

**Review Article**

Combustion of Wood by Pyrolysis: A Review

Iwuozor Kingsley Ogemdi

Department of Pure and Industrial Chemistry, Nnamdi Azikiwe University, Awka, Nigeria

Email address:

Kingsleyiwuozor5@gmail.com

To cite this article:Iwuozor Kingsley Ogemdi. Combustion of Wood by Pyrolysis: A Review. *International Journal of Atmospheric and Oceanic Sciences*. Vol. 3, No. 1, 2019, pp. 1-7. doi: 10.11648/j.ijaos.20190301.11**Received:** November 21, 2018; **Accepted:** January 17, 2019; **Published:** January 31, 2019

Abstract: Smoke is produced when wood or other organic matter burns in the presence or absence of air. The smoke from the burning of wood is composed of a mixture of gases and fine particles called particulate matter. The main gaseous pollutants in wood-smoke, such as carbon monoxide and nitrogen oxides, add to the atmospheric levels of these regulated gases coming from other combustion sources and thus have always been regulated alike with them. As the gases are indistinguishable no matter where they come from, there is urgent need to examine their particular health implications in wood-smoke. Pyrolysis is the thermo-chemical decomposition of biomass, either in total absence or limited supply of oxidizing agent that does not permit gasification. In other words, it allows the conversion of a biomass sample through the agency of thermal energy alone. Various researchers have worked on the usage of pyrolysis to determine the chemical constituent of wood-smoke and its effect on the Atmosphere as well as Human health. From their findings, It was discovered that wood burning occurs mostly in the absence of air or in the presence of insufficient air and this emits various harmful gases to the atmosphere, it also affects human health causing Lung disorders, Eye defects, Heart disorders, e.t.c. Sensitization of the effects of wood-smoke and an alternative to this type of fuel which is Biofuel should be undertaken as projects by various governments as well as International Communities.

Keywords: Fuel, Smoke, Pyrolysis, Wood, Biofuel, Atmosphere

1. Introduction

Smoke may smell good, but it's not good. The biggest health threat from smoke is from fine particles, also called fine particulate matter or PM_{2.5}. These microscopic particles can get into the eyes and respiratory system, where they may cause burning eyes, runny nose, and illnesses, such as bronchitis. Fine particles can make asthma symptoms worse and trigger asthma attacks. Fine particles can also trigger heart attacks, stroke, irregular heart rhythms, and heart failure, especially in people who are already at risk for these conditions. Smoke from wood that is not burned completely contains a number of chemicals, including carbon monoxide (CO). More than 150 people die annually from CO poisoning related to the use of home heating appliances. CO is odorless and colorless [1]. Smoke forms when wood or other organic matter burns. The smoke from wood burning is made up of a complex mixture of gases and fine particles (also called particle pollution, particulate matter, or PM). In addition to particle pollution, wood smoke contains several toxic harmful air pollutants

including: benzene, formaldehyde, acrolein and polycyclic aromatic hydrocarbons (PAHs). The more efficiently you burn wood (e.g., using an EPA-certified wood stove and dry, seasoned wood) the less smoke is created [1]. Each year, about 3,000 people die in residential fires in the U.S. – mainly from smoke inhalation. A properly installed and maintained smoke alarm is one of the best and cheapest ways to be warned early of a potentially deadly fire.

Wood smoke can affect everyone, but children, teenagers, older adults, people with lung disease, including asthma or people with heart diseases are the most vulnerable. Research indicates that obesity or diabetes may also increase risk [2]. New or expectant mothers may also want to take precautions to protect the health of their babies, because some studies indicate they may be at increased risk.

Wood now ranks as the third most common heating fuel, after gas and electricity, for primary and secondary heating fuel use nationally. Recycled materials such as particle board, treated or painted wood, melamine resin-coated panels and the like are considered particularly unsuitable for use in pellets

because of ash-contamination and combustion related air pollutant emissions [1].

The largest constituent in wood is carbon, which comprises 45 to 50 percent of its mass, followed by hydrogen, at roughly 6 percent. Other major elements in order of decreasing amount are: nitrogen (N), calcium (Ca), potassium (K), sodium (Na), magnesium (Mg), manganese (Mn), iron (Fe) and aluminum (Al). Minor elements include: cadmium (Cd), chromium (Cr), copper (Cu), nickel (Ni), zinc (Zn), arsenic (As), mercury (Hg) and lead (Pb) [2].

The ash content of wood reflects its inorganic content and is highest in the parts of trees where growth occurs (e.g., stem bark and branches). Generally, the ash content of wood or woody biomass ranges from 0.5 to 3 percent dry weight (dw). Plants uptake in-organics, such as heavy metals, from soils [2]. Lead, for example, is taken up by the plant root hairs and stored as lead pyrophosphate in the cell wall. The degree of uptake varies with the plant species.

Wood combustion for residential heating has attracted increasing scientific interest in Europe and elsewhere due to its significant contribution to the OA budget. In Zurich (Switzerland) wood combustion is responsible for 45% of organic carbon (OC) in the cold season [3]. In winter, wood burning accounts for 65% of total carbon (OC and elemental carbon, EC) at a rural site in northern Italy. At rural European background sites biomass burning contribution to OC ranges between 30 and 75% [3].

Chemical and physical properties of residential wood-burning particles may vary significantly, depending on the combustion conditions, combustion appliances and wood types, and accurate emission inventories for this source are still under development. One of the main issues that needs to be solved is to what extent emission inventories should include condensable PM emissions. As the use of wood as fuel for residential heating is spreading in developed countries, the number of studies investigating related health outcomes is increasing. There is evidence of an association between wood smoke exposure and health effects, including reduced resistance to infections, decreased lung function and asthma [3]. Wood-burning particles should not be considered different from other combustion particles, regarding their health outcome. The majority of the epidemiological studies have been performed in areas affected by biomass burning where no direct marker of wood burning is available to link emissions and effects directly [3]. Although the water-soluble fraction of OA emitted by wood combustion can absorb light in the visible and ultraviolet region of the spectra, its overall absorption effect is relatively small but could be relevant over bright surfaces [3].

Developed countries are largely dependent on fossil fuels [4]. Renewable energy is now being encouraged as an alternative to fossil fuel. It has been reported that more than three billion people use solid fuels as the main source of energy in their homes. It has also been affirmed that biomass has been extensively used in developing countries such as India. Charcoal, harvest residues and wood materials are the most common biomass fuels used as energy sources. Not only is the use of natural biomass fuels becoming more common, compacted biomass, such as briquettes and pellets, is also

being used more frequently.

One of the most important advantages attributed to the use of renewable fuels such as biomass is its low cost and widespread distribution. Biomass burning, however, is frequently cited as one of the main channels through which particles and pollutant gases enter the atmosphere [4]. During biomass burning, particulate matter (PM) emissions were dominated by submicrometric particles. Particles can cause severe health effects such as lung cancer, and chronic lung and heart diseases. The damage to human health is mainly linked to exposure to PM₁₀ and PM_{2.5}.

The effect of particulate matter goes beyond risks to human health. PM_{2.5} and PM₁₀ affect weather and reduce visibility, Atmospheric aerosol alters the Earth's radiation balance and causes significant impacts on the weather system [4]. Black carbon that is produced through incomplete combustion contributes to global warming because these particles absorb solar light. It was observed that the concentration of black carbon particles has a positive correlation with environmental heat. The negative aspects related to biomass combustion emissions may prevent its use as a sustainable fuel. In order to overcome this disadvantage, detailed information is necessary regarding emissions of particulate matter from burning of different types of biomass. This information will help to identify the types of biomass that emit more particles during combustion and may lead to measures for reducing this pollutant.

Impact of pollution and the amount of emissions produced by the combustion of PM are in terms of impact on the human body and the environment is very important. Combustion belongs among the stationary anthropogenic sources of the particulate matter formation. Stationary anthropogenic sources can be local furnaces, incineration plants, agricultural activities, logging and mining and chemical production [5]. The airborne particulate matter (PM) means the small solid particles and liquid droplets dispersed in our environment. Particulate matters are a mixture of carbon, dust and aerosols. They consist of the following substances: carbon, ammonium, metals, organic materials, nitrates and sulfates [5]. They can be divided into primary and secondary particles according their creature. Primary particles are directly emitted by the source and the secondary particles are generated during the chemical reaction between oxygen in the atmosphere, water vapor and reactive components (ozone, hydroxyl and nitrate radicals, SO₂, NO_x). These emissions are considered to cause the greatest harm to human health.

Particles of different sizes behave differently and can be governed by different physical laws. The simplest way to control emissions is to use high quality fuel with low ash content, low moisture and constant particle sizes. In general, increased amounts of harmful elements in the fuel, such as sulfur, nitrogen, chlorine, is shown by increased content of harmful substances in the combustion gases. The chemical composition of the particles emitted during domestic combustion is closely connected to the combustion conditions, and thus to the concentrations and size distributions. High mass concentrations were dominated by organic material. The combustion leads to pollution with particulate matters (PM). These emissions are considered to cause the greatest harm to

human health. Particulate pollutants consist of the following substances: carbon, ammonium, metals, organic materials, nitrates and sulfates [5].

2. Pyrolysis

2.1. Principles and Products

Pyrolysis is defined as a thermo-chemical decomposition of biomass, either in total absence or limited supply of oxidizing agent that does not permit gasification. In other words, it allows the conversion of a biomass sample through the agency of thermal energy alone. It is worth noting that pyrolysis is not only a thermal conversion technology by itself, but also the first stage of both combustion and gasification. During pyrolytic process, long chains of carbon, hydrogen, and oxygen in the complex biomass macromolecules are broken down into smaller and simpler molecules, providing the three main products: gas, condensable vapors (tars or oils), and char (solid residue). The proportion of these three products can vary depending on pyrolysis process and conditions.

Because of the mentioned characteristics, pyrolysis results as a good option for studying biomass behavior, due to the fast heating mode and reaction rate (conversion within two seconds). In conjunction to this, it is also relatively inexpensive, since it requires lower temperature than gasification and combustion, and no oxidizing agent.

Furthermore, it is an efficient conversion method compared to other thermo-chemical technologies and allows feedstock flexibility. The main objective is obtaining products with better properties compared to the initial biomass. This is why especially the production of liquid bio-oil from fast pyrolysis in the last decades has attracted large attention.

2.2. Pyrolysis Mechanisms

Biomass pyrolysis is very complex process, involving both simultaneous and successive reactions that are taking place when the organic feedstock is heated in a non-reactive atmosphere. Due to the large variability of biomass in structure and composition, pyrolysis processes show different reaction pathways. In fact, the main biomass components

(carbohydrates and lignin) decompose through different mechanisms, at different rates of degradation, and different temperature ranges.

Investigations on the decomposition path of single components show that hemicelluloses are the first to decompose, between 250-350°C, followed by cellulose at 300-400°C with levoglucosan as the main pyrolysis product. The last compound to be degraded is lignin, which breaks down over a wide temperature range of 250-550°C, thus appearing the more thermally stable. Studying the thermal behavior of each single component is one approach for knowing more about pyrolytic behavior of biomass, but the interaction between these components during pyrolysis makes it difficult to predict biomass behavior simply based on the single element.

From a thermal point of view, the changes happening inside each biomass particle during pyrolysis can be divided into different stages, which are not sharply defined but overlap one into each other. In this context, thermal analysis is a useful tool for observing the transition and behavior of biomass in different stages.

Firstly, a drying phase takes place at ~100°C, when free moisture and some loosely bound water is released, and heat transfer increases temperature. Secondly, during an initial stage between 100-300°C, exothermic dehydration causes the release of water and low-molar-mass gases, like CO and CO₂. Then follows a decomposition stage at temperatures >200°C, when primary pyrolysis reactions start to decompose the large biomass molecules into char (called "primary char"), condensable gases (precursors of bio-oil) and non-condensable gases. Finally, during the last stage between ~300-900°C condensable gases may break further by secondary cracking reactions into char (called "secondary char") and non-condensable gases, such as CO, CO₂, H₂, and CH₄. The condensable gases must be removed quickly from the reaction zone, in order to condensate them as tar or bio-oil. The overall decomposition happens partially in gas-phase homogeneous reactions and partly through gas-solid-phase heterogeneous thermal reactions, catalyzed by char. The figure below showed a possible reaction pathways for pyrolysis of biomass, considering both chemical and physical processes taking place inside a biomass particle.

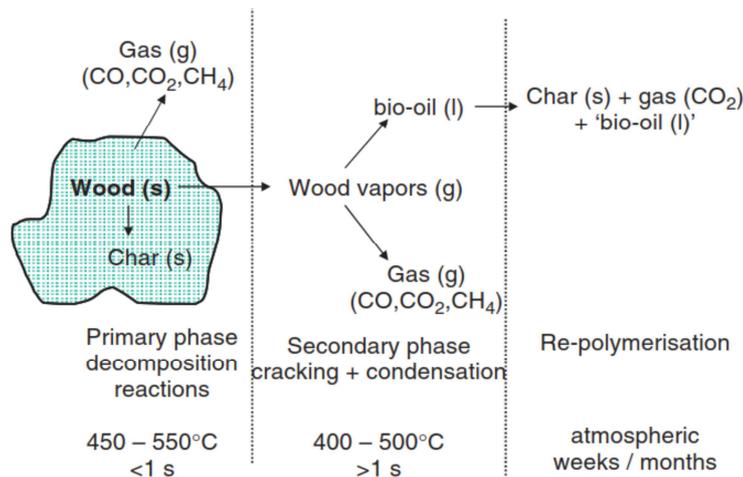


Figure 1. Representation of pathways for pyrolysis in wood substrate.

2.3. Parameters and Their Influence on Products

The thermo-chemical conversion of biomass during pyrolysis is influenced by different factors, which ultimately affect the conversion time, as well as distribution and quality of the products. The most important parameters to consider are feedstock composition and its physical and chemical characteristics, the design of the pyrolytic unit, as well as operating parameters as temperature and pressure, heating rate, and vapor or solid residence time in the reaction zone.

The type of biomass being pyrolyzed and its composition influences the process and products in several ways. Cellulose, hemicelluloses, and lignin, together with extractives and inorganic compounds are present in different proportions depending on the biomass type, and their interactions differ from biomass to biomass, influencing consequently pyrolysis performance and product distribution. Each component features unique pyrolysis reaction pathways and thermo-chemical characteristics, thus originating different products.

In general, the main biomass components contribute to products yields in characteristic way; volatiles derive mainly from cellulose and hemicelluloses, while lignin originates predominantly char residues. Extractives contribute to liquid and gas products either through simple volatilization or decomposition. In contrast minerals, especially, alkali metals, generally remain in the char with catalytic effects, which increases the char yield and degrades the oil quality. Moreover, pyrolysis process can be influenced by physico-chemical properties of the biomass, such as thermal conductivity and emissivity, permeability and density, specific heat capacity and heat reaction, particle shrinking, and moisture content. Particle size has a significant effect on heat and mass transfer phenomena, since larger particles imply larger thermal gradients, longer resident time, and possibility of secondary cracking, thus reducing liquid yields. Particle shape and orientation can also influence biomass pyrolysis due to the biomass anisotropic behavior.

Temperature significantly influences distribution and properties of products. Liquid products increase with the pyrolysis temperature but only until a maximum value, usually between 400°C and 550°C, when bio-oil yield reach its peaks. For temperature higher than 600°C gas is predominant, as bio-oils and char are converted into non-condensable gas due to secondary cracking reactions. Usually, the higher the temperature, the less is the char yield, due to higher stripping of volatile material from the char.

Heating rate is the main parameter defining the type of pyrolysis method (slow, fast, and flash) and it also largely influences the products yield. Fast heating rate means a quick fragmentation of biomass, thus more gas and less char. Rapid heating and cooling of primary vapor is required to enhance the bio-oil production and minimize secondary reactions, which have negative impact on liquid yields and quality. On the contrary, slow heating rates lead to more char production.

Furthermore, vapor residence time can also influence the type of products, since it affects the contact time between char

and vapors, thus ultimately affects the intensity of secondary reactions and the properties of volatiles. For example, a quick removal of vapors from reaction zone will minimize secondary reactions, thus increasing bio-oil yields.

Another parameter to consider is the operating pressure at which the pyrolysis is performed, as it has been found that higher pressure leads to higher concentration of volatiles, thus increasing the decomposition rates through secondary reactions and higher char fraction.

As can be seen above, operating conditions are possible to be adjusted in order to obtain the desired products and change the relative yields of gas, solid, and liquid. Given specific operating conditions, each process has its characteristic products and applications.

When considering heating rate, temperature, and gas residence time (the most influential factors on the result products) general patterns can be individuated. For instance, charcoal production is generally maximized by slow heating rate, low final temperature (300-600°C), and long gas residence time. Higher liquid yields, on the contrary, can be obtained by high heating rate, moderate final temperature (450-600°C), and short gas residence time as rapid cooling of the produced vapor, which allows condensing them into liquids. Lastly, gas fraction can be maximized by slow heating rate, high final temperature (700-900°C) and long gas residence time.

2.4. Analytical Pyrolysis

Many organic substances found in Nature, due to their complex and varying polymeric structure, are unsuitable for direct analysis. In order to investigate them, different chemical and physical degradative techniques have been used, pyrolysis being one of them. Analytical pyrolysis is a simple, rapid, and reliable analytical technique, especially for the analysis of polymeric and composite organic materials. The samples are usually not volatile and have low solubility in most solvents, thus not suitable for direct analytical determinations.

Analytical pyrolysis is defined as “the technique of studying molecules either by observing their behavior during pyrolysis or by studying the resulting molecular fragments”. It is a small-scale analytical technique, where the sample is pyrolyzed by rapid application of heat in an inert atmosphere. Pyrolysis itself does not produce any analytical data unless associated analytical instruments. This is why analytical devices for separation and quantification of the volatile fragments are usually connected the pyrolyzing unit.

The analytical pyrolytic unit has a fundamental requirement; reproducibility. This means that the same product profiles should be obtained from replicate analysis. As could be seen from the general pyrolysis process, in order to obtain reproducible results, different operating parameters must be accurately controlled.

The reactions responsible for breaking biomass compounds bonds are strongly dependent on temperature, which consequently influences the final product distribution. This is why precisely controlled temperatures must be used. For the

purpose of analytical pyrolysis, temperatures in the range of 600-800°C are preferred because when the pyrolysis temperature increases, the pyrogram is influenced by smaller and less characteristic fragments. A second important parameter is the temperature time profile, which allows the sample to be heated in a controlled and reproducible manner. In this way, the sample will be decomposed over the same temperature range, hence major control of pyrolytic behavior. The temperature rise time is also crucial, as the heating rate should be rapid compared to the degradation rate of the sample for preventing degradation to be already over before reaching the actual pyrolysis temperature. Ultimately, rapid cooling rate will ensure that the products escape quickly from the pyrolysis zone and can be transmitted entirely to proper analytical device coupled with the pyrolytic unit.

When temperature, heating rate, and time can be reproduced and controlled in a consistent way, the original macromolecule will always break down according to characteristic fragmentation pattern. Similar fragments obtained in the same conditions will then give information about the nature, arrangement, and identity of the original sample as a fingerprint.

A diversity of analytical approaches is required to understand the complex composition of biomass and its degradation products. In order to do that, different analytical techniques have been applied to study biomass thermochemical behavior. These techniques include physical and elemental analyses, as well as thermo-analytical techniques, like thermogravimetric analysis (TGA), differential scanning calorimetry (DSC), and differential thermal analysis (DTA). Furthermore, chromatographic analytical technique as gas chromatography (GC) can be used for analysis of gas products and high-performance liquid chromatography (HPLC) for liquid ones.

Together with these chromatographic methods, mass spectrometric techniques, but also infrared (IR), Raman, near-infrared (NIR) spectroscopic techniques, as well as nuclear magnetic resonance (NMR), electron paramagnetic resonance (EPR), and microscopic techniques (light microscopy (LM) and scanning electron microscopy (SEM)) are frequently used for the analysis of biomass fragmentation products.

2.5. Pyrolysis-Gas Chromatography-Mass Spectrometry (Py-GC/MS)

Analytical pyrolysis has a long history in characterizing complex samples in fields ranging from forensic science to geochemistry, archeology, and art. The coupling of the pyrolytic unit with appropriate analytical devices is fundamental for obtaining comprehensive qualitative and quantitative results. It follows that combining pyrolysis with modern analytical techniques, such as high-resolution capillary GC and mass spectrometry (MS), originates a powerful tool for the investigation of complex organic materials.

An optimal analytical pyrolysis device should produce degradation products that are representative of the sample, reproducible, and capable of successful separation and elution in the gas chromatograph for further detection. Despite some

limitations, Py-GC/MS permits the study of a wider range of molecules compared to the ones that can be detected by simple GC/MS, especially in the case of intractable, non-volatile, and high boiling point components. In fact, Py-GC/MS allows direct analysis of the original natural material, since the pyrolytic unit is able to produce volatile fragments, which can then be analyzed using GC/MS. Therefore, Py-GC/MS is a useful method for the qualification of pyrolysis products and it has a great potential for studying the decomposition pathways of various biomass types and their components.

The Py-GC/MS unit consists in a pyrolyzing system that makes possible thermal degradation of the sample by rapid application of heat. An inert gas stream, usually helium (He), sweeps the volatile products into the gas chromatographic column, where oven temperature programming separates them. Lastly, a spectrometric detector allows identification with the aid of a mass spectral library, for the qualitative assessment of the fragments.

The three commercial and most common pyrolyzing instruments for analyzing solid and non-volatile liquids are isothermal furnace, Curie-point (inductively heated) filaments, and resistively heated filaments pyrolyzers, each having their own specific design advantages. In resistively heated filament pyrolyzer very fast heating rates are achieved by a controlled current passing through a small filament. This means that the mass of the sample analyzed should be quite small, usually in the range of micrograms, in order to be compatible with the filament and successively with the chromatographic column capacity. The heated-filament is contained in a pyroprobe design, which allows precise control of temperature, time, and heating rate. The pyroprobe is placed into a heating chamber, generally connected to the injection port of the analytical device, with the column gas carrier flowing through it.

In order to exploit the rapid heating capability of the pyrolyzer and obtain efficient heat transfer to the sample, this must be in intimate contact with the heater. When the sample to be analyzed is in the form of fibers or fine powder, a small quartz tube is generally used. The sample is weighed and held in position with wool plugs inside the quartz tube, which is then inserted into the coil filament for pyrolysis, and consequent analysis. To ensure reproducibility of the results, sample handling is very important. Sample size should be small (lower than 1 mg) and homogeneous, thus representative of the all material.

2.6. Thermal Decomposition Behavior

In order to achieve a better understanding of biomass pyrolysis mechanisms, intensive studies on pyrolytic behavior of its main components are required and have been pursued. Investigations by the means of Py-GC/MS on carbohydrates and lignin have been largely reported in literature. In addition to that, the influence of the other biomass constituents, as inorganic ions and extractives, should also be considered when studying the thermal decomposition behavior of biomass material. Different qualitative and quantitative studies have been performed on various types of biomass samples, which have allowed identification and quantification

of the large variety of compounds comprised in the extractive class. Since wood contains a large range of substances classified as extractives, studies usually focus on the analysis of a single compound group.

A molecular compound undergoes pyrolysis through one or more pyrolytic reactions, which can happen simultaneously or sequentially. Many chemical reactions are taking place during pyrolysis, most of them based on free radicals. The pyrolysis products are consequently influenced by the structure of the initial molecule, together with experimental conditions. Considering the precursor molecule, the products that will be originated depend on chemical bonds and functional groups present in the compound, as well as on the stability of the resulting fragments. The most common mechanisms taking place during pyrolysis include elimination and fragmentation reactions, rearrangements, and other types of reactions, such as oxidation, reduction, substitution, and addition.

Previous investigation on resin acids under high-temperature pyrolytic conditions (800°C) found out naphthalene derivatives as major products. Levopimaric acid, abietic acid, dehydroabietic acid, and methyl dehydroabietate were the main four compounds studied, which gave the same general spectrum of products, the major ones being toluene, styrene, indene, naphthalene, 2-vinylnaphthalene, acenaphthylene, phenanthrene, fluorine, and 2-phenylnaphthalene. It was assumed that the high yield of naphthalene products during pyrolysis of resin acids must arise from cleavage in the A ring of the parent molecule before complete aromatization. This cleavage is likely to be facilitated by the ease at which the resin acids undergo decarboxylation. Beside fragmentation and carboxylation reactions, dehydrogenation is another important reaction taking place in resin acids.

3. Literature Review on Previous Work Done

Kantova, *et al.*, analyzed the particulate matters samples from wood biomass and brown coal. The analyses were carried out by elemental determinator and thermogravimetric analyzer. Thermogravimetric analyzer determines the composition of organic, inorganic, and synthetic materials. The elemental determinator is used to determine carbon, hydrogen, nitrogen and sulfur in organic matrices. Further analysis compares the size distribution of these samples. Size distribution was determined by using of vibratory sieve shaker machine. The shape of particles was observed by stereo microscope and density was also determined such as a ratio of their weight and volume. It is important to analyze chemical and physical properties of PM in order to decrease their concentration during combustion process [5].

Alen, *et al.*, investigated the thermochemical behavior of pine wood (*Pinus sylvestris*) and its main structural constituents (cellulose, hemicelluloses, and lignin) by pyrolysis-gas chromatography with mass-selective detection (Py-GC/MSD). In each case, major GC-amenable pyrolysis

products were classified into several compound groups, and changes in the relative mass portions of these monomer-related fragments were monitored in the temperature range 400–1000°C. The formation of the main products was shown to be characteristically dependent on the reaction temperature. The results also indicated that in the temperature range used, wood appeared to behave as the sum of its constituents [6].

Pyrolysis and combustion of wood under different oxygen concentrations were studied by using TG-FTIR analysis. Effects of oxygen concentration on TGA of wood and evolved gas analysis were thoroughly analyzed, and then the process of pyrolysis and combustion of wood was divided into four steps. The apparent activation energy of pyrolysis and combustion varied linearly with oxygen concentration. The effects of oxygen concentration on the mechanism of two stages of combustion of wood were also studied [7].

Thermogravimetric curves have been measured at a heating rate of 5 K/min for several hardwoods (beech, alder, birch, and oak) and softwoods (Douglas fir, two pine species, redwood, and spruce), whose chemical composition varies within the usual standards. The analysis of the devolatilization characteristics is based on the introduction of several reaction temperatures. A comparison between hardwoods and softwoods shows that, in the latter case, the decomposition starts at lower temperatures, the hemicellulose shoulder is more delayed, and both the hemicellulose and cellulose zones are wider. Furthermore, the yields of char are higher. However, a devolatilization mechanism, consisting of three parallel reactions and the same set of activation energies for hemicellulose, cellulose, and lignin (100, 236, and 46 kJ/mol), can describe the high-temperature (>553 K) degradation behavior of all of the woods with a good accuracy. Modifications for the extension of the mechanism at lower temperatures are required only for species with significant extractive contents and consist of two further reactions (activation energies of 105 and 127 kJ/mol, respectively) [8].

The increase of the price of fossil means, as well as their programmed disappearing, contributed to increase among appliances based on biomass and energy crops. The thermal behavior of *Arundo donax* by thermogravimetric analysis was studied under inert atmosphere at heating rates ranging from 5 to 20°C min⁻¹ from room temperature to 750°C. Gaseous emissions as CO₂, CO and volatile organic compounds (VOC) were measured and global kinetic parameters were determined during pyrolysis with the study of the influence of the heating rate. The thermal process describes two main phases. The first phase named active zone, characterizes the degradation of hemicellulose and cellulose polymers. It started at low temperature (200°C) comparatively to wood samples and was finished at 350°C. The pyrolysis of the lignin polymer occurred during the second phase from 350 to 750°C, named passive zone. Carbon oxides are emitted during the active zone whereas VOC are mainly formed during the passive zone. Mass losses, mass loss rates and emission factors were strongly affected by the variation of the heating rate in the active zone. It was found that the global pyrolysis of *A. donax*

can be satisfactorily described using global independent reactions model for hemicellulose and cellulose in the active zone. The activation energy for hemicellulose was not affected by a variation of the heating rate with a value close to 110 kJ mol^{-1} and presented a reaction order close to 0.5. An increase of the heating rate decreased the activation energy of the cellulose. However, a first reaction order was observed for cellulose decomposition. The experimental results and kinetic parameters may provide useful data for the design of pyrolytic processing system using *A. donax* as feedstock [9].

4. Conclusion

With the help of Pyrolysis, it has been discovered from decades of researches that wood fuel even though is an ancient form of fuel emits various gases that are toxic to Human health and the environment. It might be cheap but its aftermath which is the depletion of the ozone layer which in the long run would lead to the termination of life on earth makes this form of fuel dangerous. Alternatives such as Biofuels and other cheap form of fuel should be endorsed and researches on them sponsored by governments of various nations and international bodies such as the United Nations and the World Health Organization.

References

- [1] Zhang, Y., and Boehman, A. L. (2007). Impact of biodiesel on NOx emissions in a common rail direct injection diesel engine Energy & Fuels. *Journal of Environmental Health Perspective*, 21(4): 2003-2012.
- [2] Rehfuss, E., Mehta, S., Pruss-Ustun, A. (2006). Assessing household solid fuel use: Multiple implications for the Millennium Development Goals. *Journal of Environmental Health Perspective*, 114(1): 373-378.
- [3] Fuzzi, S., Baltensperger, U., Carslaw, K., Decesari, S., Denier, H. V., Facchini, M. C., Fowler, D., Koren, I., Langford, B., Lohmann, U., Nemitz, E., Pandis, S., Riipinen, I., Rudich, Y., Schaap, M., Slowik, J. G., Spracklen, D. V., Vignati, E. M., Wild, Williams, M., and Gilardoni, S. (2015). Particulate matter, air quality and climate: lessons learned and future needs. *Journal of atmospheric chemistry and physics*, 15(1): 8217-8299.
- [4] Amaral, S. S., Andradee, J. C., Costa, M. A. M., and Pinheiro, C. (2016). Particulate matter emission factors for biomass combustion. *Journal of Atmosphere sciences*: 7(141): 1-25.
- [5] Kantova, N., Holubcik, M., Jandacka, J., and Caja, A. (2017). Comparison of particulate matters properties from combustion of wood biomass and brown coal. *International scientific conference on sustainable, modern and safe transport*, 192(1): 416-420.
- [6] Alen, R., Kuoppala, E., and Oesch, P. (1996). Formation of the main degradation compound groups from wood and its components during pyrolysis. *Journal of Analytical and Applied Pyrolysis*, 36(2): 137-148.
- [7] Fang, M. X., Shen, D. K., Li, Y. X., Yu, C. J., Luo, Z. Y., and Cen, K. F. (2006). Kinetic study on pyrolysis and combustion of wood under oxygen concentrations by using TG-FTIR analysis. *Journal of Analytical and Applied Pyrolysis*, 77(1): 22-27.
- [8] Gronli, M. G., Varhegyi, G., and Colomba, B. (2002). Thermogravimetric Analysis and Devolatilization kinetics of wood. *Industrial and Engineering Chemistry Research*, 41(17): 4201-4208.
- [9] Jeguirim, M., and Trouve, G. (2009). Pyrolysis characteristics and kinetics of *Arundodonax* using thermogravimetric analysis. *Journal of Bioresource Technology*, 100(17): 4026-4031.
- [10] Kazanc, F., and Levendis, Y. A. (2010). Physical properties of particulate matter emitted from combustion of coals of various ranks in O_2/N_2 and O_2/CO_2 environments. *Journal of Energy fuels*, 26(12): 7127-7139.