Department of Fire Safety Engineering
Lund Institute of Technology
Lund University

Preliminary study on the role of moisture and extractives of ornamental plants on the flammability

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Marcus Larsson *Micael Lundquist*

Department of Fire Safety Engineering
Lund Institute of Technology
Lund University

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Authors: Marcus Larsson
Micael Lundquist

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Abstract

The many and costly wildland fires in later years have created a demand for better knowledge about the spreading of the wildland fire on to structures and how you should protect your home against these fires. This report is a part of a large study, “Analysis of the fire risk to structures in the southern California urban-wildland interface”, on these matters performed by the University of California at Berkeley.

One of the objectives of the study is to assemble a Vegetation Guide in which ornamental plants that are recommended, in a fire protection point of view, to grow next to your house in a urban/wildland interface. This report is a preliminary study on the role of moisture and extractives of ornamental plants which are considered to be two of the characteristics of the plant that contribute to the plants over all flammability.

The experiments were performed on Juniper Chinensis a common ornamental plant in California. The conclusions drawn in this report will act as guidelines for future test methods.

Summary

The report is based on research carried out at the Forest Products Laboratory, University of California, United States of America. The project is part of a larger study conducted on wildland fires in the urban/wildland interface, and in particular how these fires spread to residential plants close to structures and then the structures.

This report is the beginning of the experimental testing of residential vegetation. In the future there will be further testing of many species. This information will be compiled into a Vegetation Guide. The main objective of the experiments described in this report is to develop and validate procedures for analyzing and testing the fire performance of plants.

Specific objectives were the following:

1. Determine how the amount of extractives and the moisture content in the plant change when the plant is stressed.

2. Determine the role of volatile extractives on the flammability.

3. Determine the effect of the moisture content on the composition of the extractives in the plant and the overall flammability of the plant.

All experiments were performed on the species *Juniper Chinensis*.

Groups of plants were stressed to three different levels. One was watered regularly (Category 1 - green); the second was left without water for two weeks (Category 2 - dry); and the final (Category 3 - fire-weathered), was dried in a kiln to simulate the hot and dry weather that occasionally occurs in California.

After the plants had been stressed, they were chemically analyzed to determine how the stress had affected the amount of volatile extractives and the moisture content in the plant. The amount of volatiles was determined by extraction and the moisture content simply by weighing the sample before and after oven-drying it. As expected, the moisture content dropped when the plants were stressed, but the amount of volatiles did not change.

However, results from the heat value tests showed a difference between the heat value of the biomass and the extractives, and the heat values did not change when the plants were stressed. On the basis of this, it is theoretically feasible to assume that the flammability change when the relative proportions of biomass and extractives changes.

The moisture content effect on the flammability was determined by measuring the heat release rate, with an oxygen depletion system, at different levels of stress. These tests showed that the heat release rate increased when the moisture content decreased, as expected.

If the experiments described in this report are carried out on more species, a wider basis for understanding how the different characteristics correlate with the flammability will be reached. This knowledge will be the foundation when assembling the Vegetation Guide.

Acknowledgements

We would like to express our sincere thanks to our supervisor Prof. Robert Jönsson, Department of Fire Safety Engineering, Lund Institute of Technology. It was he who initiated the contact with the Forest Products Laboratory, UC Berkeley, and thereby made it possible for us to participate in their research project.

We greatly appreciate the efforts of Dr. Frank Beall and the FPL staff, in particular Tom Breiner, Kevin Flynn, Larry Cool and Dorothy Lubin for their help throughout the work. Not forgetting the encouragement from the girls at the front desk.

We would also like to send our love and gratitude to Mrs. Cecil Grant for her never-ending concern for our wellbeing. Her comments and help with the English language was greatly appreciated.

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1. Introduction

This report is presented as the final part of the Fire Safety Engineering degree requirement at the Department of Fire Safety Engineering at Lund University, Sweden.

The report is based on a research project carried out at the Forest Products Laboratory, University of California, United States of America. The project is part of a larger study, "Analysis of the fire risk to structures in the southern California urban-wildland interface", conducted on wildland fires in the urban/wildland interface, and in particular how these fires spread to residential plants close to structures and then on to structures. This report deals with the effect of volatile extractives and moisture content on plant flammability.

In addition to the report there is a video recording of the burn tests. There are copies of this recordings at the Department of Fire Safety Engineering, Lund, Sweden and at the Forest Products Laboratory, University of California, United States of America.

1.1 Objectives

The main objective of the experiments described in this report is to develop and validate procedures for analyzing and testing the fire performance of plants.

This report is the beginning of the experimental testing of residential vegetation. In the future there will be further testing of many species. Specific objectives were the following:

- Determine how the amount of extractives and the moisture content change when the plant is stressed.

- Determine the role of volatile extractives on the flammability.

- Determine the combined effects of moisture content and extractives on the overall flammability of the plant.

1.2 Thesis organization

The thesis work consists of two parts. One part consisted of developing and conducting experiments and tests, and the other evaluating the results. The project has pursued the following procedure:

1. Reviewing literature on urban/wildland interface fires in southern California.

2. Establishing procedures for treatment, chemical analysis and flammability testing of Juniper Chinensis plants.

3. Exposing the plants to simulated moisture stress treatments.

4. Analyzing chemical composition and testing fire performance and caloric content of the plants.

5. Analyzing test data.

The procedure above has been the foundation for the design of this report. Below follows a brief description of the content in the different chapters:

Chapter 2 provides background information on wildland fires and the general physics of their growth and spread. It also gives an introduction to the main study, conducted on wildland fires in the urban/wildland interface.

Chapter 3 is an explanation of the different treatments the plants were exposed to. It also deals with the desired effect of the treatments.

Chapter 4 is a description of the chemical analysis procedure and the equipment used. It also explains how the procedure was established.

Chapter 5 lists the output results from the chemical analysis.

Chapter 6 is a description of the flammability test procedure and the equipment used.

Chapter 7 lists the output results from the flammability tests.

Chapter 8 is a description of the heat value determination procedure and the equipment used.

Chapter 9 lists the heat value results.

Chapter 10 is a discussion about the practical procedures and the results of the experiments.

2. Background /1/

The steady and sometimes rapid population growth in California cities has created an urban-wildland interface that results in an interaction of suburb homes and wildland vegetation. It is well recognized that this expanding urban-wildland interface increases the risk of loss due to wildfire, making this issue one of critical national importance.

2.1 Wildland fires

Wildland fires are a costly and lethal problem in California. Every year wildland vegetation and urban structures worth billions (10^9) of dollars burn. For example, in a ten day period, 25 October to 3 November 1993, a wildland fire consumed over 79,000 ha of urban/wildland interface (UWI) area and badly damaged or destroyed 1260 structures. The fire suppression was estimated at a cost of nearly $60M. Structural damage costs was estimated at over $1B. Three people lost their lives and hundreds were injured.

Another example is the 1991 Oakland-Berkeley Hills fire that stopped just before the Clairmont Hotel, only 1-2 km southeast of the University of California at Berkeley campus. On the 19th of October approximately 3 ha of brush and pine burned and was relatively easily controlled. The day after, 20 October, the fire rekindled when fresh fuel was blown into the fire perimeter from the day before and spread rapidly downwind and downslope driven by an extremely dry and high velocity wind. 600 ha burned and damaged 2334 structures at a value of approximately $1B. 25 people were killed as a result of the fire. The fire was declared under control in the morning of 23 October /2/.

These fires occur yearly; 3130 structures were destroyed by wildfire in California between 1955 and 1979, and from 1980 to 1993 approximately 7584 structures were destroyed. That is twice the loss in about one-half the time.

2.1.1 Fire Hazard components in California

Numerous factors contribute to the large fire protection problem of wildland fires in California. Some of these factors are pre-determined such as the topography and infrastructure, while others such as weather and vegetation may change according to time. Society can control some of these factors, but not all of them.

Fire Weather Hazards

Weather is one of the factors we can not control; in addition, it is hard to predict. California weather is hot and dry in the summer, similar to that of a Mediterranean climate, and sometimes leads to large wildland fires. Because of this Mediterranean climate the growth season in California is almost throughout the entire year creating an immense fireload in some areas. Precipitation in southern California is very sparse. Dangerous Santa Ana winds from desert areas, which are notorious in California, produce the usual effects of wind: fanning and supplying oxygen, preheating fuels by bending flames from the vertical and carrying burning firebrands ahead of the point fire. But, it also brings dry air from continental high pressure areas, then heats and dries it further by compression as it flows to lower elevations at a velocity of 120+ km/h, /3/.

Topographical Hazards
Variations in the topography can cause dramatic changes in fire behavior as a fire progress over the terrain. A valley sometimes produce a chimney effect and thereby increase the wind velocity, /4/. Another example is that fire spread more rapidly up a slope than on level ground. In a guide for reducing the wildfire threat, a downhill clearance distance of 60 m for a 30 % slope is recommended /5/.

Structural Hazards
One important problem with structural hazards is that many houses are built of wood frame construction, often with wood siding and wood shingle or shake roofs. Attic and floor vents can sometime be left uncovered. Picture windows and stilted or cantilever decks facing directly into or over dense wildland fuels are common. Many roofs and rain gutters hold large quantities of dry leaves and needles. Any or all of these characteristics contribute to make these structures one of the most hazardous synthetic fuels in the UWI, sometimes referred to as the I-Zone.

Vegetation Hazards
All vegetation is more flammable at certain times than at others. In its wild state, vegetation consists of both living and dead materials. In the areas controlled by humans, the natural cycle of consumption of dead material by small wildland fires is disturbed. Instead, the fuel accumulate and when ignited hundreds or thousands of hectares burn in a short period of time. Flame lengths can exceed 30 m and radiant heat can ignite exposed flammable materials at a distance of 30 m or more, /4/.

2.2 "Analysis of the fire risk to structures in the southern California urban/wildland interface"

There is good documentation of the relationship between wildland vegetation fuel characteristics and wildland fires. However, the documentation of the relationship between residential vegetation and structural fires in the UWI is poor. Therefore the Forest Products Laboratory has designed a two-phase study to identify and clarify these problems and dangers.

2.2.1 The study design

Objective
The overall objective of the study is to develop methods to assess the fire risk to structures in the urban/wildland interface and effectiveness of fire mitigation efforts based on an analysis of vegetation, building components and other important fire parameters.

Phase I
A preliminary analysis has been conducted to identify the key factors important to understand the fire-related risk to ignition and penetration of structures. Early vegetation studies overlooked the compounding effects of plant age; moisture content; amount and distribution of dead material; size of leaves, twigs, and branches; and, the geometry of the plant, when investigating ignitability or flammability of specimen plants.

Bond and van Wilgen gives a review of the influence of plant structure and other characteristics on fire resistance. Although it is often assumed that these characteristics correlated well with the age of the plant, recent studies indicated high levels of variability in the plant age/fuel characteristic relationship. A likely contributor to the variability, expected in landscape environments, is the maintenance of a plant (pruning, watering, etc.). Combustion characteristics of the vegetation that were found to be a key factor in determining whether or not a plant could ignite a structure are:

- Total volume
- Arrangement
- Proportion of dead material
- Surface area/volume ratio
- Moisture content of the living part of the plant
- Volatile and inorganic content

The next step was to review existing lists of plants recommended for use in high fire risk environments such as the UWI and to make a master list. A preliminary search identified more than 25 different lists. The reviewed lists were based on empirical evidence, with inconsistent terminology and recommendations. In many cases it is not clear what characteristics were considered in the selection criteria. The result of the review was a new database with the combustion characteristics of plants commonly used in the UWI that can be the basis for a Vegetation Guide.

From this, an approach to risk assessment and mitigation analysis was conceived for Phase II.

Phase II
This phase of the study was designed to carry out the two projects identified in Phase I, and is focused on the development of comprehensive risk assessment and mitigation .

1. To produce a Vegetation Guide:

A vegetation analysis will identify common forms of vegetation in the I-zone and establish relationships between vegetation characteristics and fire resistance. For suggested plants for testing in Phase II, see Appendix A

Based on the analysis and fire testing of the vegetation characteristics identified in phase I a guide will be produced. This guide will provide the knowledge and help that property owners and fire professionals need to analyze the risk to buildings. It will also establish a framework for making decisions on effective methods of risk reduction, by increasing the distance between the heavy vegetation and the structure or using fire-retardant species near the structure.

2. To develop a method to assess the risk of ignition and penetration of a structure:

The focus of the development is to assemble the different components needed to realistically assess the fire risk of a structure. This fire risk assessment will be based on both the total fire environment of the structure, including nearby vegetation, and the building location and design. A new test protocol must be established, as there currently is no standard for testing the combined effects of vegetation and structure.

The goal is to develop assessment modules related to the fire performance of vegetation and building components.

Major products from Phase II will be:

- Protocols for fire testing vegetation and building components.
- Development of apparatus and equipment for use in Intermediate-Scale Biomass Calorimeter.
- Vegetation guide, including a database of approximately 1600 species classification according to fire performance, drought resistance and cold hardiness.
- Photographic guide to aid in the assessment of vegetation characteristics during site evaluations
- Development of assessment modules for incorporation into the Structural Ignition Assessment Model (SIAM).
- Partially annotated fire mitigation bibliography and library collection.
- Fire Mitigation World Wide Web home page on the Internet.

The structure of the study is illustrated in figure 2.1:

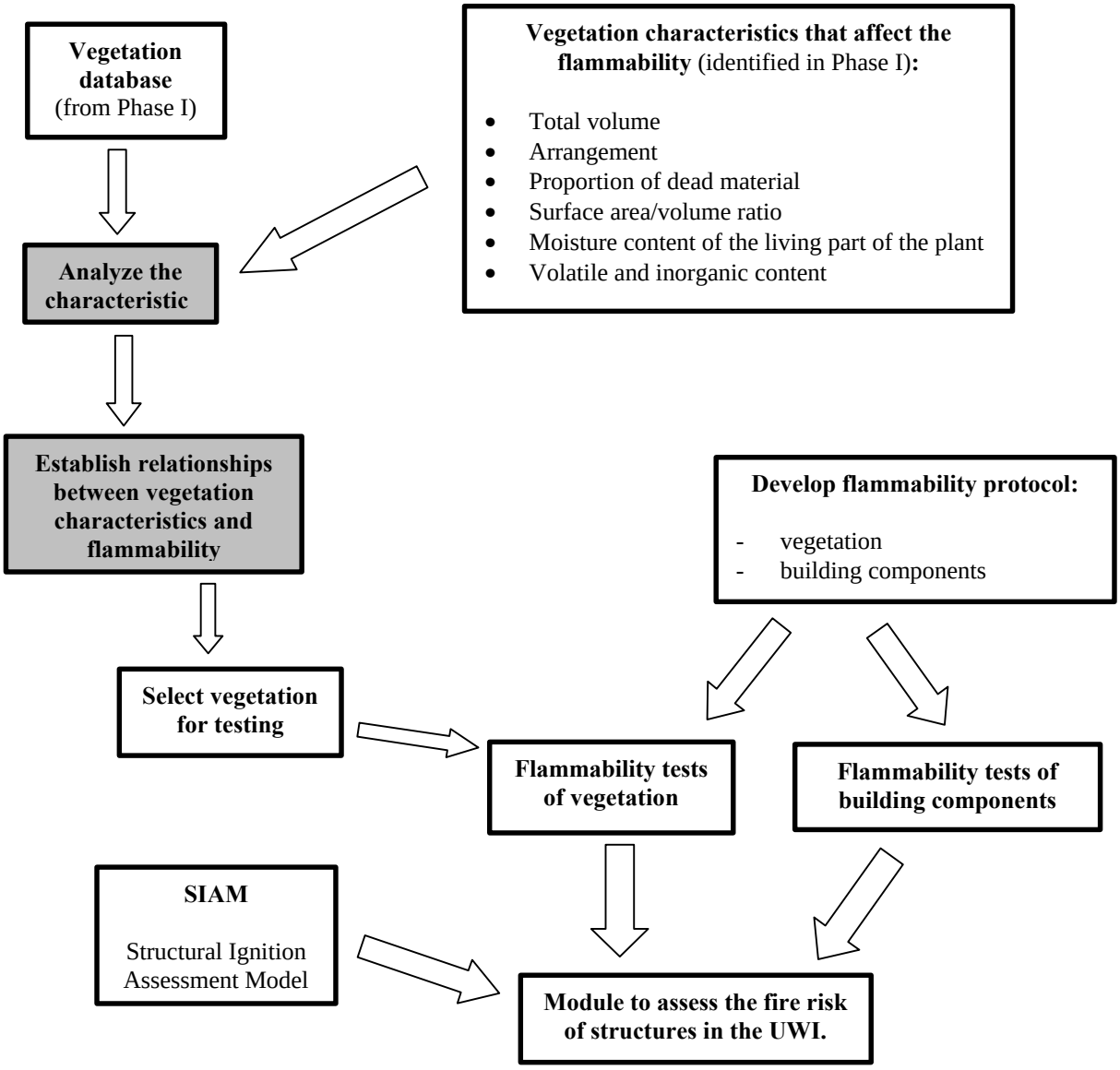


Figure 2.1: Study structure

The work presented in the report has been to develop and validate test methods for analyzing the characteristics and for establishing relationships between characteristics and flammability, i.e. the gray boxes in the figure.

3. Plant treatment

Plants were obtained from a nursery. They came in 20 l containers with holes in the bottom to drain excess water. The plants were approximately 40 cm high and 40 cm diameter (Figure 3.1). The plants were put on the bare ground in a Lath-house (Figure 3.2) at the Forest Products Laboratory and kept in their containers.

Figure 3.1: Test plant, Juniper Chinensis

The ambient conditions at the Forest Products Laboratory were:

- Evening temperature: 10-15 °C.
- Day temperature: 20-25 °C.
- Relative humidity moderate to high.

The instructions from the nursery were to give the plants one gallon of water daily. These instructions were followed until the treatment started except that the plants could not be watered on weekends when the RFS was closed. Instead the plants were given 8 l of water on Fridays. For complete watering notes see Appendix B. The nursery also advised a gentle shower when watering to avoid flushing away the soil around the stem and thereby exposing the sensitive roots. The watering of the plants was done with a watering wand showering the soil for ten seconds, which was the time required for the wand to give 4 l of water.

Figure 3.2: Lath-house where the plants were kept

3.1 Stressing the plants

The plants were divided into three treatment categories with 15 specimens each. This was done in order to achieve different levels of stress in the plants so that the change in amount of volatile extractives and moisture content could be analyzed and compared to the heat release rate when burned.

3.1.1 Category 1, green

This category represented the healthy and well-watered plants with a moisture content of 60-70 %. The plants were watered according to the nursery instructions, 4 l per day, until the day of testing when they were not watered.

3.1.2 Category 2, dry

This category was intended to represent the state of the plant after two weeks of draught. The plants were watered according to the nursery instructions until two weeks before testing. This was expected to bring down the moisture content to 40-50 %, but when the moisture content was measured on the day of burning it was approximately 60 %. The plants were probably still withdrawing the water stored in their roots and soil. This treatment will therefore need to be changed for future testing.

3.1.3 Category 3, fire-weather

This category was intended to simulate the weather condition that are referred to as fire-weather, such as the hot and dry Santa Ana winds (Chapter 2.1.1). The plants were watered according to the nursery instructions until four days before testing. The day before the tests, the stem was severed from the roots. The drying was accelerated in a dry kiln (Standard Dry Kiln Co, Indianapolis Industries) operated at an air temperature of approximately 40-45 °C to depress the relative hummidity to about 20 %. This way the moisture was forced out of the plant instead of just removing the water supply (category 2). The volume of the kiln is approximately 2 m^3 and the plants were placed in the centre of the compartment on a support frame.

The plants were weighed before they were put in the kiln, and several times during drying to track moisture content. After 20 h the plants had reached a moisture content of 30-35 %, which is approximately one-half of their green condition.

4. Chemical analysis

A plant consists of water and biomass (Eq 4.1). The unextracted biomass , m_b, can be divided in extractives, m_e, such as fats, terpenes etc and extracted biomass , m_o, (Eq 4.2). In order to determine the amount of volatile extractives in the plants and how they change when the plants are stressed, the chemical compounds must be extracted and their mass determined. Those extractives that can be removed with a natural solvent were defined as the mass of extractives. When the specimen is extracted it loses its water as well as the extractives and only the dry extractive-free mass, m_o, is left. Therefore the moisture, m_w, in the specimen must be determined so that the amount of volatile extractives can be calculated (Eq 4.3).

$$m_{total} = m_b + m_w \quad [4.1]$$

$$m_b = m_o + m_e \quad [4.2]$$

$$m_e = m_{total} - m_o - m_w \quad [4.3]$$

The amount of volatile extractives in the foliage and the twigs from the three treatment categories are given in Chapter 5.

4.1 Standards and earlier research

The first step was to review similar standards and earlier research. These were then used as a starting point for establishing the extraction procedure. The most relevant methods were the following three:

- Standard Method for Preparation of Extractive-free Wood, ASTM D 1105-84 /6/.

The main outline of this procedure is as follows:

Extraction of volatiles from the sample shall be done in a Soxhlet Apparatus. Solvents are a *Alcohol-Benzene Mixture* (one part 95 % ethanol and two parts of chemically pure benzene) and *Ethyl Alcohol (95 %)*. The specimen shall consist of air-dry ground material.

Extract for four hours with alcohol-benzene mixture. Remove excess solvent from sample with suction. Wash the sample with alcohol to remove the benzene. Extract with 95 % alcohol for another four hours, or longer if necessary, until the alcohol siphons over colorless. Extraction with each solvent should be carried out at a rate of not less than four siphonings per hour. Finally, extract sample in hot, distilled water for one hour. Repeat the last procedure three times then air-dry sample.

Calculate mass percentage of extractives relative to moisture-free sample.

For the complete procedure see Appendix C.

- Standard Test Method for Ethanol-Toluene Solubility of Wood, ASTM D 1107-96 /7/.

The main outline of this procedure is as follows:

Extraction of volatiles from the specimen shall be done in a Soxhlet Apparatus. Solvent is *Ethanol-Toluene Mixture* (1 l of absolute ethanol and 427 ml of toluene). The sample shall consist of 2 g of air-dried sawdust that has been ground to pass a 425-µm (40-mesh) sieve and retained on a 250-µm (60-mesh) sieve.

Extract with 150 ml of ethanol-toluene solution for six to eight hours, at a rate of not less than four siphonings per hour.

Evaporate the solvent from the sample, oven-dry sample and weigh. Continue the drying until there is no further loss in mass. Report the results as mass percentage of ethanol-toluene soluble matter (extractives) in the moisture-free wood.

For the complete procedure see Appendix C.

- Effective Heat Content of Green Forest Fuels, /8/.

The main outline of this procedure is as follows:

Extraction of volatile from the sample shall be done in a Soxhlet Apparatus. Solvents are *Ether* and *Ethanol-Benzene Mixture* (one part of ethanol and two parts of benzene). The sample shall consist of freeze-dried sawdust.

Extract about 2 g foliage in a dried cellulose extraction thimble with ether for 48 h at a rate of at least six cycles per hour. Vacuum-dry the sample for 24 h and weigh it. Calculate the percentage of extractives based on the dry unextracted sample mass. A portion of the sample shall be extracted in ethanol-benzene mixture by the method described for the ether extraction. Calculate the percentage of ethanol-benzene extractives based on the original dry unextracted sample mass.

4.2 Analysis

After discussions with the FPL chemical expert, Larry Cool, a procedure was put together and evaluated. The analysis consists of three steps: preparation of the specimen, measurement of moisture content and extraction.

4.2.1 Preparation of specimen

Each sample consisted of small samples from all twelve plants in each category, picked in mid-height of the plant. The foliage and the twigs were then separated and air-dried. The air-drying was done by spreading the specimen on a table. The drying was done for 48 h, of which 8 h were under an infrared heating lamp. A drying oven was not used because of the possibility of losing low-boiling temperature volatile extractives. The drying was done in

order to remove the moisture from the sample since it decreases the solvent's ability to extract the volatile extractives from the sample. Drying the sample also made it easier to grind.

The sample was ground in a Wiley mill through a 40 to 60 mesh fraction sieve and collected in three sample bottles. The sample bottles were sealed to prevent evaporation of the volatiles. The three samples were taken to obtain moisture content, extractives content and heat of combustion.

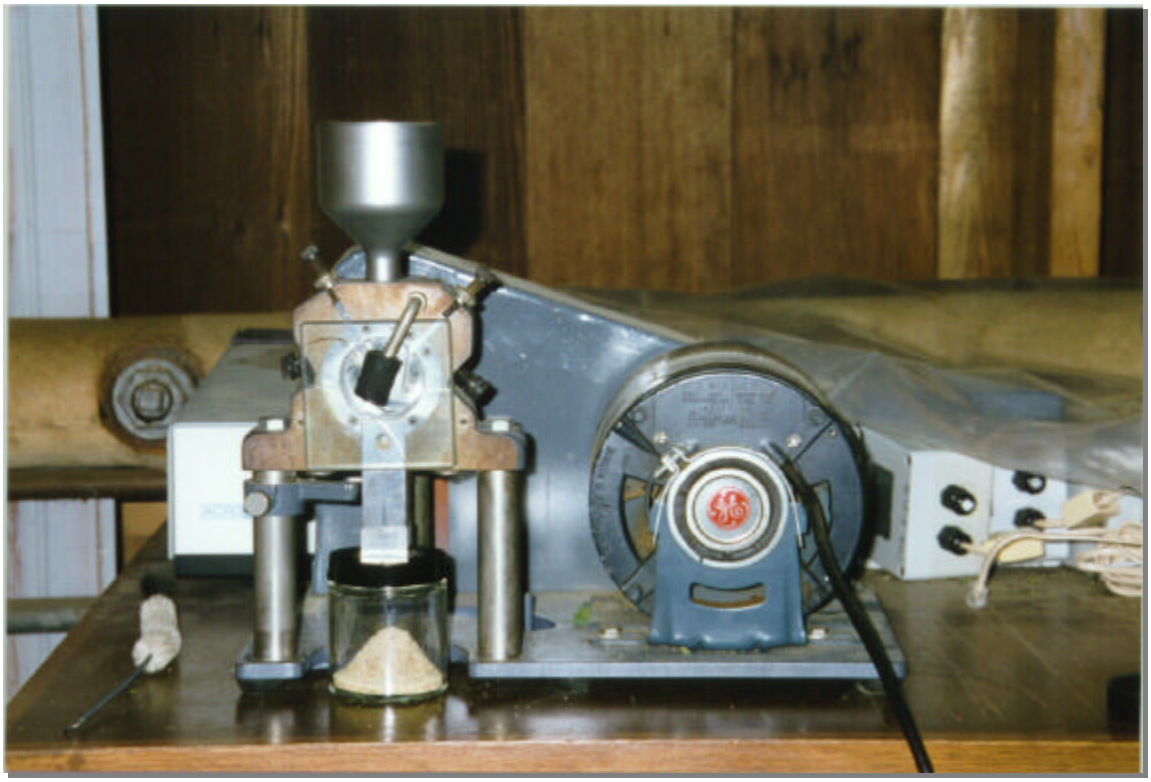


Figure 4.1: Wiley mill used for grinding the samples.

4.2.2 Measuring of moisture content

The determination of the moisture content was done according to the following method:

A weighing bottle was oven-dried and weighed. After that the sample was added to the weighing bottle which was re-weighed. Then the sample was oven-dried at 105 °C for 2 h and then re-weighed. After an additional 1 h in the oven, the sample was re-weighed. This was repeated until all the moisture was gone and there were no changes in mass. Then the mass of the dry sample and the amount of moisture lost could be calculated.

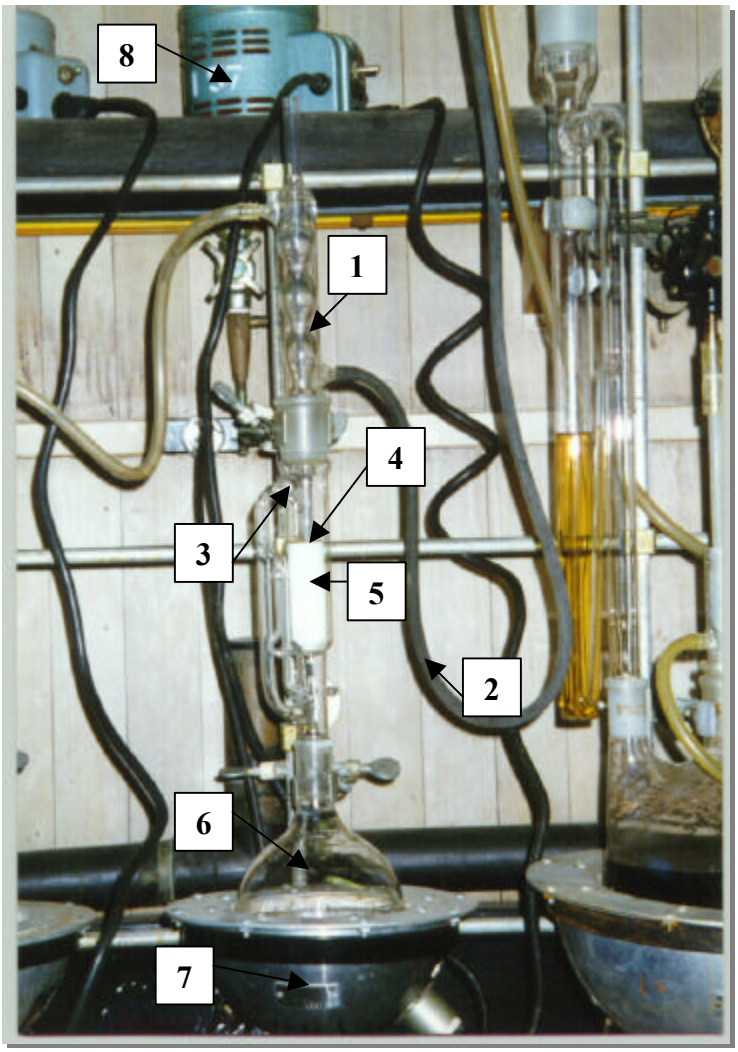
The moisture content of the air-dry sample was then calculated as a mass percentage of moisture in air-dry sample.

4.2.3 The extraction procedure

The procedure followed the step by step procedure in the Extraction Protocol, see Appendix D.

Apparatus

The apparatus used for the extraction of volatile was a Soxhlet Apparatus (Figure 4.2).



1. Graham condenser.
2. Cooling water for condensation.
3. Soxhlet extraction tube.
4. Small cone of fine mesh screen wire.
5. Extraction thimble; pre-extracted paper.
6. Extraction flask.
7. Electric heating mantle.
8. Transformer.

Figure 4.2: Soxhlet Apparatus used for the extraction of volatile.

The electric heating mantle heats the solvent in the extraction flask. The fumes rise through the Soxhlet extraction tube and further on up to the Graham condenser where condensation occurs and dripping solvent into the thimble. The specimen and solvent mix and the solvent extracts terpenes, water, fats etc. When the Soxhlet is full, it automatically drains the solvent back to the extraction flask.

Extraction procedure
Approximately 300 ml of a solution, consisting of 427 ml Ethanol and 1000 ml Toluene, is poured into the extraction flask together with some small boiling stones. The extraction flask was then placed in the electric heating mantle and the soxhlet tube was put on top.

A weighing bottle was oven-dried and weighed. Then a thimble was oven-dried and weighed with the weighing bottle so that the mass of the oven-dry thimble could be determined. Then the sample was placed in the thimble and weighed to get the sample mass. The thimble with the sample was placed in the soxhlet tube and a small cone of mesh screen wire put on top of the thimble to prevent the specimen from being flushed out of the thimble down to the extraction flask. After this the Graham condenser was put in place and the cooling water and the electric heater turned on. The liquid was kept boiling briskly so that siphoning from the extractor was not less the six times per hour.

When the extraction was finished the sample was air-dried in a hood until free of alcohol and then oven-dried to remove all the solvent and moisture. Then the oven-dried sample in the thimble was weighed and the amount of extractives was calculated.

The extractive content was then calculated as mass percentage of extractives in oven-dried unextracted sample.

4.2.4 Validation Extraction procedure

To be able to compare the results in this report to results in the article “Effective Heat Content of Green Forest Fuels”, /8/, confirmation was needed that the solvent used in these experiments would extract the same amount as the two solvents used for the article. This was done by a test-run with the one solvent procedure and then comparing its results to the tests in the article.

The test-run verified that the one solvent extracted all the volatile extractives that the two solvents used in /8/ did. The test-run also showed that no extractives were lost when air-drying the sample before extraction compared to extracting a fresh green sample.

5. Results of chemical analysis

The extraction results show that the different stressing treatments did not affect the amount of volatile extractives in the plants.

The results also show that the foliage has approximately twice the amount of extractives as the twigs (Figure 5.1).

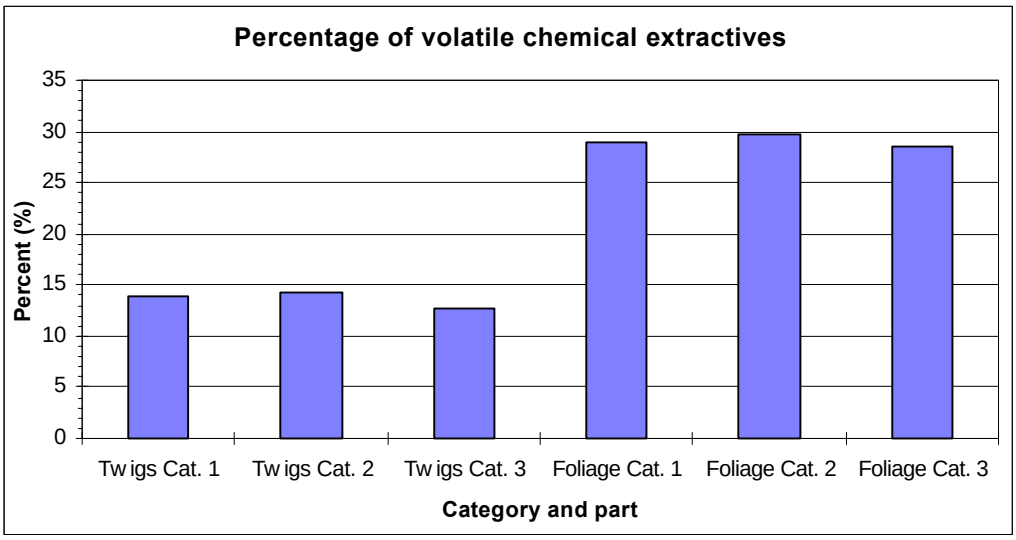


Figure 5.1: Results of chemical analysis.

Three extra analyses were done to get an estimation of the margin of error in the results. The comparison showed that the results were plus/minus one percentage point (Table 5.1).

Category	Foliage (%)		Twigs (%)	
1 green	29	28[1]	14	15[1]
2 dry	30	30[1]	14	-
3 fire	29	-	13	-

[1] Extra runs to determine accuracy in analysis.

Table 5.1: Percentage of volatile extractives in Juniper plants.

The reason that the results vary slightly is the way the foliage and twigs were separated. Since they were separated by color a greenish twig sometimes ended up with the foliage and vice versa.

No conclusions could be drawn on the effect on the amount of extractives on flammability since there were no changes in the amount of extractives among the different treatment categories. To be able to investigate if there is a correlation between the amounts of extractives and the flammability, more tests have to be conducted with other plants that have extractives of different amounts and heats of combustion.

6. Flammability test procedure

Again there were no standards for these tests, but similar tests had been performed at the Richmond Field Station, supervised by Professor Williamson of UC Berkeley. Their procedure and equipment was used for these tests, but a few adjustments were made, based on what had been learned during those experiments. The burning of the plants was done at the Fire Research Laboratory of the Forest Products Laboratory.

Earlier, four criteria have been identified for fire performance of vegetation. They are ignitability (how easily a fuel ignites), sustainability (how well it continues to burn), combustibility (how rapidly it burns) and consumability (how much of it burns). Depending on which of the four criteria you look at, the test method will be different. Combustibility may give an indication of a plants ability to ignite nearby vegetation and structures.

6.1 Test setup

The system used for the test is an Intermediate Scale Biomass Calorimeter that had been designed for this test(Figure 6.1). The system consists of equipment for determining heat release rate using oxygen depletion calorimetry, two platform loadcells, a propane lineburner, a three-sided ceramic fiberboard construction, a plant rack and a data acquisition system. The oxygen depletion apparatus and the data acquisition system were operated by personnel from the fire research laboratory, Tom Breiner and Kevin Flynn.

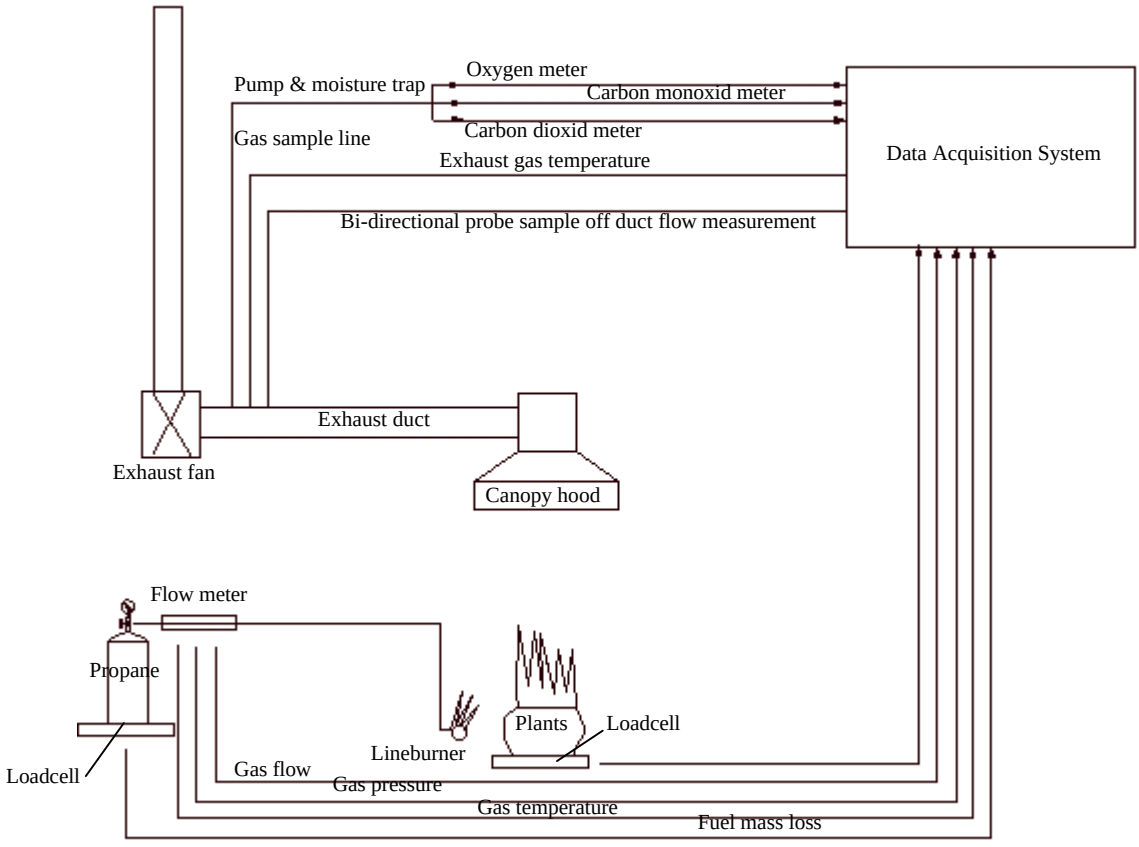


Figure 6.1: System blueprint of the Biomass Calorimeter

6.1.1 Oxygen depletion apparatus

A system for conducting oxygen depletion calorimetry was used to measure the heat release rate (HRR) from the plants. The apparatus samples exhaust gases from the burning plants, measures the oxygen concentration and compares it to the normal ambient concentration that has been determined prior to ignition of burner or test specimen.

The amount of oxygen consumed in the combustion process is calculated by knowing the flow of gases through the apparatus and the drop in oxygen concentration. Approximately 13 kJ is released for each gram of O_2 consumed in combustion.

Calibration

The Oxygen depletion apparatus calibration was checked before each test series to assure accurate outputs. The system is run for 3 min without a source of heat to get a baseline for comparison. Next the lineburner is ignited for 5 min at a heat release rate of 40 kW (based on propane flow), after which it is increased to 150 kW for 10 min. The hood collects the combustion gases that rise from the burner and transports them to a exhaust duct from where they are sampled. After 10 min the burner is turned off. The depletion system runs for another 10 min in order to get a post-test baseline to compare with the initial baseline. The output from the depletion system is then compared to the value calculated from the rate of propane consumed (Figure 6.2).

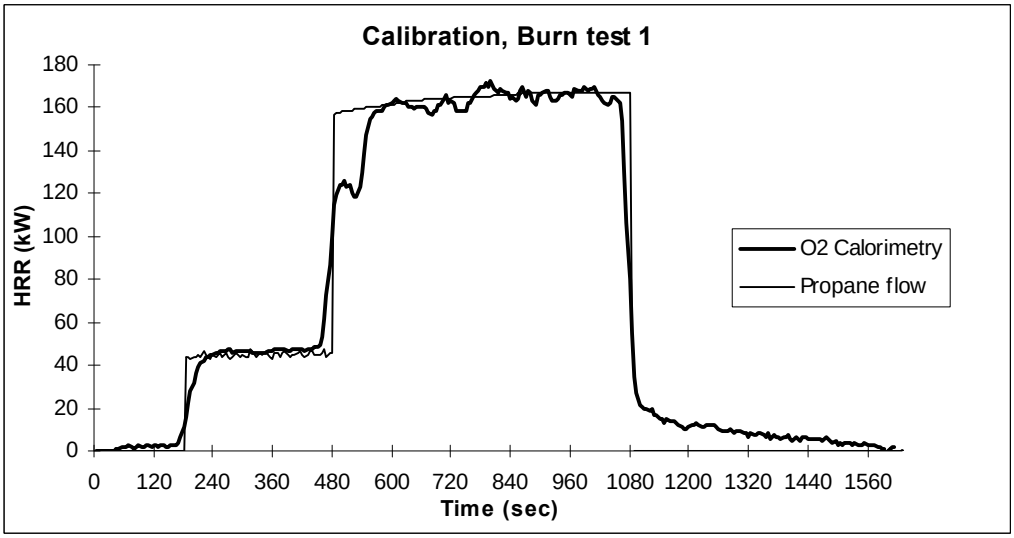


Figure 6.2: Comparison of hood value and propane calculated value.

Both lines should be the same if the oxygen depletion system is correctly adjusted. If not, adjust the output to get the correct value.

6.1.2 Platform loadcells

One of the load platforms monitored the mass of propane used for the lineburner. Four propane tanks were placed on the load platform that automatically registered the mass loss. A second load platform was used for measuring the mass lost during combustion of the plants. The output of both load platforms was recorded by the data acquisition system.

Calibration

The second loadcell needed to be calibrated in order to get a correct conversion from volts to kilograms. The calibration was done by loading the loadcell with different calibration masses (normally 0, 10, 20 and 35 kg) and then recording the output. Then a regression was made on the readings to get a conversion to kilograms.

6.1.3 Propane lineburner

One of the problems in earlier experiments in igniting vegetation was that depending on the ignition source, the entire plant might ignite or might not.

The idea of using a long lineburner was that all the vegetation would be exposed to the flame, and thereby accomplish flame impingement on the plants for ignition and sustaining the fire. To be sure that all the vegetation would get sufficient flame exposure and ignite, 150 kW was used.

To get an even heat output from the burner, propane gas was uniformly forced through 150 mm of sand (Figure 6.3). The mass loss of propane was monitored by a load platform and the mass flow by a turbine rotometer.

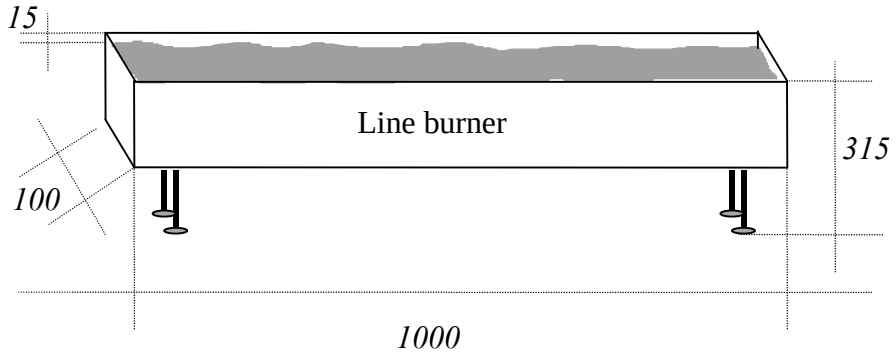


Figure 6.3: Lineburner (mm).

6.1.4 Three sided ceramic fiberboard wall

There are three ceramic fiberboard walls to keep the heat contained around the plants and to provide back radiation simulating a structure. They also make the test setup less sensitive to side drafts.

Figure 6.4: The burning setup seen from the front.

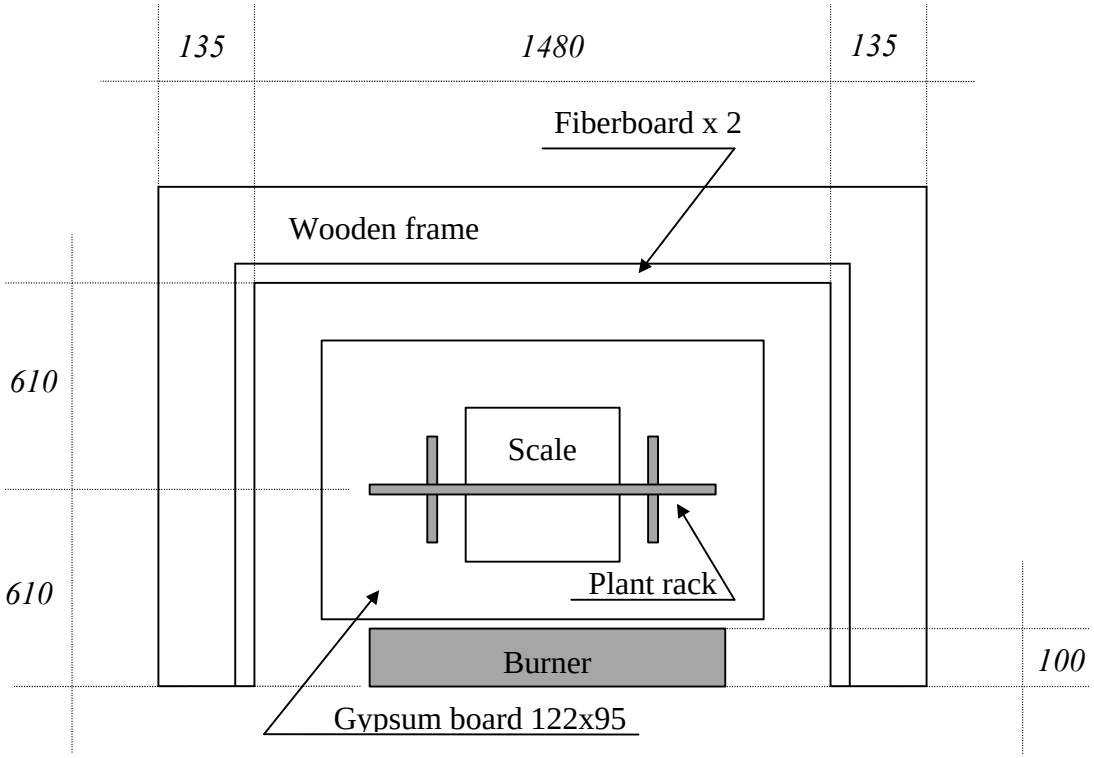


Figure 6.5: Burning test setup seen from above (mm).

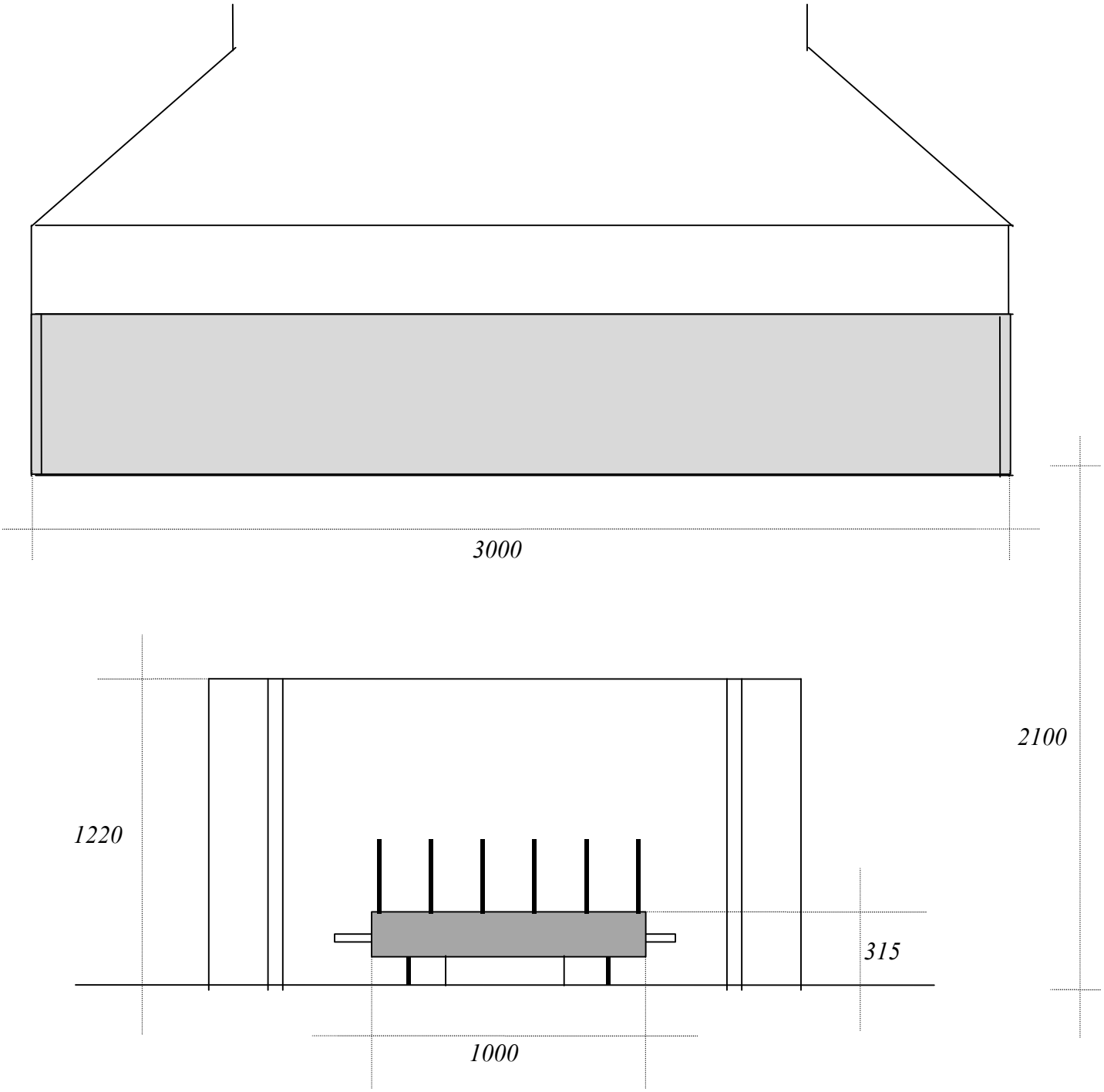


Figure 6.6: Burning test setup and hood seen from the front (mm).

6.1.5 Plant rack

A rack was used to support the plants in as natural an upright position as possible (Figure 6.7 and Figure 6.8). The four plants were mounted side by side to approximate a small bush. The rack made it easier to reproduce the plant configuration for each test. Once the plants were on the rack, it was easy to position them on the loadcell.

Figure 6.7: Support rack with plants.

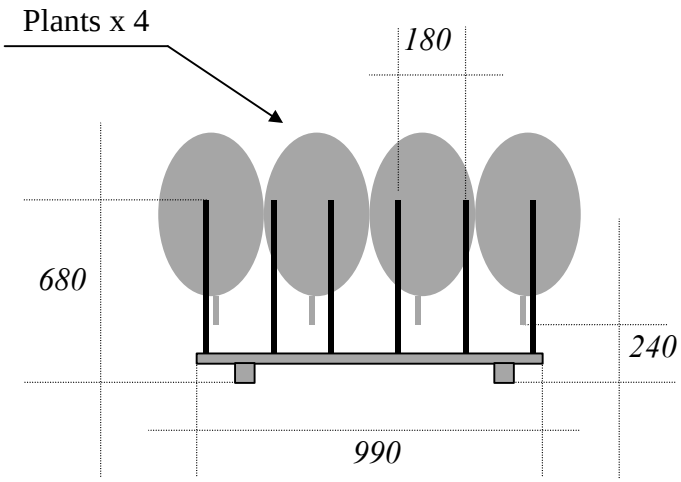


Figure 6.8: Support rack with plants (mm).

6.2 The test procedure

When the calibration of the Oxygen Depletion Apparatus and the plant load platform had been completed, a shelf was placed on the loadcell. The shelf protected the loadcell from radiation of the flames and collected ashes and embers that fell from the burning plants. It was important to collect all this material on the load platform in order to get a correct value of the mass loss.

After the boards had been put in place, the mass was recorded for future calculation of the moisture loss from the shelf during the test. The rack with wires was also weighed so that the mass of the plants could be determined from the difference.

A green moisture content specimen (15 cm long branch) was taken from each of the four plants in each test group before the roots were severed. The moisture content of each test group was then measured from these samples, Appendix E.

After the roots had been severed, the plants were mounted on the rack using steel wires. The plants were mounted in a natural like position and adjusted so that the stem started at approximately the same height for all four plants. The rack with plants was weighed before the test began, so that the mass of the plants could be determined (Appendix E).

The oxygen depletion system was started and run without any combustion for 3 min to get a baseline with which the combustion output was compared. At 3 min, the burner was ignited and burned for 2 min at 150 kW.

Figure 6.9: Base line at 150 kW

This was done to check the correlation of the burner output and the depletion system. The burner was shut down and the rack and plants were put in place.

The burner was re-ignited (150 kW) after 30 s. The center of the plants was approximately 500 mm from the burner.

Figure 6.10: 30 seconds after ignition, approximately 250 kW.

The plants from the different categories ignited at different times and had different burning periods. Tests were run for a total of 10 min for each category.

At 10 min elapsed time, the burner was turned off. The depletion system ran without any heat output to determine a post-test baseline. The rack and load platform were cleaned between each test and also weighed to calculate the amount of water the shelf had lost.

A video camera was placed directly in front of the setup to document the tests. The video camera recorded the setup, a timer, and a flame-height scale. Photos were also taken from various angles to permit comparison of ignition, burning time and flame height.

7. Results of flammability test

The outputs from the flammability tests were edited into graphs to facilitate reading and comparison of the results from different tests. The unedited graph includes the burner and the plant heat output and runs from 0 min to 20 min (Figure 7.1).

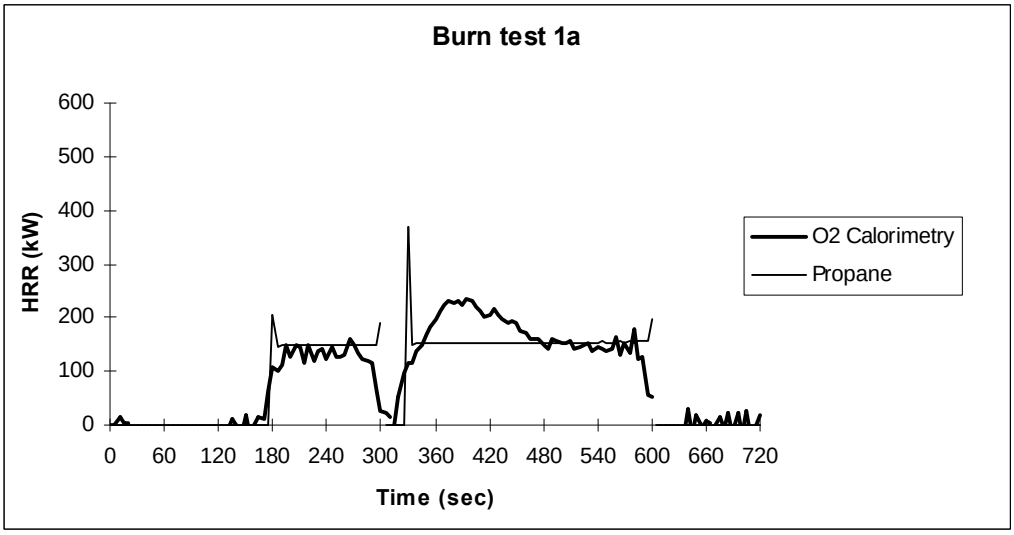


Figure 7.1: Example of unedited heat release rate curve (from test 1 a, green).

7.1 Heat release rate

The editing done to the output to simplify the heat release rate was as follows:

- Only the results between 5.5 min and 10 min were displayed.
- The heat output from the burner, recorded between 3 min and 5 min, was subtracted from the total output.
- In Figure 7.5 the curves are average values of the a, b and c tests.

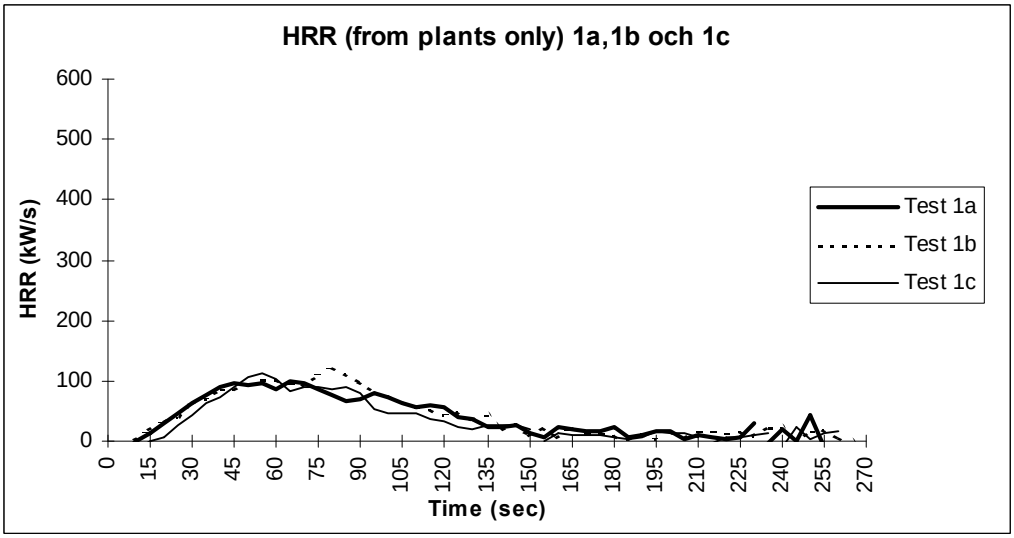


Figure 7.2: Heat release rate curves from test 1 a, b and c, green.

Moisture content and mass of vegetation in the tests were:

Test:	1a	1b	1c
Moisture content:	65.8 %	67.2 %	66.8 %
Mass of vegetation:	2.72 kg	3.21 kg	2.64 kg

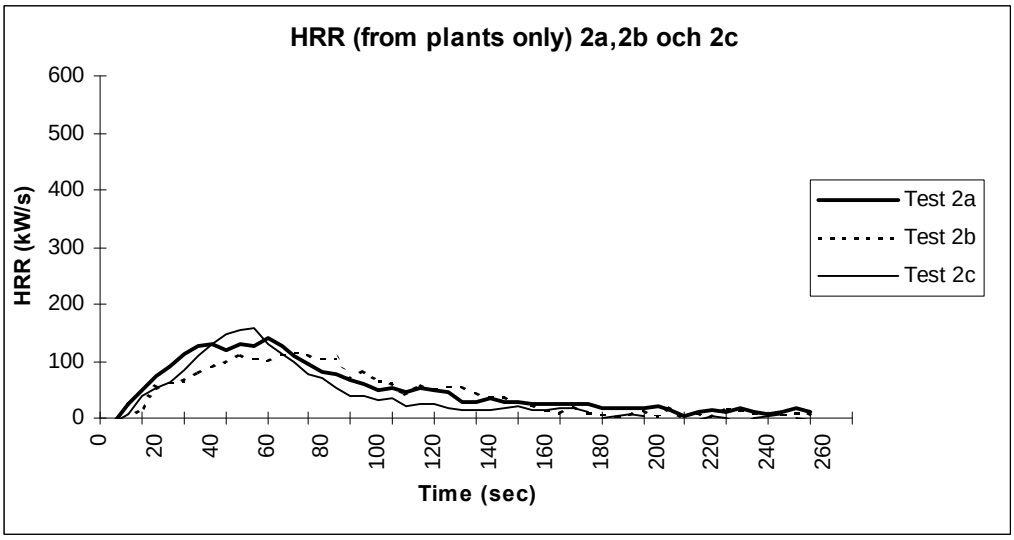


Figure 7.3: Heat release rate curves from test 2 a, b and c, dry.

Moisture content and mass of vegetation in the tests were:

Test:	2a	2b	2c
Moisture content:	62.0 %	62.3 %	62.6 %
Mass of vegetation:	2.98 kg	2.79 kg	2.54 kg

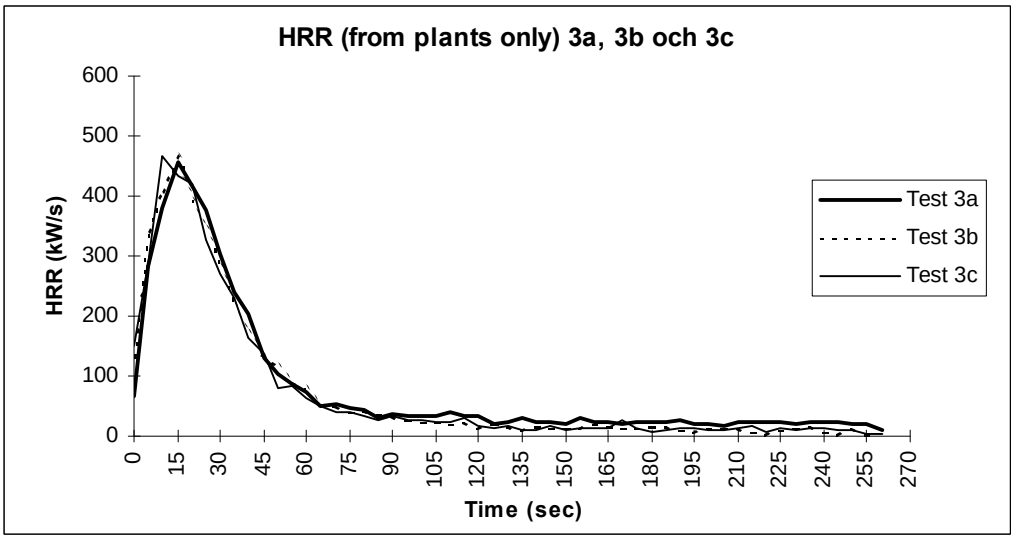


Figure 7.4: Heat release rate curves from test 3 a, b and c, fire-weathered.

Moisture content and mass of vegetation in the tests were:

Test:	1a	1b	1c
Moisture content:	30.4 %	34.5 %	32.4 %
Mass of vegetation:	1.66 kg	1.77 kg	1.60 kg

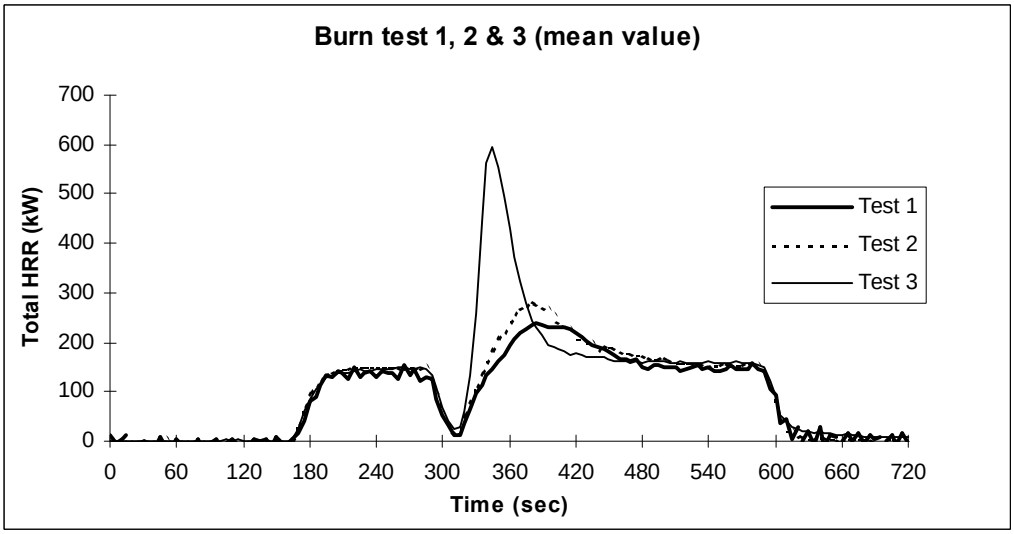


Figure 7.5: Average total heat release rate (plants and burner) curve from test 1, 2 and 3.

7.2 Mass loss

The editing done simplify the mass loss curves was as follows:

- Only the results between 5.5 min and 10 min were displayed.
- The mass loss was calculated in percentage of the starting mass since the initial masses of the plants were different. This way the comparison was simplified.
- In Figure 7.6 the curves are average values of the a, b and c tests.

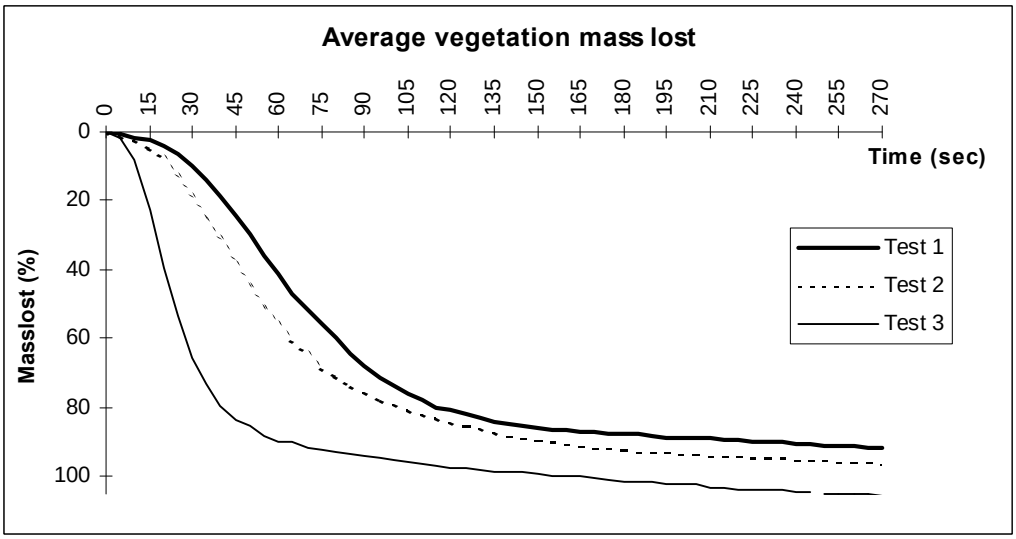


Figure 7.6: Average mass loss from test 1, 2 and 3.

7.3 HRR - Mass loss rate

The editing done to simplify the mass loss rate and heat release rate curves was as follows:

- Only the results between 5.5 min and 10 min were displayed.
- The heat output from the burner, recorded between 3 min and 5 min, has been subtracted from the total output.
- The mass loss rate was calculated in 5 s intervals.

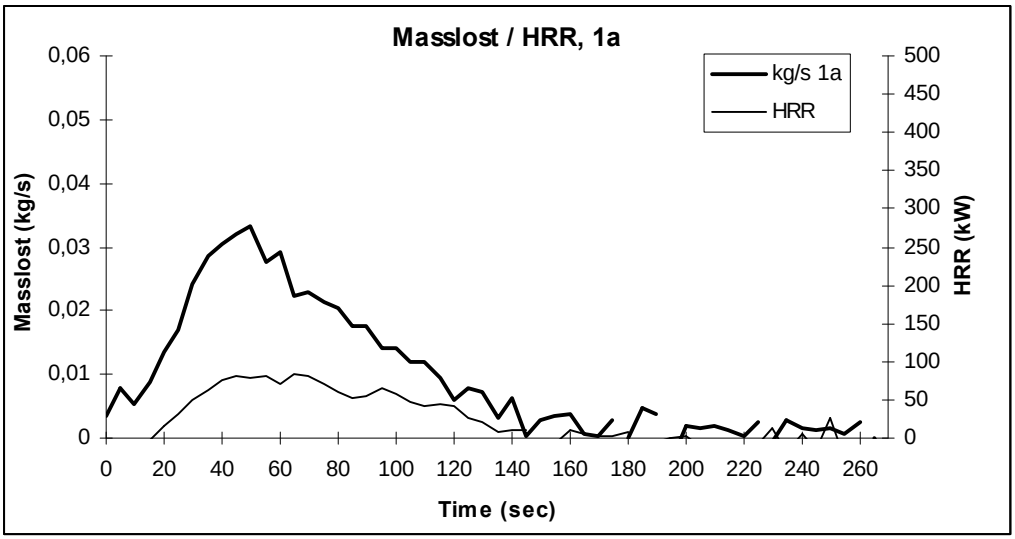


Figure 7.7: Heat release rate and mass loss rate curves from test 1 a, green.

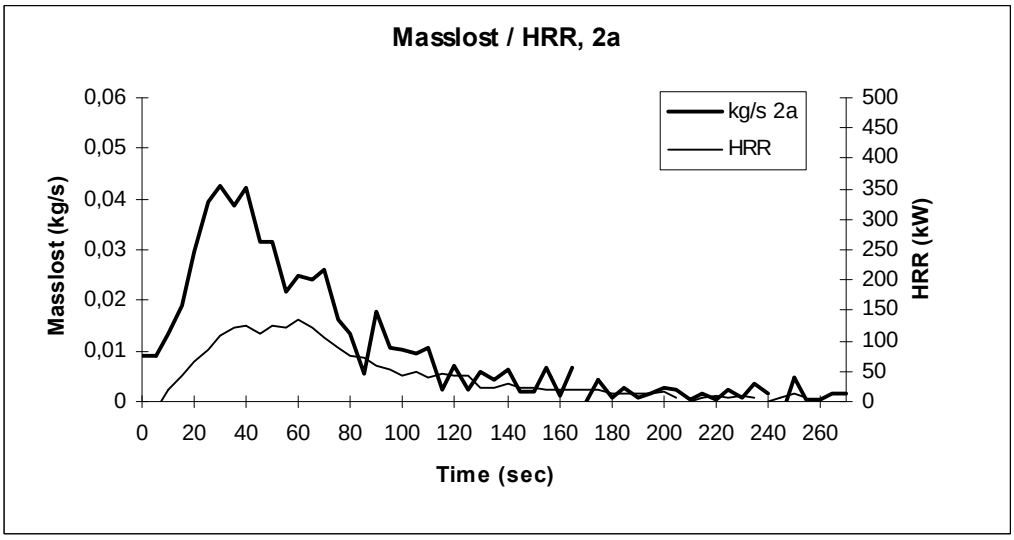


Figure 7.8: Heat release rate and mass loss rate curves from test 2 a, dry.

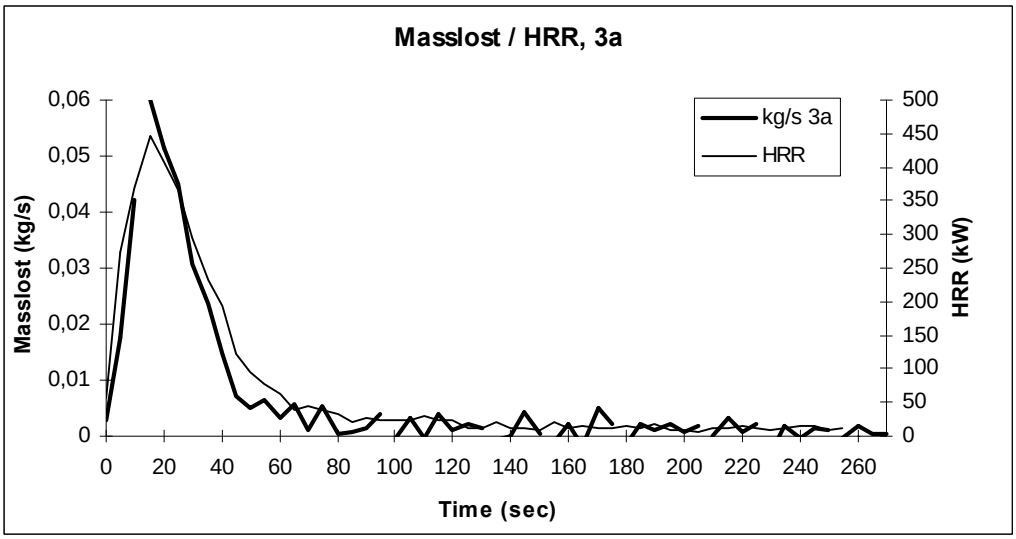


Figure 7.9: Heat release rate and mass loss rate curves from test 3 a, fire-weathered.

The reason that the curves do not correlate in test 1 (green) and 2 (dry) is that water is lost when the plants are burned, therefore, the mass loss will be higher than the HRR predicts. In test 3 (fire-weathered) the curves correlate better since the plants in that test only had half the amount of moisture.

All heat release rate and mass loss curves are listed in Appendix F.

8. Heat Value determination

Determining only the three mass categories, unextracted biomass (m_o), extractives (m_e) and water (m_w), is not sufficient. The heating value of the constituents also needs to be determined in order to calculate the heat value ratio between the biomass and extractives. This way the role of volatile extractives could theoretically be determined and the effect of the treatments established. To do this, the heat value of the extractives in the plant needs to be isolated. For this purpose the sample has to be dried of its water and the volatile chemicals extracted.

When the plant is fresh and green its mass consists of oven-dry mass, volatile extractives and water:

$$m_{total} = m_o + m_e + m_w \quad [8.1]$$

These different masses also have their own heat values:

$$h_{total} = h_o + h_e + h_w \quad [8.2]$$

If the sample is oven-dried it loses water and the remainder is:

$$h_e + h_o \quad [8.3]$$

When the heat value of the oven-dried sample is compared to an oven-dried extracted sample, the heat value of the extractives can be determined by subtraction:

$$h_e = h_e + h_o - h_o \quad [8.4]$$

8.1 The test procedure for the Adiabatic Bomb Calorimeter

The tests were carried out in the Biomass Laboratory at the University of California at Davis. The procedure followed a step by step procedure provided by the staff in the Biomass Laboratory at UC Davis, which follows the ASTM E 711-87, /9/, see Appendix G.

Apparatus
The apparatus used for the heat value determination was an Adiabatic Bomb Calorimeter (Figure 8.1).

1. Adiabatic compartment
2. Oxygen bomb
3. Water bath
4. Thermometer
5. Mixer

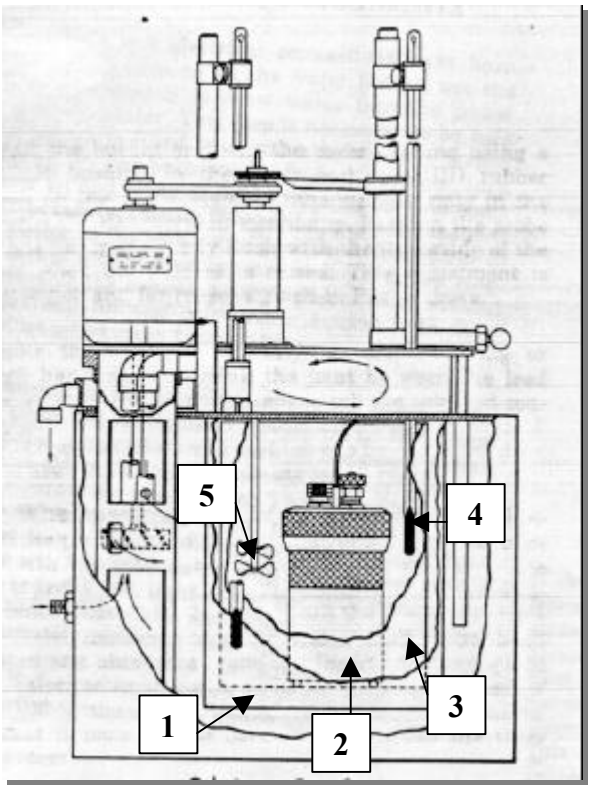


Figure 8.1: Cross-section of an Adiabatic Bomb Calorimeter.

A. Fuse wire
B. Pellet
C. Pressure valve

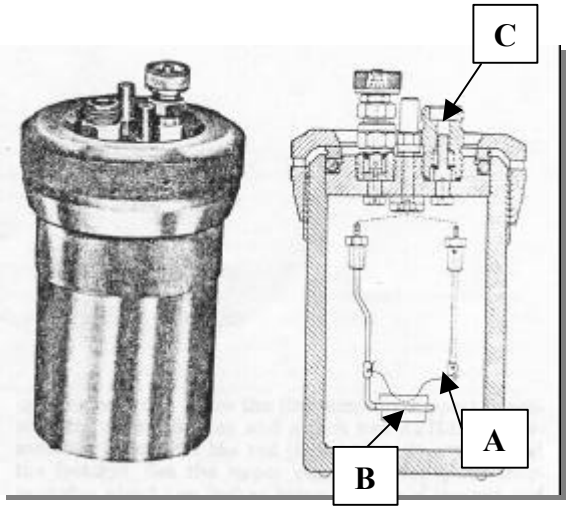


Figure 8.2: Cross-section of the Oxygen bomb.

The bomb and the water bath is placed in the adiabatic compartment. The compartment is sealed so when the sample pellet in the bomb is combusted all the heat stays within the adiabatic compartment. The computer then calculates the amount of heat necessary for the temperature rise that occurred in the compartment after the combustion.

Procedure
The general procedure was as follows:

1. The sample was made into a pellet and then weighed.

2. The pellet was mounted in the bomb with a fuse wire touching the pellet (Figure 8.2).

3. The bomb was filled with oxygen until it had an over-pressure of 30 ATM.

4. The bomb was put in a water bath with 2000 ± 0.5 g water in the apparatus.

5. The electrode for ignition were attached to the bomb and the adiabatic calorimeter compartment was sealed.

6. After this the calorimeter automatically adjusted the temperature so that equilibrium was established in the compartment. When balance was reached the sample was ignited and a new temperature equilibrium was reached.

7. The calorimeter calculated a preliminary heat value of the sample from the temperature rise, the water mass and the sample mass.

8. The preliminary heat value was corrected for the fuse and incomplete combustion and the calorimeter calculated a final heat value for the sample.

9. Results of heat value determination

The total heat value, h_o+h_e, was determined from the unextracted samples. The results show that the different treatments have not affected the heat value of either the foliage or the twigs. The small variations, plus/minus 0.1 MJ/kg, between the categories are within the margin of error from the test, see Appendix G. The results also show that the foliage releases more energy per unit of mass than the twigs (Figure 9.1 or Table 9.1).

One explanation as to why the heat value of the foliage is higher than that of the twigs could be that the foliage contains more extractives than the twigs (Chapter 5).

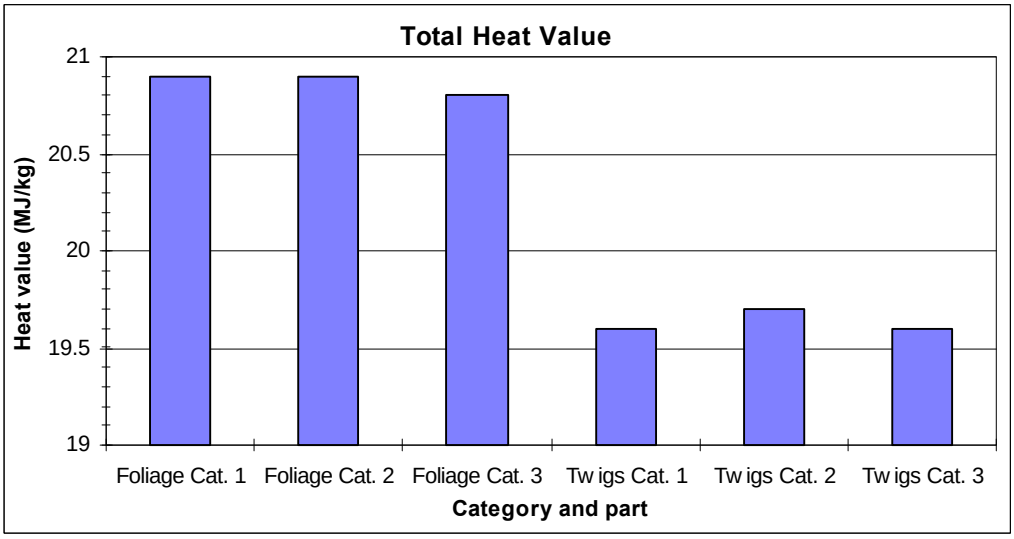


Figure 9.1: Total heat values in Juniper plants (unextracted samples).

Category	H_{Tot} Foliage (MJ/kg)	H_{Tot} Twigs (MJ/kg)
1 green	20.9	19.6
2 dry	20.9	19.7
3 fire	20.8	19.6

Table 9.1: Total heat values in Juniper plants (unextracted samples).

The heat value of the biomass, h_o, was determined from the extracted samples and the results again showed that the different treatment had not affected the heat value. The results also showed that the biomass in the twigs has a higher heat value than the biomass in the foliage (Figure 9.2 or Table 9.2). This gives a clue that the masses have different constituents. For example the twigs have more lignin, which has a high heat value, than the foliage.

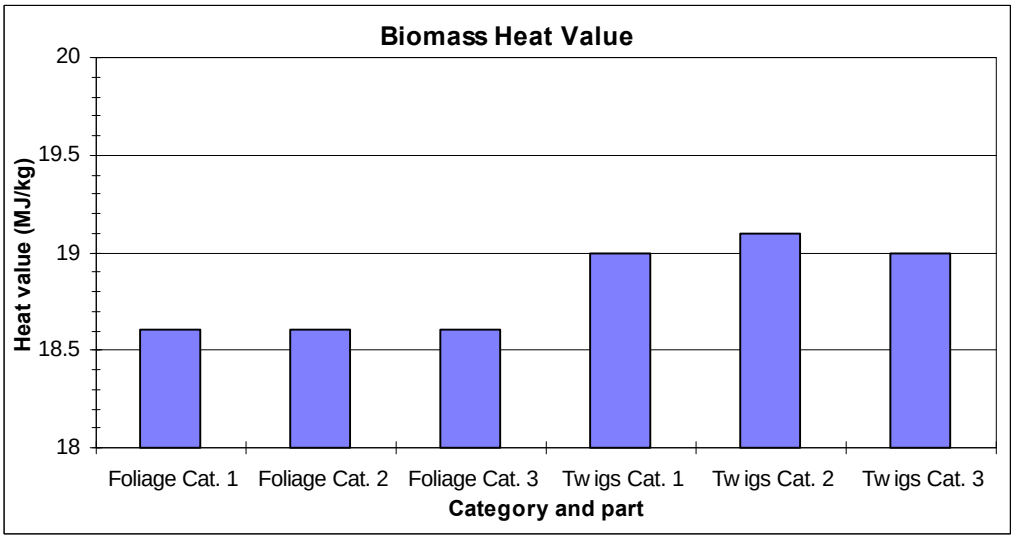


Figure 9.2: Extracted biomass heat values in Juniper plants.

Category	H_o Foliage (MJ/kg)	H_o Twigs (MJ/kg)
1 green	18.6	19.0
2 dry	18.6	19.1
3 fire	18.6	19.0

Table 9.2: Extracted biomass heat values in Juniper plants.

The heat value of the extractives could now easily be calculated since the amount of extractives in the samples is known. The extractives have a higher heat value than the extracted biomass and the heat value of the extractives in the foliage is higher than in the twigs. This confirms the suggestion that one of the reasons the foliage has a higher heat value is because of the larger amount of extractives, but it is also related to the higher heat value of the extractives in the foliage.

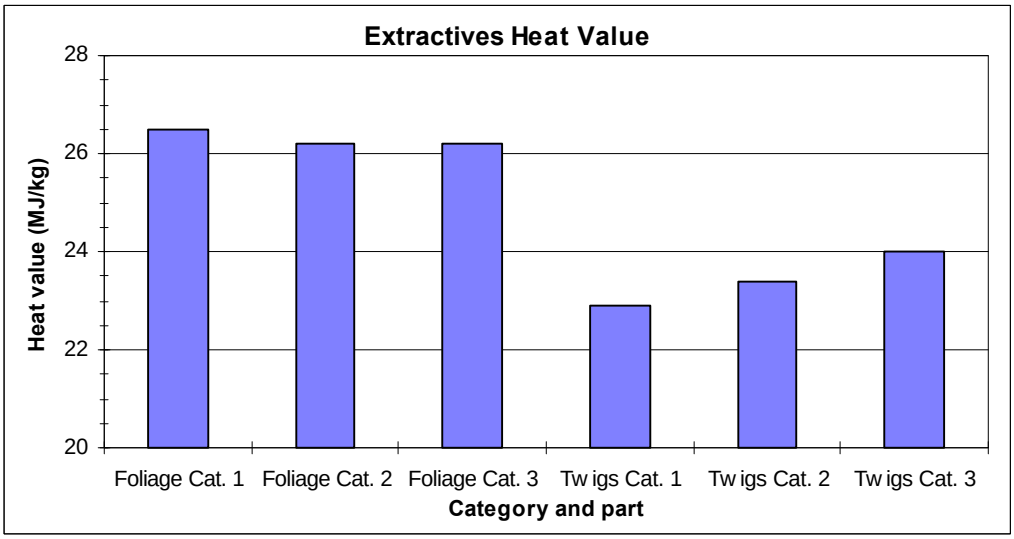


Figure 9.3: Extractives heat values in Juniper plants.

Category	H_e Foliage (MJ/kg)	H_e Twigs (MJ/kg)
1 green	26.5	22.9
2 dry	26.2	23.4
3 fire	26.2	24.0

Table 9.3: Extractives heat values in Juniper plants.

10. Conclusion

Below follows an evaluation of the experiments and after that the results from the experiments.

10.1 Lessons from the experiments

The perhaps most important part, the simulation of different states of stress in the plant, caused some difficulties. The first problem was to develop different treatments to stress the plants to natural states. The experiments showed that treatment Category 2 did not work as planned because the Juniper plants were more draught resistant then expected. Contributing factors to this might have been that the Lath-house provided some protection from the sun, that moist air, from the ocean, came in over the field station during the nights and that the roots and the soil worked as a water reservoir. Therefore the uncertainty in the results and the time to get the results were not satisfactory in treatment Category 2.

Category 3, where the moisture content was reduced in a dry kiln, provided the wanted results, but its correlation with natural stress conditions should be verified. In other words, is it defendable to severe the roots, the plants water reservoir, before drying the plant in the kiln and thereby shorten the drying time? Another way, more related to natural stressing conditions, might be to dry the plants with the roots intact and in soil. This will probably not change the results, but must still be investigated.

In the air-drying preparation of the samples before extraction the foliage was still hard to grind, because of its moisture, even when air-dried. As the tests showed that no volatiles were lost during the air-drying, the drying time could be extended to make the grinding easier. Apart from this the extraction procedure worked as planned, i.e. extraction with one solvent for six hours extracted all the volatiles. The extra analysis of some categories showed that the accuracy in the procedure is satisfactory, but to avoid errors it is recommended to at least duplicate the analysis of each category.

Supplementary analysis of the extractives will be conducted in a Gas Chromatograph with a flame ionization detector (FID), by Larry Cool at the Forest Products Laboratory, to determine the chemical composition of the volatiles and if it changed when the plant was stressed.

A problem occurred when the first category was flammability tested. The hood did not collect all the combustion gases because the plants produced more combustion gases than the hood capacity. The loss of combustion gases was small enough not to affect the registered HRR output significantly. To avoid any loss of combustion gases at the two remaining categories, where an increased HRR was expected, the capacity of the hood was increased and a gypsum-skirt was assembled on the hood. The skirt, which was hanging down 1 m from the edge of the hood, increased the capacity of the hood and reduced the distance to the fire. This way, the loss of combustion gases was minimized and a more accurate HRR value could be measured.

During the tests the gypsum drywall, which was mounted between the loadcell and the plant rack, lost some mass when its water was evaporated. The mass lost was not significant enough to affect the test results, but exchanging the gypsum drywall with a ceramic board can easily eliminate this potential error.

Generally the experiment test arrangement was satisfactory, but it is characterized by the local conditions at the fire lab at Richmond Field Station. If the procedure is to be applied in other laboratories, the arrangements ought to be adjusted so that the affect of the local conditions on the results are minimized.

The heat value determination followed a reliable standard procedure without any complications. Therefore this procedure can be used without any modifications.

10.2 Results from experiments with Juniper

The chemical analysis showed that no change in the amount of volatile chemicals appeared when the plants were stressed. It was not possible to experimentally determine how the amount of extractives affected the flammability, since all the samples contained the same amount of extractives when flammability tested.

However, the results from the heat value tests showed a difference between the heat value of the biomass and the extractives, and the heat values did not change when the plant where stressed. On the basis of this, it is theoretically feasible to assume that the flammability changes with relative proportions of biomass and extractives.

As mentioned, the moisture content of the plants decreased when they were stressed. This led to an increase in the heat release rate. When the moisture content of the plants were decreased from 60 % to 30 % the heat release rate from the plants increased from 100 kW to 450 kW.

10.3 Suggestion for additional test

To get experimental proof of how the amount of extractives affect the flammability, the amount of extractives has to be changed while keeping the moisture content constant. If this is not possible to accomplish in a plant, it is suggested that two species with similar physical characteristics but different amounts of extractives are used. Then the moisture content needs to be manipulated to the same level before tested.

If the experiments described in this report are carried out on more species, a wider basis for understanding how the different characteristics correlate with the flammability will be reached. This knowledge will be the foundation when assembling the Vegetation Guide.

11. References

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