

REGULATION AND CONTROL OF AIR EMISSIONS

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Processing trees into products may have minimal impact compared to other materials, but each step in processing does provide an opportunity for pollutants to be released. Some of these are the same volatile organic compounds (VOCs) that are biogenically released as trees grow, for example the terpenes. Others, while emitted in small quantities, are on the U.S. Environmental Protection Agency's (EPA) list of hazardous air pollutants (HAPs), for example, methanol and formaldehyde. Particulate matter (PM) is also an important air pollutant.

Air pollution is different from water or soil contamination in that air is freely exchanged among regions. A major event, such as volcanic eruption, can affect an entire hemisphere. When such pollution problems are man-made, global solutions are required. An example solution is the 1987 Montreal Protocol on Substances that Deplete the Ozone Layer which bans the manufacture of most chemicals that contribute to ozone depletion. Another problem may be global warming and the Kyoto Protocol developed in 1997 addresses this by specifying reductions of greenhouse gas emissions in developed countries. The American Forest and Paper Association (AF&PA) has assembled a Climate Change Options Advisory Group to look into issues related to the Kyoto Protocol and domestic government actions dealing with greenhouse gases and evaluate strategies for compliance (12).

For pollutants with shorter lives in the atmosphere, the effects of air pollution are regional; however, possible solutions may be difficult to implement. For example, acid rain is due largely to sulphur emissions from power plants that burn coal. Limiting sulphur emissions is technically possible, but difficult due to the cost burden that controls would place on the companies and ultimately the consumer. Other problems are more complex. For example, smog and ozone are not caused by a single pollutant and solutions are ambiguous due to the complex nature of atmospheric chemistry (see sidebar). There are also uncontrolled sources of emissions; for example, in 1997 in the U.S. there were an estimated 28,194,000 tons of biogenic VOC emissions compared to 19,214,000 tons of man-made VOC emissions (15).

Emissions From Processing Wood

Emissions start with the felling of the tree and the petroleum-fuel-powered equipment used to harvest and transport logs to the mill. Slash burning, where still practiced, emits PM. Dust can be produced as the wood is sawn, cut, or broken down into products or when pneumatic conveyance is used. While the wood is green, VOCs may also be released, for example from chip piles and conveyors.

Processes in which wood is heated result in more significant emissions. The energy for these processes often comes from wood-fired boilers which can have CO, CO₂, NO_x, and PM (Table 1). Mills that have either installed or switched to gas-fired boilers reduce the total emissions from their facility. Dryers are an important source of organic emissions because volatile compounds present in the wood are given off with

TABLE 1. Pollutants and their effects on health and the environment (14)

CO	reduced transport of O ₂ by circulatory system, reduced alertness, aggravates cardiovascular disease
NO _x	Increases susceptibility to respiratory pathogens
O ₃	coughing, chest discomfort, decreases pulmonary function; increased asthma attacks
PM	larger particles, >5 or 10 microns are deposited in nose, smaller particles go to tracheobronchial and pulmonary regions. Moved out of tracheobronchial region by fiber cilia to trachea where they are swallowed
VOC	causes increase in ozone level; absorption from airstream to body is determined by deposition of particulate and solubility
Acetaldehyde	irritation to eyes, skin, and respiratory tract; paralysis and death in high concentrations; probable low-hazard human carcinogen
Formaldehyde	eye, nose, and throat irritations, respiratory problems; reproductive problems; probable medium-hazard human carcinogen
Methanol	Visual disturbances, blindness, headache, giddiness, insomnia; no information on reproductive disorders or carcinogenicity

the water. Most notable in softwoods are α - and β -pinene. In some cases, reactions in the gas phase may occur and compounds emitted from the dryer may not have been originally present in the wood. An example of this is the air oxidation of α -pinene to ringed compounds with aldehydes, ketones, and hydroxyl groups such as verbenol, verbenone, 3-pinene-2-ol, myrtenol, and myrtenal (13). One might detect 25 or 30 compounds in the terpene family in dryer exhaust, five or 10 of which can be quantified (13, 5). Other nonterpene VOCs are formed and emitted including acids such as formic, acetic, and propionic. Total organic emissions from softwood lumber are 1 to 4 pounds per 1000 board feet (Table 2). Removing the VOCs sets the pitch making the wood suitable for appearance applications.

During drying, wood also emits some compounds that are on the EPA HAPs list. In the case of a direct-fired dryer, the combustion process also contributes to dryer HAPs. Wide ranges occur in reported values and the dominant HAP varies due to species and temperature.

History of Air Pollution in the U.S.

Air pollution concerns from burning coal go back 500 years and pollution concerns due to other odors have existed since there were cities. Modern pollution control in the U.S. probably started with the Air Pollution Control Act of 1955. This Act required the U.S. Public Health Service to assist communities in reducing a new form of pollution, photochemical smog. This was followed by additional Clean Air Acts in 1963 and 1967 which provided for research to better understand the problem. On January 1, 1970, President Nixon signed the National Environmental Policy Act. Although aimed at federal agencies, this act set the groundwork for today's environmental and pollution

TABLE 2. Summary of emissions data from steam-heated dryers.

Process	Type of wood	Emissions			
		VOC ⁶	HAPs		
			Methanol	Formaldehyde	Total ⁷
Lumber (19,11) lb/mbf	Douglas-fir	1.47	- ⁵	-	-
	southern pine	3 - 4	-	-	-
Plywood (6) lb/mft ³ (3/8")	western softwood	0.56	0.04	0.02	0.09
	southern softwood	2.8	0.04	0.01	0.06
	hardwood	0.3	0.04	0.001	0.05
Particleboard (8) lb/ODT	western softwood ¹	1.0	0.043	0.12	0.22
	southern pine	2.1	0.01	0.027	0.60
Oriented Strandboard (9) lb/ODT	southern pine	4.1	0.12	0.31	0.69
	hardwood	2.0	0.33	0.57	1.8
MDF ⁴ (7) lb/ODT	western softwood	1.5	-	-	2.1 ²
	southern pine	5.5	-	-	
	hardwood	1.0	-	-	1.2 ³
Hardboard ⁴ (10) lb/ODT	hardwood	1.6	-	-	1.04

¹Dry-furnish dryer

²Blowline addition

³Non blowline addition

⁴Tube dryers

⁵- indicates either data not available or cannot be express accurately in table

⁶includes all organic compounds measured by Method 25A

⁷may also include acetaldehyde, acrolein, benzene, phenol, toluene, zylenes and others.

control policies. Later that same year, the EPA was created by executive order. A Clean Air Act, passed in 1970 and amended in 1977, authorized the EPA to establish the National Ambient Air Quality Standards (NAAQS) for seven criteria pollutants: PM, sulfur oxides, nitrogen dioxide, lead, carbon monoxide, hydrocarbons, and ozone. Among other requirements, the act directed each state to develop a state implementation plan (SIP) to achieve the NAAQS.

Summary of 1990 Clean Air Act

The most recent amendments to the Clean Air Act (CAA), proposed by President Bush in 1989, were signed into law on November 15, 1990 (Table 2). The amendments used approaches to reducing pollution that were different from past legislation in that market-based principles and emission banking and trading were introduced. The amendments target clean fuels, energy efficiency, and acid rain and provide for extensive reporting mechanisms to assure compliance. There are eleven titles in the Act (see Table 3) with Titles I, III, and V having the most immediate effect on the Forest Products Industry.

Title I contains provisions for attainment and maintenance of NAAQS. In regions that are in attainment, New Source Reviews (NSRs) are required to assure that regional air quality is maintained under the Prevention of Significant Deterioration (PSD) program. NSRs are triggered if the expected PM exceeds 25 tons/year (t/y), the PM₁₀ (PM <10 µm) exceeds 15 t/y, or the VOCs exceed 40 t/y from new or certain modified equipment (1). Then an air quality analysis must be done and the Best Available Control Technology (BACT) may be required if PSD limits are exceeded. In nonattainment areas, new equipment or certain modifications require the installation of control technology that offers the Lowest Achievable Emission Rate (LAER) plus emissions offsets from other equipment to cause an overall improvement in air quality. For example, a wood processing facility in one of the 119 nonattainment areas might not be allowed to add capacity or might have to use a dehumidification kiln rather than a steam kiln to avoid producing emissions from a boiler.

Title III covers toxic air pollutants, typically carcinogens, mutagens, and reproductive toxins. For wood dryers, the main HAPs are methanol, formaldehyde, and acetaldehyde. The EPA is in the process of establishing maximum achievable control

TABLE 3. Titles in the 1990 Clean Air Act Amendments.

Title	Subject
I	National Ambient Air Quality Standards
I	Mobile sources
III	Hazardous air pollutants
IV	Acid deposition control
V	Permits
VI	Stratospheric ozone protection
VII	Enforcement
VIII	Miscellaneous provisions
IX	Clean air research
X	Disadvantaged business concerns
XI	Employment transition assistance

technology (MACT) standards with which major sources will have to comply. Major sources have the potential to emit 10 t/y of any one HAP or 25 t/y of any combination of HAPs. The values are for a company's contiguous property. So all sources are added together for an integrated mill.

Title V addresses permitting of major sources (>100 t/y for VOCs), the purpose of which is to ensure compliance. Permits are typically administered by states and specify how much is emitted and how it is monitored. Permit limits will be in effect for five years and reporting unit emissions (eg. mass/unit of production) that are too high may limit production while reporting values that are too low may result in large fines. All permit applications and documents are public information providing anyone with certain information that mills might consider sensitive. Fees associated with the permits cover the cost of permitting and are based on the amount of pollution produced. Non major sources usually require other types of permits issued by the states.

A tremendous amount of educational, regulatory, regional, and company specific information can be found on the EPA website. A good starting point is <http://www.epa.gov/ttn/>.

Controlling Emissions

Before end-of-pipe devices are considered, the process should be optimized so that emissions are minimized. For wood dryers this can mean lower air temperatures, drying to higher moisture contents, or, perhaps, completely redesigning the process so a liquid effluent is produced and no gases are released. Some or all of these options may not be possible or economical in an existing facility or even in a new facility.

A number of methods exist for removing emissions from exhaust gas. The organic concentration in dryer gas is usually too low to justify chemical recovery and below the lower explosive limit so the gas will not self combust. Therefore, a fuel, such as natural gas, is burned and the effluent is mixed with the combustion gas to decompose the organic compounds, usually at about 1600°F. Recuperative thermal oxidizers utilize conventional heat exchangers for energy recovery and regenerative thermal oxidizers (RTOs) use beds of hot ceramics as the heat exchange media (Figure 1). Exclusive of lumber kilns, none of which have emissions control equipment, approximately 20 percent of the dryers in the forest products industry have RTOs (17). The removal efficiencies of RTOs may be greater than 99.9%, but lower efficiencies have been reported on wood dryers (6,9), probably due to condensation of organic compounds during the intake phase being exhausted without passing through the burner.

The high temperatures which destroy VOCs in RTOs cause NO_x emissions. NO_x compounds have the potential to increase ozone levels just like VOCs. This combined with high energy consumption raises questions regarding their overall benefit. The results of a life-cycle analysis on this issue are expected from the AF&PA later this year (4).

Catalysts are sometimes used to allow the oxidation to occur at lower temperatures. This saves energy and reduces NO_x. However, the catalyst can be poisoned if temperatures are not carefully controlled. This control is more difficult with multicomponent gases in variable concentrations because the energy available from the combustion of organic compounds in the gas varies. Less than two percent of wood dryers have catalytic oxidizers.

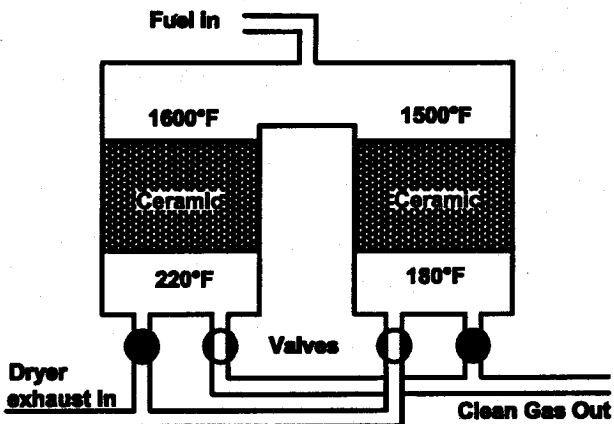


FIGURE 1. RTO. Gas flows first through one bed to be heated, then flows through the other to be cooled. Valves control which bed is first so energy is recovered. Usually there are three or more beds.

Biofilters decompose organic compounds using microorganisms at a low temperature. Biofilters require pretreatment of the gas to ensure that it is at a low enough temperature and a high enough moisture content so the organisms can survive. They work best when the organisms are fed a steady diet of the same compounds. They operate at low temperatures so they do not create NO_x compounds like RTOs. There are few, if any, biofilters on wood dryers, but some are used on the exhaust from hot presses (18).

Adsorption can be used to take organic compounds out of the effluent and onto a media such as carbon, silica gel, or zeolite. Similarly, absorption into a liquid can be done in a packed bed. In either case, the sorption media is then stripped and the organic compounds obtained in gas at a much higher concentration. At that point they can be burned or recovered. The range in molecular weights and solubilities of the organic compounds and high moisture content of dryer exhaust might make it difficult to use these techniques.

PM is controlled in a variety of ways. Dust is often collected with the cyclones and filtration systems (baghouses) commonly seen at mills. Other PM can be controlled with scrubbers and electrostatic precipitators (ESPs). Scrubbers pass exhaust air through a water spray. ESPs create gas ions by corona discharge which, in turn, charge the PM. The PM is then collected on an oppositely charged wall. Approximately 40 percent of wood dryers have particulate control (17). These systems are generally not effective on VOCs or HAPs. In a scrubber, for example, an organic molecule follows the air stream lines around the water droplets. PM, due to its mass, impinges with the water droplets and is collected. Similarly, in an ESP, individual molecules, even if charged, are not moved rapidly enough to the plate to be collected.

Test Methods to Measure Pollutants

Measuring or estimating emissions is required for reporting purposes under Title V and may also be necessary to demonstrate that a facility does not come under Title V. To avoid measuring, emission factors for various types of equipment and processes in the Wood Products Industry can be found in Chapter 10 of EPA document AP-42 (16). Emission factors relate the quantity of a pollutant to the activity associated with its release, for example, pounds of hydrocarbon released per thousand board feet of production. Even though this document comes from the EPA, companies that use the information are responsible for assuring that the values apply to their facility. The factors in AP-42 are rated for general reliability based on the number of tests, acceptability of test procedures, and applicability to sources nationwide. No confidence intervals are associated with the values and emission factors are often only an order of magnitude estimate of the actual emissions.

For many processes, the simplest way to determine emissions is to do a material balance. This method works well in operations such as paint line where the use rate and solvent content are known. This approach has been applied to wood drying with results (3) that are in reasonable agreement with other test data.

EPA Method 25A is often used to estimate the VOC emissions. The method requires that the exhaust flow rate and its hydrocarbon concentration be measured. A total hydrocarbon analyzer is used for the concentration measurement and the mass of VOCs released is reported "as carbon." This value would be the actual mass of the carbon atoms emitted if the detector response was not affected by carbon substitution. For example, formaldehyde, methanol and methane would have different responses. Sometimes (parts of AP-42, for example) the emissions are reported "as propane" meaning that the mass includes eight hydrogen atoms for every three carbon atoms. Reporting VOCs as carbon is most common in the forest products industry because it is consistent with Method 25.

Methanol and formaldehyde can be measured by drawing a gas sample through chilled aqueous impingers in series. The gas flow rates from the process and through the impingers are measured. Based on the gas flows and the quantity absorbed in the impingers, the average emission rates over the collection interval can be determined. This is often referred to as the NCASI (National Council for Air and Stream Improvement) Chilled Impinger Method. Other HAPs are measured by collecting a gas sample and measuring the components with GC/MS.

For accurate stack measurements of PM, EPA Method 5 may be used. In this method a sample is drawn isokinetically from the exhaust and PM is collected on a glass fiber filter. The particulate mass is dust plus any material that condenses at or above the temperature of the filter (usually 120°C). It is often argued that some hydrocarbon gets counted twice, once before it condenses in Method 25A and then after condensation in Method 5.

For day-to-day compliance purposes, the percent opacity of the gas plume may be monitored by qualified observers to demonstrate compliance (EPA Method 9). While the observation process is not as simple as it sounds, it is an easy way to tell when particulate emissions are too high (2). Qualified observers must be recertified every 6 months by an EPA-approved school. The facility's Title V permit contains specific measuring intervals and limitations. Usually 80 percent of the light must pass through the plume. Continuous measuring systems are also available, but these have trouble distinguishing water droplets from particulate.

Small-scale kilns (<75 bf) were constructed at Mississippi State and Oregon State Universities to estimate emissions from lumber drying. Method 25A and the NCASI Chilled Impinger method are used to determine emissions. Values for VOCs measured at the OSU kiln compared favorably with field measurements on Douglas-fir (19). Measurements made at both facilities on southern pine also compared well with each other and with field studies conducted by NCASI (11). Besides predicting emission factors, the small-scale kilns are useful for predicting how process changes affect emissions. Similar small-scale dryers might be useful for experiments on veneer, particles, and flakes.

Current Regulatory Changes

The CAA requires that HAPs from major sources be controlled using MACT standards determined by the EPA. Because all test data is available to the EPA (this occurs through reporting to the states), the EPA can compare data from controlled and uncontrolled sources to help in determining MACT standards. One look at AP-42 will give the reader a good idea of the large variability in data available to the EPA. Industry concerns regarding the lack of good quality data resulted in an AF&PA-funded study to obtain better data.

NCASI carried out the MACT study at 29 facilities manufacturing hardwood and softwood plywood, engineered lumber, particle board, medium density fiberboard, oriented strandboard, and hardboard. The study covered many types of equipment with the objectives to determine the potential for emissions and efficiency of existing controls. The EPA will use this and other information to set MACT standards. Nothing is certain, but it appears that most rotary, tube, and softwood veneer dryers at major source plants will be subject to 90 percent control efficiency for HAPs (18). Presses at major composite panel plants may also be subject to the 90 percent control efficiency requirements (18). A decision from the EPA is expected in December with final rules promulgated in February of 2002 (4). Mills will then have three years to come into compliance (4).

Methanol emissions are a significant factor in determining if a mill is a major source and must comply with the MACT standards. In plywood manufacturing, methanol emissions account for well over half of the dryer and press HAPs. A petition submitted by the AF&PA to delist methanol as a HAP underwent review and the EPA will either issue a notice of denial or propose rule making by August 2000 (4). New significant evidence on the issue would extend EPA's deadline to 18 months.

Current NAAQS cover PM₁₀. These are 50 µg/m³ for an annual mean and 150 µg/m³ for a 24-hour mean. In 1997, the EPA promulgated a final decision on standards for PM smaller than 2.5 µm (PM_{2.5}) to be 15 µg/m³ for a 99th percentile, 3-year mean and 65 µg/m³ for a 24-hour mean. The annual PM₁₀ standard would also change to a 99th percentile, 3-year mean. Last October, the U.S. Court of Appeals ruled that the EPA overstepped its constitutional authority because the rule created double jeopardy in that a violation of the PM_{2.5} rule could also result in a PM₁₀ violation. It is likely that new rules will be formulated for PM_{2.5} and PM_{2.5-10}. This would cause industry to have to introduce improved particulate control. The actual effects of this are a few years away because, by the standard's definition, the ambient air quality data will take three years to collect. Implementation of this would vary by airshed according to PSD requirements in SIPs under Title 1.

What the Future Holds

In the 20-year picture, we will probably see emission control on most dryers and other equipment. In the 50- to 100-year outlook, it is likely that technology will be developed so that all processes will be closed except, from dryers, the water removed.

In the meantime, dryers may be operated at lower temperatures and wood dried to higher moisture contents or with more careful control of final moisture content to reduce emissions. Improved sorting practices for veneer and lumber might make final moisture content control easier. There are many research opportunities available to determine relationships between emissions and wood properties, equipment operating conditions, and processing methods. A method for fixing the wood resins so they are not emitted from the wood would be useful. Better insulation, the use of energy recovery units, and other measures, especially on dryers heated by wood-fired boilers, will help to minimize emissions during energy production. Controls that even out the steam demand on the boiler will be important to its clean operation. Using electrical energy, such as heat pump units, for drying may also reduce a mill's emissions but need to be evaluated for their overall environmental impact.

Industrial enterprises are working to control emissions from their processes. But industry can only do so much. A clean environment also depends on the personal habits and choices of individuals, with automobile use being the major factor.

References

1. Bassett, S. 1996. Cutting the red tape: EPA tailors NSR. *Pollution Engineering*, 28(6):56-60.
2. Bengtsson, J. 1997. Going through the Title V process. In *Proceedings of the Western Dry Kiln Association*. May 7-8. Reno, NV. p. 64-68.
3. Dallons, V. C. L. M. Lamb, M. R. Peterson. 1994. An alternate method for estimating VOC emissions from lumber dry kilns. *AIChE Symposium Series No. 302 Vol. 90:19-32*.
4. Hunt, T. AF&PA. Personal communication. March 24, 2000.
5. Lavery, M. R. 1998. Total hydrocarbon emissions from lumber dry kilns. M.S. Thesis. Oregon State University, Corvallis, OR 133 pp.
6. National Council for Air and Stream Improvement. 1999. Volatile organic emissions from wood products manufacturing facilities, Part 1 - Plywood. Technical Bulletin No. 768. NCASI, Research Triangle Park, NC.
7. _____. 1999. Volatile organic emissions from wood products manufacturing facilities, Part III - Medium Density Fiberboard. Technical Bulletin No. 770. NCASI, Research Triangle Park, NC.
8. _____. 1999. Volatile organic emissions from wood products manufacturing facilities, Part IV - Particleboard. Technical Bulletin No. 771. NCASI, Research Triangle Park, NC.

9. _____. 1999. Volatile organic emissions from wood products manufacturing facilities, Part V - Oriented Strand Board. Technical Bulletin No. 772. NCASI, Research Triangle Park, NC.
10. _____. 1999. Volatile organic emissions from wood products manufacturing facilities, Part VI - Hardboard and Fiberboard. Technical Bulletin No. 773. NCASI, Research Triangle Park, NC.
11. _____, Mississippi State University, and Oregon State University. Work in progress.
12. Pugh, T. AF&PA. Personal communication. March 23, 2000.
13. Punsuvon, V. 1994. Identification of volatile materials emitted during the drying of southern pine lumber. Ph.D. Thesis. Mississippi State University. 128 pp.
14. U.S. Environmental Protection Agency. 1998. Unified Toxics Website. Office of Air Quality and Planning and Standards. (<http://www.epa.gov/ttn/uatw/hlthef/acetalde.html>)
15. _____. 1999. National air pollution emissions trends update 1970-1997. Office of Air Quality and Planning and Standards. May, 1999. (<http://www.epa.gov/oar/aqtrnd97/figlist.html>)
16. _____. 1999. AP-42 Fifth Edition. Office of Air Quality Planning & Standards. Clearinghouse for Inventories and Emissions Factors. (<http://www.epa.gov/ttn/chief/ap42c10.html>)
17. _____. 1999. Unified air toxics website. Office of Air Quality and Planning and Standards. <http://www.epa.gov/ttn/uatw/plypart/plypart.html>
18. David Word. NCASI. Personal Communication. February 22, 2000.
19. Wu, J. and M. R. Milota. 1999. Effect of temperature and humidity on the total hydrocarbon emissions from Douglas-fir lumber. *Forest Products Journal*. 49(6):52-60.