Analysis of Combustion Emissions and Char from CCA- and ACQ-Treated Wood

Lin, Han Chien
College of Agriculture, National Chiayi University

Ouchi, Takeshi
Faculty of Agriculture, Kyushu University

Murase, Yasuhide
Faculty of Agriculture, Kyushu University

https://doi.org/10.5109/9288

出版情報：九州大学大学院農学研究院紀要. 52 (1), pp.91-98, 2007-02-28. Faculty of Agriculture, Kyushu University
バージョン：
権利関係：

J. Fac. Agr., Kyushu Univ., **52** (1), 91–98 (2007)

Analysis of Combustion Emissions and Char from CCA– and ACQ–Treated Wood

Han Chien LIN[1], Takeshi OHUCHI[2], Yasuhide MURASE[2]

Laboratory of Wood Material Technology, Division of Biomaterial Science, Department of Forest and
Forest Products Sciences, Faculty of Agriculture, Kyushu University,
Fukuoka 812–8581, Japanese

(*Received November 6, 2006 and accepted December 1, 2006*)

This study used *Taiwania cryptomerioides* Hay as a specimen to be treated with CCA–3 or ACQ–1 preservatives. CCA and ACQ–treated woods, the preservatives themselves as well as their individual ingredients during combustion were investigated. The emission gas concentrations of O_2 and CO_2, the emission contents (CO, SO_2, NOx), and the temperature of the emission gases were measured using a Flue–gas Analyzer at the exit of a 45˚ flammability testing cabinet as specified in the continuous emission monitoring (CEM) techniques. The specimens were analyzed with an Energy Dispersive X–ray Spectrometer (EDX), and were examined in a 45˚ flammability testing cabinet before and after the analysis. The residual elements in the char were also analyzed using an Elemental Analyzer (EA). The results indicated that the emission gas temperatures of all samples rose rapidly to about 200–250 ˚*C* and then slowed down to a temperature range of 200 ˚*C*, shown as a plateau curve. The concentration of O_2 decreased from 20.7% to about 17.0–19.8% linearly, and contrary to the concentration of CO_2 increased from 0.2% to about 1.8–2.8%. Both O_2 and CO_2 then approached the shape of a plateau curve until the end of the combustion time, and were closely related during the combustion. The highest emission quantity of CO was about 179.3 ppm for the ACQ specimen, 157.0 ppm for As_2O_5, and about 85.5 ppm for BKC. The emission quantity of SO_2 for each type of sample was zero. The maximum NOx for the ACQ specimens and ACQ–1 preservatives were about 23.5–26.5 ppm, and about 32.0 ppm for BKC. The result of the EDX analysis indicated that the main element is C (77.89%), and that the relative proportion of Cu was 2.67% for the ACQ specimen, but that ACQ–1 was left with a high amount of Cu, of 50.14%. The result of the EA analysis inferred that the ACQ specimen could produce NOx gases during combustion, because the amount of N (1.42%) was higher for ACQ–1 than for the other specimens, and the BKC was almost burned out.

INTRODUCTION

The pursuit of economic development by the human has come at a great cost to the animals and plants of this planet, and has damaged the quality of our air and water. In the last 100 years more problems have come to threaten the environment, such as vanishing forests, acid rain, the burning of fossil–fuels and global warming. Currently, researchers are focusing on so–called "eco–materials", materials that make effective and environmentally friendly use of natural resources, such as the recycling of industrial wastes, the development of new environmentally friendly materials, etc (Okuma, 1998). Recycling of wood products generally includes two kinds of methods. The first type is recycling of discarded forest products or resource–recovered (renewable) materials, which means to develop new wood–based materials in accordance with the principle of cascade utilization (Akiyama, 1998; Kuwahara, 1996). The second type is demolition and combustion (Jang, 1997). However, discarded wood, especially wood that has been processed with different types of waterborne salts, such as chromated copper arsenate (CCA), is extremely difficult to be recycled as a raw material, because the waste stage has a very significant impact on the life cycle assessment results (Esser *et al*., 2000).

No timber is immune to deterioration if not protected, and wood preservatives are important in the industry for long lasting results (Connell, 1991). Different types of waterborne salts have been used to preserve wood from insects, fungi, and water damage for the past few decades. One of the more common formulations contains copper, chromium and arsenic salts, known as CCA, but environmental concerns have drastically changed the allowable active ingredients of wood preservatives, resulting in the restricted use of CCA (Sanders and Wimdom 1980, Sanders and Riedel, 1987; Weis J. and Weis P. *et al*. 1992a, 1992b, 1996, 1999; Cooper, 2001), especially since substantial amounts of CCA remain in the treated wood for many years creating a growing problem of scrap wood disposal (Solo–Gabriele *et al*., 2003). Today, a copper–based preservative, ammonical copper quats (ACQ), which is comprised of a combination of copper and organic biocides, is the main wood preservative for wood products in many countries. However, in the future, the discarded ACQ–treated woods will still need to be reused, recycled, or disposed of in an environmentally acceptable manner (Lin *et al*. 2006). In many cases the preservative treatment is removed by the recycling process, or destroyed by combustion when used as fuel (Jang, 1997). The gases emitted as a result of the burning of

---

[1] Department of Forest Products Science, College of Agriculture, National Chiayi University, Chiayi, Taiwan, ROC.

[2] Laboratory of Wood Material Technology, Division of Biomaterial Science, Department of Forest and Forest Products Sciences, Faculty of Agriculture, Kyushu University, Japanese.

* Corresponding author (E–mail: alexhlin@mail.ncyu.edu.tw)

preservative–treated woods, such as carbon monoxide (CO), carbon dioxide (CO_2), sulfur dioxide (SO_2), nitrous oxides (NOx) and so on are discharged into the atmosphere and pollute the environment.

Because wood preservatives are generally produced with various chemical compounds, it is necessary to understand the composition of the gases that are emitted when burning these preservative–treated woods, and the amount of char formed (residual metal) during combustion (Jang, 1997; Kercher and Nagle, 2001; Humphrey, 2002). The recognition of the need for abatement of air pollution has led to further interest in, and investigation of combustion as a major issue when disposing of cellulose wastes and cellulose residual materials (Helsen and Bulck, 1998). Regardless of waste minimization efforts, improved disposal–end management practices will play a key role in minimizing the impacts of disposed of CCA–treated wood in the next 25 to 40 years (Cooper, 2003), and of the ACQ–treated woods as well (Lin *et al*. 2006). To provide an understanding of the disposal of CCA– and ACQ–treated woods and the basic emitted gases generated by burning these materials, this study has been divided into two categories of examination. The first is related to the research in combustion emissions from preservative–treated woods. The data produced from this research is used as a reference for the gas emitted from air pollution hopefully. The second category of examination applies both the Energy Dispersive X–ray Spectrometer (EDX) and the Elemental Analyzer (EA) to examine certain residual elements of the char. Our goal in the second portion was to acquire fundamental knowledge of the disposal–end practice (residual elements) reference for the char. The emissions from the discharge gas during the preservative–treated specimen combustion and the residual elements of the char after combustion were investigated, respectively.

MATERIALS AND METHODS

Wood preservatives

The commercial wood preservatives used were provided by Kunnyih Co. Ltd., Taiwan. The main details of these preservatives are as follows:

a. Chromated Copper Arsenate (CCA): the type 3 of CCA (CCA–3) is employed in this study, and is produced by Tanalith C Corp., England. CCA–3 oxide is light yellow in color and contains a mixture of 28.90 *wt %* of chromium trioxide (CrO3), 10.60 *wt %* of cupric oxide (CuO), and 16.70 *wt %* of arsenic pentoxide (As_2O_5).
b. Ammonical Copper Quats (ACQ): the type 1 of ACQ (ACQ–1) is used in this study, and it was obtained from Koshi Corp., Japan. ACQ–1 oxide is deep green in color, and includes CuO with 9.00 *wt %*, as well as 7.20 *wt %* of N–alkyl benzyl dimethyl ammonium chloride (BKC).

To clarify the residual elements of discarded woods treated by either CCA–3 or ACQ–1, the main ingredients of CrO_3, CuO, As_2O_5, and BKC (Shimakyu's pure chemicals, Japan) were also prepared as experimental samples.

Preparations of the preservative–treated woods

Taiwania cryptomerioides Hay (Taiwania) was used as a control specimen (untreated wood). Tangential sections of clear specimens measuring 110 *mm* long × 75 *mm* wide × 6 *mm* thick were prepared. The specimens were air–dried at ambient temperatures until they had a moisture content of less than 15.0%. CCA–3 was adjusted to an oxide–based 2.5% CCA–3 solution, and its solid content was about 2.32%, specific gravity was 1.065 (28.0 *°C*), and the pH value was 3.6. For ACQ–1, its solid content was about 0.95%, specific gravity was 1.008 (27.8 *°C*), and the pH value was 10.3, after adjusting the concentration of ACQ–1 to 6.0%. The specimens were then impregnated with CCA–3 or ACQ–1. The manufacturing standard of the preservative–treated woods was in accordance with CNS 3000 (2001).

The procedure "Breant–Bethell", a full–cell treatment, was applied using a laboratory type of pressure impregnation equirement. The vacuum was kept at over 600 *mmHg* for 30 *min*, and the wood was then impregnated with the preservatives. The pressure was then increased to 15 ± 1 *kgf/cm²*, and maintained in this condition for 4 *h*. Finally, the pressure was released, and then a vacuum of 600 *mmHg* was applied for 20 *min* to prevent bleeding of preservatives from the surface of the treated wood. All specimens were placed in a conventional oven with air–circulation at a preset temperature of 30 *°C* for 60 *min*. The average amount of impregnation for CCA–treated woods was over 6.20 kg/m^3 (4.87 kg/m^3 for heartwood; 7.60 kg/m^3 for sapwood), and for the ACQ–treated woods the average was over 4.80 kg/m^3 (3.96 kg/m^3 for heartwood; 5.70 kg/m^3 for sapwood). Both treated woods are considered grade k 3 in the CNS 3000 O1018 (2001) in Taiwan. All specimens were prepared according to the requirements for the emissions test of the discharge gases during combustion. The crushed wood particles, between 40 to 60 *mesh*, were dried in a convection oven at 40 ± 3 *°C* for 3 *h* to prepare them as control specimens for comparison of the char.

Experimental combustion methods

The measuring of flue–gas emissions is required by environmental legislation. One of the better measuring methods of flue–gas emissions is during the combustion of waste products (Jang, 2000). Continuous Emission Monitoring (CEM) techniques are widely utilized for detecting gaseous emissions such as carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen oxides (NOx), and oxygen (O_2)/carbon dioxide (CO_2) concentration at the chimney exit of furnaces to determine the concentration of various pollutants (Jang, 2000; Ladomersky, 2000).

The experimental design is shown in Fig. 1. This method involves two different combustion treatments based on the type of sample. For the first combustion treatment, used for preservative–treated specimens

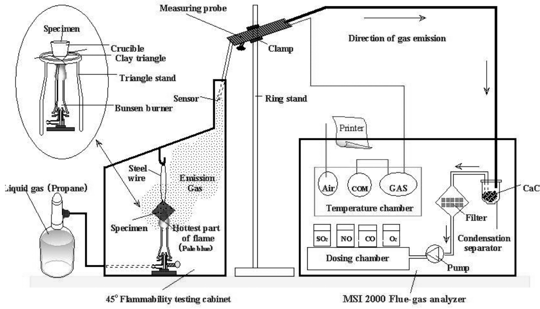

Fig. 1. Experimental diagrams of emissions gas measuring apparatus.

($110\times75\times6$ *mm*), the specimens are hung inside a test cabinet with a steel wire. For the second combustion treatment, about 4 grams of wood particles, preservatives, and ingredients are each placed individually into a crucible on a clay triangle with a triangle stand after being dried in a conventional oven at 105 ℃ for 24 *h*. This method is shown in the oval figure at the upper left corner in Fig. 1. The specimen was burned with a Bunsen burner adjusted to about 850 to 980 ℃. The flame temperature was verified using a temperature–element apparatus (MMS–3000, T6V4).

A Flue–gas Analyzer (MSI, 2000 W. Germany) was used to examine the gas emitted from a flammability test cabinet (with reference to CNS 7614, NCYU handmade). The fuel used was liquid propane. The gas flow direction during the combustion was determined using a gas–measuring probe (MSI 2000 type B). The gas temperature was measured using a sensor at the tip of the probe. The emissions were directed, by means of a connecting hose, through a coarse filter into a condensation trap filled with calcium chloride ($CaCl_2$). From there the emissions entered, via a fine filter, into the measuring instrument. The emission gas was moved along by an electronically controlled suction pump which pumped a stream of gas at a constant rate of flow into the measuring chamber. Equal quantities of gas were directed towards electro–chemical sensors through dosing chambers after passing through a damper. The emission gases, CO, NOx, SO_2 and O_2 and CO_2 concentration were then calculated and printed.

Six replicates of each sample were prepared for each type of preservative–treated specimen, as well as the main ingredients of CrO_3, CuO, As_2O_5, and BKC. The first cycle run in the Flue–gas Analyzer involved no combustion with a specimen in the test cabinet to be certain that the measured value of various emission gases was zero and that the gas temperature was at room temperature. The specimen was then ignited and continuously examined for 9 cycles. A measuring cycle for the emission gas concentrations and the emission gas temperature during specimen combustion was about 40 *sec*. The unit of measurement for CO, SO_2 and NOx gases was parts per million (*ppm*). The O_2 and CO_2 concentrations were defined as the volume percent (*VOL %*) of the air in the emission exit. The gas temperature (in ℃) was measured as well.

Energy Dispersive X–ray Spectrometer (EDX)

In the experiments, the residual char was analyzed using a SEM–EDX (Hitachi High–Technologies Corporation, Japan). SEM pictures were taken using a Hitachi S–3400N scanning electron microscope. For all the investigations the beam energy was 10 *nm* at 15.0 *kV* with a distance of 10.0 *mm* to the specimen, in order to obtain the excitation of all the elements. Analysis of the elements was carried out by EDX analysis using a Horiba EDX 7021 H system. To determine their distribution, Smart Map acquisition was used, which performs the simultaneous acquisition of the X–ray data from each pixel on the image area with 2.00 *k SE* of magnification. The results of the residual elements in the char for all specimens were analyzed.

Elemental Analyzer (EA)

The samples (the char), about 2–4 *mg* each, with preservative–treated specimens that were individually impregnated with CCA–3 and ACQ–1, as well as preservatives (CCA–3 and ACQ–1) and their main ingredients of CrO_3, CuO, As_2O_5, and BKC were analyzed after combustion using an Elemental Vario CHNS/O analyzer (EA, Germany). The result for the carbon (C), nitrogen (N), sulfur (S), and hydrogen (H) elements was then determined

RESULTS AND DISCUSSION

Emission gas from wood and preservative–treated woods

Basically, both woods treated with CCA–3 or ACQ–1 are considered to be a type of cellulose material (Humphrey, 2002). The recognition of the need to reduce air pollution has led to further interest in, and the investigation of the feasibility of combustion to dispose of cellulose wastes and residual materials (Helsen and Bulck, 1998). To investigate the different emission gases when burning preservative–treated woods, this experiment examined the relationship between them, including the emission gas temperatures, concentration of O_2 and CO_2, and the combustion times, as shown in Fig. 2. The results show that the increase in emission gas temperature correspond to the increase in combustion time for *Taiwania cryptomerioides* Hay (Taiwania) and for each treated sample. The emission gas temperature increased linearly to between 215 and 245 ℃ from the start of the combustion treatment. The emission gas temperature for Taiwania was found to be higher than that of the treated specimens by about 30 ℃. This indicates that the ignition point and/or the heat decomposition temperatures of wood and preservative–treated woods are different because of the CCA–3 or the ACQ–1 component in the wood. This decrease in emission gas temperature resulted in a decomposition temperature ranging between 205 to 230 ℃. After that, the emission gas temperature became a plateau until the end of the combustion time.

The Flue–gas Analyzer used in this study determined the standard value of the O_2 and CO_2 concentra-

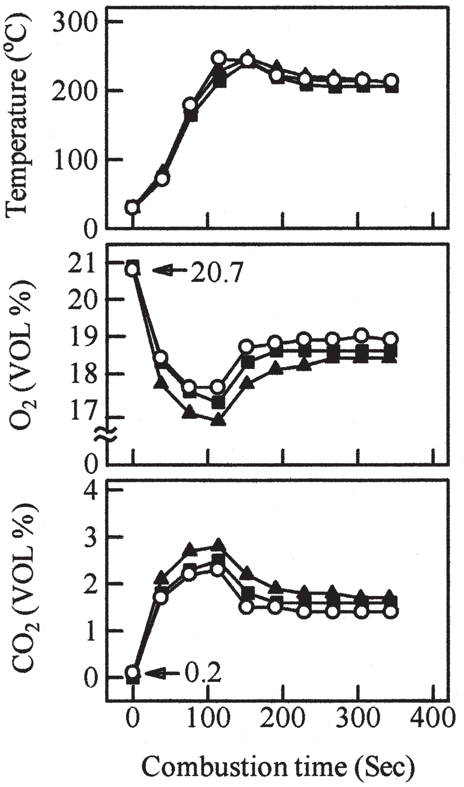

Fig. 2. Relationships between combustion time and emission gas temperature, O_2, CO_2 concentration for various experimental specimens.
Symbols: —●— : T, —■— : CCA specimen, —▲— : ACQ specimen.
Notes: T: *Taiwania cryptomerioides* Hay; CCA specimen: T treated with chromted copper arsenate; ACQ specimen: T treated with ammonical copper quate.

tions (*VOL %*) as 20.7% for O_2 and 0.2% for CO_2. This experiment examined both O_2 and CO_2 concentrations at the emission gas exit, similar to a chimney exit. The results showed that an increase of CO_2 and a decrease of O_2 corresponded to the increase in combustion time for the specimens shown in the middle and bottom of Fig. 2. After the peak point of CO_2 and the lowest point of O_2 was reached, both rates slowed down until complete combustion was reached. The concentration of O_2 was shown to be negatively related and CO_2 was shown to be positively related to the emission gas temperature. The concentration of O_2 and CO_2 are closely related to each other. These results agree with those of Lin *et al.*, 2001; Lin and Huang, 2004; Lin, 2005; Lin *et al.*, 2005.

The results of the emission contents for Taiwania and the two types of treated woods are shown in Fig. 3. The peak for CO gas for the samples of Taiwania was found to be 40 *sec* with 116.0 *ppm* after the beginning of combustion, after which it showed a decreasing tendency until it became a plateau curve until the end of the combustion time,. However for the CCA specimens a maximum value of CO was obtained at about 115 *sec* with 108.0 *ppm*, and for the ACQ specimens the rmeasurement of the CO gas increased linearly to about 80 *sec* with 159.3 *ppm* from the start of the combustion. After that, both became a plateau curve and remained so until the end of the combustion time. This indicated that the emission of CO gas not only was concerned with the ignition time (Ladomersky, 2000; Lin *et al.*, 2001), but also because it resulted in complete combustion at a different combustion time due to the different types of preservatives. This experiment found no SO_2 being emitted gas by any of the specimens during combustion. The results (the bottom of Fig. 3) also showed that the specimens whether or not they were impregnated with preservatives all produced NOx gas. Although it was insignificant for the amount of wood and CCA specimens during the combustion, the peak of NOx gas for the ACQ specimens was about 26–26.5 *ppm* at about 75 to 115 *sec* of the combustion time. NOx is considered the main source of pollution from burning wood treated with ACQ–1. The reason for NOx occurring from the burning of preservative–treated wood is because N is included in both the wood (Shirokae and Samezima, 1996; Kuwahara, 1996; Kercher and nagal, 2001; Humphrey, 2002) and in the preservatives (Lin *et al.*, 2006). Either the O_2 or the N_2 reaction from the air and the samples or the fuel, propane, produced the N residues (Lin, 1992; Takabashi *et al.*, 1995; Kuwahara, 1996). It is inferred that the ignition point and/or the heat decomposition of the preservatives may influence the combustion time and the quantity of emission gases, NOx.

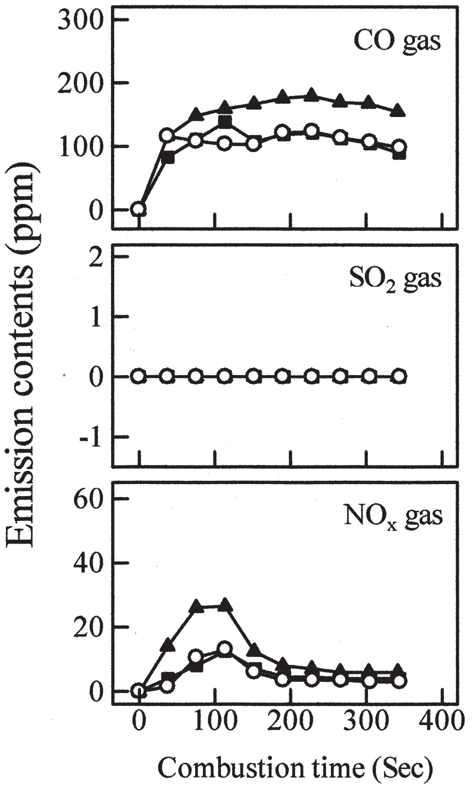

Fig. 3. Relationships between combustion time and emission contents for various experimental specimens.
Note: Symbols and abbreviations are the same as Figure 1.

Emission gases from wood preservatives and their make–up

Figure 4 shows the relationships between emission gas temperatures, the concentration of O_2 and CO_2 and

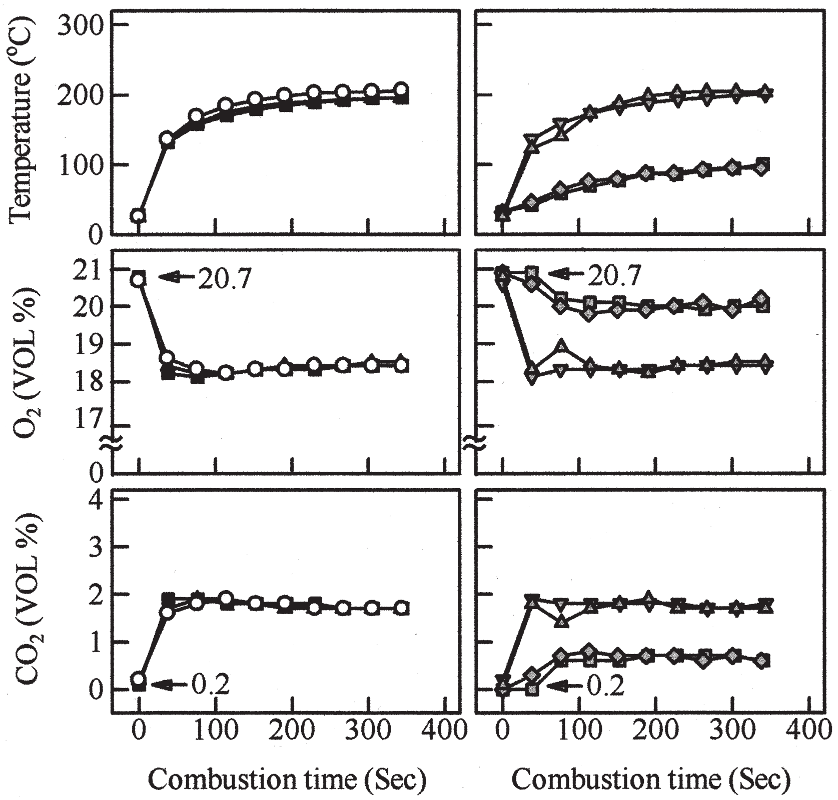

Fig. 4. Relationships between combustion time and emission gas temperature, O_2, CO_2 concentration for various wood preservatives and the main components of CCA–3 or ACQ–1.
Symbols: –○– : wood particles (T); –□– : CCA–3 ; –△– : ACQ–1;
–▨– : As_2O_5; –◇– : CrO_3; –▽– : CuO; –▲– : BKC.
Note: Symbols and abbreviations are the same as Figure 1.
CCA–3: the type 3 of chromated copper arsenate;
ACQ–1: the type 1 of ammonical copper quats;
BKC: N–alkyl benzyl dimethyl ammonium chloride.

the combustion time for two types of preservatives and their ingredients. The gases emitted by 42 samples during combustion for each specimen were examined. The samples were divided into 7 groups with 6 samples in each group. Results similar to the earlier experiment (Fig. 2) for untreated wood and preservative–treated woods were obtained. The increase in either emission gas temperature or CO_2 production, or a decrease in O_2 corresponded to an increased combustion time. These phenomena were consistent throughout the duration of the combustion. The lowest % O_2 for wood particles and both preservatives was about 18.2%, and the the peak for CO_2 was about 1.9%. The gas temperature reached about 170 to 180 °*C* after 180 *sec* and remained stable until the end of combustion time. For the ingredients, the emission gas temperature of CuO and BKC rose rapidly to about 160–170 °*C* and then slowed down reaching a plateau of 195–203 °*C*. The concentration of O_2 decreased linearly from 20.7% to about 18.1–18.3%. On the contrary the concentration of CO_2 increased from 0.2% to about 1.8–1.9%. Both O_2 and CO_2 then reached a plateau until the end of the combustion time, and they were closely related during combustion. However, the main ingredients of CCA–3, AS_2O_5 and CrO_3 showed that the decreasing tendency in O_2 and the increasing tendency in CO_2 slowed with the combustion time. The concentration of was about 19.5–20.0% for O_2 and about 0.6–0.7% for CO_2 at the end of combustion.

In order to understand which preservative–treated specimen produced the more serious pollution, the combined results of the emission contents for seven of the samples are shown in Fig. 5. The above–mentioned situation of incomplete combustion for wood particles (Taiwania) produced CO during combustion. This is attributed to the fact that the particles are wood and are a carbon–hydrogen compound. (Shirokae and Samezima, 1996; Helsen and Bulck, 1998). The same tendency was evident for the CCA and ACQ specimens. In other words, the influence of different types of preservatives on the production of CO was insignificant during combustion. However, among the ingredients of the preservatives, AS_2O_5 (157.0 *ppm*) and BKC (85.5 *ppm*) were more significant on the emission of CO during combustion than the others. As expected there was no SO_2 in the emission gases in this experiment during the combustion of the wood, the preservatives or their ingredients because there was no sulphur content in either of the 2 types of preservatives (Nicholas and Schultz, 1994). It is suggested that CCA–3 and ACQ–1 are not the source of the SO_2 in the environment. The

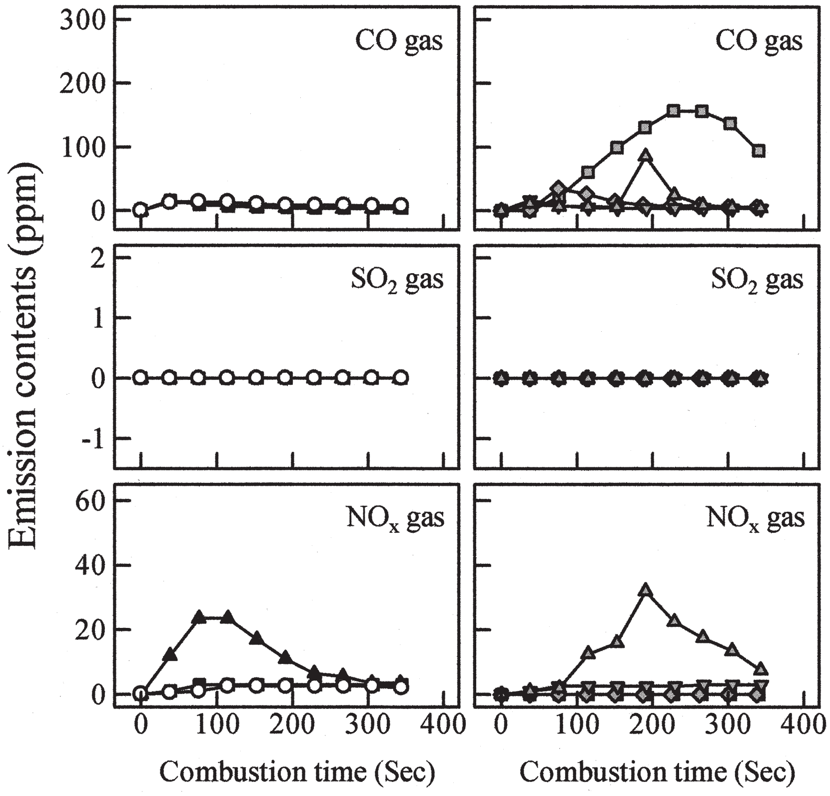

Fig. 5. Relationships between combustion time and emission contents for various wood preservatives and the main components of CCA–3 and ACQ–1.
Note: Symbols and abbreviations are the same as Figure 1 and 3.

results also showed that the ingredients of the preservatives all produced NOx in the emission gases. However, during the combustion of the wood particles, CCA–3, AS_2O_5, CrO_3, and CuO, produced less NOx than the ACQ specimens and ACQ–1. Of these samples, ACQ–1 and BKC were more significant for the emission of NOx during combustion than the others chemicals (ingredients). The maximum NOx of the ACQ and ACQ–1 specimens was about 23.5–26.5*ppm*, and was about 32.0*ppm* for BKC. This is because the main combinations of ACQ–1 are BKC, and in addition nitrogen (N) is also included in the BKC (Nicholas and Schultz, 1994). This indicates that NOx is a main source of pollution in wood with ACQ preservatives (ACQ–1).

EDX and EA analysis of preservative–treated woods, preservatives and their ingredients

The scanning electron microscope combined with the energy dispersive X–ray spectrometer (SEM–EDX) analysis can be applied directly to a material to determine the amount of all the elements in a single image analysis. It is a powerful tool for studying the mineral distribution and more precisely the effect of the elements on this distribution, especially for metal elements (Kotz *et al.*, 1990). In this portion of the experiment, all samples,after having been examined before/after in a 45° flammability testing cabinet, were analyzed with an Energy Dispersive X–ray Spectrometer (EDX). The results are shown in Table 1. The main elements of Taiwania (untreated specimens), both preservative woods and preservatives were C, 56.35% for the untreated specimens, 47.96% for the CCA specimens, and 50.24% for the ACQ specimens. For the preservatives, CCA–3 was 4.30%, and ACQ–1 was 3.74%. For both of their ingredients, AS_2O_5 was 3.25%, CrO_3 was 1.50%, CuO was 3.76%, but BKC was 89.35%. After combustion, the relative proportion of C was higher, 89.42% for the untreated specimens, 60.42% for the CCA specimens, 77.89% for the ACQ specimens, and 2.70% for CCA–3, and 22.13% for ACQ–1. In addition AS_2O_5 was 1.47%, CrO_3 was 1.33%, CuO was 14.02%, and BKC was unmeasured (trace amount). The results of element O showed that it had relatively decreased for all samples after being burned. The results also showed that the amount of Cr for the CCA specimens was 7.38%, for CCA–3 it was 34.99%, and the CrO_3 was 64.15% after being burned. Three of them were obviously more than the relative amount of As (4.08% for the CCA specimen, 11.89% for CCA–3, and 36.92% for AS_2O_5), and Cu (5.18% for the CCA specimen, 16.69% for CCA–3, and 58.39% for CuO). This is because the Cr from the char of the CCA preservatives is a stable element (Hirata *et al.*, 1993; Kercher and Nagle, 2001; Cooper, 2003; Helsen and Bulck, 2005; Lee *et al.*, 2005). The char of the ACQ specimens left an amount of inorganic metal elements, Cu (2.67%). As the results (Table 1) indicated, the main char of the ACQ–1 and CuO was Cu, 50.14 and 58.39% which was almost unable

Table 1. EDX analysis of various experimental samples before and after the combustion

Unit: weight (%)

Element	Orbital	*Taiwania cryptomerioides* Hay		CCA specimen[1]		CCA–3[1]		As_2O_5		CrO_3		CuO		ACQ specimen[1]		ACQ–1[1]		BKC1[1]	
		before	after	before	after	before	after	before	after	before	after	before	after	before	after	before	after	before	after
C	K	56.35	89.42	47.96	60.42	4.30	2.70	3.25	1.47	1.50	1.33	3.76	14.02	50.24	77.89	3.74	22.13	89.35	–
O		43.45	8.09	49.43	20.55	59.78	33.50	28.59	49.23	28.14	34.52	24.69	21.89	49.30	7.17	29.94	26.38	–	–
Al		–	–	–	–	–	–	–	3.81	–	–	–	0.21	–	–	–	–	–	–
Mg		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0.36	–	–
Na		0.10	2.20	–	1.43	–	–	–	–	–	–	–	–	–	–	–	–	–	–
S		–	–	0.06	0.96	1.39	0.86	–	–	–	–	–	0.25	–	–	–	0.66	–	–
P		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
K		0.10	–	–	–	–	–	–	–	–	–	–	5.24	–	0.09	–	0.33	–	–
Cl		–	–	–	–	–	–	–	–	–	–	–	–	–	0.14	0.55	–	10.65	–
Ca		–	0.23	–	–	–	–	–	–	–	–	–	–	–	0.24	–	–	–	–
Cr		–	–	0.08	7.38	7.41	34.99	–	–	70.36	64.15	–	–	–	–	–	–	–	–
Cu	L	–	–	1.75	5.18	16.29	16.69	–	–	–	–	71.55	58.39	0.45	2.67	65.76	50.14	–	–
As		–	–	0.72	4.08	10.21	11.89	68.16	36.92	–	–	–	–	–	–	–	–	–	–

[1] Abbreviations of CCA specimen and ACQ specimen are the same as Figure 1, as well as CCA–3, ACQ–1 and BKC are the same as Figure 3.

[2] Race amount (can not be measured).

Table 2. EA analysis of various experimental samples after the combustion

Unit: %

Element	*Taiwania cryptomerioides* Hay	CCA specimen[1]	CCA–3[1]	As_2O_5	CrO3	CuO	ACQ specimen[1]	ACQ–1[1]	BKC[1]
C	79.58 (0.03)	75.38 (0.54)	0.03 (0.01)	–[2]	87.04 (0.17)	63.73 (0.08)	80.93 (0.20)	4.51 (0.11)	–[2]
N	0.28 (0.04)	0.15 (0.01)	0.05 (0.01)	–	0.97 (0.05)	0.03 (0.02)	0.33 (0.01)	1.42 (0.01)	–
S	1.17 (0.62)	0.60 (0.04)	0.36 (0.02)	–	3.22 (0.02)	0.53 (0.17)	0.54 (0.08)	0.41 (0.07)	–
H	3.27 (0.03)	2.90 (0.04)	0.19 (0.01)	–	2.68 (0.20)	0.36 (0.59)	3.13 (0.03)	0.55 (0.03)	–

[1] Abbreviations of CCA specimen and ACQ specimen are the same as Figure 1, as well as CCA–3, ACQ–1 and BKC are the same as Figure 3.

[2] Race amount (can not be measured).

to be combusted toward the end of the combustion (Kercher and Nagle, 2001; Lee *et al.*, 2005; Lin *et al.*, 2006). Furthermore, the samples after having first been examined in a 45° flammability testing cabinet were analyzed with the Elemental Analyzer (EA). The results are shown on Table 2. In addition to the high level of carbon (C), the amount of N (1.42%) was higher for ACQ–1 than that for the other specimens, and the BKC was almost burned out (could not be measured). This inferred that the ACQ specimen could greatly produce NOx gases (Fig. 2) during combustion. The above results suggest that by using EDX and EA to analyze the residual elements in char, the results can provide experimental data for referencing the char of preservative–treated woods in CEM tests.

ACKNOWLEDGEMENTS

The authors are grateful to the Kunnyih Co. Ltd., Taiwan, for providing the experimental materials. We offer our sincere appreciation to the National Science Council through Grant No. NSC 94–2313–B–415–008 for financial support.

REFERENCES

Akiyama, T. 1998 *Wood Recycles.* Sunchoh Publication (Japan), pp. 7–29

Baker, B. B., Jr. and M. A. Kaiser 1991 Understanding what happen in a fire. *Anal. Chem.*, **63**: 79–83

China National Standard CNS 3000 O1018 2001 Preservative Treatment of Wood by Pressure Processes, *China National Standard in Taiwan*

China National Standard CNS 7614 1994 Method of Test for Flammability of Thin Materials, *China National Standard in Taiwan*

Cooper, P. A. 2001 Analysis of Consumer Lumber Waste Management Options. *Final report prepared for Wood Preservation Strategic Options Process*, Manufacturers/Treaters Steering Committee and Consumer Waste Lumber Working Group

Cooper, P., T. Ung, F. Kazi and D. Qi 2003 Two Approaches of CCA Treated Wood: Extraction for Recycling and Wood Cement Composites. *Presented at the AWPA Annual Meeting, Boston*, MA

Connell, M. 1991 Industrial Wood Preservatives – The History, Development, Use, Advantages and Future Trends. In: Thompson R, ed. The chemistry of wood preservation. Cambridge, *Royal Society of Chemistry*, pp. 16–34

Esser, P., P. Eggels and A. Voss 2000 Waste Management of Wood Products in Life Cycle Assessment. *Presented at the*

31st Annual IRG Meeting, Kona, Hawaii, US IRG/WP 00–50154

Helsen, L., E. Van den Bulck 1998 The Microdistribution of Copper, Chromium and Arsenic in CCA Treated Wood and Its Pyrolysis Residue Using Energy Dispersive X–ray Analysis in Scanning Electron Microscopy. *Holzforschung*, **52** (6): 607–614

Helsen, L. and E. Van den Bulck 2005 Review of Disposal Technologies for Chromated Copper Arsenate (CCA) Treated Wood Waste, with Detailed Analyses of Thermogravimetrical Conversion Processes. *Environmental Pollution*, **134**: 301–314

Hirata, T., M. Inoue and Y. Fukui 1993 Pyrolysis and Combustion Toxicity of Wood Treated with CCA. *Wood Sci Technol*, **27**: 35–47

Humphrey, D. G. 2002 The Chemistry of Chromated Copper Arsenate Wood Preservatives, *Reviews in Inorganic Chemistry*, **22** (1): 1–40

Jang, Y. M. 1997 *Waste Processing (in Chinese)*. WEN–JING Book Corp. (Taipei), pp. 49–85

Jang, Y. M. 2000 *Technique of Burning Process*. WEN–JING Book Corp Taipei, pp. 62–81, 213–221, 421–430

Kercher, A. K. and D. C. Nagle 2001 TGA Modeling of the Thermal Decomposition of CCA Treated Lumber Waste. *Wood Science and Technology*, **35**: 325–341

Kotz, R., H. Gerischer and C. W. Tobias (Eds.) 1990 Advances in Electrochemical Sciences and Engineering, *VCH* **1**, Weinheim

Kuwahara, M. 1996 *Wood and Environment*. Kasesya (Japan), pp. 29–32

Ladomersky, J. 2000 Emission analysis and minimization from the wood waste combustion. *Drevarsky Vyskum*, **45** (4): 33–44

Lee, H. L., T. C. Shiah, F. L. Hsu and S. J. Lin 2005 Effects of New Waterborne Wood Preservatives on the Durability and Thermal Properties of Wood. *Taiwan J. For Sci.*, **20** (2): 139–156

Lin, H. C., J. C. Huang, Y Fujimoto and Y. Murase 2001 Analysis of gases emitted from particleboard combustion. *Forest Products Industries*, **20** (2): 165–174

Lin, H. C. and J. C. Huang 2004 Analysis of Combustion Emissions from Wood Coatings after QUV Degradation, *Journal of National Chiayi University*, **1** (1): 50–68

Lin, H. C. 2005 Potential Application of FTIR to Combustion Emissions Analysis of Degradation Coatedwood. *Journal of Agriculture and Forest, National Chiayi University*, **75**: 15–40

Lin, P. C., H. C. Lin, J. C. Huang and T. C. Shiah 2005 Evaluation on Strength Properties and Combustion Emissions from Particleboards with Various Manufactured Factors. *Quart. Journal Forest Research of Taiwan*, **27** (1): 53–66

Lin, J. F. 1992 Precaution of Special Chemical Substance. *Labors Department in Taiwan*, pp. 105–107

Nicholas D. D. and Schultz T. P. 1994 Biocides That Have Potential as Wood Preservatives – An Overview. *Proceeding from the Conference sponsored by the Forest Products Society, Georgia, USA*, pp. 169–173

Okuma, T. 1998 *Wood–Based Resource Materials*. Tokyo University Publication (Japan), pp. 17–20

Sanders, J. G. and H. L. Windom 1980 The Uptake and Reduction of Arsenic Species by Marine Algae. *Environment*, **10**: 555–567

Sanders, J. G. and G. F. Riedel 1987 Control of Trace Element Toxicity by Phytoplankton. *Recent Adv Phytochem*, **21**: 131–149

Shirokae, S, and I. Samezima 1996 *Wood Science Series 4 Chemistry*. Kaseisya Japan, pp. 15–19

Solo–Gabriele, H. M., T. G. Townsend and J. Schert 2003 Environmental Impacts of CCA Treated Wood: A Summary from Seven Years of Study Focusing on the US Florida Environment. *Presented at the 34th Annual IRG Meeting*, Brisbane, Australia, IRG/WP 03–50205

Takabashi, T., M. Suzuki, and Nakano, T. 1995 *Wood Science Series 5 Environment*. Kaseisya Japan, pp. 7–15

Weis, J. S. and P. Weis 1922a Transfer of Contaminants from CCA–Treated Lumber to Aquatic Biota. *J Exp Mar Biol Ecol*, **161**: 189–99

Weis, J. S. and P. Weis 1922b Construction Materials in Estuaries Reduction in the Epibiotic Community on Chromated Copper Arsenate (CCA)–treated wood. *Mar Ecol Prog Series*, **83**: 45–53

Weis, J. S. and P. Weis 1996 Reduction on Toxicity of Chromated Copper Arsenate (CCA)–Treated Wood as Assessed by Community Study. *Mar Environment Res*, **41**: 15–25

Weis, J. S. and P. Weis 1999 Accumulation of Metals in Consumers Associated with Chromated Copper Arsenate–Treated Wood Panels. *Mar Environment Res*, **48**: 73