

ORGANIC EMISSIONS FROM COMBUSTION OF PLYWOOD AND PARTICLEBOARD

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INTRODUCTION

Large amounts of wood, wood waste and manufactured wood products are burned on grates to produce process heat and electricity in industrial boilers. Industrial combustion chambers generate high temperatures for relatively long residence times, however emissions of volatile organic substances are of concern if the residence time, temperature and turbulence are inadequate. The typical industrial plant does not measure volatile organic emissions, but does measure oxygen and carbon monoxide concentrations. With sufficient excess O_2 and low enough CO , the organic emissions are thought to be acceptably low. For example, the Wisconsin Department of Natural Resources specifies good combustion practice as CO less than 600 ppm corrected to 7% oxygen plus temperatures greater than $675^\circ C$ for 1.0 s. The purpose of this project was to determine the adequacy of this criteria with respect to volatile organic emissions for selected wood and manufactured wood products in a laboratory combustor.

Manufactured wood products contain wood, wood fiber, and non-wood additives such as adhesives, wood preservatives and fire retarding chemicals. Secondary manufacturing processes can add plastic overlays, paints, varnishes, lacquers, fillers, strength additives, and dyes. Primary wood products include lumber, plywood, composition board, and pulp and paper. Primary residue is in the form of edge trimmings, sawdust, sander dust, shavings, and fiber sludge, which could be used to replace fossil fuels for steam generation at the industrial site. Eventually the manufactured products are discarded, and rather than going to a landfill, the wood products may be burned in a boiler.

Particleboard is made from sawdust and contains 6% phenol-formaldehyde resin solids. Because of the phenol formaldehyde resin, there is concern that the formaldehyde emissions may be higher than in pure wood. Formaldehyde is considered a hazardous air pollutant by the 1990 Clean Air Act. Under proper operating conditions a wood-fired, spreader-stoker boiler has low formaldehyde emissions, however when the temperature and/or excess oxygen are too low, the formaldehyde emissions can be high [1].

TEST SETUP

The combustor is a 13 cm i.d. by 5 m long chamber made from low density Ceraform ceramic risers which are 13 cm i.d., 30 cm o.d. by 30 cm long. The insulation tubes were force fit into a long steel tube assembly which was hung vertically from a fixed platform as shown in Fig. 1. A propane burner was fitted into the bottom of the combustor for startup, and a mullite honeycomb grate was mounted 60 cm above the burner. Two underfire air opposed jets were located 20 cm below the grate and two overfire air opposed jets were located 40 cm above the grate. The fuel feeder was mounted in a stainless steel tee at the top of the combustor. The combustor exhaust flowed to a wet scrubber and induced draft fan.

Single 11 mm pine plywood cubes were fed at constant rate into the top of the combustor and fell quickly by gravity onto the grate. The cube feed rate must be very constant to maintain constant combustion conditions. The cube feeder consisted of a vibrating hopper feeding the cubes onto a stainless steel, Teflon coated chute. Cubes were held at the bottom of the chute until a rod driven by a pneumatic cylinder, pushed the cube into the combustor. A solenoid turned the air to the cylinder on and off. A pulse generator controlled the timing of solenoid and a counter, which gave the time between pulses, indicated the feed rate of the cubes.

The untreated southern pine cubes had a density of 0.55 g/cm^3 and contained about 8% moisture. The particleboard, which was

southern pine with 6% phenol-formaldehyde based resin, had a density of 0.80 g/cm³. The plywood was made of southern pine and had a density of 0.65 g/cm³.

MEASUREMENT METHODS

For detection of aromatic compounds during combustion, a known volume of sample gas was drawn through a collection tube which was connected to the side of the combustor through a 200 mm long, 3 mm id. stainless steel transfer line. To obtain an accurate sample volume of gas, a graduated sealed 3 liter acrylic tube was filled to a known level with water. During the sampling process the water was pumped out of the tube at a known rate. Displacing the water in the tube was the sample gas that was drawn through the adsorbent tube. The difference in volume from the initial and final level of water in the acrylic tube indicated the exact volume of gas that passed through the adsorbent tube. Two types of collection tubes were used. The first was a glass lined thermal desorption tube packed with 250 mg of Tenax-GR adsorbent. The second was a solvent desorption tube, ORBO-32 standard charcoal tube (Sulpelco).

The thermal desorption system was attached to the injection port of a Hewlett Packard 5890 Series II GC using both a 5971 Mass Selective Detector and a Flame Ionization Detector. The desorption heater was maintained at 300°C for the 10 min. desorption process. The sample was then cryo. focused at the injector end of the GC column. The peaks were identified with the Wiley NBS library using Hewlett Packard Chemstation software. The GC capillary column is a 30 meter 0.53 mm i.d., 0.88 µm film thickness HP-5 Column (Hewlett Packard). A short 0.5 m by 0.53 mm i.d. deactivated fused silica guard column was used on the injection port end of the capillary column to provide an area for cryo focusing and to protect the capillary column. For solvent desorption, NIOSH method 1501 was used. After a known amount of sample gas was drawn through the desorption tube, the contents of the tube were added to 1 ml of carbon disulfide. A 1 µL sample was taken from this solution and injected into the same GC and column described above.

Single point calibration was performed every day for aromatic compounds being analyzed using certified calibration test mixes. For the thermal desorption, a known amount of calibration mix was added to the desorption tube through a special fitting (from Scientific Instruments) while passing He gas through the tube for 30 min. The tube was then analyzed in the typical manner. For solvent desorption a known amount of test mix was injected into the desorption tube, then the tube was capped and let stand overnight. The tube was then analyzed in the usual solvent desorption way.

CO, CO₂ and O₂ were continuously monitored during each run at the same sample point in the combustor that the GC sample was taken. These meters were calibrated daily with certified gas mixes.

TEST RESULTS AND DISCUSSION

Some tests were run using both underfire and overfire air, and some were run using extra nitrogen to lower combustor temperatures. However, the best operation was obtained using only underfire air, which is the condition reported here. Air flow was varied from 0.3 m³/min. (std) to 0.9 m³/min. (std) (1 m/s to 4 m/s). Residence time was varied from 0.5 s to 3 s by adjusting the air flow and by changing the sampling location. Sample ports were located at 1.9 m and 3.8 m above the grate. Fuel flow rate was varied to control combustor temperature and ranged from 15 g/min. to 70 g/min. The combustor required about 10 min. to warm up with the propane burner and about 10 min. to reach steady state with the wood cubes feeding. Combustor gas temperatures were measured at the centerline of tube at 0.9 m, 1.9 m, 2.5 m and 3.8 m above the grate. The vertical temperature drop above the first thermocouple was 50°C/m to 100°C/m depending on the conditions. The emissions data was correlated based on the gas temperature at the point of sampling.

The emissions of volatile organic compounds from the wood cubes depended on the excess oxygen, the gas temperature, and the residence time. Under fuel rich conditions high concentrations

of benzene, PAH's and formaldehyde were observed, with major abundances of benzene, naphthalene, acenaphthylene and anthracene. (Fig. 2). With high excess oxygen in the combustion products, polynuclear aromatic compounds were not observed, but benzene, and toluene were observed unless the temperatures were above 650°C. When excess oxygen was greater than 6 %, benzene concentrations ranged from undetected to 2 ppm, and toluene concentrations ranged from undetected to 0.4 ppm as the temperature was decreased.

The wood feed rate and the ppm concentration data were converted to an emission factor basis of $\mu\text{g/g}$ wood. The results are plotted versus temperature at the sampling point, for two groups of residence times and for excess oxygen above 4% in Figs. 3 and 4 for benzene and toluene. For a residence time of 0.5 s to 1.5 s benzene emission factor averaged $7 \pm 5 \mu\text{g/g}$ wood for temperatures above 600°C, whereas below 600°C the emissions increased rapidly. When the residence time was increased to 2 s to 3 s, the emissions did not increase until the temperature dropped below 400°C. Toluene exhibited a similar behavior but the emissions were lower by a factor of 2. Carbon monoxide concentrations were below 1000 ppm when the temperature was above 650°C for residence times of 0.5 s to 1.5 s, and above 450°C for residence times of 2.0 s to 3.0 s. The CO increased rapidly for temperatures below these values. A cross plot of the benzene emissions versus CO concentration (Fig. 5) shows that the benzene is below 20 $\mu\text{g/g}$ wood when the CO is below 4000 ppm. As the CO rises above 4000 ppm, the benzene emissions increase rapidly. Toluene shows a similar behavior.

Formaldehyde concentrations are plotted versus temperature at fuel rich conditions and 3% O_2 for particleboard (Fig. 6). Under rich combustion conditions, as the average temperature is reduced below 700°C the formaldehyde increased rapidly. At 3% oxygen the formaldehyde was less than 25 ppm. For pine plywood, concentrations of formaldehyde plus acetaldehyde were tested with O_2 at 15% and residence times of 0.9 sec. Tests were made using Kitagawa gas detector tubes. At 460°C 11 ppm (500 $\mu\text{g/g}$) of formaldehyde plus acetaldehyde was detected and at 530°C 3 ppm (130 $\mu\text{g/g}$) was detected at CO levels of 5000 - 6000 ppm.

Hubbard [1] measured benzene and formaldehyde emissions from a 20 million Btu/hr wood fired stoker boiler at a lumber and veneer plant. Benzene emissions ranged from 1 to 11 $\mu\text{g/g}$ and formaldehyde ranged from 1 to 6 $\mu\text{g/g}$, and CO levels were between 200 and 700 ppm during the tests. Fritz and Hubbard [2] measured CO emissions from six wood fired boilers with a heat capacity of 7 to 20 million Btu/hr and found many exceedances above 600 ppm with some levels above 10,000 ppm. They suggest an upper CO limit of 1080 ppm in addition to an 8 hr ave. limit of 600 ppm for CO to give low VOC emissions. Fig. 5 indicates that benzene emission increase rapidly when the CO exceeds 4000 ppm. Low formaldehyde emissions require CO levels below several hundred ppm.

REFERENCES

1. Hubbard, J., Encouraging Good Combustion Technology at Wood-Fired Facilities in Wisconsin, National Biofuels Conference, Newton, MA, 1992.
2. Fritz, R.A. and Hubbard, A.J., Control of Hazardous Air Emissions from Wood-Fired Boilers, Bioenergy 94, pp. 335-341, 1994.

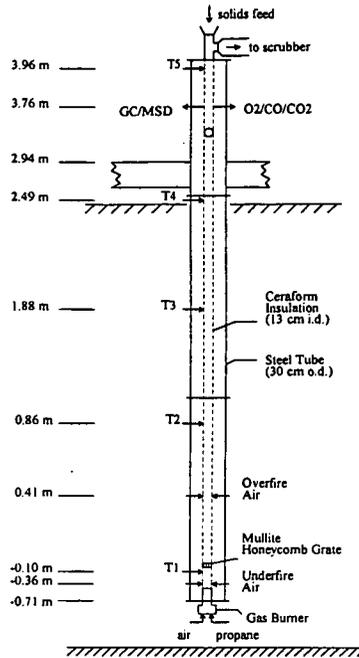


Fig 1. Fixed Bed, Up-Draft Combustor

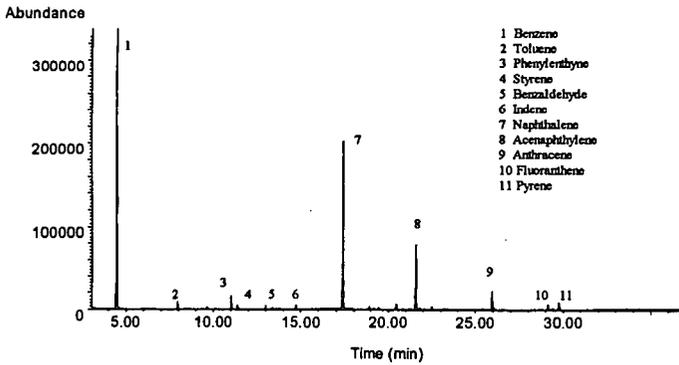


Fig 2. Chromatogram of rich fuel conditions

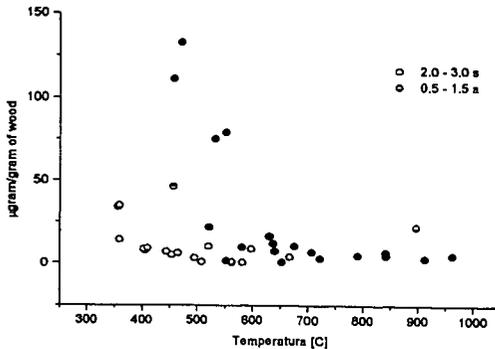


Fig 3. Benzene emission vs. temperature for 2 different residence times

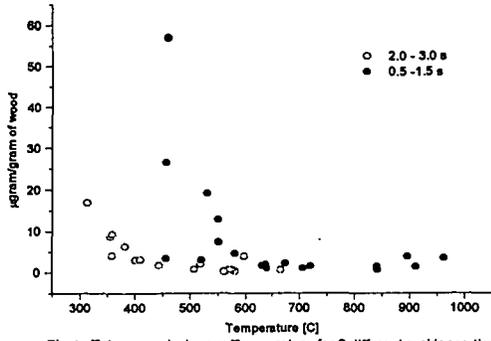


Fig 4. Toluene emission vs. Temperature for 2 different residence times

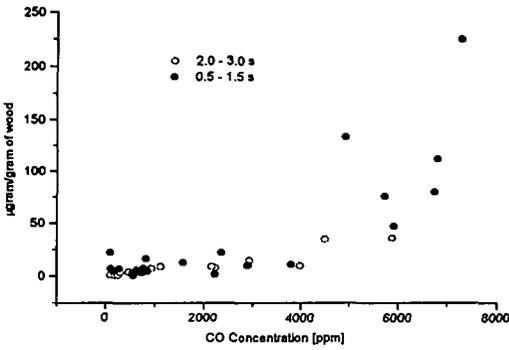


Fig 5. Benzene emission vs. CO concentration for 2 different residence times

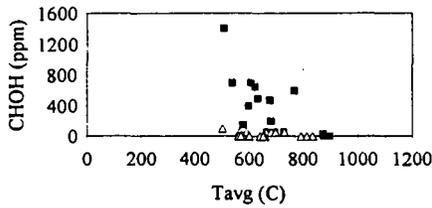


Fig 6. Formaldehyde Concentration vs. Average Temperature for Particleboard
Solid squares indicate rich combustion and open triangle indicates 3% O₂