Study of the Main Factors Responsible for the Phenomenon of Self-Combustion Observed in Solid Biomass Waste Piles

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This article discusses the causes of wood-derived biomass self-combustion. We researched technical and academic literature on chemical processes at SENAI CIMATEC. The factors influencing spontaneous combustion are microbial activity, temperature, humidity, and the concentration of O_2 and CO_2. Fungus and bacteria play a leading role in microbial activity, degrading organic matter and releasing toxic and flammable gases. The temperature is crucial for monitoring this phenomenon.
Keywords: Self-Combustion. Biomass. Energy. Wood. Microorganisms.

Introduction

During these last two decades, considerable efforts to reduce greenhouse gas emissions and implement the circular economy model have led to the establishment of a chain of processes, ranging from developing environmentally friendly technologies to the need for waste treatment and/or mitigation [1]. Various industrial sector companies, aiming to comply with current environmental regulations, have proposed replacing non-renewable energy sources with clean energy, such as substituting mineral/vegetable coal and natural gas with solid biomass derived from wood processing waste [2]. The physical treatment applied to biomass, such as that used with different types of wood, results in a significant amount of bark, chips, and sawdust, which, due to their relatively lower thermal efficiency compared to pellets used in boilers, have been discarded in landfills or even piled up in warehouses without proper safety precautions. This use of this new fuel source in larger-scale processes also leads to increased demand for waste storage. Self-combustion occurs when storing this material, which is often done in piles or spaces with insufficient ventilation, leading to accidents and even fatal incidents [3]. This article aims to shed light on the causes of the self-combustion phenomenon, presenting an analysis of the contributing factors based on a review of academic and technical literature. The article also presents some real-life incident cases where the phenomenon of self-combustion or the generation of toxic gases resulted in fatal accidents.

Materials and Methods

This article was built based on the technical expertise of the research team in the field of chemical processes at SENAI CIMATEC, as well as on the review of relevant academic and technical literature from leading scientific journal platforms, such as Scopus and Elsevier.

The strategy used in the search for literature about that matter was based on separating keywords into groups such as 'material," 'agent," 'effect," and "impact on the system" (Table 1). We did not restrict the research concerning the publication date or journal.

Results and Discussion

Spontaneous combustion, also known as self-combustion, is an event that occurs when a

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Table 1. Bibliographic search strategy.

Material	Agent	Effect	Impact on the System
Biomass pile	Fungus	Gas emissions	Self-combustion
	Bacteria	Gas emissions	
	Temperature	-	
	-	Incidents	

specific body or surface emits certain gases/vapors and comes into contact with oxygen, resulting in an exothermic reaction, leading to combustion without an external heat source. In the storage of wood chips, especially in piles, spontaneous combustion is frequently observed due to certain factors that promote an increase in temperature and emission of gases capable of undergoing combustion, thereby enhancing autoignition. One of the significant contributors to this process is microbial activity. Due to its chemical composition (hemicellulose, cellulose, and lignin), wood is generally highly susceptible to organic decomposition, involving the action of fungi and bacteria [4-6]. Fungi are microorganisms with the most significant ability to decompose biomass material. They are classified as decayers, mildews, and stain-causers (Table 2).

Associated with microbial activity, which can attack the woods cell structure, leaving it more exposed to oxidative processes, self-heating is also a significant factor in spontaneous combustion, leading to the formation of hotspots, reaching temperatures of up to 140°C [7,8]. The formation of hotspots is directly related to the height of the storage piles of the material, which increases the potential for combustion due to reduced air circulation, hindering heat dissipation. Additionally, the moisture content present in the material contributes to self-heating because the heating of water caused by organic matter decomposition can increase the temperature of the wood chip pile, leading to evaporation and subsequent shifts in chemical equilibrium, favoring combustion reactions and replenishment of evaporated water, [9]. Moreover, moisture levels above 16% create favorable conditions for the proliferation of fungi and bacteria, increasing microbial activity, which can initiate system heating in aerobic respiration processes and eventually lead to spontaneous ignition [7,10].

The degradation process of organic matter causes uncontrolled emissions of greenhouse

Table 2. The action of each class of fungus in the decomposition of organic matter [5,6].

	Fungus Class		
	Decayers	**Mildews**	**Stain-Causers**
Action on Organic Matter	Responsible for decay (white, brown, and soft rot) resulting from the decomposition of cellulose, hemicellulose, and lignin Causes loss of mass and color change	Induces surface alterations Does not affect the thermal properties of the material May degrade the cell wall, leading to physical and mechanical changes	Secrete colored substances into the albumen Cause surface or deep stains Reduce density, hardness, flexural strength, and impact resistance

gases, posing risks to the health of people in the vicinity, as well as operators working in enclosed or semi-open environments. The deterioration of organic matter can also occur in anaerobic processes, resulting from the depletion of oxygen in the environment, known as off-gassing [11].

Relevant Scale Experiments

Large-scale experiments were conducted to simulate industrial-scale storage or practical pile setups to investigate the self-combustion process and understand how the storage conditions of the material are related to its physicochemical properties, potentially leading to spontaneous ignition. These experiments allowed for the observation of thermal dynamics, moisture content evolution, degassing, and microbial communities [12,13]. The investigated biomass from wood consists of wood chips from forest residues, wood bark, and wood pellets, with moisture content ranging from 5% to 10%, stored in small piles of tens of cubic meters, with residence times varying from one month to over a year [13-15]. The experimental factors and variables include biomass species (fresh or aged), moisture content, particle size, storage height, shape, density, and volume of the pile, storage strategy (internal vs. external, with or without covering), storage time and duration, preservatives, among others.

Microbial Activity

During the investigation, it was evident that microbial activity and heat release in the initial phase increased the pile temperature, leading to a transition from mesophilic to thermophilic microbial communities and finally back to mesophilic communities at lower temperatures. It was identified that temperature, moisture, nutrient supply, concentrations of O_2 and CO_2, and pH are factors that directly influence the colony's development [16].

Temperature

Temperature is one of the most critical parameters, as it is a reliable indicator of microbial activity, material degradation, and storage performance. Microbial degradation can significantly increase the system's temperature due to the exothermic nature of degradation reactions, balanced with heat transfer within the pile [17].

In the study conducted by Anerud and colleagues, the temperature behavior over the storage time of a pile measuring 15 m in width, 35 m in length, and 6.5 m in height, representing an estimated volume of 1450 m^3, was described. The pile consisted of wood chips ranging from 8 to 45 mm in size. The pile used in this study contained a mixture of the following plant species: Picea abies (in larger quantities), Pinus sylvestris, and Betula spp, harvested in the region of Skinnskatteberg, Sweden. This material was segmented into four regions, with two consisting of material collected in September 2013 (residing for 3 months) and the other two regions in January 2014 (residing for 7 months). Each region (regions A and B) was exposed to precipitation (Figure 1) [17].

The pile exposed for three months had its temperature data measured every two weeks. Figure 2 displayed the acquired sensor data.

We observed that there is a temperature gradient in the studied pile, with the maximum temperature reaching around 67°C in the northern region of the pile. Notably, in the first month, all points reached a temperature of 60°C. Additionally, a 1.4% loss in mass was identified during the experimental period. These findings indicate significant microbial activity, especially in the initial storage stages.

Concentration of CO_2 and O_2

The concentration of CO_2 and O_2 is a parameter capable of indicating microbial activity, which is dominated by aerobic processes, thereby reducing the concentration of O_2 and increasing the concentration of CO_2. The emergence of CO indicates chemical oxidation occurring at

Figure 1. Organization of the pile for the experiment [17].

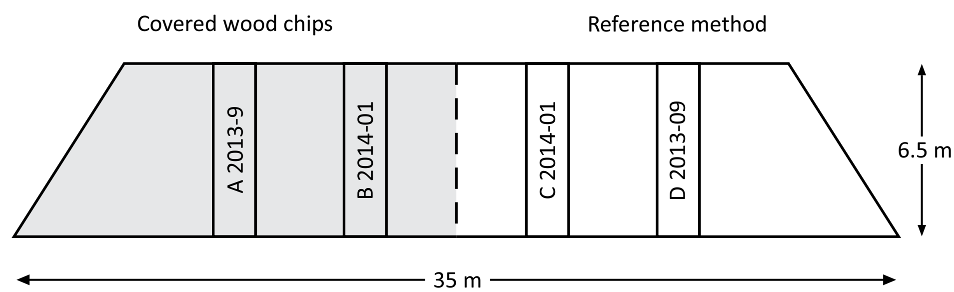
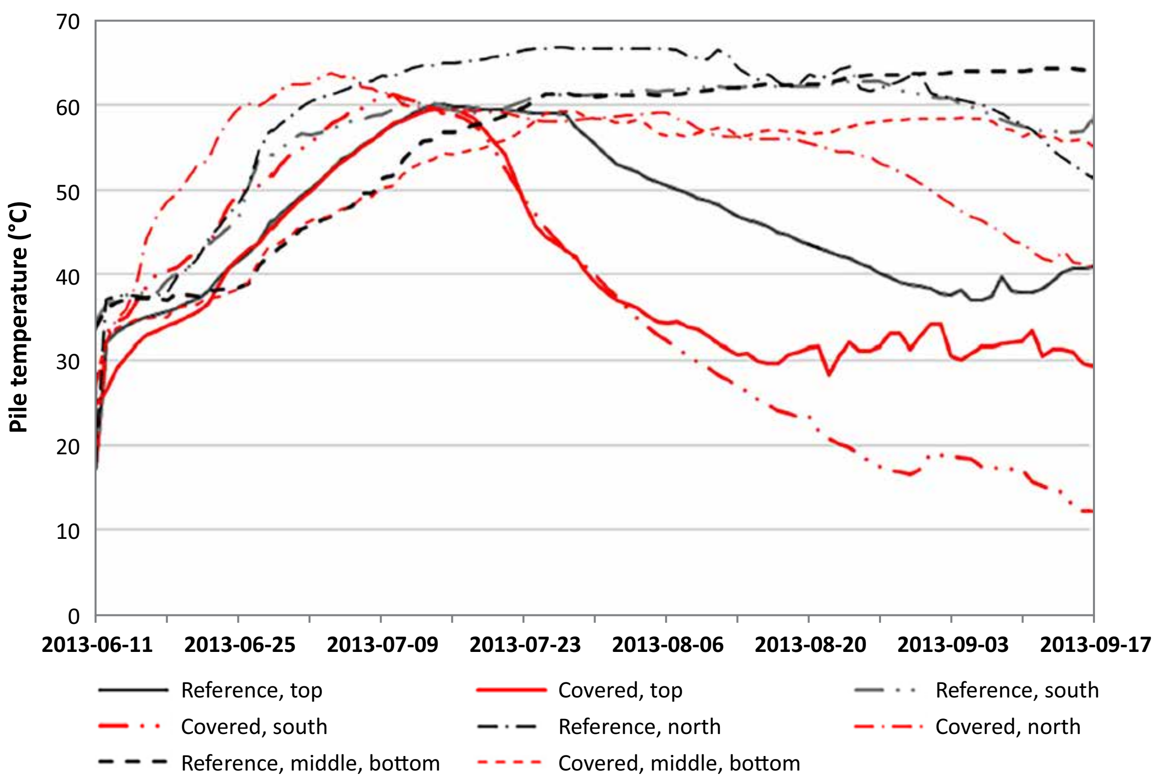


Figure 2. Evolution and temperature distribution in the regions of the pile over 3 months [17].



relatively higher temperatures caused by microbial heating. It is worth noting that the presence of CH_4 indicates the anaerobic activity of microorganisms, and depending on the stage of decomposition, its emission can also be detected [13,18].

Accident Involving Lignocellulosic Biomass Storage

In this context, addressing the accident on the commercial ship AMIRANTE (IMO 7425334) on July 15, 2009, is crucial. The vessel departed from Riga (Latvia). It was loaded with 2600 tons of wood pellets destined for the Amagerværket power plant, owned by Wattenfall, which had recently converted one of its coal blocks to solid biomass [19]. It was reported that two crew members were missing on the ship and were later found dead at the bottom of the stairwell leading to the bow compartment. Surviving crew members mentioned that they experienced great difficulty in breathing and strong weakness while trying to remain in that area.

During the investigation, it was identified in the wood pellet sample that the concentration of CO in the environment was above 150 ppm, information that, together with the autopsies, confirmed death by CO poisoning, indicating levels of COHb saturation in the blood at 52% and 60% for each of the crew members. The inhalation occurred due to a gap in the door's opening, through which gases traveled from the hold to the bow [19].

Conclusion

It is understood that spontaneous combustion is directly linked to certain factors related to storage conditions, such as temperature, light, time, humidity, and gas concentration, mainly CO_2 and O_2. These factors, in turn, impact microbial development and the action of fungi and bacteria in the deterioration of organic matter, further influencing temperature, humidity, and gas concentration parameters. It is also possible to produce some flammable gases, increasing the chance of spontaneous ignition. Linked to this is the health risk to people located in the vicinity of areas susceptible to spontaneous combustion due to the strong inhalation of toxic gases, as occurred in the AMIRANTE ship accident, where operators in a confined space lost their lives due to CO poisoning. Therefore, spontaneous combustion is a phenomenon that should be further investigated to fully understand the factors that contribute to its occurrence, enabling the development of solutions to reduce accidents and greenhouse gas emissions in the atmosphere.

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