# BURNED EMISSION PROFILES OF COMMONLY USED LUMBERS IN SOUTHERN CALIFORNIA STRUCTURES

By

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## ABSTRACT

This study investigated the emissions from three different wood materials, hem-fir wood, alkaline copper quaternary (ACQ) treated wood, and pressed wood, all commonly found in housing structures. The lumber was burned in a controlled burn chamber with a sampling system pulling burn emissions onto filters, sampling media, and a gas analyzer so further analysis could be conducted. OCEC analyzer data showed that organic carbon dominated the emission profile of each lumber sample, with an average organic carbon to total carbon ratio of 86%. Ion chromatography and X-ray fluorescence compared charged ions and metals, which showed clear differences between the materials, particularly in ACQ treated wood with its metal based production treatment. A major observation found was that certain metals are not immediately mobilized into the emission plumes, suggesting that metal concentrations found in communities following major urban fires are attributed to ash mobilization that takes place after a fire has occurred. A Horiba 5 gas analyzer was used to acquire real time data for emission gasses throughout each burn and was used to calculate the modified combustion efficiency (MCE). Material treatment and production products have an influence on emission profiles, signifying the importance to understand material properties that influence released emissions during structural fire events.

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## Introduction and Background

Southern California's wildfires have grown increasingly destructive in recent years, increasing the concern for the effects to the environment and public health. Cal Fire reports that two of the state's most destructive structure fires in California history occurred in 2025 (Cal Fire Statistics, 2026), which includes the Palisades Fire and Eaton Canyon Fire. These two wildfires saw destruction of homes, infrastructure, and vegetation affecting a combined total of thirty-eight thousand acres of land with over 16,000 structures affected. These fires highlight the importance of structural material behavior during combustion and understanding how material treatment and composition affect pollutant emissions and burn behavior.

In order to fully understand the impact of structural losses during wild fire events, a look into combustion behavior during structural burning is essential. Combustion is chemical processes where oxygen is consumed and heat is released (NASA, n.d.). When natural biomass, such as lumber, is burned, the combustion process can produce various gases depending on the amount of oxygen available and the type of biomass fuel used. Complete combustion occurs when there is enough available oxygen so the fuel burns efficiently, mainly producing carbon dioxide and water vapor. On the other hand, incomplete combustion occurs when there is insufficient oxygen available and mainly produces carbon monoxide as well as other pollutants during this incomplete process. It is incomplete combustion that is common with wildfires, as various fuels are burning with varying oxygen supply (McMahon, 1983). Incomplete combustion becomes more hazardous when chemically treated wood burns, as metals and other additives are not completely burned and released into the atmosphere during wildfires.

This experimental project focuses on three different types of lumber materials: untreated hem-fir wood (HF), alkaline copper quaternary (ACQ) treated wood, and pressed wood. The

purpose was to determine if differences in the wood's processing or treatment have an effect on emissions or combustion characteristics. Structures contain a mixture of processed materials, so understanding how treatments release different emissions is vital to public safety.

The hem-fir wood aims to represent untreated, natural wood that underwent minimal processing. The wood is simply cut, dried, and shaped to a desired dimension. Since there are no preservatives added during processing, natural elements such as lignin, cellulose, and hemicellulose primarily make up hem-fir's composition. ACQ treated wood, however, contains additional elements because alkaline copper quaternary is infused into the wood to increase insect resistance and reduce decay and moisture damage. Pressed wood is manufactured from wood fibers and wood chips that is firmly pressed together by heat and pressure, and is then bound by adding adhesives. This process also introduced additional compounds that have an effect on emissions. Each material's production method is important as the manufacturing process directly affects the chemical composition and flame behavior. By comparing these materials, this project demonstrates how the different treatments and production processes in structural materials contribute to emission profiles and environmental impacts during wildfire events.

**Table 1**

*Process and Production of Each Media Type*

| Type | Raw Material | Process Type | Chemicals Added |
|---|---|---|---|
| Hem-Fir Wood | Whole logs | Cutting and drying | N/A |
| Treated ACQ | Whole logs | Pressure impregnation | Copper-based preservatives (Alkaline Copper Quaternary for rot and insect resistance) |
| Pressed Wood | Wood chips/fibers | Chemical bonding and hot pressing | Adhesives (resins, formaldehyde-based) |

## Methods

### Media Preparation

The burn chamber experiments used a controlled burn pit sampling system to compare the emissions from each of the three lumber samples: hem-fir (HF) wood, Alkaline Copper Quaternary (ACQ) treated wood, and pressed wood (PW). Each of the wood types was cut to approximate 4 inch x 1 inch chips to around 300 grams and then placed in the burn chamber configured in a log house formation.

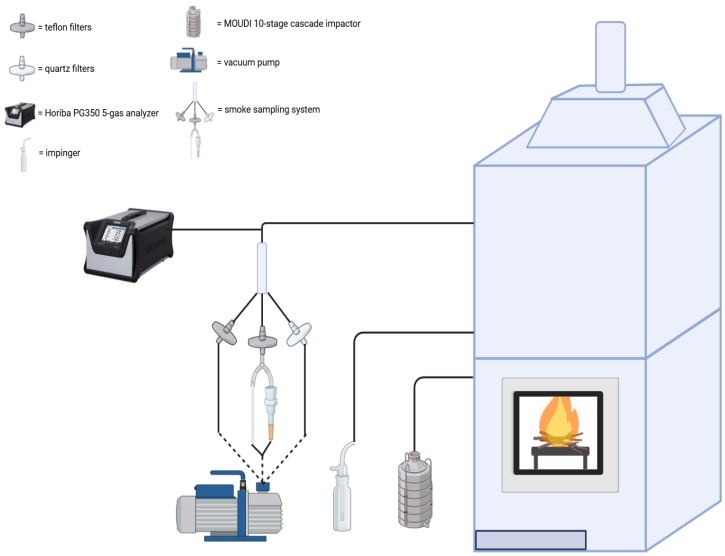
### Burn Pit and Sampling System

The burns were conducted in the “Pit Master 2.5” burn chamber, shown below in Figure 1, constructed from aluminum sheets to withstand the temperatures of the burning media. The chamber has dimensions of 4 x 4 x 8 feet with aluminum extrusions that locks the sheets into

place. Caulking glue was placed along the grooves of the sheets and extrusions to ensure that the emissions are confined within the chamber. The roof of the chamber has a filtered vent that is filled with Purafil potassium permanganate pellets to capture the remaining emission smoke that is not captured by the sampling system to ensure the pollutants eluding the sampling system does not enter the atmosphere. Emissions from each of the burns were pulled by a sampling line that split between an instrument called the Horiba and a splitter, divided into three different lines. The splitter channeled samples into a quartz filter, teflon filter, and a third line which led to a thermal desorption spectroscopy (TDS) tube and a dinitrophenylhydrazine (DNPH) cartridge. This setup allowed the lumber emissions from each burn to be sampled while reducing the amount of uncaptured smoke entering the atmosphere.

**Figure 1**

*Animated Schematic of the Burn Chamber*




*Note.* This figure is courtesy of UCR, School of Medicine. They use the chamber for their collaboration with the Atmospheric Processes Laboratory, which includes an impactor and impinger, both of which were not used in this study.

**Filter Types and Other Sample Collection**

Depending on the targeted analysis, different types of filters were used to gather sample emissions. Quartz filters were used since they are able to withstand the high temperatures needed in analysis to distinguish organic carbon from elemental carbon; while Teflon filters were used for X-Ray Fluorescence (XRF) and ion chromatography (IC), as they are compatible with metal and ion analysis. These filter samples collected from the three media burns were later used to find carbon ratios, metals, and charged ions in the emissions from each wood type. A TDS tube and a DNPH cartridge were also used in sample collection for each of the burns, both of these collected lumber emission samples and were used for analysis by methods explained further.

**Elemental Carbon / Organic Carbon Analysis**

The elemental carbon and organic carbon was found with Elemental Carbon / Organic Carbon (EC/OC) analysis. This method gave the amounts of both elemental and organic carbon to the total amount of carbon present in each of the samples. The organic carbon is carbon that is associated with organic compounds, it is volatile and evaporates at low temperatures (Lepore et al., 2003). Elemental carbon, on the other hand, remains solid even at high temperatures and oxidizes at higher temperatures in the presence of oxygen (Watson et al., 2005). Using the ratio of organic carbon to total carbon from EC/OC analysis helps to distinguish between the emission profiles of the three media types whether elemental carbon or organic carbon is dominant in the sample.

**X-Ray Fluorescence**

X-Ray Fluorescence was used to report any metals present in the samples from the media's emissions. This method allowed inorganic species, the metals, to be detected from the Teflon filters with emission samples. X-Ray Fluorescence was crucial in comparisons between

the lumber samples, especially with alkaline copper quaternary treated wood, as this is a metal based treatment.

**Ion Chromatography**

Ion Chromatography was used to identify the charged species collected from the filter samples. The following was employed to extract the sample from the Teflon filter to prepare for Ion Chromatography analysis of both cations and anions. An empty 25 mL plastic vial was filled with MilliQ water and sonicated for 15 minutes and emptied to ensure there is no contamination. 0.5 mL of isopropyl alcohol was pipetted on the entirety of the Teflon filter's surface and immediately placed back in the vial. 20 mL of MilliQ water was added into the vial and was sonicated for 15 more minutes. Ion Chromatography analysis helped determine how charged elements contributed to the sample's emission profile.

**Horiba Gas Analyzer**

A Horiba gas analyzer was used in order to find the gas phase emissions of each media throughout the burning process. The Horiba gathered gases commonly found in the combustion process, such as nitrogen oxides, carbon monoxide, carbon dioxide, sulfur dioxide, and oxygen (Okawa et al., 2021). The data gathered from each of the gases also determined the modified combustion efficiency of each of the burns, this aids in classifying the burn stages as either flaming or smoldering. The Horiba gave the carbon dioxide gas data as percent volume, this was then converted into ppm by multiplying the percent volume by 10,000. Then, 430 ppm was subtracted from the new ppm value of carbon dioxide to account for the ambient carbon dioxide present. Finally, the modified combustion efficiency was calculated using Equation 1. The Horbia data gave real time analysis on the changing combustion conditions throughout the burn and allowed for further comparison between the three lumber types.

$$Modified\ Combustion\ Efficiency\ = \frac{CO_2}{CO_2 + CO}\ \times 100 \quad (1)$$

where $CO_2$ and $CO$ are in parts per million (ppm) gathered from the gas data during a burn.

**High-Performance Liquid Chromatography Analysis**

High-Performance Liquid Chromatography (HPLC) analysis targets carbonyl compounds, which includes aldehydes and ketones. Each of the media samples were gathered on a dinitrophenylhydrazine (DNPH) cartridge and prepared for HPLC analysis. For extraction of a DNPH sample, a pipette tip was broken to a straight edge and inserted into the reverse direction of the flow in which the cartridge was sampled from. Acetonitrile was used to elute and extract the derivatized species from the DNPH cartridge. The sample was then brought to a 5 mL volumetric flask to be used in HPLC analysis. Unfortunately, complications with the HPLC machine did not allow the samples to be run in the timeframe of this project, however, its sample preparation was completed and will be included in future work.

**Thermal Desorption Spectroscopy**

Thermal Desorption Spectroscopy (TDS) analysis is used to identify C4 to C12 carbon species present in the sample. The TDS tubes were collected for each of the samples and ran, however there was heavy condensation inside each of the tubes which labeled the results unusable.

## Results and Discussion

The results from this project show that the production process of lumber contains some similarities and differences between the emissions generated when burned. These samples aimed to represent various types of lumber that are used in modern day structures or housing related construction. Hem-fir lumber was used as a control to understand emissions from lumber that do not undergo further treatment. ACQ treated lumber and presswood are both commonly found in

the structure of homes and thus were picked to represent modern construction materials. All different in their manufacturing, but expected to have differences as treatment processes used to create these lumbers cause slight differences during burning, thus producing unique emission profiles.

Overall, the experimental results from elemental carbon / organic carbon (EC/OC) analysis indicates that these wood materials can not be distinguished by EC/OC data by itself, as there are more clear differences between the three sample types in metal content, charged elements, burn duration, and gas phase behavior. However, the EC/OC data did help determine composition of the emission smoke. More prominent differences were shown in the X-Ray fluorescence (XRF) and ion chromatography (IC) results, where treatment, additives, and media composition likely had a larger influence in the emission profiles. The modified combustion efficiency (MCE) gathered from the Horiba was also beneficial, since the data was able to show how real time combustion conditions changed throughout the duration of the burn for each of the media types.

EC/OC analysis obtained a ratio of organic carbon to total carbon. Total carbon contains both elemental and organic carbon for each of the samples. Table 2 displays the organic carbon to total carbon ratio as a percent, where there is no substantial difference between the media's emission profiles. Hem-fir wood had an organic carbon to total carbon value of 85.30%, ACQ treated wood's value was 84.71%, and pressed wood had a value of 88.07%. There was an average of 86% between the samples, showing that EC/OC data does not have a large role in distinguishing the emission profiles of the wood types.

**Table 2**

*Organic Carbon to Total Carbon Ratio per Sample Type*

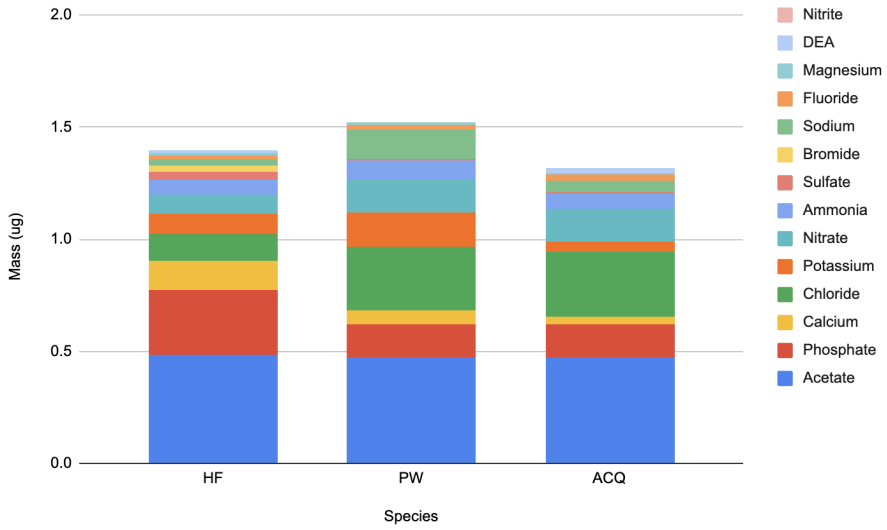
| Lumber Sample | Organic Carbon / Total Carbon |
|---|---|
| Hem-Fir Wood | 85.30 % |
| ACQ Treated Wood | 84.71 % |
| Pressed Wood | 88.07 % |

Regardless of the lack of differences, the results did indicate that the majority of the carbon collected from all three sample types was organic carbon. This result is reasonable, as a previous study by Zhang et al. (2023) found that burning wood is a major source of various organic aerosols, with trace amounts of elemental carbon and inorganics appearing in their results as well. Pressed wood did contain the highest organic carbon to total carbon ratio, at 88.07%, suggesting that the resins or adhesives present in the sample contain organics which would increase the ratio compared to the other two types of wood. ACQ treated wood had the lowest organic carbon to total carbon ratio, with a value of 84.71%. It could be speculated that this is the case, as this wood type contains the most inorganic compounds during treatment. The value is less than a percent difference between the next closest value though and should not be used as an indicator of differences in burning lumber on its own. Even though each wood type underwent different treatment processes during production, organic carbon dominated the emissions across each of the burns and only concluded that all three wood types produced primarily organic emissions which is commonly seen in all biomass.

Ion chromatography analyzed the charged ions, both anions and cations, from the three samples. Each sample had a mixture of anions and cations, they are as follows: acetate, phosphate, calcium, chloride, potassium, nitrate, ammonia, sulfate, bromide, sodium, fluoride, magnesium, diethylammonium, and nitrite. Figure 2 displays the amount of ions present in each lumber sample. It is clear there is a similar total ion mass shared between the three samples, with pressed wood having the largest total mass present in the sample with a value just over 1.5 µg. Further, Figure 2 clearly shows that the acetate ion was a majority in composition found across all three samples. This is evident because acetate is a known product of the combustion of organic material. Wood being primarily composed of cellulose, lignin, and hemicellulose, breaks into other organic compounds during combustion. Acetate specifically is formed from the combustion of hemicellulose, which implies that organic compounds were formed during burning (Ndao et al., 2025).

**Figure 2**

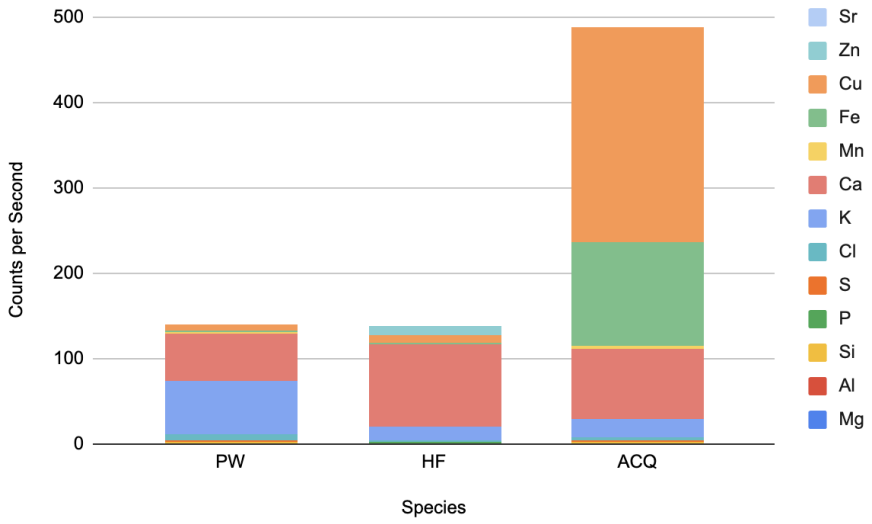
*Results from Ion Chromatography by Sample*



X-Ray Fluorescence provided metal species in the burn samples, with each lumber sample ran before and after burning. The pre-burn run was conducted in order to see what metals were to be expected in the elemental emission profile of each sample. Shown in Figure 3, alkaline copper quaternary (ACQ) had the highest total signals with strong copper and iron signals that are not present in hem-fir (HF) or pressed wood (PW). The high copper signal found in ACQ treated wood directly mirrors its treatment process, as ACQ contains a copper based chemical, copper oxide, as one of its core components during production (US EPA, 2026). Running the samples before burning allows for us to understand which elements are likely emitted from the lumber samples, and to limit our scope of interest to those compounds when analyzing smoke samples after the burn.

**Figure 3**

*Pre-burn X-Ray Fluorescence Displaying Metals Present by Sample*

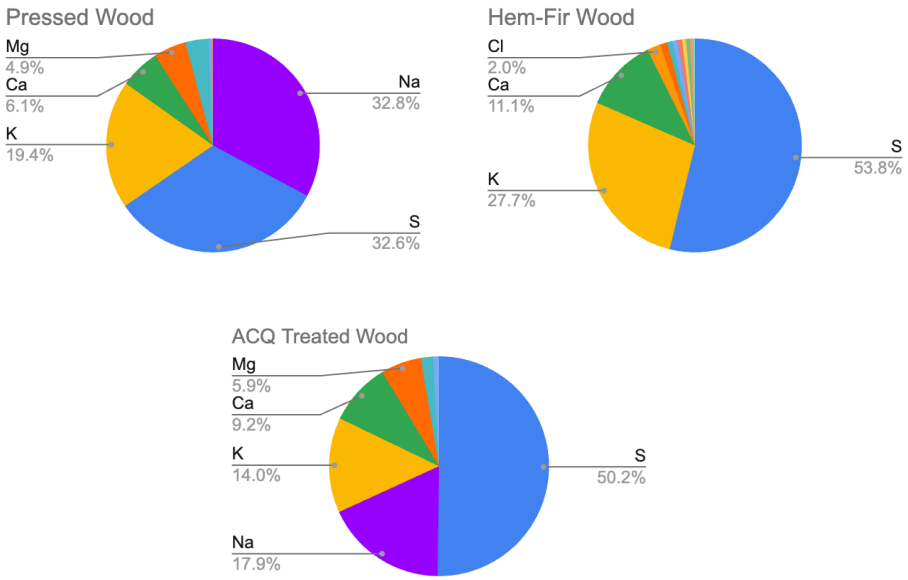



The X-Ray fluorescence results of the emissions for each of the samples after burning displayed that different metal elements were present between the three lumber samples. Figure 4 displays the types of metals that were present in each of the species, with sulfur, potassium, and

calcium being the shared metals found in pressed wood, hem-fir wood, and ACQ treated wood. Potassium and sulfur remained as dominating elements between the three lumber samples, while sodium was only a dominating element in pressed wood and ACQ treated wood, absent in hem-fir wood. Between all three lumber samples, the top metals being sodium, sulfur, potassium, calcium, and magnesium, track with a previous study that reported the top elements in "woody biomass," all of which were present in each of the lumber samples both pre-burn and post-burn (Werkelin et al., 2010). An interesting note though was that the metals copper and iron, present in the pre-burn analysis of ACQ treated wood, are below detection limits and absent in the analysis of ACQ's emissions. This finding does suggest that there are some metals that are not immediately mobilized into the atmosphere during burning; rather, these metals that are absent from emission results remain on the ground, potentially remaining concentrated in the ash following a burn.

**Figure 4**

*Elemental Emission Analysis of Each Lumber Sample*



Total burn time seemed to be affected by the properties of the lumber as pressed wood had a longer total burn time of 23 minutes and 43 seconds compared to around 15 minutes for ACQ treated wood. Table 2 displays the total burn time for each of the lumber samples, suggesting that pressed wood burned more slowly than the other lumber samples. The longer burn time experienced by the pressed wood could be related to its production process. The wood is tightly pressed together, increasing the density of the wood and could affect oxygen availability in the wood which could decrease the combustion time. ACQ treated wood had a shorter burn time in comparison to pressed wood, demonstrating that the lumber sample experienced a faster burn.

**Table 2**

*Compilation of Burn Times for Each Sample*

| Lumber Sample | Total Burn Time |
|---|---|
| Hem-Fir Wood | 14 mins, 10 secs |
| ACQ Treated Wood | 15 mins, 26 secs |
| Pressed Wood | 23 mins, 43 secs |

The Horiba gas analyzer provided real time emission data for gases present in each burn. The gas data collected throughout each burn included nitrous oxides (NOx), sulfur dioxide ($SO_2$), and oxygen ($O_2$). Carbon monoxide and carbon dioxide were also collected and used to calculate the modified combustion efficiency for each of the lumber sample's burn.

Figures 5-7 in Appendix A show the NOx and $SO_2$ concentrations for each of the lumber samples throughout the duration of their respective burn. In hem-fir wood, pressed wood, and ACQ treated wood, NOx concentrations in the emissions were significantly larger than $SO_2$ concentrations. ACQ treated wood displayed the largest concentration peak of NOx of around 14 ppm compared to pressed wood and hem-fir wood who had more relatively tame NOx peaks in comparison. NOx peaks reflect active burn periods as NOx formation takes place during high temperatures in the combustion process.

The $SO_2$ peaks that are seen in each of the burns indicate sulfur-containing compounds present in the lumber sample being released as part of the samples emissions as a result of burning. The $SO_2$ gas data from the Horiba directly reflects the previous X-Ray fluorescence (XRF) data, with sulfur being present in the XRF emission data from each lumber sample. Both of these results validate that components containing sulfur were present in each of the species and were released during each of the burns. Regarding $SO_2$ concentration, pressed wood was seen to have the highest concentration peak, at 3.6 ppm. Interestingly, pressed wood was the only wood species that experienced a double peak of $SO_2$, shown in Figure 6. This is compared to hem-fir wood's peak displaying an increase to its peak concentration of 3 ppm and ACQ treated wood's very gradual increase to its respective peak of 1.97 ppm, seen in Figure 7. Since ACQ was the only wood species to have a $SO_2$ concentration below 2 ppm, it could be suggested that ACQ's production process plays a role in the emissions given off during burning.

Next, oxygen composition present in the emissions of each sample was collected by the Horiba and used for comparison. Oxygen composition would decrease during combustion periods and is expected to recover once combustion halts. From a study by Belcher et al. (2010), a burning fire is “rapidly enhanced” when emission composition is between 19% and 22% $O_2$, inhibited below 18.5% $O_2$, and would be fully extinguished below 16% $O_2$. Seen in Figures 8-10 from Appendix B, oxygen compositions never dropped below 19% $O_2$ and, based on Belcher's study, stayed in an active burn state. We do see the oxygen composition increase towards the end of the burns as time increases, but this is due to the oxygen actively returning inside the chamber as the lumber sample is consumed and the flames are extinguished due to spent media, not lack of oxygen present. Although there were no significant outliers between the burn emissions of each wood species, the oxygen data provides important insight into the role of oxygen availability in suppressing, sustaining, or enhancing fire activity.

The final pieces of data collected was the modified combustion efficiency (MCE) of each species throughout their burn. MCE is a calculated value, based on the carbon monoxide and carbon dioxide concentrations throughout the burn displayed as a percentage. The MCE of a burn essentially measures how completely a fuel burns, where higher carbon dioxide values indicate there was more complete combustion. A MCE value below 85% indicates that a fire is smoldering, while a MCE value above 95% indicates that the fire is flaming. Figure 11 in Appendix C shows initially, for hem-fir wood, the MCE dipped below 85% but then increased and remained above 95% for more around half of the burn before gradually decreasing to a MCE of around 90% for the remaining burn time. Figure 12 in Appendix C also shows a similar trend with pressed wood, where MCE dips then increases before decreasing once more. However, the MCE of pressed wood remained above 85%, and once increased, the MCE remained above 95%

for ten minutes before decreasing and eventually reaching an MCE of about 82%. Figure 13 in Appendix C shows ACQ treated wood experiencing the same trend, the difference here though is that the MCE for ACQ treated wood never fell below 90%. ACQ treated wood was also the only wood species that remained in the flaming phase the longest, having a MCE value of over 95% for over 15 minutes.

Lower MCE values mean that there is less complete combustion; this is associated with a smoldering fire with increased emissions a**s** all the compounds are not reaching complete combustion. Even though the flames never reached a value below 85%, the lower MCE value below flaming in transitional stages could contribute significantly to the emissions that were analyzed with methods mentioned earlier. Pressed wood had the longest burn time of the three wood species, this means that this sample had a longer time below the flaming phase. An elongated period of inefficient combustion could suggest that pressed wood could contribute more emissions when burned.

## Future Research Directions

Future research should be focused on obtaining a complete data set of each media's emission profile. Measurements that were planned never took place as two of the analytical machines had issues in the laboratory. Data acquired using both the High Performance Liquid Chromatography (HPLC) and Thermal Desorption Spectroscopy methods should be used to allow for more comparisons between the three lumber samples. Specifically regarding the HPLC method, it is expected that, at least in an emission sample from pressed wood, there would be signals of carbonyl groups; adhesives used in its production are formaldehyde based, a type of carbonyl group, which is why its signal would be expected to show (Pizzi et al., 2020).

Further, real time burn temperature data should be measured as well. The acquired temperature data would bridge the gap between combustion conditions and results. For example, smoldering conditions with a higher temperature could yield different gas phase emissions than smoldering conditions with a lower temperature. Improving on these methods ensures that there is a more comprehensive comparison, it could also lead to the determination of what material's emission, when burning, is the most hazardous and should be of concern.

Lastly, further analysis of the lumber ash should also be considered as there were metals, such as copper and iron, that did not appear in the ACQ treated wood emissions after burning. It can be suggested that these metals, absent from smoke emissions, are present in the ash left behind after the metal containing wood is burned (Pohlandt et al., 1993). Pohlandt found that large concentrations of inorganic materials are found in ash from treated lumber, therefore analysis of ash could play a role in understanding the impact metal treated wood has on the environment.

## Conclusion

All in all, this research demonstrated how different wood species can produce different emission profiles when burned. The results from this experiment are relevant now more than ever, as wildfires become more destructive and frequent. The wood species analyzed were hem-fir wood, ACQ treated wood, and pressed wood, as each of these materials is commonly found in housing structures. Elemental Carbon/Organic Carbon analysis showed that emissions from all three species were dominated by organic carbon, while ion chromatography and X-ray fluorescence showed clearer differences in the charged species and metals present in their emissions. ACQ treated wood showed higher metal concentrations due to its production and treatment process, while pressed wood had unique gas emission peaks and the longest burn time.

These findings aid in the understanding of structural fire emissions, especially as wildfires like the Eaton Canyon Fire and Palisades Fire became some of the most destructive structure fires in California history. This becomes especially important during wildland-urban interface fires, where engineered and processed wood can burn together with vegetation, creating more complex emission profiles than vegetation alone.

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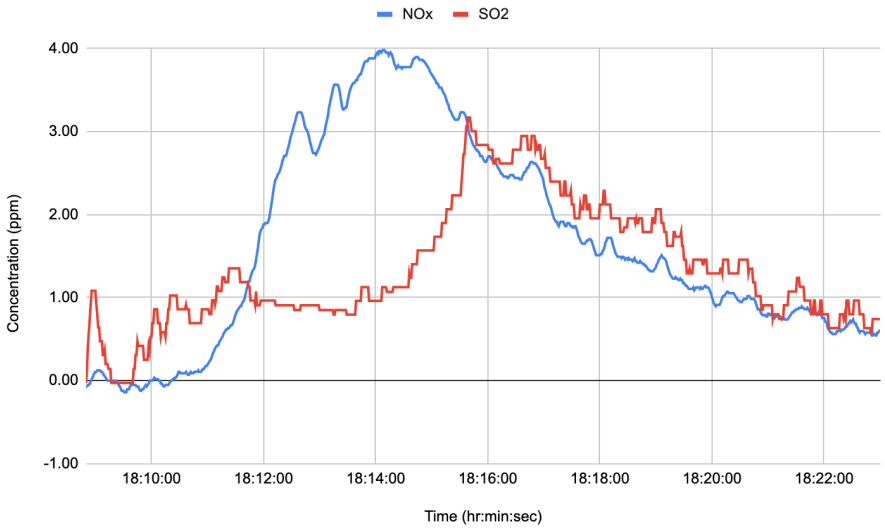
## Appendix A: NOx and $SO_2$ Concentration Graphs

### Figure 5

*NOx and $SO_2$ Concentrations from Hem-Fir Wood*




### Figure 6

*NOx and $SO_2$ Concentrations from PW Wood*

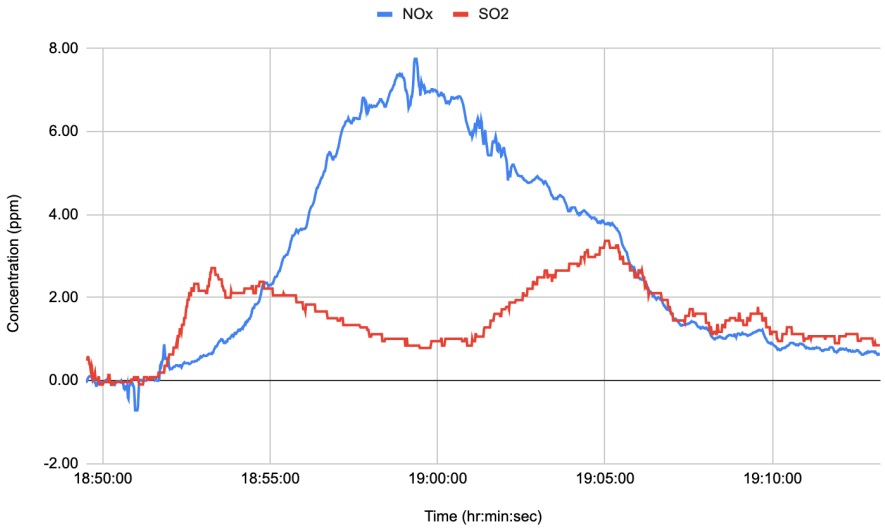
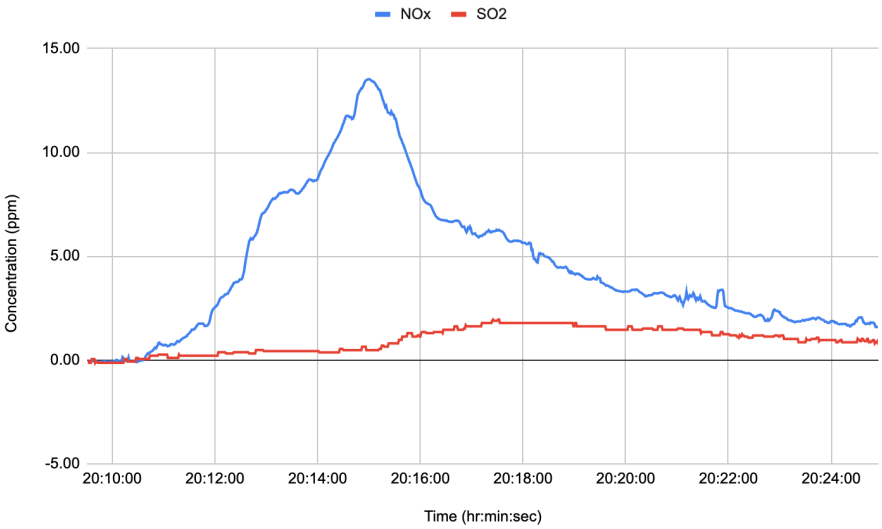


**Figure 7**

*NOx and $SO_2$ Concentrations from ACQ Wood*



## Appendix B: Oxygen Composition During a Burn for Each Sample

**Figure 8**

*Oxygen Composition of hem-fir Wood During its Burn*

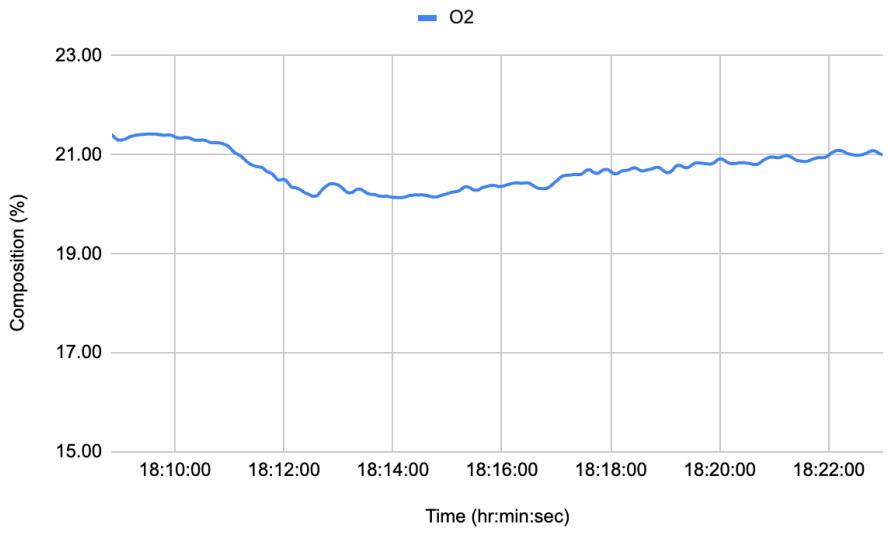



**Figure 9**

*Oxygen Composition of Pressed Wood During its Burn*

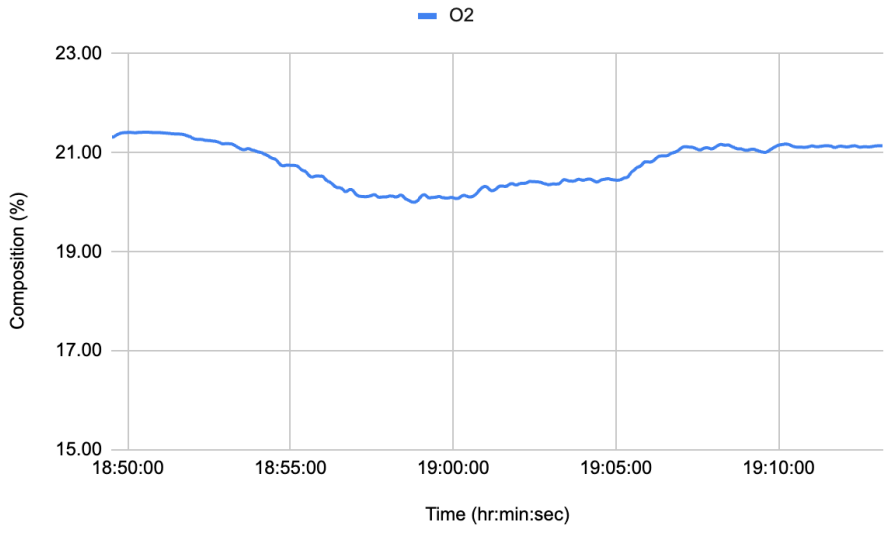
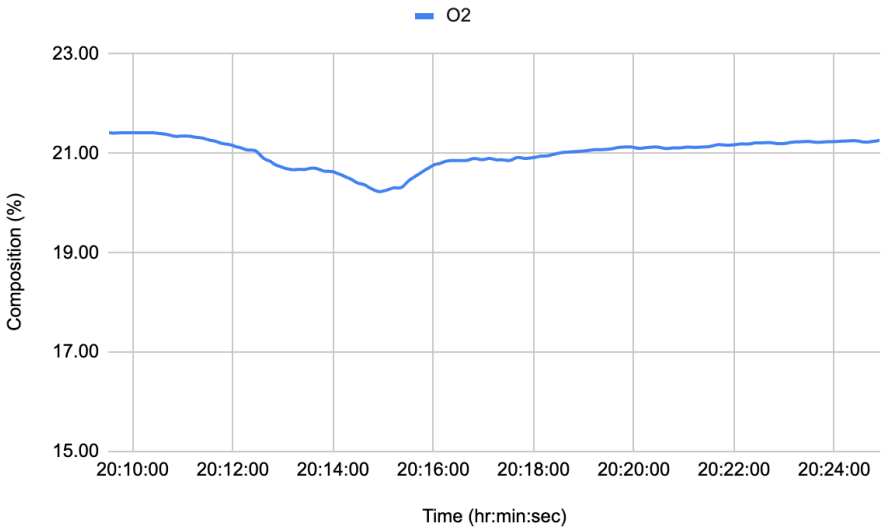


**Figure 10**

*Oxygen Composition of ACQ Wood During its Burn*



## Appendix C: Modified Combustion Efficiency (MCE) of Each Sample

**Figure 11**

*MCE of hem-fir Wood*

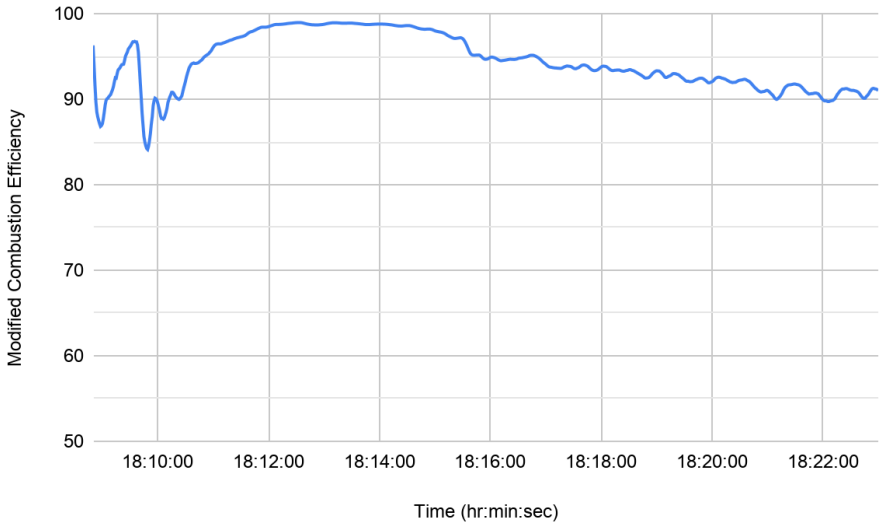



**Figure 12**

*MCE of Pressed Wood*

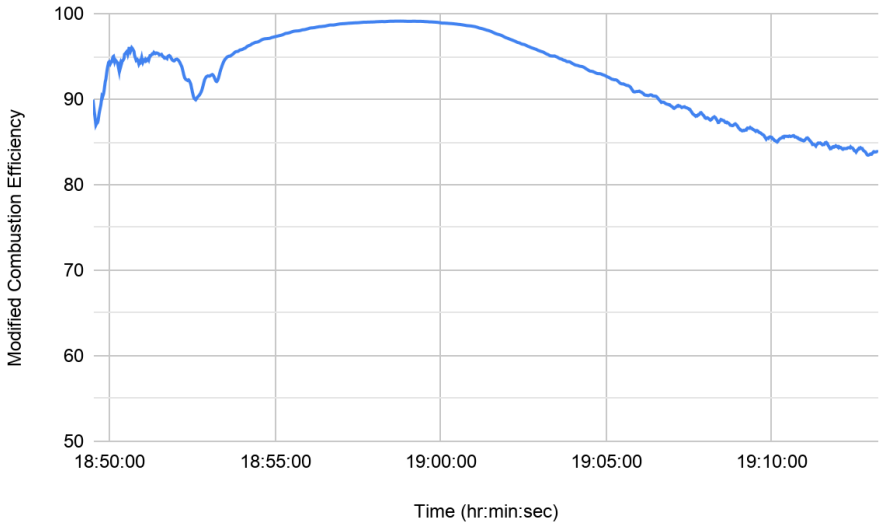


**Figure 13**

*MCE of ACQ Treated Wood*