

## EFFECT OF STORAGE TIME AND CONDITIONS ON BIOMASS CHARCOAL PROPERTIES

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**ABSTRACT:** In this work, effects of storage time and conditions on the properties of one woody charcoal were studied. Analyses results showed that the volatile matter content of the charcoal samples collected from the bottom section of containers changed significantly more than those collected from the top section. Compared to small size charcoal samples, a higher increase in volatile matter content was detected in large size charcoal samples, and increasing with increasing storage time. The fixed carbon content of all charcoal samples changed along the storage time. Results from this work suggest that long storage/transportation time at unfavorable conditions should be avoided, in order to maintain the as loaded charcoal properties during long-term transport and storage.

**Keywords:** charcoal, wood, pyrolysis, storage.

## 1 INTRODUCTION

Biomass charcoal production is a highly promising way for sustainable energy generation and displacing fossil fuel use while combating global climate change at the same time. For industrial applications, for example as solid fuel for energy generation or as reductant in metal production, large amounts of biomass charcoal are produced, stored and transported to final utilization [1]. The storage and/or transportation of biomass charcoal might last for days, weeks or even months. Properties of biomass charcoal might change due to this long-term storage/transportation time and variations in the storage/transport conditions [2]. The present work aims at studying effects of storage time and conditions on the properties of one woody charcoal.

## 2 MATERIALS AND METHODS

### 2.1 Samples

Charcoal produced from conventional kilns was used in the present work and was transported to the laboratory in sealed plastic boxes. In each box the charcoal pieces ranged in size from 1x1 cm to 10x10 cm. Considering possible effects of particle size on changes in charcoal properties, the charcoal was sorted into small and large pieces before starting storage testing. Small pieces of charcoal ranged in size from 1x1 cm up to 3x3 cm, whereas large pieces ranged from 6x6 cm to 8x8 cm. Sorted charcoal was then separated into re-sealable plastic bags until starting storage testing, to avoid moisture absorption from the ambient air.

### 2.2 Equipment and storage testing

A climate cabinet (Vötsch VC3 0100) was used to control the temperature and relative humidity, between 10 and 90°C and 10 and 98%, respectively. The charcoal samples were stored in the climate cabinet for 6 weeks under various conditions. For the first four weeks, the conditions in the climate cabinet were held constant at 35°C and 98% relative humidity, simulating storage/transport under hot and humid weather

conditions. In the last two weeks, the charcoal samples were stored at a low temperature, 10 °C, and 98% relative humidity. Polystyrene containers with lids were used to hold the charcoal samples due to their high heat transfer resistance. 6 small containers (36 x 36 x 20 cm) and 2 big containers (36 x 36 x 36 cm) with charcoal loaded were put into the cabinet for storage testing. In the small containers, charcoal pieces with size in the range of 1 x 1 cm to 3 x 3 cm were loaded. The large containers were filled with big charcoal pieces with size of 6 x 6 cm to 8 x 8 cm. Each container, regardless of charcoal size, was filled with approximately 3 kg of charcoal. After covered with a lid, there is a certain headspace in each container. 4 vents (2 x 2 cm) were cut near the top and on each side of each container. These vents can allow the conditions in the container to reach the conditions in the cabinet. In addition, these vents would allow for some gases to escape/enter the container, yet only a small amount such that the container's internal conditions would not change significantly. Two different combined temperature-humidity sensors (Tinytag Plus and Omega OM-EL-USB-2) were utilized in the present work. Both sensors simultaneously recorded temperature and relative humidity values in the containers and can be programmed to record offline. During loading of the charcoal pieces, one sensor was submerged in the charcoal bed, located approximately in the center of one container. A Testo 350-454 XL gas analyzer was set up to measure concentration of gases in the cabinet, including CO, NO, NO<sub>2</sub>, H<sub>2</sub>, and NO<sub>x</sub>. Charcoal samples were collected from each container at different storage time, in order to study the effect of storage time on charcoal properties. For example, container #1 was opened almost every week for charcoal sampling, while container #6 was opened only week 6 for charcoal sampling. As one container was opened, charcoal samples were collected from both the top and bottom section of it.

### 2.3 Analysis of charcoal samples

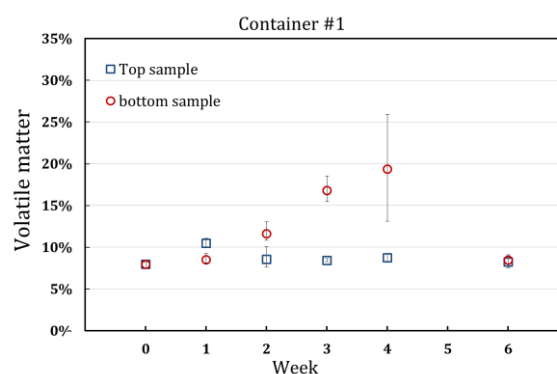
Triple proximate analyses were done for all sampled charcoal pieces, following the procedures described in ASTM standard D1762-84, Standard Test Method for Chemical Analysis of Wood Charcoal.

### 3 RESULTS AND DISCUSSION

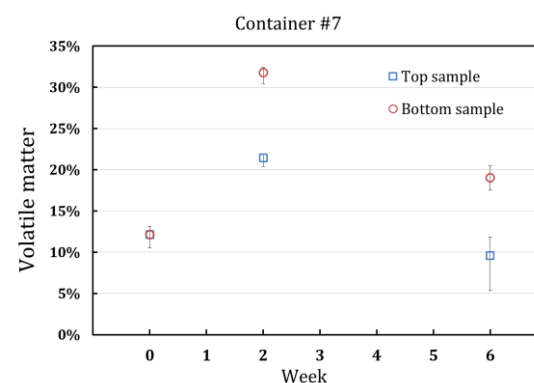
#### 3.1 Change of charcoal properties

Figure 1 shows volatile matter content of charcoal samples collected from container #1 during the entire storage test. The volatile matter content of charcoal sampled from the top section of container #1 increases significantly, and is about 10% higher than that of the initially loaded charcoal sample. However, the measured volatile content of charcoal samples collected week 6 decreases, and is only approximately 1% higher than that of initial loaded sample. In addition, Figure 1 shows, for charcoal samples collected week 3 and 4, that the deviation in the volatile matter content measured three times is considerable large. According to the procedures described in ASTM standard D1762-84, approximately 1 gram charcoal is needed for measuring the volatile matter content. In order to prepare 1 gram charcoal powders, normally several pieces of sampled charcoal are ground and used for the analysis. The properties of charcoal pieces from the same section of one container might be quite different, even if they were carefully selected based on appearance and apparent density. Therefore deviation in the volatile matter content might be related to heterogeneity of the charcoal samples selected and studied. On the other hand, the volatile content of charcoal sampled from the top section in container #1 only increases slightly. Figure 2 illustrates that the volatile content of large charcoal pieces stored in container #7 varied during the storage test. The volatile content of charcoal samples collected from the bottom and top sections are about 32% and 21%, respectively. These values are about 20% and 10% higher than those of the initially loaded charcoal pieces. After stored in the container for 6 weeks, the volatile content of charcoal samples collected from the bottom section is about 19%, which is substantially higher than that of the initial charcoal pieces. However, the volatile content of the charcoal samples from the top section decreases and is lower than those of initial charcoal pieces and charcoal samples collected in week 2.

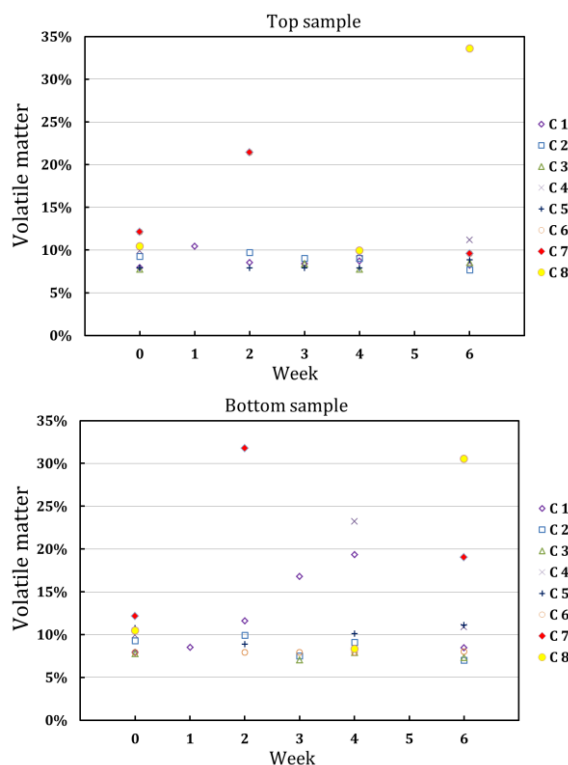
Figure 3 displays that, in comparison to those collected from container #1, volatile matter contents of small charcoal pieces sampled from container #2 to #6 along the sampling time are slightly changed. However, for large charcoal pieces collected from container #7 and #8, the volatile matter contents increase significantly, as they were sampled at week 2 and week 6, respectively. Figure 3 also shows that for small charcoal pieces collected from the bottom sections of container #2 to #6, their volatile matter contents vary more evidently compared to those from the top section. It indicates that the properties of charcoal in the bottom section are readily changed, which might be related to more isolated conditions in the bottom section in terms of mass and heat transfer. On the other hand, changes in volatile contents of charcoal samples collected from the top and bottom sections in container #7 and #8 are quite similar. The comparison of changes in volatile contents of large and small charcoal samples implies that charcoal size also play a certain role regarding changes in charcoal properties during long term storage/transportation.



**Figure 1:** Volatile matter content of charcoal sampled each week from container # 1



**Figure 2:** Volatile matter content of charcoal sampled at week 2 and 6 from container #7



**Figure 3:** Volatile matter content of charcoal sampled from 8 containers at different weeks

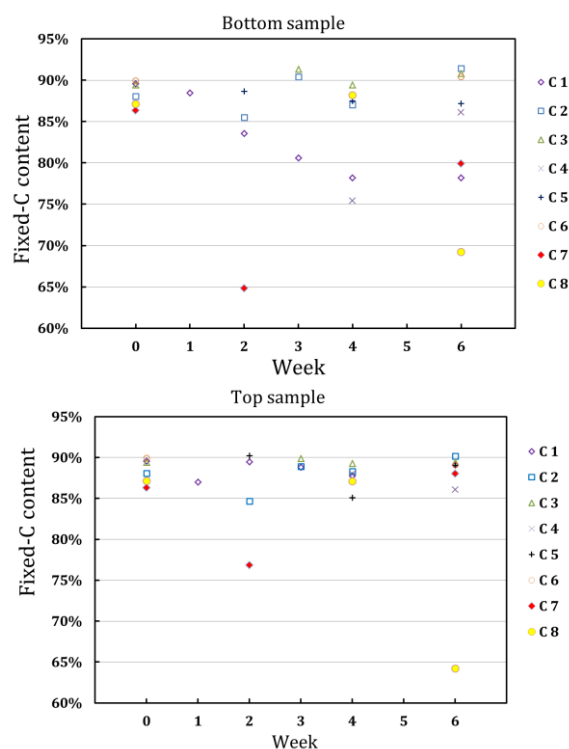
Fixed carbon content is one of the most important properties of charcoal, for the energy content and further

application of charcoal produced from biomass materials. In this work, the fixed carbon contents of sampled charcoals were calculated and results are shown in Figure 4. For charcoal samples collected from the bottom section of the containers, the fixed carbon contents decrease overall more than for the samples collected from the top section of the containers. The fixed carbon content of charcoal is calculated by difference of 100% and the sum of volatile and ash content. Since the ash content of the sampled charcoal varies only slightly during the entire storage test, the fixed carbon content of the sampled charcoal heavily depends on the determined value of the volatile content. Therefore, it is critical to get a better understanding of the change of volatile content in the charcoal samples during storage and transportation. Such kind of knowledge is important for preventing change of charcoal properties and reduction of its value (i.e., energy and fixed carbon content) during and after long time storage and transportation.

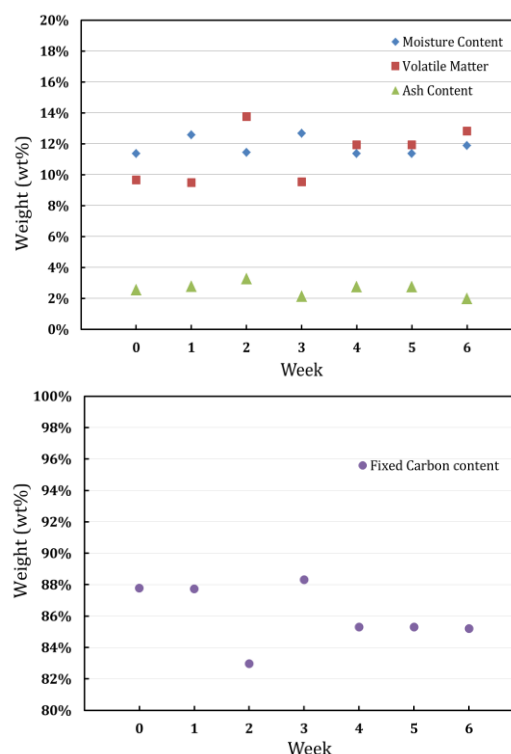
Figure 5 shows average values of moisture, volatile matter and ash content measured from samples collected from 8 containers during the storage process. In general, the average charcoal volatile content increased about 3%. At the same time, the average moisture and ash content only slightly changed. As a result of this, the average fixed carbon content of the sampled charcoal decrease gradually along the storage time. Compared to the initially loaded charcoal, the fixed carbon content of charcoal after the storage test is about 3% less. Such decrease of fixed carbon of charcoal will cause considerable reduction of profitability for an industry that consumes large amounts of charcoal with a high price in industrial processes [3]. In addition, if the decrease of fixed carbon content of charcoal is related to conversion of solid material into volatiles and/or gases, it might lead to emission of greenhouse gases and fatal accidents during storage and transportation.

### 3.2 Discussion about increase of volatile content

Volatile matter in the biomass material is those substances, other than moisture, that are given off as gas and vapor during thermal decomposition. The volatile matter of a charcoal is usually a mixture of short- and long-chain hydrocarbons/aromatic hydrocarbons and some sulfur[2]. Increase of volatile matter content might relate to degradation of charcoal during the storage in the container. Under controlled conditions, biomass materials degrade both biologically and chemically. Some bacteria, fungi and microorganisms can modify and decompose dry and even charred wooden structures, lignite and even hard coal, causing formation of low molecular carbohydrates on surfaces[2, 4]. On the other hand, at certain temperature, heat induced degradation may also occur in presence of oxygen [4]. This process is often due to oxidization of organic constituents in the wooden materials, which is accompanied by formation of one-carbon gases such as CO, CH<sub>4</sub> and CO<sub>2</sub> [4,5]. In the present work, a low CO concentration in the climate cabinet was monitored, up to 4 ppm. It indicates possible heat induced decomposition of charcoal during storage.



**Figure 4:** Fixed-carbon content of charcoal sampled from 8 containers at different weeks



**Figure 5:** Average values of properties of charcoal sampled from 8 containers at different weeks

#### 4 CONCLUSIONS

In the present work, the effects of storage time and conditions on the properties of one woody charcoal were studied. It was found that the volatile content of charcoal generally increased along the storage test time. The ash content of the sampled charcoal only changed slightly. The fixed carbon content of collected charcoal samples decreased about 3%. Analyses results showed that the volatile matter content of the charcoal samples collected from the bottom section of containers changed more significantly than those collected from the top section. In addition, more evident increase of volatile matter content and decrease of fixed carbon content were measured for the large charcoal pieces. Findings of the present work indicate that properties of charcoal might change considerably after certain time during storage and transportation. Such changes of charcoal properties are affected by the storage conditions and are also influenced by the charcoal size.

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#### 6 ACKNOWLEDGEMENTS

The authors acknowledge the financial support from

- The Research Council of Norway, and from the BioCarb+ project industry partners:
- Elkem AS – Department Elkem Technology,
- Norsk Biobrensel AS,
- AT Biovarme AS,
- Eyde-nettverket,
- Saint Gobain Ceramic Materials AS,
- Eramet Norway AS,
- Alcoa Norway ANS.

#### 7 PROJECT LOGO

