Appendix C. Memorandum

TO: Beverly Werner, Manager
Regulatory Assistance Section
Stationary Source Division

FROM: Dale Shimp, Manager /s/
Emission Inventory Analysis Section
Planning and Technical Support Division

DATE: August 17, 2000

SUBJECT: Agricultural Burning Emission Factors

This memo is in response to your request for our assistance in compiling the best available emission factors for the open burning of agricultural residues such as crop stubble and orchard prunings. We understand that these factors will be used for estimating emission reduction credits, and we also expect that they will be used as needed for Title 17 smoke management efforts.

The emission factors included in the attachment to this memo are based on results from ARB sponsored emissions tests. To encourage statewide consistency, we encourage the use of these emission factors, however, districts have the flexibility to use other factors if they have data which can be shown to be more applicable or relevant to their specific region.

The attachment includes background information about the emission factors, the rationale for selecting them and their limitations, and a table of the factors and their sources. Except for a few examples, this summary does not include emission estimates for burning grasslands, chaparral, and forest materials. These will be provided in a separate analysis. If you have any questions regarding the provided factors, please contact Patrick Gaffney of my staff at 916-322-7303 or pgaffney@arb.ca.gov.

Attachment

cc: Patrick Gaffney
Staff Air Pollution Specialist
Planning and Technical Support Division

Emission Factors for Open Burning of Agricultural Residues

Introduction

Within California substantial quantities of agricultural residues are burned in the field as a way to dispose of the material. The materials typically burned include orchard prunings, straw stubble, and other biomass. To estimate air emissions from these burning activities, typically a limited number of emission tests are performed under either field or laboratory conditions, and the emissions are measured. These measurements, combined with knowledge of the quantity of material burned, are used to develop emission factors, which are an *estimate* of the quantity of emissions per amount of material burned. Emission factors for agricultural burning are generally expressed as pounds of pollutant per ton of material burned.

Open burning of agricultural materials provides a diverse mix of pollutants. At this time the pollutants that are most commonly quantified are particulate matter (PM), oxides of nitrogen (NO_x), oxides of sulfur (SOx), volatile organic compounds (VOCs), and carbon monoxide (CO). In addition, some information is available providing information on the individual toxic species and organic compounds produced during open burning, but they are not provided in this summary.

Prior to this analysis, the emission factors used in California for agricultural burning were typically from the U.S. EPA's "Compilation of Air Pollutant Emission Factors"[1], which is often referred to as AP-42. These factors are based on ARB sponsored tests performed in 1974 and 1977. This summary provides some new emission factors based on more recent measurements by Jenkins[2] at the University of California at Davis in 1992 and 1993. When these more recent data were not available, then the default AP-42 factors were used or emissions.

Using These Emission Factors

The emission factors summarized here are recommended for use in California under "typical" conditions. Because of the nature of the testing used to measure the open burning emissions, it is unlikely that these factors will exactly quantify the emissions from any specific fire. However, it is assumed that the factors will generally provide a reasonable overall estimate of emissions. In those cases when region specific, fuel specific, or condition specific emission factors are available, they may be used when it is clear that they are more representative of the emissions than the generic factors.

If it is necessary to refer back to the original literature citations used for this emission factor summary, it is important to note that there is a reporting inconsistency in the reports which was rectified here. Specifically, the AP-42 emission factors, based on the work of Darle

are reported on the basis of field condition fuel moisture (i.e., lbs of pollutant/ton of field dry fuel). But, the newer emission factors by Jenkins are reported in terms of bone dry fuel mass, which is zero percent moisture (i.e., lbs of pollutant/ton bone dry fuel). These distinctions and the corrections applied are described fully in the emission factor notes, which follow, and the notations included with the emission factor table.

General Notes for Agricultural Burn Emission Factors

Emission Factors. Where available, the emission factors from Jenkins[2] were used in preference to AP-42[1] or values from Darley[3]. This is because the Jenkins data are more recent, they were fully quality assurance and quality control checked, complete documentation of the testing and results are readily available, and all relevant pollutants were measured using the current best available methods. When Jenkins data were not available, AP-42 values or averaged Jenkins and Darley values were used, as described in the emission factor table notes for each specific material burned.

PM_{10} and $PM_{2.5}$. Where possible, the directly measured Jenkins data were used for the PM_{10} and $PM_{2.5}$ emission factors. For those crops not tested by Jenkins, AP-42 values were used. Because AP-42 provides only PM_{30}, ARB size scaling factors (based on averaged Jenkins data) were used to scale the PM_{30} values to PM_{10} and $PM_{2.5}$. For field crops, the PM_{10} scaling fraction is 0.9835; for $PM_{2.5}$, the scaling fraction is 0.9379. For orchard and vine crops, the PM_{10} scaling fraction is 0.9814 and for $PM_{2.5}$ the scaling fraction is 0.9252.

NO_x and SO_2. These pollutants pose special problems because of the variations in measurements between Jenkins and Darley (1979), and because AP-42 does not include NO_x and SO_2. For NO_x, there are significant differences between the Darley and Jenkins measurements.

Darley states that his testing in 1978 was one of the first attempts to measure NO_x from the actual burning of agricultural residues. Jenkins performed his testing in 1992 and 1993. The Jenkins data were selected as the default NO_x values for the following reasons: 1) the Jenkins combustion process more accurately simulate field burning conditions; 2) the Jenkins data were performed more recently using modern equipment and full QA/QC processes; and, 3) Jenkins data are used for the other pollutants, so using the Jenkins NO_x provides a consistent data set.

For comparison, the average Darley NO_x value for prunings is 3.1 lbs/ton burned versus the 7.0 value from Jenkins. For field crops, the average Darley NO_x value is 4.1 lbs/ton burned versus 4.9 from Jenkins.

The SO_2 measurements also vary significantly between Darley and Jenkins. For SO_2, Darley acknowledges (pgs. 20, 43) that his estimates are biased high because it was not possible to directly measure the SO_2. Instead he computed the difference in sulfur between the unburned fuel and the ash, and assumed that all of the sulfur lost to combustion was converted to SO_2. Because these estimates are not based

on measurements of the combustion gases, they are viewed less robust than the Jenkins stack measurements.

For the Jenkins SO_2 measurements, the report states that the SO_2 emission estimates may be low by a factor of 2 to 3 (pg. 102). However, with the understanding that these estimates may be biased low, they are the current best available data, and are provided as an initial estimate based on combustion gas measurements.

For comparison, the average Darley SO_2 value for prunings is 0.6 lbs/ton burned versus the 0.2 value from Jenkins. For field crops, the average Darley SO_2 value is 2.8 lbs/ton burned, versus 0.7 from Jenkins.

Computation of VOCs from Jenkins and AP-42. The Jenkins report provides several measurements of hydrocarbons. For example, Table 4.1.3, and 4.5.1 provides the following:

Species	**Name**	**Notes**
THC	total hydrocarbon	continuous measurements, best hydrocarbon value (section 2.2.2.1)
HC (by GC)	hydrocarbons by gas chromatograph	includes only CH4, C2H2, C2H4, C2H6, C3H8 (section 2.2.2.2)
CH4 (by GC)	methane by gas chromatograph	grab sample
NMHC	non-methane hydrocarbons	this is THC – CH4 (by GC), some round-off variations occasionally
NMHC (by GC)	non-methane hydrocarbons by GC	used primarily as THC check, not primary measurement
VOC	volatile organic carbon	Includes a selected set of VOCs that were evaluated using GC (section 2.2.3); not all species of VOCs were identified

There are two possible ways to compute the VOC values. The first approach is to sum the individual emission factors for the species provided in Table 4.5.1 of Jenkins. Because not all VOC species were identified and quantified in this analysis, this estimate would tend to be lower than the actual level of VOCs produced. (Ref. email from Jenkins 1/11/00, and letter 7/29/97)

The second approach is to use the total hydrocarbon value (THC) and then use the existing ARB fraction of reactive gas profiles (FROGs) to estimate the fraction of THC that is considered reactive (or volatile) for agricultural burning. Currently, this is the preferred approach because using only the Jenkins emission factors for the measured VOC species will underestimate the total VOC.

In AP-42, values for Total Organic Carbon (TOC) are provided which are assumed to be equivalent to THC. Therefore, VOC is computed as either THC (Jenkins) or TOC (AP-42) multiplied by the ARB fraction of reactive gas (FROG) which is 0.5698 for agricultural residue and prunings burning.

Computation of EFs from Jenkins. The Jenkins emission values are provided as Average Emission Factor (% dry fuel). The 'Average All Tests' values were used. The % dry fuel values were converted to pounds/ton (i.e., % dry fuel x 2000 lbs/ton ÷ 100% = lbs emitted/ton burned). This applies to data in Jenkins Tables 4.1.1 to 4.1.8.

Moisture correction. After the Jenkins emission values were converted to pounds/ton, they were then adjusted for fuel moisture levels. This was needed because the Jenkins emission factors were reported in terms of emissions per bone dry fuel mass (0% moisture). Because most users of these emission factors generally do not have access to bone dry fuel loading values, the Jenkins emission factors were converted to a field condition fuel moisture basis. The AP-42 emission factors are published on a field condition fuel basis so no conversion was needed.

The Jenkins factors were converted by subtracting the average percent moisture for each fuel from the emission factors, thereby reducing the emission factor by the amount of moisture in the fuel, and putting them on a moist fuel basis. Looked at another way, if a ton of wet material was burned and the Jenkins factors were applied to this wet ton, the emissions would be overestimated. Because of the water in the fuel, the mass would be artificially elevated for use with the Jenkins dry fuel factors. As an example, for wheat straw, the wet fuel loading is 1.9 tons/acre. But, 7.3% of that is water, so the bone dry fuel loading is actually 1.9 tons/acre - 7.3% = 1.8 tons/acre, so only 1.8 tons of dry fuel are burned. For these factors, rather than adjusting the fuel loadings, the emissions factors were reduced to allow the moist loadings to be used.

Fuel Loading. For nearly all cases, the default fuel loading values for field crops are from AP-42. Other fuel loading values were not readily available. Using knowledge of local conditions and practices, fuel loading values can be adjusted as needed to more completely reflect actual conditions. The fuel loading values are provided as field condition fuel loadings which include varying degrees of moisture in the fuel. For example, the percent weight of moisture for wheat straw prior to burning averaged 7.3%. The default fuel loading and fuel moisture levels are provided in the emission factor table. Using the default fuel moisture, bone dry fuel loadings can be calculated if needed.

Emission Factors for Chaparral and Forest. These values are provided primarily for comparison purposes and they are not recommended for use to compute official emission estimates. Instead, more region specific data should be identified and used if available. The ARB will evaluate the current emission factors and prepare a companion to this report which addresses emissions from grass, brush, and forest burning.

References

[1] 'Compilation of Air Pollutant Emission Factors'. Volume 1: Stationary Point and Area Sources, Fifth Edition, AP-42, January 1995, U.S. EPA. Table 2.5-5.

[2] Jenkins, B., 'Atmospheric Pollutant Emission Factors from Open Burning of Agricultural and Forest Biomass by Wind Tunnel Simulations', April 1996, UC Davis. Tables 4.1.1 to 4.1.8.

[3] Darley, E.F., Hydrocarbon Characterization of Agricultural Waste Burning, April 1979. Statewide Air Pollution Research Center, UC Riverside, under contract to the California Air Resources Board, #A7-068-30.

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