lignocellulosic biomass as a feedstock to obtain solid biofuels has several key advantages; first of all, it helps reduce dependence on fossil fuels, thus contributing to climate change mitigation and energy security. In addition, these biofuels are carbon neutral, since the carbon dioxide (CO_2) released during their combustion is equivalent to the amount that plants absorbed during their growth, making them a more environmentally sustainable option (Morales-Máximo et al., 2022).

Solid biofuels. These biofuels are an alternative to fossil fuels and are primarily used for heat and power generation in industrial, commercial and residential applications. In general, solid biofuels are firewood, chips and charcoal, and straws and other solid biofuels from agricultural waste can also be considered (Camps and Marcos, 2008), in addition to densified ones such as pellets and briquettes (Velázquez-Martí, 2018). Table 1 shows a general classification of biofuels (Camps and Marcos, 2008).

TABLE 1. GENERAL CLASSIFICATION OF BIOFUELS

Biofuels		Size	Primary use	Alternative uses
Solids	Firewood	Variable	Domestic combustion	Charcoal, chips, soil improver
	splinters	L = 3 to 10 cm; A = 2 to 6 cm; E = 2cm	direct combustion	Pulp for paper and cardboard, fiber boards, particle boards, pellets, briquettes,
	Charcoal	Variable length D = 5 to 50cm	Domestic	Industrial, activated carbon
Densified solids	Pellets	L = 1 to 7cm; D = 6 to 25mm	Domestic heating	Automatic stoves, gasifiers, boilers
	Briquettes	L=32cm; D = 7.5 to 9 cm	Domestic heating	Boilers, wood-saving stoves

Below, you can see some relevant generic aspects of solid biofuels and later a brief description of densified solid biofuels (pellets and briquettes) derived from lignocellulosic byproducts is given.

1. Types of solid biofuels:

- Firewood: cut and dried wood used for heating and energy.
- Agricultural waste: crop remains such as straw, corn husks, etc.

- Forest waste: organic materials from forests and jungles, such as branches and leaves.
- Biomass pellets: small compressed cylinders made of materials such as sawdust, wood chips, etc.

2. Advantages:
- They are a renewable energy source, since they come from natural resources that can be regenerated.
- They reduce greenhouse gas emissions compared to fossil fuels.
- They can be a more economical option in regions with limited access to conventional fuels.

3. Challenges:
- Raw material availability may be limited and is subject to seasonal variations.
- They require specific conversion technologies and storage systems.
- They can generate emissions of fine particles and other pollutants if they are not burned efficiently.

4. Applications:
- Residential and commercial heating.
- Generation of electrical energy in biomass plants.
- Industrial processes that require heat, such as steam production in the paper or chemical industries.
- Appropriate rural technology (firewood-saving stoves, wood dryers, food cooking stoves, etc.).

5. Sustainability:
- The sustainability of solid biofuels depends on responsible forestry and agricultural practices to ensure the regeneration of the biomass used.
- Proper supply chain management is essential to minimize environmental impact.

Pellets. These are cylinders that are obtained by compaction. Briefly, the material is fed to the hopper of the pelletizing equipment and is pushed against the matrix that has circular holes through which the pellets finally emerge (Camps and Marcos, 2008).

Briquettes. They are biofuels and are also formed by compaction of lignocellulosic biomass. The shape is usually cylindrical, but there may be others. Briquettes can be obtained using heating and pressure (Camps and Marcos, 2008), but they can also be formed without the need for high pressure and at room temperature (Morales-Máximo et al., 2020).

Characteristics and properties of pellets and briquettes. The main characteristics and properties of these solid biofuels are: physical (humidity, shape, size, appearance, density and friability), chemical (elementary and basic composition, and calorific value, chemical physical (coefficient of thermal conductivity, combustibility, flammability, temperature maximum flame, heating power and energy density) (Camps and Marcos, 2008).

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CHAPTER 2

EVALUATION AND DIAGNOSIS OF LOCALLY AVAILABLE BIOMASS

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Summary

The diagnosis of energy needs through biomass is crucial to efficiently and sustainably evaluate and satisfy the energy demand in a specific region; This multidisciplinary evaluation considers technical, environmental, economic and social factors, seeking to balance human needs with environmental conservation, lignocellulosic biomass, coming from plant materials rich in cellulose, hemicellulose and lignin, stands out as a promising source of renewable energy. However, its use poses technical and economic challenges.
Keywords: Diagnosis, biomass, biofuels, local bioenergy.

Introduction

Lignocellulosic biomass, derived from agricultural and forestry waste, is considered a valuable source of renewable energy (Cai et al., 2017). This type of biomass, by capturing carbon through photosynthesis, offers environmental advantages, although it also presents challenges in efficiency and sustainable management (Orihuela et al., 2016). Technology in this field evolves to improve processes and expand applications, contributing to a more sustainable energy context.

This diagnosis focuses on evaluating and quantifying the quantity and quality of biomass available in a specific location, this provides a solid basis for strategic planning and informed decision making in relation to the use of biomass, whether for the generation energy, biofuel production, product manufacturing or soil restoration (Rezeau et al., 2018).

Performing a diagnosis of locally available biomass involves a series of key steps that allow you to collect data, analyze trends and make informed decisions.

Diagnostic Methodology

The diagnostic methodology begins with the clear definition of objectives, followed by the identification of the locality of interest, the collection of geographical data and the inventory of biological resources are key steps, the precise quantification of biomass, quality analysis and evaluation of its energy potential are essential, the consideration of social and environmental factors, together with technical and economic feasibility, guide decision making.

Steps for Diagnosis:

Definition of objectives: Before starting the diagnosis, it is crucial to clearly define the objectives being pursued, this could include evaluating the potential of biomass as a renewable energy source, identifying priority conservation areas or analyzing its use in agricultural production (Isaac et al., 2007)shade provision and low access to fertilizers often result in the purposeful integration of upper canopy trees in cocoa (Theobroma cacao.

Location Identification: Defines the geographic area of interest (region, community or specific area).

Geographic Data Collection: Gathers information on geography, topography, climate and soils, influencing the distribution of biomass.

Inventory of Biological Resources: Classifies available biological resources, including plants, trees, agricultural and forestry waste.

Identification of Biomass Sources: Maps potential sources of biomass, collaborating with local institutions and communities.

Biomass Quantification: Measures the amount of biomass using sampling methods and detection technologies, ensuring accuracy.

Biomass Quality Analysis: Evaluates moisture content, density, chemical composition and other critical factors.

Energy Potential and Uses: The energy potential of biomass is calculated and its possible applications analyzed, this may include electricity generation, heating, biogas production, biofuels and more (Morales-Máximo et al., 2021).

The energy potential of biomass is obtained from the relationship that exists between the mass of dry residue (Mrs) and the energy of the residue per unit of mass (E), also known as Calorific Value (PC). Equation 1 expresses the relationship between the variables and proposes an approximate mathematical model (Serrato Monroy & Lesmes Cepeda, 2016).

$$PE=(Mrs) * (E) \tag{1}$$

Where:
PE: Energy potential [Tj/year]
Mrs: Mass of dry waste [t/year]

E: Energy of the residue per unit of mass [Tj/t]
PC: Calorific value (MJ/kg)

Sampling and Measurement: Select representative areas for sampling, guaranteeing accuracy and proper location.

Analysis of data: Processes data collected with statistical tools and specialized software.

Interpretation and Evaluation: Analyzes results in relation to established objectives, considering the potential of biomass for specific uses.

Social and Environmental Considerations: Evaluates impact on biodiversity, water, soil and local communities.

Communication and Action: Share results with interested parties, using the information for informed decisions and management strategies.

Conclusion

The diagnosis of local biomass is essential for sustainable development, it allows efficient resource planning, cost reduction, diversification of energy sources, and contributes to local economic growth. In addition, it provides objective information for government decisions, investments and business strategies, facilitating the balance between human needs and the preservation of the environment.

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CHAPTER 3

PROSPECTIVE EVALUATION OF THE ENERGY POTENTIAL OF SPATIALLY AND TEMPORALLY AVAILABLE BIOMASS

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Summary

Below is a general description for the determination of the energy potential available in specific populations, based on spatial and temporal identification, through quantitative diagnoses, as well as the determination of the calorific value of certain types of biomass. The main interest of this proposal is oriented towards the use of agricultural and agro-industrial waste, to know the bioenergy intensity for certain areas and periods of time, in a participatory manner, and to infer the viability of implementing value chains for the generation of biofuels. solids from these wastes.
Keywords: rural energy, sustainability, community, bioenergy.

Introduction

One of the most studied renewable energy resources in recent years is biomass, this is because millions of people in the world depend on this resource to satisfy their basic daily needs (Manzano-Agugliaro et al., 2013; Serrano-Medrano M, Arias-chalico, Ghilardi and Masera, 2014; Tauro, Serrano-Medrano and Masera, 2018). Biomass as fuel is a renewable resource when managed sustainably, it is low cost, accesible and has low environmental impact.

In many rural populations, biomass is one of the most widely used energy sources (García-martínez et al., 2022; López-Sosa and García, 2022)where the production, distribution and final consumption of energy are involved in an efficient, affordable, and non-polluting way. This proposal analyzes, for a rural community in Mexico, the economic and environmental impacts associated with meeting the energy demand for lighting, cooking, entertainment and technology needs, hygiene, education and mobility; by formulating three different scenarios: (a, and is the majority source of energy, above collective and productive needs, where the latter tend to be of low consumption.

This section generally comments on the identification of agricultural, agroindustrial and community productive sector biomass residual resources. That, based on its spatial and temporal disposition, and by determining the calorific value of these wastes, it is possible to preliminarily estimate the energy potential for a certain biomass, in a certain place and with a limited time frame.

The energy potential available locally

When it comes to addressing estimates that validate the relevance of implementing technologies that take advantage of renewable energy, it is necessary to investigate the evaluations of available resources (Velasco, 2009; Jorge I., Fabio M., Paloma M., 2015). Prior to any construction process of plants or processes related to these energies, which require physical infrastructure and, therefore, investments, theoretical estimates that show the abundance or limitations of energy resources are necessary. In the case of biomass, one of the preliminary analysis tools is the estimation of the energy potential, which allows knowing the amount of energy resources that may be available in a certain place for a certain first-use or residual biomass. Estimating the available energy is not simple; it is a complex issue because it is a multidimensional resource and has diverse applications. The literature refers to biomass potential in various ways.

A high-value energy chain considers everything from the identification of biomass resources of interest to the final and useful disposition that they provide energetically for specific tasks or processes in different sectors.

Below, some recommendations will be mentioned for the study of the energy potential available from local biomass. And some considerations are assumed:

- Energy applications are estimated for solid type biofuels.
- Ideal use cases are established considering the energetically available biomass free of toxic agents.
- Biomass resources mainly refer to waste generated from agricultural and agro-industrial processes and activities.
- Biomass resources are freely accessible, without tabulated, systematized or cataloged costs for goods or services.
- The objective is to show a panorama of local management of biomass resources, attached to removal, processing and final disposal processes.
- The main classification of solid biofuels is the densified material in the form of pellets or briquettes.
- Components of the residual biomass resource management process have been identified, through previous experiences and research, from which recommendations are generated for the estimation of energy potential.

In this sense, the identification of the energy potential available for biomass that can be applied in solid biofuels does not consider aspects of technical, economic or implementation potential (Offermann et al., 2011; Ruppert, Kappas and Ibendorf, 2013; Arne Roth, 2016) only analyzes the theoretical and geographical potential, and this perspective is approached from three stages:

Identification of the available energy resource

The theoretically available energy resource is estimated from the diagnostic data of first-use or residual biomass produced in the area of study or interest. There is specialized literature on diagnostic performance that can be used for this objective (López-Sosa & Mario-Morales, 2022). Some resources from the exploratory and quantitative diagnostic methodology can be used to serve as a basis for this type of estimates. Firstly, it is necessary to generate diagnostic instruments that consider the identification of the biomass resources of interest: (a) their morphological, innocuous, dimensional, and available frequency characteristics (b) the management characteristics, how it is collected, where it is collected. groups, what processing it receives and what its use and final residence are (c) what are the possibilities of access, removal/collection and use of the waste and (d) depending on the characteristics of the biomass, investigate the information that contributes to knowing contextually the characteristics that enable its energy use. Subsequently, it is necessary to characterize the biomass resources, considering the theoretical or experimental estimation of the calorific value. In such a way that the identification of available biomass resources is combined with the unitary energy content, per unit of mass or unit of volume (cubic meter). Thus, the energy potential of biomass is obtained from the relationship between the mass of dry biomass resource (Mrs), commonly at less than 15% humidity, and the energy of the residue per unit of mass (E), also known as calorific value (PC). Equation (1) shows the relationship between the variables and proposes an approximate expression to determine the available energy potential (Morales-Máximo et al., 2023)

$$P_{e} = M_{rs} * P_{c} \tag{1}$$

where:
P_e: Potential energy [TJ/year]
M_{rs}: Mass of dry biomass resource [t/year]
P_c: Residue energy per unit of mass [TJ/t]

Although this general approximation is common to know preliminarily the energy potential, in these cases the biomass is considered to have the lowest possible moisture content, which is mostly close to 12%, and due to the estimated values of the calorific value it assumes a value higher than what biomass has under conditions of daily use for energy purposes; because it gains humidity from the environment or sometimes does not lose enough to be combusted.

The moisture content is decisive when estimating the theoretical and geographically available energy potential. Under real conditions, it is difficult to know the entire moisture content of biomass resources (FAO, 2004)and in other major databases on biomass-based energy sources. Hence, whether for energy use or otherwise, estimating the moisture content of biomass resources from a universe of samples in different locations is complex and statistically limited. This is why, in many of the generic and preliminary approaches, estimates are made where the calorific value of the dry biomass is considered. In this sense, under controlled and fairly defined conditions, in companies, workshops, generation plants or cultivation areas, statistical analyzes can be carried out that allow knowing the value of the moisture content of the biomass that is potentially willing to be burned or that is combusted or can be used in the solid biofuel manufacturing process. With this precision it is possible to know the moisture content, by ranges, averages, medians, or normal distribution. In these cases mentioned, the real net calorific value ($H_{v(w)}$), which considers the calorific value of the dry matter $H_{v(wf)}$, and the moisture content of the biomass (w), can be estimated more precisely, and is estimated with equation 2 (Kaltschmitt, Thrän and Smith, 2003; FAO, 2004):

$$H_{v(w)} = \frac{H_{v(wf)}[(100-w)-2.44w]}{100} \tag{2}$$

The constant 2.44 results from the heat of evaporation of water (Kaltschmitt, Thrän and Smith, 2003). Combining equations 1 and 2, equation 3 shows a way to estimate energy potential under humid conditions (P_{eh}) that can be statistically estimated.

$$P_{eh} = M_{rs} * H_{v(w)} \tag{3}$$

Humidity is a determining factor for the use, management of biofuels and fulfillment of tasks, but it can be overcome with adequate processing.

The technical-energy provision

Although the calorific value data and the estimation of available resources are useful to know the energy potential, it should also be noted that it is important to establish some recommendations to prioritize the technical feasibility of the waste or biomass resources analyzed from its diagnostic phase, for example:

- Collection and processing.
- Collection affordability.

Spatial and temporal arrangement

Also the estimation of the waste/biomass generated and the available energy depends on a time scale. Limited to the period of productivity, in some cases linked to harvest times, the importance of organic resources, or simply to the productive vocation of the regions, companies or farmers of interest. In any case, a monthly or annual time scale must be defined, and periodic estimates must be made to know the energy potential available during a "model year", that is, a year that is statistically common according to the recent time scale without presenting anomalies (Recent years).

On the other hand, to incorporate elements of geographical potential (the location of waste production and available energy), it is recommended to make a spatial delimitation (latitude and longitude) of the generation points of biomass resources, and combine the production intensity with the energy potential. This is achieved through the geolocation of points of interest, articulated with regional geostatistical frameworks; which, in the case of Mexico, are usually available on platforms of the National Institute of Statistics and Geography (INEGI, 2017). Thus, through the use of spatial analysis software, it is possible to create energy distribution maps by areas or focal points.

Figure 1, for example, shows an energy mapping based on the identification of waste production from 50 artisan workshops that manufacture wooden furniture in the indigenous community of San Francisco Pichátaro. Using geostatistical frameworks of the community, as well as a diagnosis of wood waste and estimating its calorific value, it was possible to know the available energy, spatially and temporally, which is around 2.8 TJ/year at its upper limit. Certainly, it is a fairly generic approximation, because the calorific value of the resource in dry matter is considered, and because estimates of waste production with little variation are assumed. But they are reference data that help build prospective scenarios, to make decisions and seek the management of alternative fuels when considered appropriate, as well as identify possible end-use technologies to optimize tasks and processes.

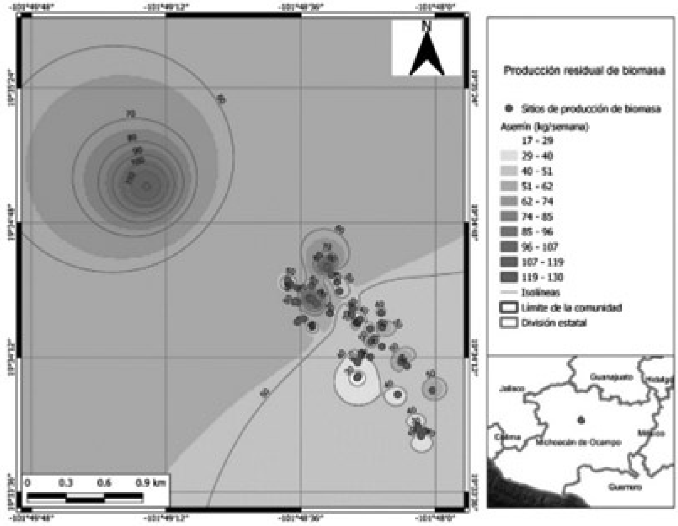

Figure 1. Energy mapping of wood waste available in 50 artisanal furniture manufacturing workshops (Morales-Máximo *et al.*, 2023).

Final comments

In this section, some aspects linked to the identification of biomass resources have been addressed, which, in short, their characterization and the identification of production in a spatial and temporal manner contribute to the determination of the available energy potential. Allowing inferring possible scenarios to define waste management production chains for the development of solid biofuels, the solid biofuel management strategy is not only linked to the estimation of biomass potential, some other aspects that are linked to the dimensions of sustainability. Although these recommendations may be general and have limitations, they represent results of common experiences of various local-scale implementation projects of resources and solid waste for rural populations. In addition, they are elements that suggest some guidelines can be considered when starting from the identification of theoretical and geographical energy potential from biomass resources, and intending to migrate to energetically productive chains supported by local solid biofuels, whose benefits in addition to energy can also be be economic and socio-environmental and generate energy democratization schemes and promote, as a goal, the construction of sustainable rural energy systems.

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CHAPTER 4

PHYSICOCHEMICAL CHARACTERIZATION OF BIOMASS RESOURCES FOR SOLID BIOFUELS: SEM, FTIR, RAMAN AND DRX

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Summary

This section descriptively addresses some characterization techniques that can be used for morphological and physicochemical analysis in biomass resources. Characterization techniques such as X-ray Diffraction, Fourier Transform Infrared Spectroscopy, Scanning Electron Microscopy and Raman Spectroscopy are mentioned. In general, in each technique, its principle of operation is discussed and the results that arise are described, emphasizing its use in biomass for use as solid biofuels.

Keywords: morphology, bioenergy, characterization, chemical analysis, materials.

Introduction

One way to analyze the insides of biomass materials is through their smallest components. That is, at the level of its atomic and physicochemical structure through specialized non-destructive techniques such as X-ray Diffraction (XRD), Fourier Transform Infrared Spectroscopy (FTIR), Scanning Electron Microscopy (SEM), Raman Spectroscopy (Raman), all specialized analysis techniques that are used in specific laboratories to know in detail the materials, their properties and possible energy applications of biomass.

These analyzes can be performed after a preparation process of the biomass samples of interest. Starting with washing to eliminate impurities that can bias sample analysis; Subsequently, drying must be carried out that adapts to the needs of the person carrying out the analysis, using conventional fuels or using renewable energy sources. After drying, the samples must be crushed by mechanical grinding, with equipment that is within reach or, using industrial crushers; This will also depend on the characteristics of the biomass resources or waste, which sometimes after drying continue to be fibrous and have a rigid consistency that is difficult to crush, as is the case with mango waste (Tiwari, Sharma and Sharma, 2016; Larios et al., 2019), while others can be easy to powder even with an agate mortar, as is the case of medicinal plants or some algae such as sargassum (López-Sosa, Alvarado-flores, et al., 2020; Khallaf and El-Sebaii, 2022). Once the samples of interest have been pulverized, different characterizations can be carried out, which are described below. This chapter generally describes the operation of the characterization techniques mentioned, and the reader is invited to delve deeper into them in specialized books for this objective (Whan, 2004; Edwards, 2005; Egerton, 2005; Abidi, 2022)the development of the Universal Attenuated Total Reflectance (UATR.

X-ray diffraction

This is one of the most used characterization techniques for the analysis of the structure of materials, that is, to know how the atoms that make up any material are organized, specifically those that have well-defined structures and form crystals. It is a non-destructive test and is the main tool for determining the phases of a crystalline material. The equipment used for this analysis is known as an X-ray diffractometer, and it works by incidenting X-rays that interact with the sample being analyzed, which in certain cases generates specialized detector. The equipment processes the X-rays that are generated after interaction with atoms (Askeland, DR, & Phulé, 2004). To process the results it is necessary to use reference standards, that is, specific data on diffraction peaks that are already known and that are contrasted with the results. This is achieved through software or with the use of cards that contain information about certain compounds, and in both cases are compared with the results obtained from the analysis with the X-ray diffractometer. X-ray Diffraction (XRD) provides information on structures of materials, organization of atoms, size of particles (Grains), among other important information (Bunaciu, Udriştioiu and Aboul-Enein, 2015)phases, preferred crystal orientations (texture. A general example of the X-ray diffractometer results can be seen in Figure 1, which shows the XRD patterns of graphite, graphene oxide and graphene from a work where graphene was synthesized using the Hummers method (Johra, Lee and Jung, 2014).

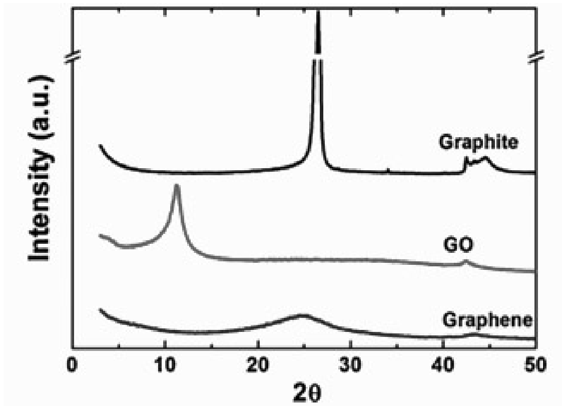

Figure 1. Comparison of the XRD patterns of graphite, graphene oxide and reduced graphene oxide (graphene)(Johra, Lee and Jung, 2014)graphene was prepared from graphite by a very simple and easy process. The two-step protocol involves conversion of graphite to graphene oxide (GO.

This technique applied to biomass resources is useful to know, for example, the content of compounds such as cellulose, hemicellulose and lignin that are useful in the study of solid biofuels (Morales-Máximo et al., 2022), as well as compounds linked to liquid type biofuels, such as some carbohydrates. This technique can be used as a base analysis to know the content of certain compounds in biomass resources.

Fourier Transform Infrared Spectrometry (FTIR)

Fourier Transform Infrared Spectroscopy (FTIR) is an essential characterization technique for determining the structure of matter at a molecular scale and is widely used to identify functional groups in solid, liquid and gaseous materials. This technique allows us to know the chemical composition and the arrangement of bonds of the constituents of a material (Salame, Pawade and Bhanvase, 2018). The molecular vibrations of some materials can be identified to know the bonds present in the sample that is of interest to analyze.

Typical FTIR equipment consists of an infrared light source (Electromagnetic Energy), a sample holder, an interferometer, a detector, an amplifier and a computer. The infrared light source generates radiation that passes through the interferometer and hits the sample, subsequently reaching the detector. The signal is amplified by the amplifier and converted to a digital signal or interferogram. Finally, the interferogram is converted into a spectrum using the Fourier transform algorithm (Kumar, 2018). An infrared spectroscopy equipment measures the absorption of infrared radiation made by each bond in the molecules and results in an absorption spectrum (database).

Using FTIR, functional groups (group of atoms responsible for the properties of the molecule) that are associated with certain compounds present in the organic matter of biomass resources can be identified, just like X-ray diffraction, but from the identification of functional groups it is possible to determine the presence of polymeric compounds useful for the development of solid biofuels. The result of the FTIR analysis is a spectrum that allows identifying transmittance bands that are identified by the equipment's software and that can also be analyzed with what is reported in specialized literature (Abidi, 2022).

An example of the results of an FTIR analysis is seen in Figure 2, where the FTIR spectra of two samples of TiO_2 nanoparticles are presented. Both samples were obtained by the sol-gel method (Bagheri, Shameli and Abd Hamid, 2013).

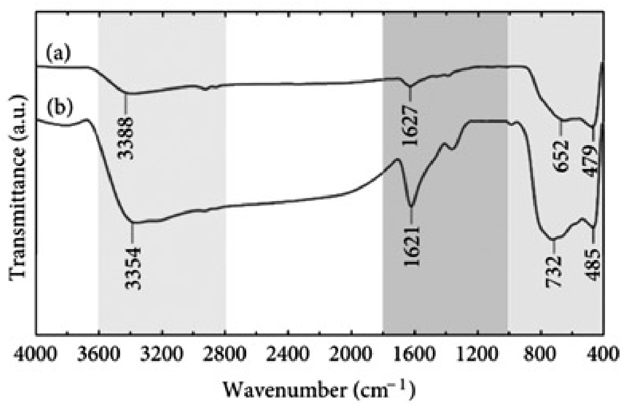

Figure 2. FTIR spectra of titania nanoparticles [5].

Some applications of FTIR analysis in solid biofuels have been previously reported and can be consulted in greater depth (López-Sosa, Alvarado-Flores, et al., 2020; Morales-Máximo et al., 2022; Morales-m et al., 2023).

Scanning Electron Microscopy

Electron microscopy has the advantage of producing high-resolution images, in addition to offering a wide range of magnification, generally in a range of 10 – 500,000 times for the Scanning Electron Microscope (SEM), the equipment with which this technique is used. This allows the characterization of microstructures of different materials at different scales, from the microscale imperceptible to the human eye, to the nanoscale imperceptible to an optical microscope (Inkson, 2016).

What light is useful to the optical microscope, electrons are to the SEM. Additionally, the electrons, having a negative charge, interact strongly with the atoms of the analyzed sample, generating a wide range of phenomena that emit different signals. These signals can be detected and processed to obtain chemical images of specific areas of the sample. The Scanning Electron Microscope (SEM) is a versatile instrument that is widely used to observe the surface morphology of materials. In an SEM equipment, the sample is bombarded with a high-energy electron beam usually produced by a tungsten filament, and the electrons and X-rays emitted by this interaction are analyzed, providing information on the topography, morphology, composition, grain orientation, crystallography, etc., of a certain material (Kumar, 2018).

In the case of biomass resources, the SEM analysis process must consider a sample with the lowest possible moisture content and crushed, requiring only a few milligrams of sample to be studied, which will be placed in a sample holder and introduced into a vacuum chamber where they will be analyzed using detectors that record the aforementioned interactions of the electron beam with the biomass sample.

An example of the result of an SEM analysis for forest biomass residues with solid biofuel applications is shown in Figure 3.

Where you can see the identification of the waste, its morphology and a semi-quantitative chemical analysis of the percentage by weight of the elements present in the waste of Bursera cuneata Schltdl (Copalillo), which results from the manufacture of wooden masks in the community of Tócuaro, Michoacán, Mexico.

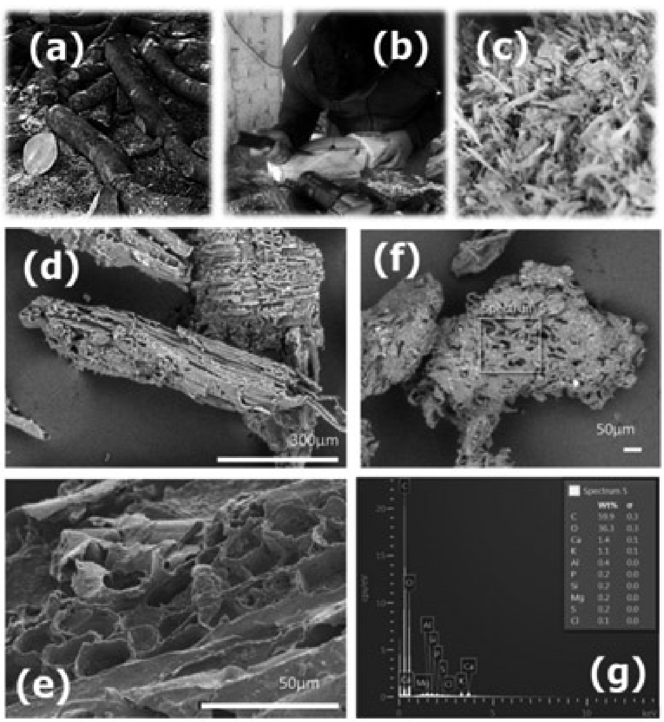

Figure 3. *Bursera cuneata Schltdl* waste generation process: (a) cutting (b) manufacturing of crafts (c) waste accumulation. SEM: (d), (e) morphology (f) (g) semi-quantitative chemical analysis (SEM-EDS)(Catillo-Tera et al., 2023)

Raman spectroscopy

Raman spectroscopy is one of the most robust and versatile characterization techniques for analyzing materials, both in the laboratory and under field conditions (Kudelski, 2008). A Raman spectroscopy equipment is composed of a light source, a monochromator, a sample holder and a detector. Different lasers are used with various wavelengths (Electromagnetic Energy), some of the most common are He:-Ne (λ = 632.8 nm), argon ion (488.0 and 514.5 nm), and diode lasers (λ = 630 and 780 nm). An example of the use of this technique is shown in Figure 4, where a Raman spectrum can be seen (Graph where it results from the processing of the data obtained from the analysis) of Zea mays (stubble) residues, the product of an investigation to identify the energy potential of that resource. In this analysis it was possible to identify compounds such asglucose and cellulose, compounds made up of carbon, hydrogen and oxygen (Morales-Máximo et al., 2022).

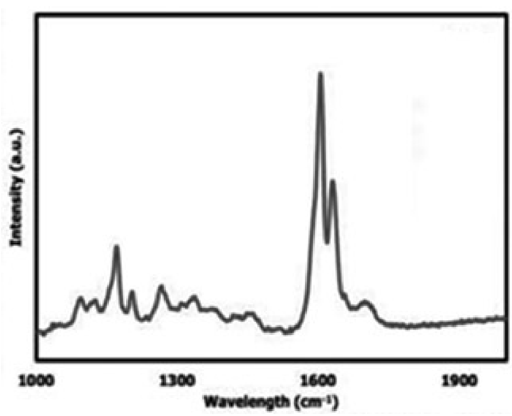

Figure 4. Raman spectrum of Zea mays residues (Morales-Máximo et al., 2022).

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CHAPTER 5

PROXIMATE ANALYSIS OF SOLID BIOFUELS: HUMIDITY, VOLATILE MATTER, ASH AND FIXED CARBON

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Summary

The proximal analysis of solid biofuels such as wood, charcoal, pellets, briquettes and other lignocellulosic materials allows us to obtain a profile of the quality of these fuels for their possible commercialization and design of the equipment for their combustion. This chapter addresses the methodologies to determine moisture content, proximal analysis, ash and fixed carbon, based on international standards. It is concluded that proximal analyzes help determine the quality of solid biofuels for commercialization, in contrast, if they do not comply with the standardizations they can be used locally.

Keywords: briquettes, pellets, biomass, lignocellulosic materials, calorific value.

Introduction

Biomass is the organic matter generated in biological processes, and within the reach of man, it has been used for energy purposes since the discovery of fire (Velázquez, 2018). Biomass can be transformed into fuel substances called biofuels (firewood, charcoal, pellets, briquettes, bioethanol, biodiesel, biogas, others), which are obtained from the physical, chemical, thermal or microbial transformation of biomass. Currently, bioenergy is the main source of renewable energy; It represents about 10% of global energy use and 77% of all renewables (biofuels, hydroelectric, solar, wind, geothermal). Most bioenergy comes from solid biofuels, which represent more than 80% of total demand (Masera and Sacramento, 2022). However, biomass is a renewable energy source that presents great structural, anatomical and chemical heterogeneity (Bustamante et al., 2016). Therefore, knowledge of the physical, chemical, proximal, and energetic characteristics of the different biomass sources is of utmost importance (Alvarado and Rutiaga, 2018). In this chapter the topic of proximal analysis will be addressed; these methods are the most used for the characterization of solid biofuels; They include the determination of the percentage of humidity, volatile matter, ash, and fixed carbon (García et al., 2012). In this sense, in order to standardize, classify and guarantee the quality of solid biofuels based on their source of origin, it is necessary to carry out proximal analyzes based on international standards (Francescato et al., 2008).

Humidity

The determination of the water content in lignocellulosic materials is a very important aspect that includes the energetic properties of biomass and in other physical and chemical conversion systems of lignocellulosic materials. The humidity of green biomass is always high, presenting values between 50% and 300% based on anhydrous weight (equation 1). The biomass exposed to the environment will reach values close to 30% (equilibrium moisture content). The moisture content of lignocellulosic materials is influenced by atmospheric humidity and can vary even on the same day and at different times. The moisture content of the biomass is an important factor that directly influences the magnitude of important parameters of biofuels such as; mass, density, and mainly in the calorific value (Núñez-Retana et al., 2019). The humidity percentage of different lignocellulosic materials is highly variable due to their hygroscopic nature. For example, different biomasses collected and characterized in the Mexican territory where ranges from 1.59 to 15.91% humidity are reported (Rutiaga-Quiñones et al., 2020). One of the methodologies used to determine the moisture content of solid biofuels is through the gravimetric method based on the UNE-EN ISO 18134-1 (2015) standard, based on the following equations where: CHh (%); moisture content based on wet weight, CHa (%); moisture content based on anhydrous weight, Ph; weight of wet sample, Pa; weight of the anhydrous sample.

$$\text{CHa (\%)} = \frac{\text{Ph} - \text{Pa}}{\text{Pa}} \text{ X } 100 \qquad (1)$$

$$\text{CHh (\%)} = \frac{\text{Ph} - \text{Pa}}{\text{Ph}} \text{ X } 100 \qquad (2)$$

Volatile material

The volatile matter is determined by the loss of mass, minus the corresponding humidity, when the solid biofuel is heated without contact with air under standardized conditions (UNE-EN ISO 18123, 2015). According to the literature, volatile matter is the fraction that transforms into gas in the combustion process; it is released when the biomass is heated from 200°C to 500°C (Velázquez, 2018). This fraction can be subdivided into light hydrocarbons, tar, carbon monoxide, carbon dioxide, hydrogen, sulfur dioxide, nitrogen oxide and water (García et al., 2012). Various investigations on the proximal analysis of different lignocellulosic materials have reported values for biomass that range between 61.2 to 90.5% and for charcoal from 28.40 to 34.25% (Ruiz-Aquino et al., 2019; Rutiaga-Quiñones et al., 2020). Below, the mathematical equation is described to determine the percentage of volatile material in biomass by gravimetry, after a pyrolysis process with heating up to 900 ±10 °C, in accordance with the UNE-EN ISO 18123 (2015) standard. based on the following equations where: A; matter lost during pyrolysis, Pi; initial weight of the sample plus crucible with lid, P; weight of residue after heating plus crucible, Pa; initial weight of the sample.

$$\%\text{Matter lost during pyrolysis} = A = \frac{Pi - P}{Pa} \times 100 \quad (3)$$

$$\%\ \text{Volatile matter} = \%\ A - \%\ \text{humidity}. \quad (4)$$

Ashes

The ash content is an important parameter to consider in the selection of a biomass as a fuel, because ash is a byproduct of combustion and can be considered an environmental pollutant, which ends up as bottom ash or fly ash and needs to be removed. Ash can be deposited or used for the production of other products, and understanding how ash gets into a fuel can have economic consequences. Furthermore, the chemical composition of ash contributes to slagging and corrosion in combustion equipment and, therefore, knowledge of the amount of ash contained in a fuel is important (UNE-EN ISO 18122, 2015). Also, it allows determining the amount of waste generated in the combustion process and is useful for the design of biomass combustion equipment (Velázquez, 2018). The main inorganic elements present in solid biofuels are: Ca, K, P, Mg, Na, Al, Cl, Fe, S, Mn, Si and Ti (Vassilev et al., 2017). The content of inorganic substances is an important characteristic of a solid biofuel (Obernberger and Thek 2010). The ash content is calculated by the percentage represented by the weight of the sample calcined at 550 °C and the weight of the anhydrous sample according to the UNE-EN ISO 18122 (2015) standard and based on the following equations where: PaM; anhydrous weight of biomass sample, Ph; wet weight, %H; humidity percentage, PaCe; anhydrous weight of ashes plus crucible, Pac; crucible anhydrous weight

$$\text{Determination of the anhydrous weight of the sample} = PaM = Ph\left(1 - \frac{\%\,H}{100}\right) \quad (5)$$

$$\%\ \text{Ashes} = \frac{PaCe - PaC}{PaM} \times 100 \quad (6)$$

Fixed carbon

Fixed carbon is the mass of the remaining organic matter, after the volatile material and moisture is released, it is considered the most energetically important component. It can be determined using some data previously obtained from the proximal analysis based on equation 7 (García et al., 2012). In the literature, fixed carbon ranges have been reported in biomasses that range from 3.44 to 23.1%, in charcoal from 62.61 to 70.36% (Ruiz-Aquino et al., 2019; Rutiaga Quiñones et al., 2020).

$$\% \text{ Fixed carbon} = 100 - (\%\text{Ash} + \%\text{Volatile matter}) \quad (7)$$

Conclusion

Proximal analyzes allow obtaining an immediate profile on the quality of solid biofuels, raw materials such as: wood and the byproducts of its primary transformation in its various physical sizes: chips, shavings, sawdust, bark, firewood, etc., and the densified materials that include pellets and briquettes made from various biomasses, charcoal and other lignocellulosic materials. These characterizations are important for their commercialization and the design of combustion equipment, supported by international standardizations. However, if solid biofuels do not meet the technical aspects, they can be used locally, for domestic use such as cooking food, heating, or industrially in the generation of energy through boilers that use biomass as fuel.

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CHAPTER 6

ELEMENTAL CHARACTERIZATION OF BIOMASS WITH A FOCUS ON ITS ENERGY POTENTIAL

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Summary

Elemental analysis is essential to quantify carbon, hydrogen, nitrogen and sulfur in biomass, influencing its quality and energy potential. During combustion, carbon and hydrogen are oxidized, forming CO_2 and water, affecting the heating value. Oxygen indicates the degree of oxidation, especially in the formation of nitrogen oxides, and can reduce the calorific value. Nitrogen in biomass can cause harmful emissions, and it is crucial to limit chlorine and sulfur to avoid environmental problems and damage to combustion equipment. Knowing the elemental composition is essential to understand the reactions, release of heat and products during combustión.

Keywords: ultimate analysis, Kjeldahl method, biomass, biofuels, CHONS.

Introduction

The elemental analysis technique allows the quantification of carbon, hydrogen, nitrogen and sulfur in various samples, whether of organic or inorganic origin, in solid or liquid states (ICB, 2016). The term “biomass” refers to all organic matter, living or dead, originated by photosynthesis of plants or animals, directly or indirectly. It is essential to note that biomass excludes coal, oil and fossilized remains. This material constitutes the most abundant form on Earth, estimating around 550 to 560 billion tons of carbon in the form of biomass (Pocha *et al.*, 2023). In another sense, the use of biomass as an energy source offers a significant advantage by contributing considerably to the reduction of CO_2 emissions in contrast to the use of hydrocarbons. This characteristic results in a substantial reduction of the adverse impact that fossil fuels exert on climate change (Callejas and

Quezada, 2009). Biomass is mainly composed of carbon, oxygen and hydrogen, although nitrogen and sulfur may sometimes be present in smaller proportions. These elements have a significant impact on the quality of biomass as fuel (Raju *et al.*, 2014).

According to Rutiaga-Quiñones *et al.* (2020), it is essential to understand in detail the elemental composition of biomass, especially when thinking about its application for energy generation. This information allows us to understand the reactions in combustion, as well as identify reactants, products and the amount of heat released. Referring to Table 1 provides relevant details on the elemental composition of biomass for energy purposes.

TABLE 1. TECHNICAL PARAMETERS OF ELEMENTAL ANALYSIS IN BIOMASS ACCORDING TO STANDARDS FOR SOLID BIOFUELS AND EFFECTS ON THE BIOFUELS INDUSTRY

Test	Analysis techniques	Technical parameters	Aspects in the Biofuels industry
Elemental analysis	The analysis of carbon, hydrogen and nitrogen is determined based on the UNE-EN ISO 16948 (2015) standard, while the oxygen content is determined by difference according to Ghetti *et al.* (nineteen ninety six). For sulfur and chlorine, the standard UNE-EN ISO 16994 (2017) is used. The Kjeldahl method is crucial in agri-food and pharmaceutical industries, and includes three phases: digestion, distillation and ammonia titration (Sáez *et al.*, 2013).	S< 0.08 % No. 0.3% [1] **S< 0.03 % N≤ 0.5% [2]** **N: 0.10 to 0.50%[3]**	During combustion, both carbon (C) and hydrogen (H) undergo oxidation through exothermic reactions, leading to the formation of carbon dioxide (CO_2) and water, which influences the properties of the fuel (Obernberger and Thek, 2004). Oxygen plays a crucial role as an indicator of the degree of oxidation in various processes, especially in the generation of nitrogen oxides released during the combustion of gases. The elevated presence of oxygen can result in a decrease in the heating value of the fuel (Calventus et al., 2009). Herbaceous biomass varieties exhibit lower carbon content compared to woody biomass variants, which has a direct impact on their gross heating value. Consequently, a higher gross heating value is observed in woody biomass (Obernberger and Thek, 2004). According to Obernberger and Thek (2004), in cases where the samples present high concentrations of nitrogen, their use will be directly linked to prohibited substances during the biomass densification process, since this leads to an increase in NOx emissions. It is essential to limit the presence of chemical contaminants, such as chlorine (Cl) and sulfur (S), in the raw material or additives, as they can have detrimental effects on the combustion process. High concentrations of these elements can generate problematic emissions, such as HCl and SOx, in addition to promoting the formation of deposits and corrosion in combustion equipment (Obernberger and Thek, 2004).
[1]ÖNORM M 7135 (2000), [2] EN 14961-2 (2011), [3]ISO 17225-2 (2014)			

Conclusion

CHONS elemental analysis in biomass is essential to understand its chemical composition, fundamental in its application as a renewable resource for energy production. By accurately determining the amounts of carbon, hydrogen, oxygen, nitrogen and sulfur, a detailed understanding of the reactions in combustion is achieved, identifying reactants, products and the amount of heat released. This knowledge allows us to design efficient and sustainable technologies to take advantage of biomass as a source of energy, evaluating both the economic and environmental viability of projects related to its use.

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CHAPTER 7

ANALYSIS OF INORGANIC SUBSTANCES IN LIGNOCELLULOSIC BIOMASS

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Summary

Wood generally contains a low concentration of ash, a material that remains after a combustion process; Values for conifers fluctuate from 0.1 to 1.0%, while in broadleaf trees there are usually slightly higher values. In other lignocellulosic materials, a greater amount of ash has been detected (10 to 22%). In the ash, different inorganic substances may be present. For the identification of inorganic compounds, present in wood, other lignocellulosic materials or other materials such as rocks, the so-called wet chemistry techniques, or more recently instrumental methods or techniques, have been used.

Keywords: inorganic substances, wet chemical analysis, instrumental analysis, XRF, ICP-AES.

Synthesis

Soil is a system made up of solids (organic and inorganic), water, air and microorganisms, in which plants grow, and reactions occur that are affected by factors, such as energy derived from the photosynthetic process, climate, change of gases with the atmosphere and by the mineral composition of the soil (Ortega-Torres, 1981). Through the process of photosynthesis, carbohydrates are synthesized, and this process plays an important role in the production of non-fossilized organic matter, that is, biomass (Ortega-Torres, 1981; Velázquez-Martí, 2018).

An example of biomass is lignocellulosic biomass, formed by cellulose, hemicelluloses, lignin, extractable substances and inorganic substances (Fengel and Wegener, 1983), and which comes from forest systems, various tree species, as well as remains and residues derived from the use of wood (Velázquez-Martí, 2018). The final analysis of the wood reflects an average of 50% carbon, 43% oxygen and 6%

hydrogen, and the rest corresponds to nitrogen and inorganic substances; For its part, the ash content in temperate woods varies from 0.1 to 1.0% and in broadleaf woods it is usually higher (Fengel and Wegener, 1983).

There are different techniques or methods used to identify the inorganic composition in plants, which have been useful in wood technology, forestry, agronomy, biology, nutrition, physiology and genetics, in addition to soils and fertilizers for crops, and in other areas.

Analysis by wet chemistry. It is also known as wet analysis and involves the identification and quantification of the chemical elements present in a sample, and can be divided into qualitative analysis (Brumblay, 1983) and quantitative analysis (Ayres 1970). The technique known as cation marching or cation analysis helps in the separation of 24 cations. Although the separation of negative ions present in a sample is not as systematic as in the case of the separation of cations, procedures must be applied that help investigate the presence of all anions. Of the 30 or 40 common negative ions, 18 are the most representative (Nordmann, 1979). Other special experiments are: a) Borax beads, b) Flame tests, c) Fluorescence, d) Use of dithizone, e) Microscopy.

Analytical instrumental techniques. For the analysis of mineral substances, there has been a shift from traditional techniques to instrumental techniques in the middle of the last century (Murfunin, 1995; Ostrooumov, 1999). Modern instruments have better possibilities for knowing the elemental composition of mineral substances over traditional methods or techniques (Ostrooumov, 2009). Some techniques used in the analysis of inorganic substances from lignocellulosic materials are the following: Atomic Absorption Spectrometry, which is often also called Atomic Absorption Analysis (AAA) (Ostrooumov, 2009), Atomic Emission Spectroscopy (AES) (Uden, 1992), Flame Emission Spectrometry (FAES) (Rolka et al., 2023), Plasma Atomic Emission SpectrometryInductively Coupled (ICP-OES) (Dahlquist et al., 1978), Spark and Arc Atomic Emission Spectroscopy (Ostrooumov, 2009; Harvey, 2023), Inductively Coupled Plasma Mass Spectrometry (ICP-MS) (Ostrooumov, 2009), Atomic Emission Spectrometry Inductively Coupled Plasma Analysis (ICP-AES) (Raja and Barron, 2023), X-ray Photoemission Spectrometry (XPS) (Padilla-Cuevas et al., 2020), X-ray Fluorescence Analysis (XRF) (Ostrooumov, 2009; Padilla-Cuevas et al., 2020), Particle-Induced X-ray Emission Spectrometry (PIXE) (Padilla-Cuevas et al., 2020) and Energy Dispersive., 2020).

In addition to the methods or techniques seen above, there are also chromatographic methods, which are useful for separating organic compounds, but also inorganic substances (Schwedt, 1994; Smith and Feinberg, 1979; Chen et al., 2007).

Influence of Chemical Elements on Combustion. The ash content is relatively low in lignocellulosic biomass, but it is important to take it into account when combusting the biomass, and it is also important to know its mineral composition, since high ash concentrations negatively affect the efficiency and combustion process (Fengel and Wegener, 1983; Bhatt and Todoria, 1992; Obernberger and Thek, 2010) and also the calorific value (Bridgeman et al., 2008).

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CHAPTER 8

THERMOGRAVIMETRIC ANALYSIS APPLIED TO BIOMASS CHARACTERIZATION

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Summary

Today, the use of agroforestry waste for the generation and optimization of energy is essential. The TGA-DTG analysis allows the simultaneous measurement of temperature, time and mass of a sample in a controlled dynamic atmosphere, allowing the determination of mass loss characteristics, its associated reaction kinetics, as well as the main thermodynamic parameters of the biomass.

Keywords: Lignocellulosic materials, TGA-DTG analysis, kinetics, mathematical modeling, thermodynamic analysis.

Introduction

Thermogravimetric analysis (TGA) is an experimental technique where the analysis of the mass change of some material, whether organic or inorganic, is carried out with respect to time and temperature, this is the foundation of the technique and in this sense, it is considered as a thermal analysis. Figure 1 illustrates a schematic of TGA equipment.

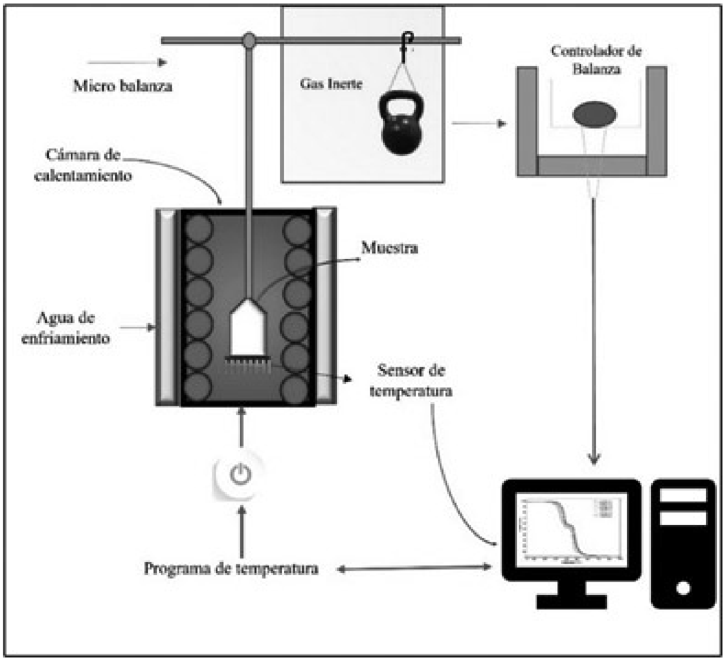

Figure 1. General diagram of a thermogravimetric analyzer (own elaboration).

An important aspect is the gas (N_2, Ar, He) used in the experiment, which can have an oxidizing, reactive or inert character. As the experiment is performed, a graph known as a thermogram is obtained. Such a graph allows the visualization of temperature or time on the horizontal axis, and the percentage of mass loss on the vertical axis (left side). Generally it is necessary to analyze the speed with which such mass loss changes with respect to time and/or temperature (DTG).

The optimization of biomass degradation can be achieved through the analysis of kinetic and thermodynamic parameters with the aim of generating high value-added products such as hydrogen with application in fuel cells (Alvarado et al., 2022).

Overview of Thermogravimetric Analysis (TGA)

Team classification for TGA

As shown in Figure 2, in general and according to the location of the sample holder, thermobalance equipment can have the load arranged in an overhead, suspended and/or horizontal manner (Auroux, 2013, Gallagher and Brown, 2003).

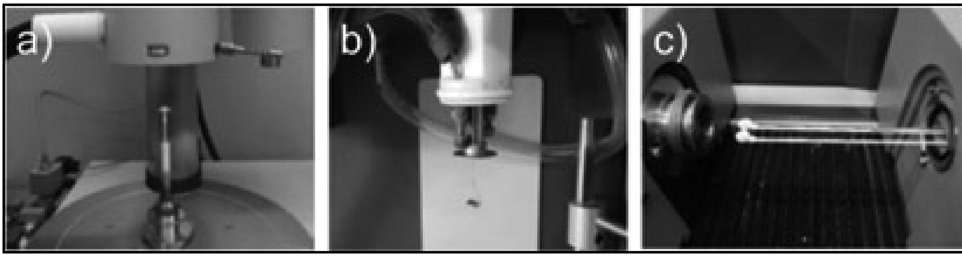

Figure 2. Classification of thermobalances, a) upper, b) suspended and c) horizontal (Auroux, 2013).

Characteristics of samples for TGA analysis

Generally, a small sample between 400-450 microns is more recommended (Alvarado et al., 2020). Not all equipment accepts the same amount; generally, loads of 10, 1.0, and 0.1 grams can be accepted, although there are equipment that can accept up to tens of grams. The above becomes more important when the analysis of very heterogeneous materials is required (Bensharada, 2022). Small mass samples can protect the thermobalance in the event of an exothermic thermal incident (Craig and Reading, 2006).

Sample temperature measurement and thermobalance

In TGA analyses, it is very common that there is a doubt about taking the temperature of the sample or the equipment for subsequent calculations such as in the kinetics of the thermal process. In this case it is necessary to know how much sample is used and how the equipment measures the temperature of the sample. Although not very reliable, in TGA equipment that uses large samples, up to tens of grams, the temperature of the sample is measured by a thermocouple embedded in the sample. In analytical TGA equipment, it is usual to use small samples (mg). In this sense, it is recommended to make temperature measurements separating the oven and the sample, therefore, care must also be taken when selecting the type of thermocouple. In general, thermocouples are classified as type B (1700°C), E (430°C), J (370°C), K (870°C) and T (200°C), which correspond to elements and/or or platinum-rhodium, nickel, iron, nickel-chromium and copper alloys respectively (Gallagher and Brown, 2003).

Mass and temperature calibration in TGA analysis

Regarding mass, there are standardization norms and they can be classified, for example, in class S (100mg) or S-1, where a maximum tolerance of 0.025 mg is considered for the first type, and double that for the second (Gallagher, 1997).

For temperature calibration, the Curie point technique is widely used for this purpose, which consists of reducing the magnetic force to practically zero values, generating an apparent loss of mass of some ferromagnetic material used, which is heated until it loses such magnetic property. Another way is the calculation of the DTG (Brown *et al.*, 1994). The "fuse-link" method is another alternative (Vyazovkin *et al.*, 2010, Vyazovkin *et al.*, 2020).

TGA-DTG analysis results report

For the TGA graph, the temperature and/or time variables are considered on the horizontal axis, and the mass degradation on the vertical axis. When you want to make the comparison on normalized data, it is convenient to show the mass in percentage. On the other hand, if the time parameter is considered on the horizontal axis, it is advisable to graph another curve of the temperature variation and its behavior over time in parallel. Figure 3 and 4 show an example of the thermogravimetric and differential analysis of marine biomass (Alvarado *et al.*, 2022).

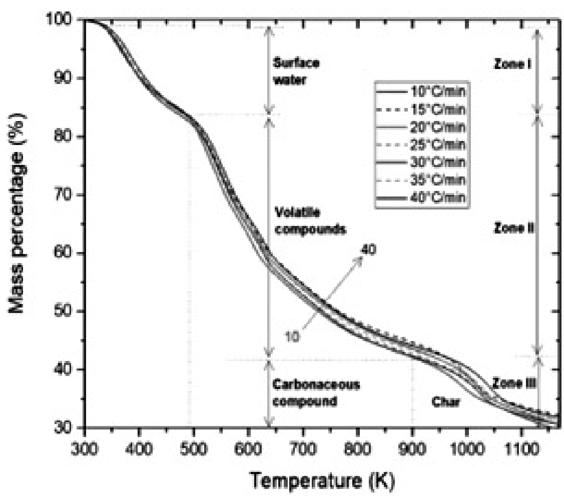

Figure 3. Thermogravimetric analysis curves of marine biomass in nitrogen (Alvarado *et al.*, 2022).

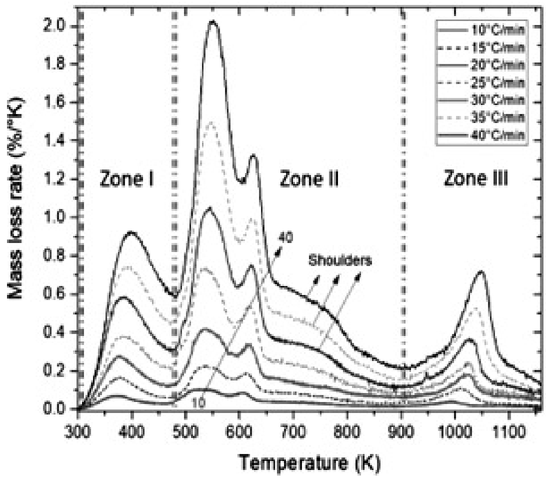

Figure 4. Curves of the differential analysis of marine biomass in nitrogen (Alvarado *et al.*, 2022).

It is worth mentioning that both the TGA and DTG curves can also be represented in the same graph. This is not very convenient in analyzes where a considerable number of heating ramps are included, unless it is required to observe the evolution at various heating speeds (see figure 4).

Derived from the treatment of TGA data, it is possible to work with empirical correlations, models and mathematical software for the determination not only of the aforementioned parameters, but also of the primary constituents of biomass such as hemicellulose, cellulose and lignin (Alvarado *et al.*, 2022; Saldarriaga *et al.*, 2015).

Primary characterization of biomass using TGA-DTG

It is essential to know the way in which mass and time are directly correlated in the DTG signals, which allows the kinetic analysis of biomass subject to thermal processes such as pyrolysis, which is the first step to be carried out (Zha *et al..*, 2023). The importance of carrying out kinetic studies lies mainly in the design of reactors and at the same time in the bioenergetic optimization of biomass as raw material. In this way, by carrying out a more in-depth analysis to calculate the kinetic parameters (activation energy, reaction order and pre-exponential factor), the operating conditions as important as biomass residence time can be correctly designed, start and end temperatures, gas pressure, flow rates of the oxidizing medium and concentrations of reagents, making it possible to scale up to biomass pyrolytic plants where it is possible to obtain high value-added products such as pellets, briquettes, coal, hydrogen and methane. Kinetic methods in pyrolysis processes make the aforementioned possible.

Kinetic and thermodynamic analysis in TGA

From the data obtained from the TGA analysis and its subsequent calculation of the derivative with respect to time or temperature, it is possible to determine the degree of advance or mass conversion of the biomass. In this way, the kinetic parameters of such conversion can be extrapolated to different temperatures (fixing the partial pressure of the gas), for isothermal series, or different heating rates for non-isothermal series. The Arrhenius expression represents the thermal decomposition of biomass as a function of the reaction rate and time under conditions where the temperature is constant. Considering the decomposition rate ($d\alpha/dt$) in non-isothermal condition, the degree of progress (α) in thermal degradation, the heating rate (β) and the approximate resolution through Doyle's method (Doyle, 1962), The pyrolysis process can be described from equation 1. However, it is necessary to consider that the temperature difference between the sample and the reference is not significant (Ali *et al.*, 2018).

$$G(\alpha) = \int_{T_0}^{T} \frac{A}{B} \exp\left[-\frac{E_a}{RT}\right] * dT \qquad (1)$$

There are dozens of mathematical models for determining kinetic parameters (Aranzazu *et al.*, 2013). There are currently six of the most widely published models today. Five of them are iso-conversional and non-iso-thermal and correspond to the mathematical models of Friedman (Luo *et al.*, 2020), Flynn-Wall-Ozawa (Rahib *et al.*, 2020), Kissinger-Akahira-Sunose (Clemente *et al.*, 2022), Starink (Singh *et al.*, 2020) and finally the Popescu iso-conversional model (Yu *et al.*, 2020). Due to the different curves and heating rates that are used with the same conversion value, these models have the advantage of obtaining a more exact profile of the activation energy depending on the degree of progress in the pyrolysis process, therefore, errors are reduced depending on the reaction mechanism (Khawam, and Flanagan, 2005). The sixth model indicated as Kissinger, unlike the previous ones, is non-iso-conversional (Vyazovkin, 2020).

To calculate the activation energy (*Ea*) in each of the methods, it is necessary to consider the value of the slope (*m*) that is formed in the resulting graph of each method. The pre-exponential factor (*A*) is directly related to the value of the ordinate or intercept at the origin according to each graphed model.

Thermodynamic analysis is part of the optimization of the thermal process of biomass waste. Once the activation energy has been obtained with each of the six aforementioned mathematical models, it is possible to calculate the thermodynamic parameters such as enthalpy (ΔH), Gibbs free energy (ΔG) and entropy (ΔS). It is advisable to calculate the thermodynamic parameters at a low heating rate between 10-15°C/min. The equations to calculate each thermodynamic parameter are well known (Alvarado *et al.*, 2022).

Conclusion

Thermogravimetric analysis (TGA) and its derivative (DTG) have been used in various materials including biomass for the study of the main reactions and primary transformations in their decomposition in inert or reactive atmosphere, in this way, one of the objectives is the analysis of thermal decomposition. It is also possible to study the reactions that occur between the sample and the purge gas if it involves mass variation (increase or decrease). Therefore, it is possible to classify the thermal processes that occur in a TGA device according to the positive (adsorption, oxidation and reduction) or negative (desorption, thermal decomposition with formation of volatiles, oxidation or combustion, vaporization and sublimation) variation of the mass. According to the data treatment and through the first derivative, it is possible to interpret the primary composition of the material, as well as the kinetic and thermodynamic parameters of thermal degradation. In this sense and once the thermal process, such as pyrolysis, has been optimized, it is possible to capture products such as methane, hydrogen, propane that can be stored and redirected for direct use in fuel cells as an alternative for the generation of electrical energy in areas that are difficult to access, where electrical networks cannot supply energy to rural communities.

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CHAPTER 9

ENERGY CHARACTERIZATION: CALORIFIC VALUE, POLYMERIC COMPOUNDS

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Summary

Polymers are organic macromolecules of high molecular mass, naturally present such as cellulose, starch and proteins, or created synthetically, such as polyethylene and polystyrene. Natural polymers composed mainly of cellulose, hemicellulose and lignin, are part of the lignocellulosic biomass of wood, crops, agricultural and forestry waste. The heating value, an important parameter of biofuels, is related to the amount of carbon-oxygen and carbon-hydrogen bonds, its determination is based on ASTM, ISO and UNE standards and methods, the value varies between 14 and 23 MJ/kg depending of its composition, which allows it to be used as an energy resource. Predictive models of heating value have been developed: some based on the ligno-holocellulosic and extractable proportions, others on the content of fixed carbon, volatile matter, ash and humidity and a third group that considers the content of elements (C, H, N, S, Cl, O and ashes).

Keywords: Biomass, volatile material, carbon, cellulose, hemicellulose, lignin, standards.

Introduction (polymeric composites)

Polymers are a diverse range of extremely heterogeneous materials that are formed by the union of smaller units called monomers. They have multiple uses in industry, from supplements in animal feed to fuel production. They are also used in the prevention of diseases and as reinforcements in thermoplastic polymers (Sánchez et al., 2022). Its low cost, wide variety of properties and versatility have boosted its use worldwide. In 2018, global production exceeded 359 million tons (Posada & Flores, 2022). Therefore, the main objective of this research is to determine and compare the heating value of polymeric compounds and their potential as a renewable energy source.

The calorific value and its relationship with other parameters in polymeric compounds of natural origin

Calorific value refers to the heat released when a mass is completely oxidized at a specific temperature and pressure, expressed in units of energy per quantity (MJ/kg or MJ/m^3). The amount of energy released can vary according to the conversion technology and the type of fuel (McKendry, 2002). The heating value may vary depending on the composition (synthetic or natural polymers) (Table 1).

TABLE 1. VALUES OF THE UPPER AND LOWER HEATING VALUE OF DIFFERENT POLYMERIC MATERIALS (IOELOVICH, 2018)

Polymeric Materials	Higher heating value (MJ/kg)	Lower heating value (MJ/kg)
Synthetic rubber (elastomer)	45.0	42.4
Polyethylene (PE)	47.1	44.6
Polystyrene (PS)	41.7	40.0
Soft woods	20.2	19.1
Bagasse	19.3	18.2
Corn stubble	17.7	17.5

Cellulose, hemicellulose, lignin and other compounds form the majority of biomass. This biomass is a renewable source of energy and its effective thermal processing requires detailed knowledge of its moisture content, heating value, fixed carbon, volatile material, ash and lignocellulosic proportion, as each impacts the available heating value. The heating value varies depending on the type of biomass, climate and soil where it is grown. The difference in the chemical composition and the proportion of these compounds in the different biomasses generate variations in the calorific value (18.6 MJ/kg in cellulose+holocellulose and 23.3-25.6 MJ/kg in lignin) (Maksimuk et al., 2021). Lignocellulosic biomasses (biopolymers) are composed in first order of the elements carbon (37-56%), hydrogen (5-7%) and oxygen (32-46%) (Huang & Lo, 2020) while the contents of sulfur and nitrogen are low. Biomasses have a high oxygen content with respect to hydrocarbons, which does not contribute to the calorific value.

Methods for the characterization of biopolymers

The characterization of biopolymers is essential to determine their energy efficiency. This is carried out through analyzes such as heating value, proximal analysis (moisture content, ash, volatile material, fixed carbon) and elemental analysis (carbon, oxygen, hydrogen, nitrogen). These values are essential to determine its energy efficiency. The detailed description of the properties is carried out following standards such as ASTM, ISO, UNE and other standardized methods.

Predictive models of calorific value

These models are based on chemical analyzes of lignocellulosic materials (biopolymers) and are divided into three groups. The first is based on structural analysis that determines the proportions of holocellulose (cellulose plus hemicellulose), lignin and extractables of the biomass. The second group comprises models based on proximal analyses, considering the content of fixed carbon, volatile material, ash and humidity. Finally, the third group consists of models based on elemental analyzes that include carbon, hydrogen, nitrogen, sulfur, chlorine, oxygen and the ash content in the biofuel.

Conclusions

Biomass is a key energy resource in the field of renewable energy. Mainly composed of three essential organic polymers: cellulose, hemicellulose and lignin, it is a polymeric product where these structural components are intertwined in a complex way, giving them their versatility and usefulness in various industries. Since it is constantly regenerated, it can be considered a fundamental polymeric compound for the production of energy and other materials. The calorific value contained in biomass varies depending on the type and growth conditions, which influences its quality as a biofuel. Its complex structure requires a multidisciplinary approach for its study and optimal use.

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CHAPTER 10

MONITORING EMISSIONS FROM THE USE OF SOLID BIOFUELS

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Summary

Currently, biofuels are little used nationally, and firewood is the most widely used biofuel. Biofuels are an alternative to reduce pollutants emitted in the different productive sectors of the country. Monitoring pollutants will allow emissions to be regulated that impact health and the environment, which will guarantee the well-being of the population, avoiding premature deaths due to smoke inhalation and contributing to conserving ecosystems. In Mexico, there is capacity and experience to evaluate and monitor the use of solid biofuels and energy eco-technologies. The evaluation and monitoring of emissions will allow the local and regional markets that use solid biofuels to be detonated in a regulated manner.

Keywords: ecotechnologies, gaseous pollutants, monitoring, economic sectors, bioenergy.

Solid biofuels in the country's productive sectors

The use of solid biofuels is a daily necessity in the different economic sectors of Mexico, mainly the residential, commercial and industrial sectors. Like firewood, which is a common biofuel for cooking, heating homes and water, and even smoking food in the residential sector (Ruiz-García et al., 2021). Charcoal is another solid biofuel used in homes in Mexico. In the commercial sector, there are charcoal grilling, bread baking, and wood-fired tortilla cooking, just to name a few. For the industrial sector, especially on a small scale, alcoholic beverages are distilled in stills that use firewood, charcoal kilns in pottery, brick kilns that use chips and waste from the wood industry, and even charcoal production kilns that use firewood. On the other hand, there are emerging solid biofuels such as pellets and briquettes. These biofuels are made with waste - such as sawdust, stubble, and fruit peels and bones - the waste is pressed to generate small cylinders that are combusted to generate heat (Musule et al., 2021), or electricity (Tauro et al, 2018) (see Figure 1).

The use of solid biofuels solves basic needs of the population. However, there is a relationship between the use of solid biofuels with the technology in which it is used; this relationship can generate abundant or zero amounts of contaminants (Serrano-Medrano et al., 2018).

Figure 1. Types of solid biofuels, on the right pine sawdust pellets, in the center white oak firewood, and on the left agricultural pruning stubble

Emissions monitoring

To evaluate emissions, there is various measuring equipment; some equipment is installed in the field while others are for exclusive use in the laboratory. On the one hand, for field measurements, there are portable gas flow analyzers. These devices are small and have integrated sensors for measuring gaseous contaminants. The sensors are calibrated to ensure correct readings, and at the end of their useful life, They are replaced with new ones. The equipment has metal probes that are placed directly in contact with the combustion gases. On the other hand, there are very robust and complex equipment, which is installed in a laboratory, and is connected to special voltage currents, to gas lines that allow to operate them, and in rooms under controlled temperature and humidity conditions (Figure 2). An example is gas chromatographs, which have a column with a length of 30 m. The column is a type of hose with a very small diameter through which the gases pass, and whose objective is for the gases to interact with the walls. inside the column to delay the passage of larger molecule gases, and allow small molecule contaminants to exit first. Each molecule will come out at a different time, these times are known as residence time, and are very important to identify contaminants (Quiñones-Reveles et al., 2021; Ruiz-García et al., 2022).

Figure 2. Equipment for measuring emissions. On the right a gas chromatograph and on the left a set of gas flow analyzers.

The captured soot has various diameters/sizes, usually the diameters of 2.5 and 10 microns are the most analyzed, known as particulate matter $PM_{2.5}$ and PM_{10}. By means of a cyclone and variations in the sampling flow, it is possible to select the particle size. The capture of particulate matter in filters is known as the gravimetric method, and consists of taking small samples of pollutants that come from chimneys of wood stoves, ovens, and boilers, just to mention a few devices, and then passing the emissions sample through a cyclone at a desired and manipulable speed that allows us to have the desired particle diameter. Finally, these particles are impacted on filters that are weighed to determine the particulate matter collected. The filters used to capture soot are of various sizes and materials (see Figure 3). Monitoring gaseous contaminants allows us to know the impacts they have on the population due to nearby sources of contaminants and/or due to the replacement of new technologies. Studies carried out on health issues show that the appropriate use of biofuels complies with air quality with respect to CO and $PM_{2.5}$ concentrations, which means that users have a greater probability of not having respiratory diseases and having years of healthy life (Ruiz-García et al., 2018).

Figure 3. Management of filters used to capture particulate matter

Monitoring equipment, whether portable or for exclusive laboratory use, must have minor annual maintenance, and major maintenance depending on its years of useful life. Unfortunately, there is a dependency on foreign equipment manufacturers, which makes the acquisition, training and maintenance of gas measurement equipment expensive. Usually, universities, government agencies and some private institutions have equipment and infrastructure to carry out this type of analysis. In Mexico, there is the Laboratorio de Innovación y Evaluación en Bioenergía (LINEB) of the Universidad Nacional Autónoma de México (UNAM), Campus Morelia, with unique capabilities and infrastructure to carry out measurements of biofuels and energy eco-technologies.

Challenges and opportunities of pollutant monitoring

The monitoring of gaseous contaminants allows us to contribute to the generation of regulations, laws and regulations to establish the maximum and minimum permissible limits of contamination, not only in environmental terms, but also in health terms (Schilmann et al., 2021). Currently, in Mexico the existing information focuses on the use of fossil fuels, and details the emissions from fixed and mobile sources, the way to measure it and there are even regulations on the subject, in the case of biofuels, the information available is very poor. Recently, the law and regulations on bioenergy were updated, which will promote the development of regulations and standards on the issue of emissions from the use of solid biofuels. For now, there is only one regulation on evaluations of wood stoves (NMX-Q-001-2018-NORMEX), which details how to measure emissions, the maximum values allowed, and the relevant equipment for measuring and collecting gases (Economy, 2018), This regulation presents the appropriate way to measure emissions for stoves that use iron and chimney, also reflected in international protocols (ISO, 2018).

Regarding the cost of the equipment, the institutions focused on monitoring gaseous contaminants are in the constant search to develop low-cost national technology, to be able to implement constant measurement campaigns and be able to document the environmental and health impacts in the various sectors, which have been evaluated on very few occasions (Figure 4).

There are some studies carried out on biofuel emissions, some focused on greenhouse gases and others on indoor air quality. The conclusions of these studies recommend the use of eco-technologies and quality biofuels. Using dry solid biofuels (humidity less than 10%) allows the combustion reaction to improve, reducing the production of pollutants. On the other hand, the use of insulators in the combustion chambers of the technologies helps conserve a greater amount of heat and benefits combustion. Ecotechnologies with chimneys used in the residential sector to carry out cooking tasks are capable of ventilating between 95-99% of the emissions to the outside of the cooking room (Figure 5).

Figure 4. Emissions in the various sectors, on the left an oven for charcoal production, in the center an oven for firing brick, and on the left an open fire for cooking.

There is a need to have more studies of this type, which will allow us to identify more types of biofuels, their qualities, identify whether they are suitable for energy purposes or should have another use, all of this will allow us to reduce the impacts on our planet and the population. These studies will even make it possible to show that the proper use of solid biofuels helps to mitigate greenhouse gases, allows for air quality inside homes, promotes local energy production at the same time that the types of biomass that are used are revalued. Previously, they were considered waste and were burned in the open air to free up the spaces where they were dumped. In this way, access to clean energy will be achieved in a more equitable manner among the most energy-vulnerable population.

Figure 5. Rural kitchen with good air quality while using a wood stove (courtesy of the Solid Biofuels Cluster).

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CHAPTER 11

APPLICATION AND EVALUATION OF THERMOGRAPHY FOR SOLID BIOFUELS

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Summary

The applications of Thermography in the analysis of Solid Biofuels (BCS), a technique based on the detection of infrared radiation, is presented as a valuable tool in the analysis (BCS) derived from lignocellulosic biomass, this method offers detailed information on the temperature and thermal variations in the production, storage and combustion stages of BCS, although thermography is essential to evaluate the quality, efficiency and safety of these renewable fuels, the importance of combining it with other analysis techniques is highlighted to obtain a complete understanding of its properties.
Keywords: Thermography, Biomass, Solid biofuels.

Introduction to thermography: Principles and Applications

Thermography is a technique used to detect and measure infrared (IR) radiation emitted by objects due to their temperature. This technique is based on the principle that all objects with a temperature above absolute zero (-273.15°C or 0 Kelvin) emit thermal radiation in the form of infrared light (from Prada Pérez de Azpeitia, 2016).

Thermography, based on the detection of infrared radiation emitted by objects according to their temperature, uses thermal imaging cameras to convert this radiation into visible images; These images, presented in colors that indicate temperature variations, are fundamental for the analysis of solid biofuels. See Figure 1. The application of thermography in this area focuses on the generation of thermal images to evaluate the quality, efficiency and behavior of the BCS, especially during combustión (Balageas, 2007).

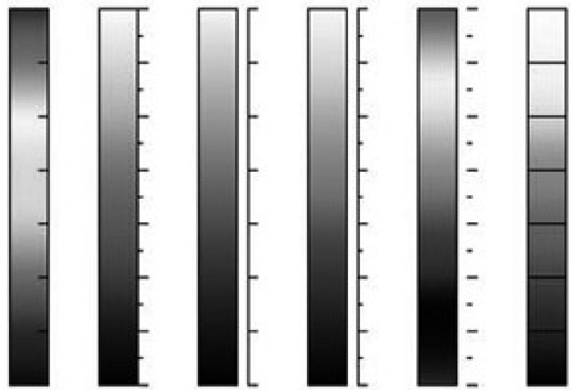

Figure 1. Color image emitted when measuring through a thermal imaging camera

In itself, thermography provides thermal images that allow studying the temperature distribution during combustion and other thermal processes. Its application is valuable to improve the efficiency, quality and safety of these fuels. Its usefulness is highlighted to evaluate the uniformity of the distribution. temperature, identify impurities and optimize combustion processes, thus contributing to the sustainable development of renewable energy sources.

Characteristics and Applications of Thermography in Solid Biofuels

Thermography stands out as an essential tool in the characterization of BCS derived from lignocellulosic biomass. Its ability to detect hot and cold spots on the surface of these fuels allows the identification of quality problems, such as uneven distribution of humidity or the presence of impurities. Furthermore, thermography is crucial in temperature control during drying and production processes, contributing to maintaining optimal ranges and improving the quality of the resulting biofuel (Gomez-Heras et al., 2013). The application of thermography extends to the detection of irregularities during the manufacture of BCS, identifying areas with problems of density, humidity or uneven energy content. In the field of combustion, thermography is revealed as an effective tool to monitor and prevent problems during long-term storage, as well as to study thermal decomposition processes (Morales-Máximo, López-Sosa, & Rutiaga-Quiñones, 2018).

Operation and Processing of Thermographic Images

The quality of thermographic images depends on careful camera configuration, proper selection of the thermal imager and prior calibration. Image processing and analysis are carried out with specialized software to identify temperature distribution patterns and anomalous areas, interpretation of results are crucial, as anomalies can indicate problems in biofuel quality, combustion efficiency or heat distribution.

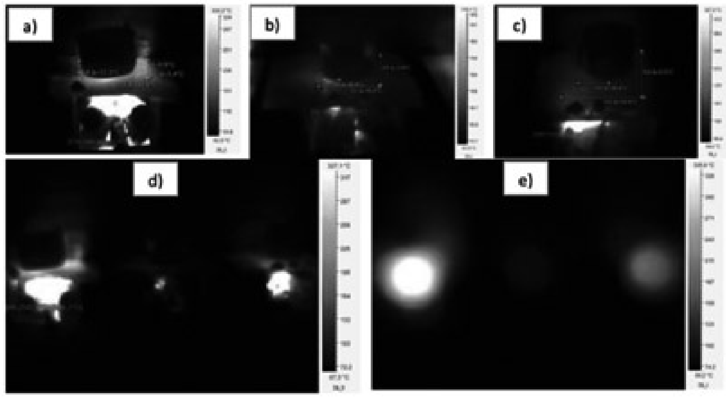

Figure 2. Distribution and measurement of thermography at different times with their respective energy emission: a) Analysis point 1, b) Analysis point 2, c) Analysis point 3, d) Analysis point 4, a) Analysis point 5.

As shown in Figure 2, comparison and follow-up analysis can be performed through the comparison of thermographic images taken at different times or conditions to evaluate changes in temperature distribution, this can provide information on the evolution of the combustion, ash formation and other related thermal processes.

Finally, the study of combustion and energy efficiency can be used in solid biofuels in combustion processes, thermography can be used to analyze the temperature distribution in the combustion bed, this can help optimize energy efficiency and reduce emissions. harmful emissions by adjusting the distribution of air and fuel flow. In itself, thermography can provide information in real time about the distribution of temperatures in the combustion zone, which can be called “hot spots”, in this sense this analysis can determine the combustion of briquettes, pellets, firewood or some other other biomass, this tool helps, as mentioned above, in the thermal release achieved by fuels at different times, which thermally visualizes the energy performance, which thermography can be used to evaluate the energy efficiency of combustion systems where solid biofuels are applied, helping to identify areas where unwanted heat loss could be occurring, as has been done and reported in previous work (Mario Morales-Máximo, 2019).

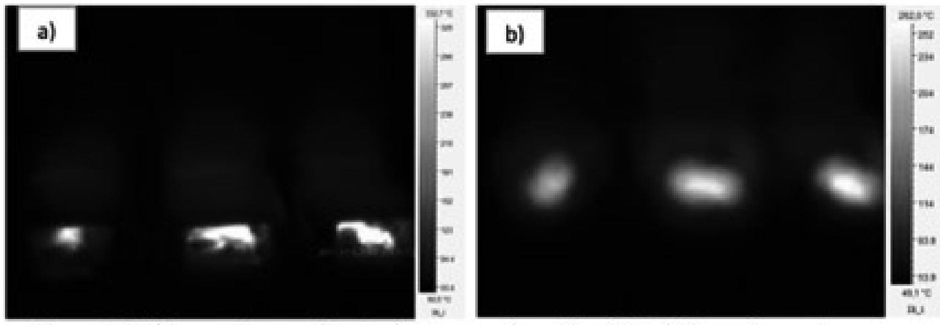

Figure 3. Combustion analysis with different approaches of the thermal imaging camera: a) Minimum blurring, b) Maximum blurring

Conclusions and Future Perspectives

In conclusion, thermography emerges as a valuable technique for the comprehensive analysis of solid biofuels, offering detailed information about their temperature and thermal distribution; However, the need for experience and specialized knowledge to correctly interpret the images is emphasized, and the importance of establishing consistent measurement and analysis protocols is highlighted to obtain reliable and significant results. Thermography not only improves the efficiency and quality of current solid biofuels, but is also positioned as an essential tool in the research and development of new types of fuels derived from lignocellulosic biomass.

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CHAPTER 12

SUSTAINABILITY OF SOLID BIOFUELS

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Summary

Biomass is the main source of renewable energy in the world. There are solid biofuels (BCS) such as firewood and charcoal, which are widely used for cooking in rural and urban areas, however, there are other so-called modern BCS, such as pellets and briquettes. All BCS have impacts on sustainability, both in positive and negative terms. The main impacts on the sustainability of BCS are in air polluting emissions and their respective damage to health, the potential deforestation and degradation of forests if these are not produced carefully, the possible contribution to climate change if technologies are not used. adequate, as well as impacts on biodiversity. In positive terms, BCS can contribute to rural development and job creation, to the substitution of fossil fuels in industry in a cost-effective manner, while mitigating greenhouse gas emissions.

Introduction

Energy obtained from biomass is the main source of renewable energy globally with around 10% of energy consumption (IRENA, 2022). Most of this energy comes from so-called solid biofuels (BCS), mainly from firewood used in homes for cooking, especially in rural and peri-urban areas. The use of BCS in modern applications contributes to 41% of BCS consumption.

BCS are varied in terms of their origin, transformation and final uses. In general we can find firewood and charcoal; forest and forestry industry waste; pellets and briquettes and; agricultural and agroindustrial waste.

The use of BCS requires understanding the impacts on sustainability[1] of these fuels, so that they can be used in a lasting way in the long term and enhance their

1 This chapter uses the definition of sustainability as established by Vallesi et al. (2012) "a production and use of biomass without harming nature and maintaining nature's ability to produce biomass permanently in the future." The environmental, social and economic dimensions of sustainability are also considered.

environmental and socioeconomic benefits, while reducing their negative impacts.

The sustainability impacts of BCS are varied, both in a positive sense, that is, they promote improvements in the social, environmental and economic dimensions, and negative impacts in these same dimensions. In terms of positive impacts, in general BCS represent comparative advantages with respect to other renewable energy sources, for example, they generate greater job creation and rural development, while allowing for improved energy security, since they have with the potential to mitigate greenhouse gas emissions (Manzini et al., 2021; WBGU, 2009).

Sustainability impacts of solid biofuels (BCS)

Below, a general review of the sustainability impacts of BCS is presented, starting with the fuels used in rural homes, to continue with the so-called modern fuels.

Firewood and charcoal

Firewood is the most used BCS globally and in Mexico. It is estimated that around 2.8 billion people in the world rely heavily on this fuel to meet their cooking, water heating and heating needs. The use of firewood occurs mainly in inefficient devices, which causes unnecessary extraction of forest resources and has a negative impact on forests (Ahmed et al., 2022). The devices traditionally used also have disadvantages in terms of damage to health, this is because the gases and particulate matter resulting from combustion are in contact with users (generally women and children in rural and peri-urban areas) in closed spaces, so they are inhaled.

To alleviate the effects of the inefficient use of firewood, a change to cleaner and more efficient technologies has been proposed. These technologies are varied and have different degrees of emissions, however, advantages have been documented due to their implementation not only in the field of health, but also in saving monetary resources, usually scarce in rural contexts.

For its part, charcoal is perceived as an environmental problem, mainly in terms of deforestation and forest degradation (because charcoal is produced from wood in natural forests). The production of charcoal presents negative impacts such as high emissions of particulate matter during its production, as well as impacts on the soil. For its part, the positive impacts reported were low greenhouse gas emissions compared to fossil fuels, little use of water for its production, positive energy returns (a much smaller amount of energy is required to produce it than the energy it delivers) and high job creation, although with low remuneration.

Waste (forest and agroindustrial)

The energy use of forest residues and the forestry industry makes it possible to avoid some of the impacts generated by these forms of biomass. For example, forest waste can contribute to forest fires, while waste from the forestry industry, when disposed of in landfills, can decompose and release carbon dioxide and methane. As with other organic waste, its accumulation can cause leaching (Beaumont-Roveda, 1994).

For its part, the use of biomass of agricultural and agroindustrial origin would allow us to mitigate some environmental impacts, for example, sugar cane straw is usually left in the field for subsequent burning, which generates, among other things, emissions of particulate matter. and black carbon (which has a high global warming potential); orange peels and oil palm waste are dumped in the open, causing them to decompose and emit methane; in addition, this residual biomass can produce leachates that affect water quality. The use of the indicated waste would allow these impacts to be eliminated or mitigated.

The use of agricultural waste can also allow economic benefits in its application in industry, for example, fossil fuels can be replaced with savings with the use of cane bagasse in sugar mills. Likewise, BCS can mitigate greenhouse gas emissions compared to fossil fuels in residential and industrial applications and allow the creation of jobs and income in rural areas. In this sense, it has been documented that cogeneration in sugar mills can produce 20 times more employment than electricity generation with fossil fuels (Manzini et al, 2021).

Pellets and briquettes

There is a great debate about the real environmental impacts on forests and on the climate of the use of biomass from forests or the forestry industry, either in its direct use as chips, or of processed biomass, such as the production of pellets or briquettes. It has been argued that the production of pellets affects forests by using tree trunks, which would also bring about an increase in carbon emissions into the atmosphere, with consequent climate change (Searchinger, 2018). Other authors point out that the pellets are produced from sawmill residues or forest exploitation residues (mainly tips and branches) and not from the trunks, so that there are no effects due to deforestation while the carbon released It does not represent net CO_2 emissions, since this carbon is captured as the trees grow back. The impact of the forests could in turn have negative impacts on biodiversity. In any case, sustainable forest management can allow only the biomass that is grown year after year to be used without affecting carbon stores, at the same time, implementing systems that ensure that only those biomasses that do not have more relevant commercial uses in terms of income are used.

On the other hand, during the combustion of pellets and briquettes, emissions are generated into the air, mainly of particulate matter, while their benefits in mitigating greenhouse gases depend on their form of production and the origin of the biomass. These BCS can also create jobs and income in rural areas by allowing the formation of small businesses that seek to generate production chains and use of these fuels.

Conclusion

BCS represent the most used renewable energy source in the world. The challenges and opportunities related to the sustainability of BCS are varied and largely depend on the origin of the biomass, its transformation and its final uses. The BCS have advantages for generating employment, diversifying sources of income and improving living conditions at the rural level. Likewise, BCS can mitigate greenhouse gas emissions both at the residential and industrial levels and for electricity generation. Some industrial applications of BCS would allow replacing fossil fuels for heat generation and cogeneration in a cost-effective manner. Among the challenges of BCS are deforestation and forest degradation, higher emissions of particulate matter and polluting gases compared to fossil fuels. There are measures that can contribute to a more sustainable application of BCS, where we can find the use of waste instead of biomass from energy plantations; use of efficient technologies; certification in sustainable forest management and; the implementation of technologies and optimization of processes to reduce emissions from combustion.

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CHAPTER 13

PRODUCTION AND RURAL TECHNOLOGY APPROPRIATE FOR END-USE OF SOLID BIOFUELS IN RURAL COMMUNITIES

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Summary

The production of solid biofuels, such as pellets or briquettes derived from lignocellulosic biomass, is vital for sustainable development in rural communities. Community appropriate technology focuses on solutions adapted to local needs, avoiding the indiscriminate adoption of advanced technologies, recognizes traditional knowledge and empowers communities in the design, implementation and maintenance of technologies, ensuring long-term acceptance and sustainability. The implementation of biofuels and appropriate technologies can improve sustainability, resilience and quality of life in rural areas, but it is essential to carry out a comprehensive analysis of the local context to ensure long-term effectiveness.

Keywords: Appropriate technology, end-use devices, Solid biofuels

Introduction

The production of solid biofuels (BCS) and the implementation of appropriate technologies in rural communities are crucial aspects for sustainable development and improving the quality of life in these áreas (Morales-Máximo et al., 2018). Solid biofuels, such as pellets or briquettes derived from lignocellulosic biomass, are renewable energy sources that can partially replace fossil fuels, thus reducing dependence on non-renewable resources in these communities (Chen et al., 2009). Community Appropriate Technology seeks to provide technological solutions tailored to the specific needs of local communities, recognizing their traditional knowledge and empowering them in the process of designing, implementing and maintaining technologies that impact their lives.

The production of solid biofuels involves various methods, such as chipping, compaction, bulk waste, sawdust and charcoal, coming from lignocellulosic materials such as forest biomass, agricultural and organic waste, the manufacture of these biofuels follows a process that includes crushing, drying, hammer mill, sieving and pressing, whether industrial or non-industrial (Reyes et al., 2016). Devices that generate solid biofuels play a crucial role in the transition towards more sustainable energy sources, contributing to the reduction of greenhouse gas emissions and promoting the responsible use of natural resources.

Industrial context: Industrialized technology for the manufacture of solid biofuels

In the industrial context, the technology focuses on industrialized methods for the manufacture of solid biofuels, such as pellets and briquettes. The use of pelletizers and briquettes allows the transformation of biomass materials into compact forms suitable for use as fuel. These equipment require an initial investment, but have advantages such as energy efficiency, low environmental impact and local employment generation; In addition, the importance of complying with environmental and safety regulations throughout the manufacturing process is highlighted (Orisaleye et al., 2020).

Local context: Local technology, use of firewood to generate thermal energy

In the local context, the use of firewood as a biofuel in rural communities is examined, although firewood is a renewable and accessible energy source, it poses environmental, social and health challenges, the importance of addressing these challenges through the implementation of improved technologies, sustainable practices and alternative energy options, advantages and challenges associated with the use of firewood are explored, highlighting local availability, low initial cost, employment generation, but also pointing out problems such as deforestation, air pollution and risks for health (Francisco Arriaga et al., 2011). The use of firewood as biofuel in rural communities has endured throughout history, being a practice rooted in the need to cook, heat homes and carry out industrial activities. Although firewood is a renewable and locally abundant energy source, its use poses environmental, social and health challenges. Community Appropriate Technology emerges as a comprehensive approach to addressing these challenges, focusing on culturally relevant and sustainable solutions.

Advantages of firewood as biofuel:

- *Local availability:* Firewood is often widely available in rural areas, reducing dependence on imported energy sources.
- *Low initial cost:* In many communities, firewood is an economical option for heating and cooking.

- *Employment generation:* Collecting and processing firewood can boost the local economy.

Community Appropriate Technology

Community appropriate technology emerges as a culturally embedded approach to addressing local challenges through technological solutions tailored to the specific needs of communities, this contrast with the indiscriminate adoption of standard technologies highlights its commitment to the development and implementation of sustainable, accessible and culturally relevant. The fundamental objectives of this philosophy include:

- **Cultural and Local Relevance:** The integration of technological solutions must be aligned with local cultural practices and ways of life, facilitating smooth acceptance.
- **Accessibility:** Community-appropriate technologies should be designed to be affordable and accessible, removing economic or infrastructure barriers that could hinder their adoption.
- **Community participation:** Active community collaboration is essential throughout the process, from the identification of needs to the implementation and maintenance of technological solutions.
- **Adaptability:** Technologies must be flexible and adaptable to adjust to changing local conditions and needs over time.
- **Participation and Empowerment:** Communities are protagonists in making technological decisions that affect their lives, promoting active participation and empowerment through training.
- **Adaptation to Context:** Technological solutions must be designed considering the natural environment, available resources, culture and specific needs of the community.
- **Sustainability:** They seek to create affordable, maintainable and environmentally friendly solutions to ensure their durability.
- **Knowledge Transfer:** Valuation and use of local knowledge in technological design and development, promoting the exchange of knowledge between generations and communities.
- **Use of Local Resources:** Minimize dependence on external resources by using materials and skills available within the community, strengthening the local economy.
- **Holistic Approach:** Appropriate community technology is not limited to devices, it considers social, economic and cultural aspects, seeking the general well-being of the community.
- **Innovation:** Although it focuses on simple and accessible solutions, it does not rule out innovation, seeking creative ways to address local challenges.

Solid biofuels, derived from organic materials such as wood, agricultural waste, biomass pellets and other byproducts, are used in end-use devices such as stoves, boilers and ovens, offering a renewable energy source. This approach presents notable advantages, but also challenges that require careful consideration as mentioned below:

Advantages of Solid Biofuels:

- **Environmental sustainability:** They contribute to the reduction of greenhouse gas emissions compared to fossil fuels.
- **Accessibility in Remote Areas:** They offer a more affordable option in rural areas where conventional energy infrastructure is limited.
- **Sustainable Resource Management:** They use agricultural and forestry waste, promoting the sustainable management of natural resources.

Challenges

- **Polluting Emissions:** Combustion can generate fine particles and volatile organic compounds.
- **Varied Efficiency:** Combustion efficiency varies depending on the type of biofuel and the device used.
- **Availability and Quality:** The constant availability and quality of biofuels can be challenging.
- **Environmental and Economic Impacts:** Production and transportation can have environmental and economic impacts.

Use of Pellets and Briquettes

Advantages:

- **Energy efficiency:** High energy content and density facilitate handling and storage.
- **Low Environmental Impact:** They burn cleaner and emit fewer greenhouse gases.
- **Waste management:** Often made from agricultural or forestry waste.

Considerations:

- **Startup costs:** Investment in equipment may be high, but it is offset by fuel savings.
- **Biomass Supply:** Ensure constant supply in rural areas.
- **Storage:** Store in a dry place to maintain energy efficiency.
- **Maintenance:** Periodic maintenance necessary for efficient and safe operation.
- **Training and Education:** Users must understand proper operation and maintenance.

Practical Applications of Solid Biofuels

- **Heating and Electrical Generation Systems:** Boilers and cogeneration systems can provide heat and electricity in rural communities.
- **Decentralized Generation with Biofuels:** Biogas microturbines or biomass generators can supply electricity to small communities.
- **Biofuel Stoves and Cookers:** Designed to burn biofuels efficiently, they improve energy efficiency and reduce exposure to toxic fumes.
- **Residential Heating with Biomass Pellets:** Organic waste pellets can be used for heating in cold regions.

Conclusion

The implementation of appropriate and sustainable technologies in rural communities is essential to take advantage of the benefits of biomass energy without compromising the environment or people's health; The adoption of briquetting machines, pelletizers and solid biofuels, together with community appropriate technology principles, offers comprehensive solutions to address energy challenges effectively and sustainably. Finally, the effective application of solid biofuels in end-use devices requires a comprehensive approach that considers both advantages and challenges, along with careful attention to practical considerations, these renewable energy sources can offer sustainable and efficient solutions, especially in rural or local environments.

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CHAPTER 14

POLITICAL AND ENERGY GOVERNANCE CHALLENGES, A LOOK FROM LOCAL EXPERIENCES IN MEXICO

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Summary

From the international conferences of Stockholm, Rio, Agenda 21, Kyoto, and the Paris Agreement, the need to promote principles of protection, prevention and management of environmental policy emerged. Mexico incorporates into law these instruments that regulate and manage the territory, ecological planning, environmental impacts, environmental education, among others, based on the safeguarding and improvement of environmental public goods. This study seeks to analyze the connection between energy governance and local actions that allow the success of energy innovation projects based on community forest management. The main findings suggest that there are complex socio-ecological systems that, through local self-management in the co-production of collective knowledge, can carry out early actions in favor of environmental balance and climate justice, particularly in the generation of affordable and renewable energy such as the use of solid biofuels.

Keywords: Environmental policy, territory, social actors, governance, decarbonization.

Introduction

Environmental policy is the result of global commitments to ecological conservation and environmental balance, and based on the scope of classical economics, the distortion in production and consumption processes that motivated ecological concern was appreciated, damaging not only environmental goods, but limiting environmental services (Ostrom and Ostrom, 1977, 1997; Buchanan, 1965; Samuelson, 1954).

The role of the State in the control of public goods implies regulating behaviors that can unbalance the environment, but it must also motivate those that support and favor environmental balance. That is, it has a double role in the exercise of its functions, both coercive and compensatory, in the first case it is only necessary to apply environmental regulations and in the second it implies a convincing approach to recognize and encourage positive behaviors (e. g. environmental management of waste, environmental certifications, reforestation and forest care actions, among others), in the latter it can even make use of its supervisory power to reduce taxes or obtain subsidies.

To achieve the functions of the State in safeguarding and improving environmental public goods, there are environmental public policy instruments (IPPA) that are globally perceived as tools that involve a set of techniques through which government authorities exercise power in the attempt to bring about social change.

An IPPA is the tool that restricts, promotes, guides or induces certain policy objectives, either through voluntary application or through coercive (command-control) action.

According to Acciai and Capano (2021), public policy is the set of constitutive elements that are interrelated in the design, application, monitoring and evaluation of the IPPA that interact at various scales and that in the literature has been called a factor. hybrid that suggests the combination between environmental planning with the legitimacy and legitimation of said policy (Ávalos et al., 2021).

The hybrid scheme includes the IPPAs that suggest social actions to avoid generating ecological imbalances and in this, governance has a central role because it implies a process of decisions and interactions where it configures the participation of various actors in a certain time and space (Pahl- Wostl, 2019; Kellogg and Samanta, 2018; Birkenholtz, 2008; Eberhard et al., 2017; Armitage et al., 2012; Lane et al., 2011; Lockwood and Davidson, 2010).

The need to reflect on anthropogenic behaviors goes beyond the adoption of IPPAs, it implies proposing effective environmental governance schemes, one of which aims to move towards decarbonization and generate resilient schemes for adaptation and mitigation of the effects of climate change taking into account conditions of danger and risk and to achieve it it is necessary to evaluate and value the local capacities of the different social actors in the adoption of these strategies. This generates a need to reinforce local knowledge that motivates and builds collective knowledge according to identified needs.

The objective of this project is to analyze the connection between energy governance and local actions through tools for the transmission of knowledge and the construction of collective knowledge, called Field Schools, which can be models of systemic innovation that generate spaces for incidence and political effectiveness in specific cases of Michoacán.

Global and local experiences of systemic innovation to move towards energy governance

In Sweden between 2016 and 2018, programs were implemented under this vision, such as BioInnovation and Re: Source; the former sought to support a complete transition to a bio-based economy by 2050, while the latter promoted a world-leading circular economy that minimizes and reuses waste, with a particular focus on materials supply, an energy system sustainable and more efficient use of resources in companies and society (Grillitsch et al., 2019).

In the case of Mexico, one of the experiences that can be linked to the systemic innovation policy is the program called the State of Mexico Innovation System (SIEM), promoted in 2011 by various global and local actors seeking recognition of the interaction and dynamism of local agents according to their own knowledge. Hence the importance of considering this community approach in the structuring of energy projects that promote conditions for regional development and that some of them fall like IPPA.

One of the IPPAs is sustainable forest management understood as the forest management instrument resulting from a rational planning process based on the evaluation of the characteristics and forest potential of the area to be used, prepared in accordance with the standards and prescriptions of protection and sustainability. It involves the responsible use of the forest, the activities and practices applicable for sustainable performance, the replenishment, qualitative and quantitative improvement of resources and the maintenance of ecosystem balance (Von et al., 2004).

So far it has been identified that there are complex systems at various spatial and temporal scales that are key to local self-management of the co-production of collective knowledge to carry out early actions in favor of environmental balance and climate justice that can bring decarbonization closer in Mexico and motivate the sustainable production of energy such as that derived from hydrogen.

Commercial hydrogen production in Mexico is close to 2,700 tons per year and is focused on three international companies. Although the academic community offers findings on the country's energy potential, there are still challenges that generate social and economic barriers, because the regulations present areas of opportunity in the regulation of hydrogen that promote alignment with international commitments such as the Paris Agreement.

Some political challenges to motivate energy governance in Mexico

The political challenges that Mexico faces to generate good energy governance are different. Firstly, we can locate the regulatory (legality)-political (legitimacy)-technological and innovation (legitimation) alignment that motivates the success of decarbonizing projects, such as the use of hydrogen through fuel cells or the use of biomass, mainly forestry, agriculture and livestock, taking into account the primary activities of Mexico.

The use of hydrogen is a possible response to the circular economy that motivates the energy transition and decarbonization, generating energy governance, it is only one of all the possibilities, but perhaps it could be the most interesting because some global agendas have bet on energy from hydrogen and roadmaps are currently in operation that motivate its environmentally appropriate management.

Mexico is part of the hydrogen market, mainly due to the refinery and petrochemical industry, although of 100% of the hydrogen in Mexico, only 1.4% is commercial, the rest continues to be produced forself-consumption in industrial plants such as PEMEX.

One of the options that have been considered for the generation of green hydrogen in Mexico is the use of waste derived from the pulp and paper industry; Up to 17 mmole H_2/reactor have been reported as the maximum amount of hydrogen accumulated at the end of the incubation period. In addition, the reaction of aluminum with sodium hydroxide (NaOH) has been studied, according to a consumption of 3878 grams of NaOH, with 100 aluminum cans and with a molar ratio of Al/NaOH =2, up to 5.35 kW/hour can be produced at a cost of $3.9 Mexican pesos (Martínez and Perry, 2015).

Final thoughts

There are various perspectives that point to considering that Mexico has the ecological elements to think about immediate decarbonization, because it has natural wealth that would offer viable alternatives in the promotion of renewable energies. However, achieving the energy transition is a challenge that goes beyond the existence of renewable energy pathways; it is preceded by economic and social aspects that, without a doubt, can be placed as priorities on public agendas and that are key elements to motivate energy governance.

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