Emission Testing of an Indirect-Fired Batch Lumber Kiln with Conventional Roof Vents

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NCASI West Coast Regional Meeting

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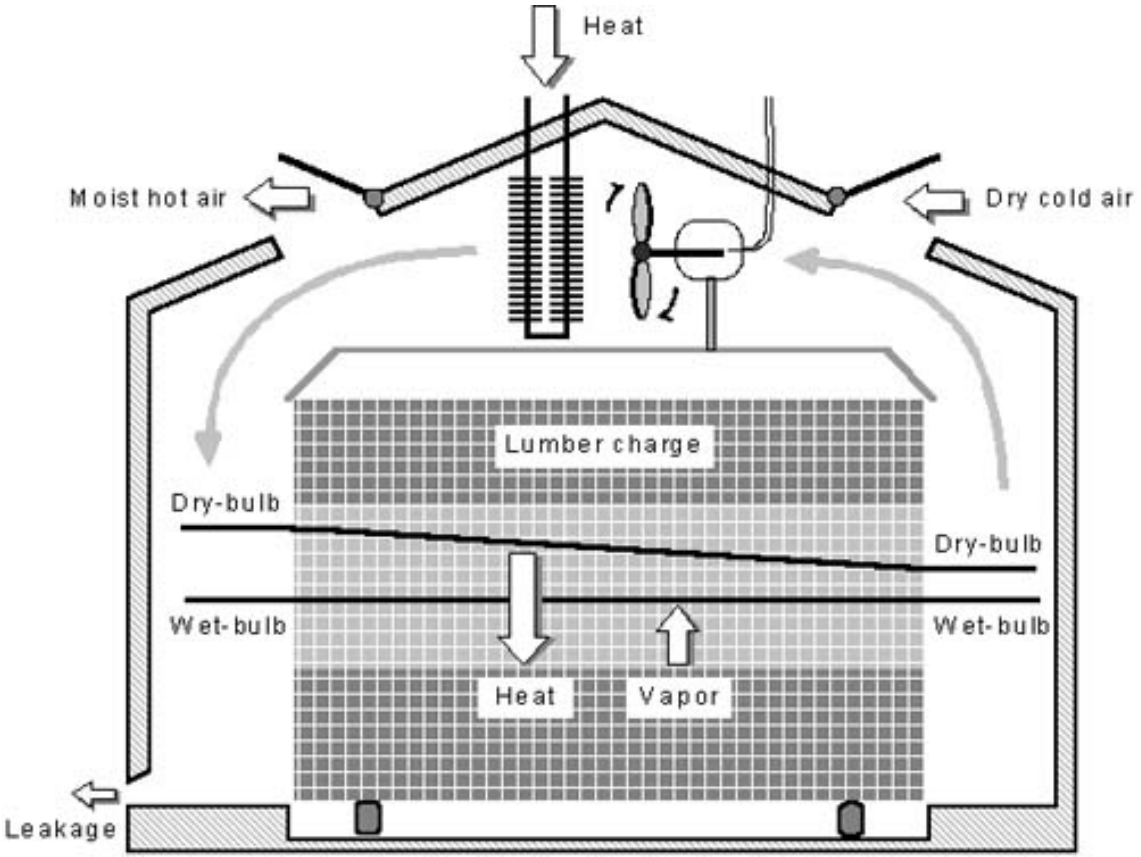
Overview

- Lumber Kiln Testing Challenges
  - Description of Batch and Continuous Lumber Kilns (CDK)
  - Testing challenges & past attempts
- Results from recent NCASI test effort at an INDF Batch Lumber Kiln
  - Direct-$PM_{2.5}$[1] : no historical data, first attempt
  - TGOC[2] and total HAPs[3]: historical data available to compare with recent test results
  - If favorable comparison is found for TGOC and total HAPs, then direct-$PM_{2.5}$ results representative

1. Direct-$PM_{2.5}$ = filterable $PM_{2.5}$ + CPM; 2. TGOC = Method 25A total gaseous organic carbon; 3. total HAP = acetaldehyde, acrolein, formaldehyde, methanol, and phenol

Batch Lumber Kiln Schematic



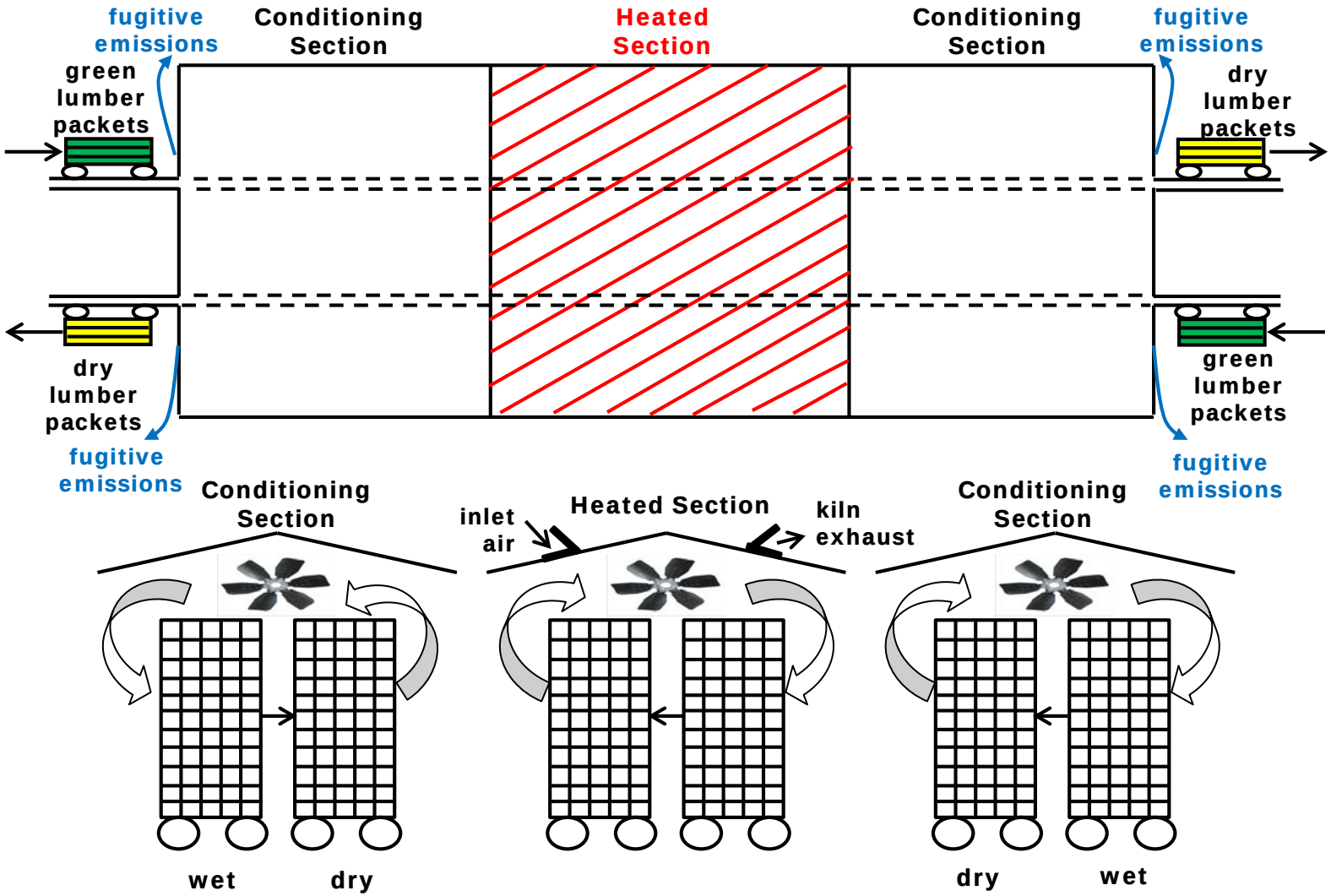
Maderas, Ciencia y tecnologia 11(1): 33-46, 2009


Batch kiln
roof vent

Kiln Testing Challenges

- Primary challenge: Characterization of kiln exhaust flow rate (dscfm)
  - Accurate flow rate characterization needed for calculating mass emission rates; ppmvd not that hard to get
  - Traditional batch kilns have two rows of roof vents
    - Roof vents are NOT fan-driven or "power vented"
    - Instead, kiln's exhaust flow pushed out by the fans within the kiln that move air across the charge
  - Continuous kilns have vents in the heated middle section similar to batch kilns but they also have open ends

Continuous Dry Kiln Schematic



Characterization of Kiln Exhaust Flow Rate (dscfm)

- Batch kiln considerations
  - Multiple roof vents means multiple measurement points
  - Not a traditional emission source with stack and test platform
  - Other considerations
    - All vents are closed at the start of the drying cycle while kiln is warming up
    - Then each row of vents will alternate between venting and intake air based on direction of air flow within the kiln

Characterization of Kiln Exhaust Flow Rate (dscfm)

- Variability of exhaust flow
  - Traditional Batch Kilns: exhaust flow tends to vary during the drying cycle as roof vents control heat and moisture levels
    - Increases the complexity of PM sampling since PM methods require steady-state stack gas conditions
  - Power Vented Batch Kilns: various designs have been attempted with varying degrees of success; all designs tend to have 1 or 2 emission points; flow more controllable and steady-state
    - NCASI TB845 has 18 INDF kiln tests: 6 full-scale kiln and 12 small-scale kiln
  - Continuous Kilns: exhaust flow expected to be more steady state from the vents over the heated mid-section of the kiln; however, characterizing fugitive flow out of kiln ends is a significant challenge

Kiln Testing Challenges

- Fugitive emissions
  - Batch Kilns
    - warm-up periods can take 3 to 4 hours during which steam can be observed leaking through doors, walls, vent seals
    - the impact of fugitive losses on mass emissions can be evaluated by conducting a water balance; the amount of water exhausted at the measurement point(s) versus the amount of water to be extracted from the charge
    - contribution of $PM_{2.5}$ and total HAP mass that is associated with fugitive emissions during warm-up is expected to be minimal due to lumber being below 212˚F

NCASI Miscellaneous Source Survey

- Facilities asked to rate their kilns based on testability
  - Unsuitable, less suitable, very suitable

Type	Responses	Unsuitable	Less Suitable
Batch	174	159	15
Continuous	13	8	5

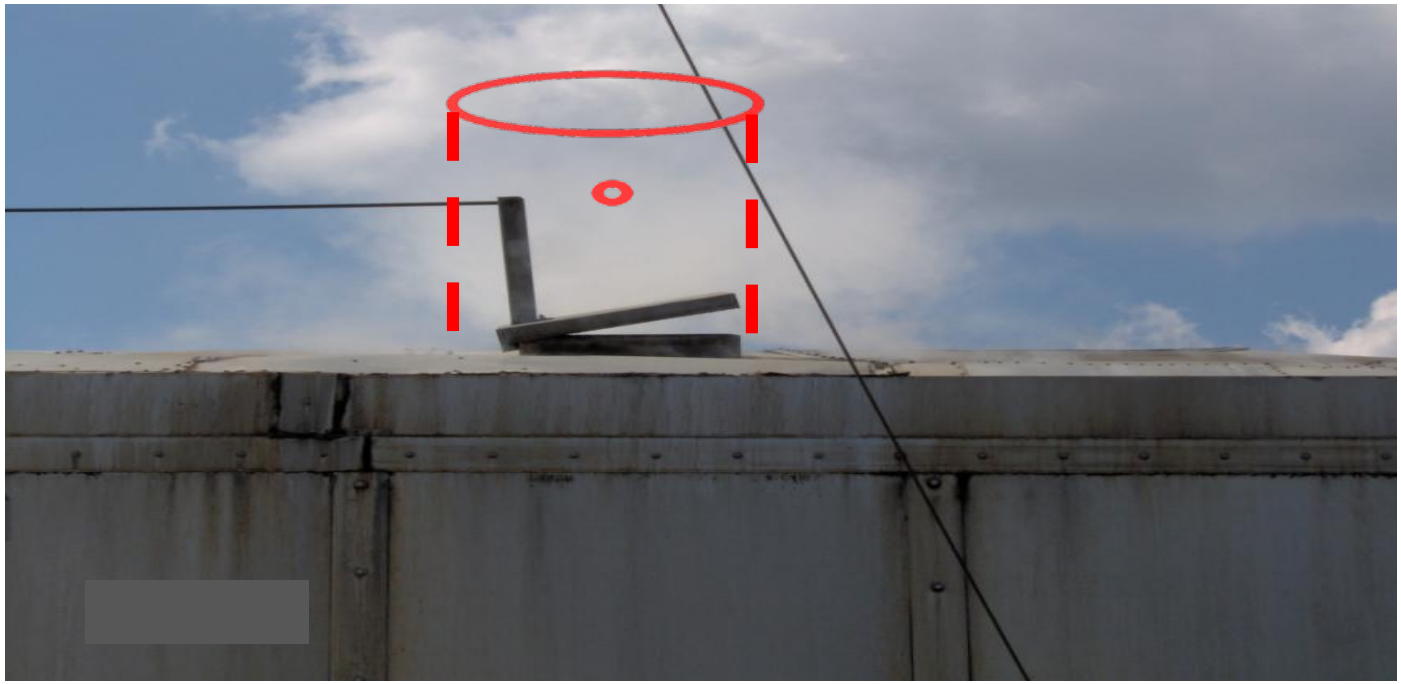
- Majority agree that traditional lumber kilns are unsuitable to test

Kiln Testing Approaches – Past Attempts

- Most testing approaches designed for gaseous emissions testing
- Majority of studies conducted on batch kilns
  - Continuous kilns are relatively new, so fewer testing attempts
- Each approach comes with pros and cons
  - Representative vent
  - Duct to stacks
  - Octopus method
  - “John Deere” method for CDKs
  - Small-Scale kilns

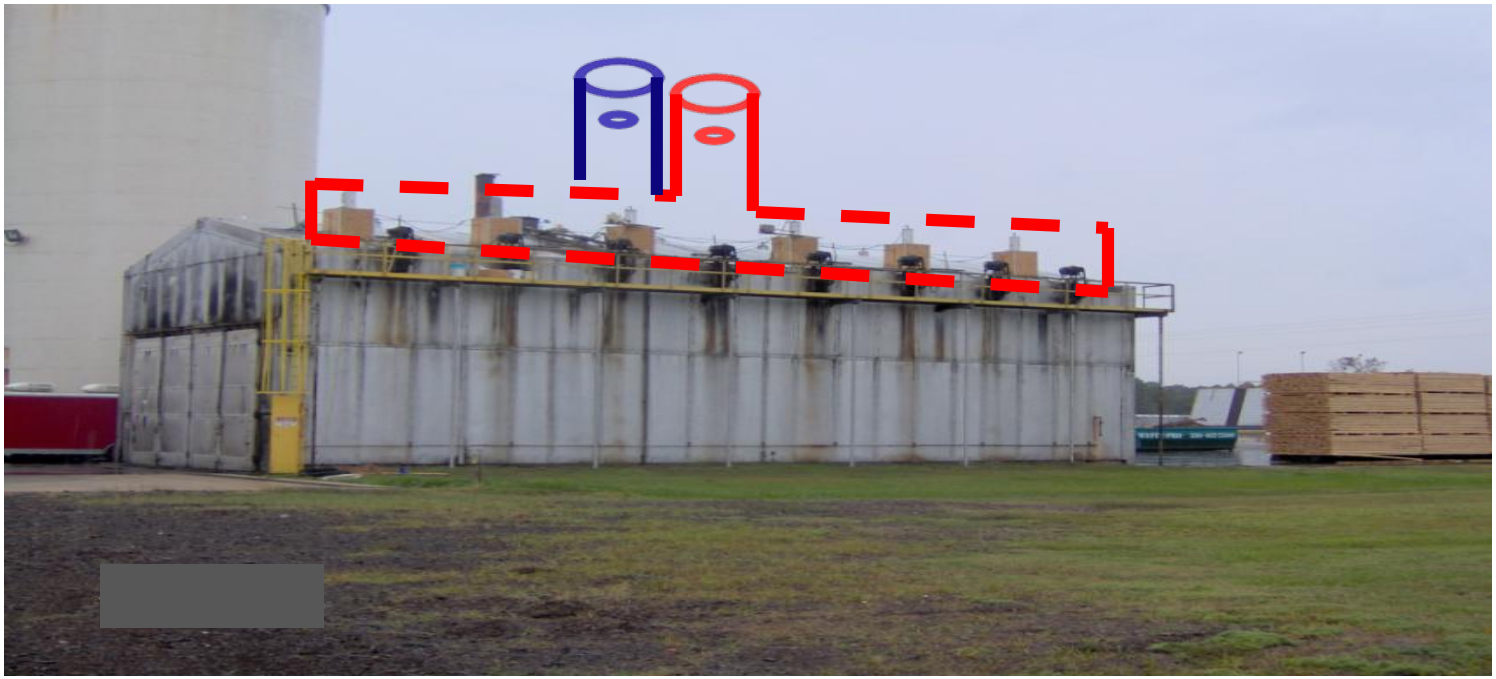
Testing Strategies (and Limitations)
Representative Vent

- Pick one representative vent from each side of kiln
- Construct 2 temporary stacks to test



Testing Strategies (and Limitations)
Ducts to Stacks

- Ductwork collects emissions from all vents on one side and sends to common stack
- Test each stack



Testing Strategies (and Limitations)
Octopus Method

- Central collection point with “arms” (sample lines) reaching every vent
- Temporary boxes with stacks attached to each vent
- Stacks have individual probe and anemometer for flow
- Composite, continuous sample is obtained from each vent row

Testing Strategies (and Limitations)
"John Deere" Method for CDKs

- Large exhaust fan powered by John Deere tractor attached at representative point in side of kiln
- RPMs increased until fugitive exhaust is eliminated
- Flows and concentrations measured at temporary exhaust stack

Testing Strategies (and Limitations)
Small Scale Kilns

- Able to program drying cycle to match indirect- and direct-fired kilns
- Flow and fugitives controlled
  - Forced inlet air eliminates many of the problems associated with flow characterization
- Challenges
  - Obtaining representative sample is difficult
  - Requirement to transport and store sample charges
  - Cannot simulate formaldehyde emissions from direct-fired kilns

2016 NCASI Lumber Kiln Test Effort

- Located an indirect-fired lumber kiln with conventional roof vents that were non-power vented (NPV)
- Total of 8 roof vents, with 4 roof vents on each side; paired vents ducted to a common stack; this kiln had 4 stacks
- No test platform or sample ports
- Due to access challenges, NCASI tested two stacks using multiple manlifts
- Wood species was Southern pine

2016 NCASI Lumber Kiln Test Effort

2016 NCASI Lumber Kiln Test Effort

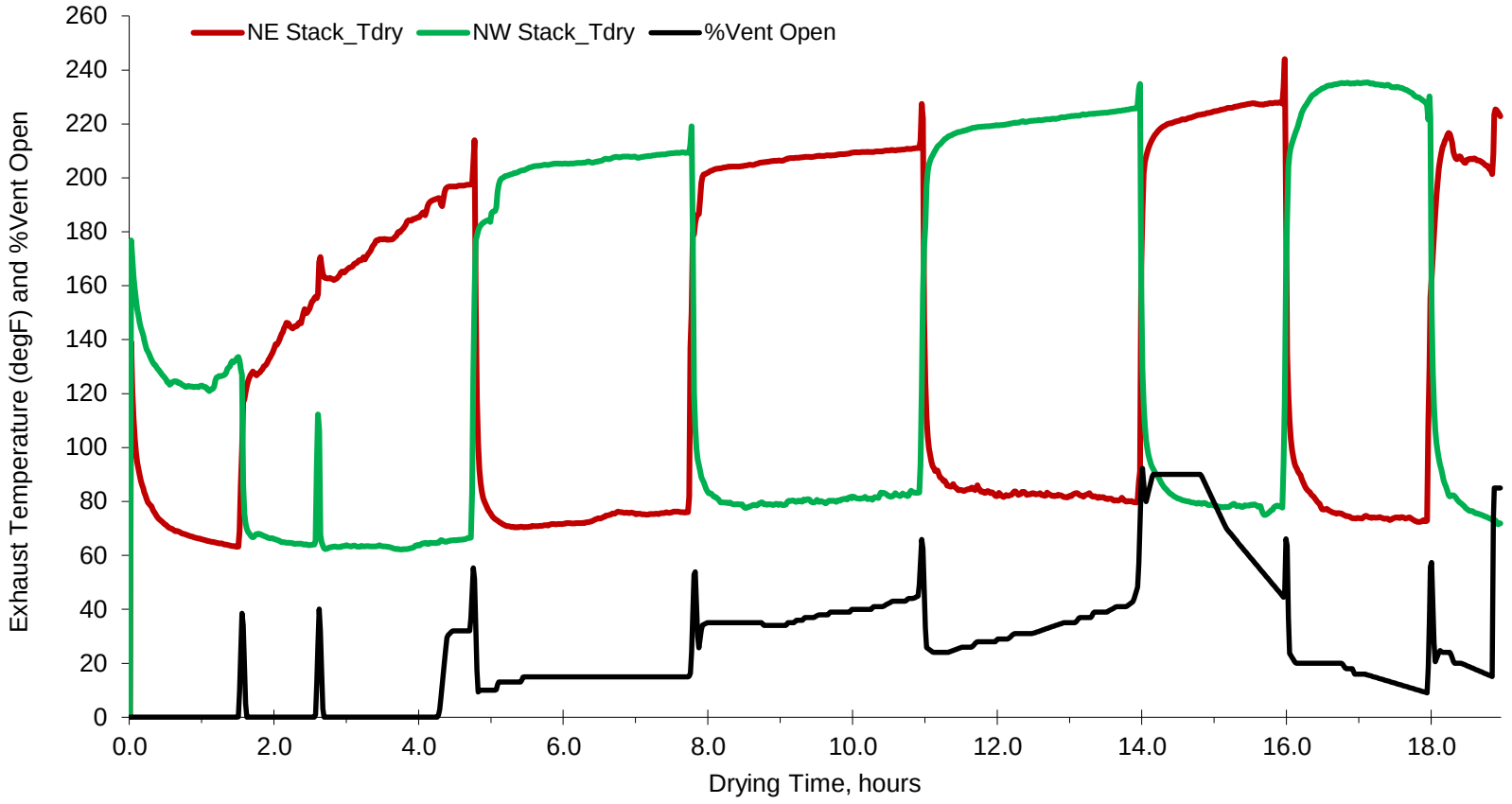
- Targeted parameters
  - Measurement of continuous kiln exhaust flow
  - Direct-$PM_{2.5}$[1] : fill data gap; no historical data; first attempt
  - TGOC[2] and total HAPs[3]: historical data available; included in test effort so that test results could be compared to historical results
    - If favorable comparison is found between the current and historical datasets for TGOC and total HAPs, then direct-$PM_{2.5}$ results representative

1. Direct-$PM_{2.5}$ = filterable $PM_{2.5}$ + CPM; 2. TGOC = Method 25A total gaseous organic carbon; 3. total HAP = acetaldehyde, acrolein, formaldehyde, methanol, and phenol

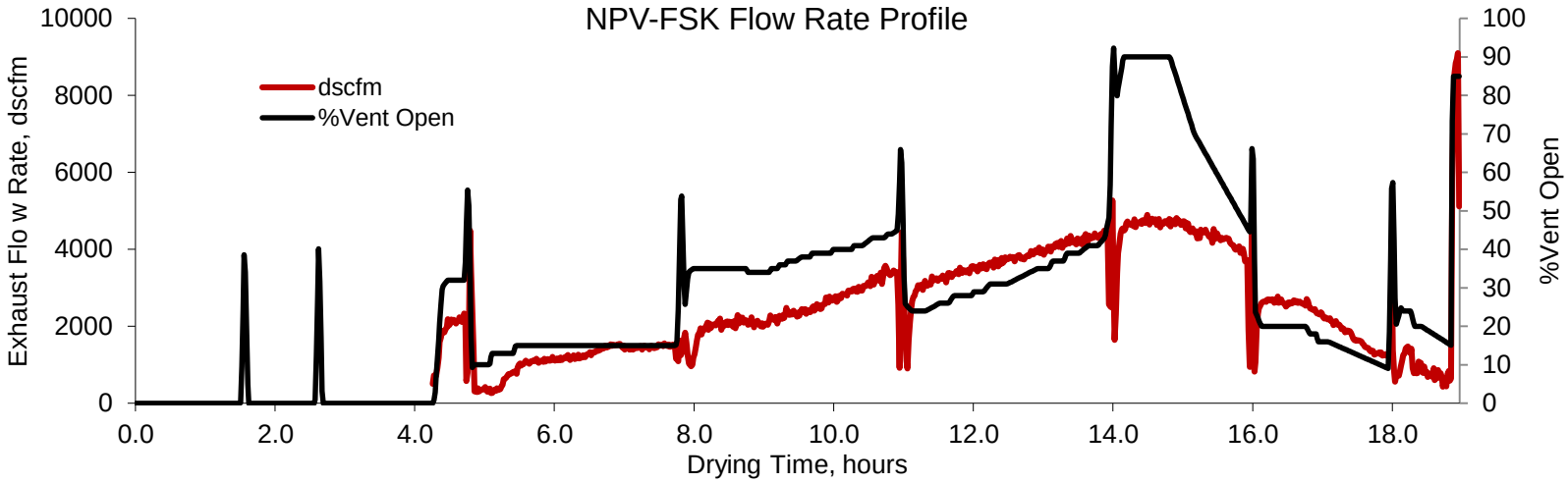
2016 NCASI Lumber Kiln Test Effort

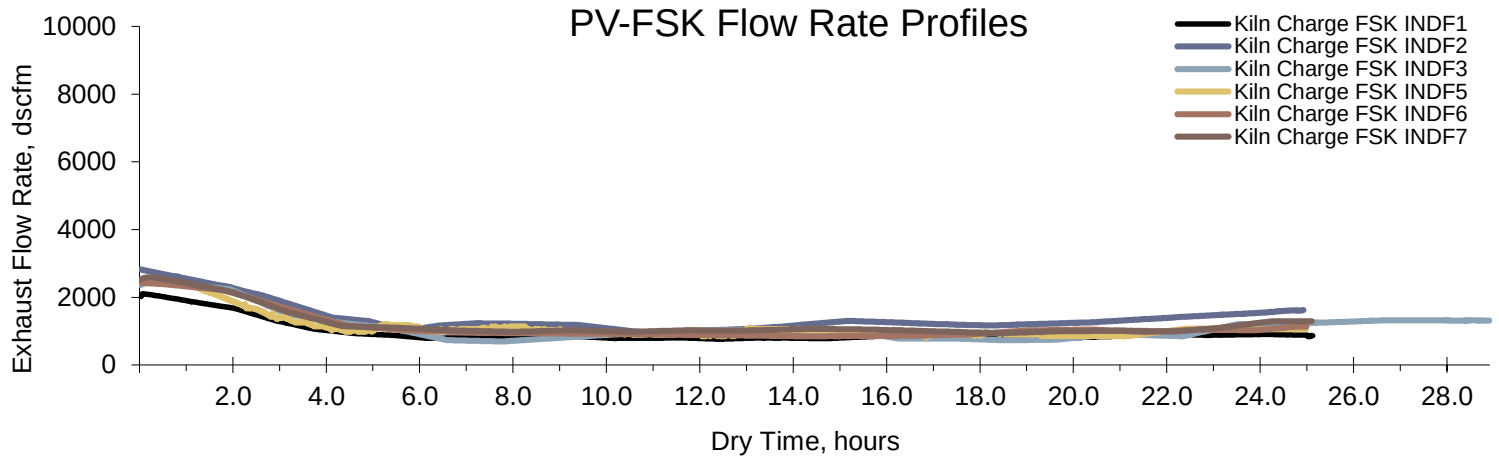
- Flow rate determined by a continuous flow measurement system (CFMS)
  - Manual input data
    - $\%O_2/\%CO_2$, stack diameter, and Pitot tube coefficient (Cp)
  - Automated input data
    - Relative humidity, stack dry bulb temperature, delta-P readings, and ambient and static pressures
  - Data acquisition program to log the flow parameters
  - Software program to calculate continuous flow

Example of CFMS data: Stack Dry Bulb Temperature vs %Vent Open (recent NCASI lumber kiln test effort)



Comparison of Stack Exhaust Flow Rate Profiles for the NPV-FSK[1] and PV-FSK[2] tests





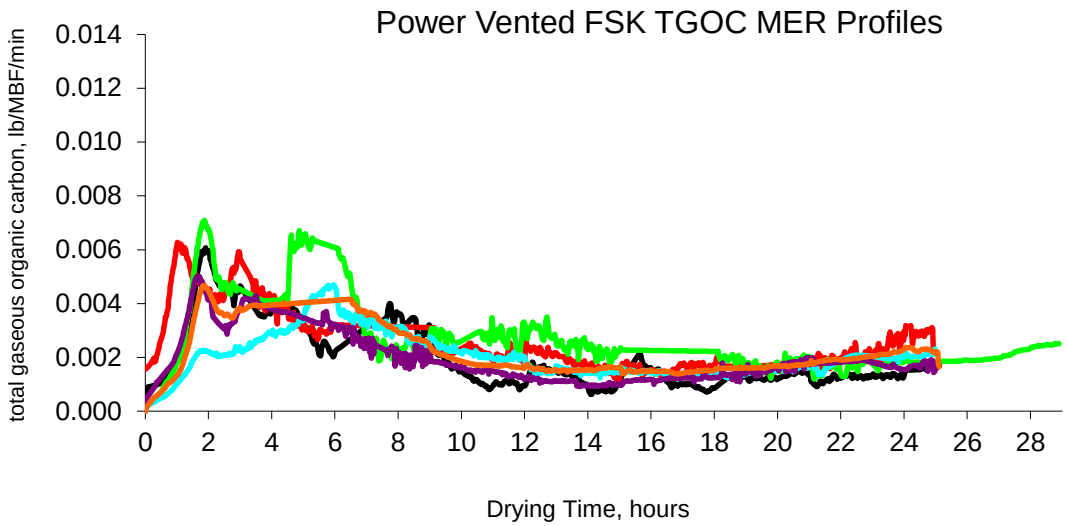
1. NPV-FSK = non-power vented full-scale lumber kiln NCASI test 2016; 2. PV-FSK = power vented full-scale lumber kiln NCASI TB845

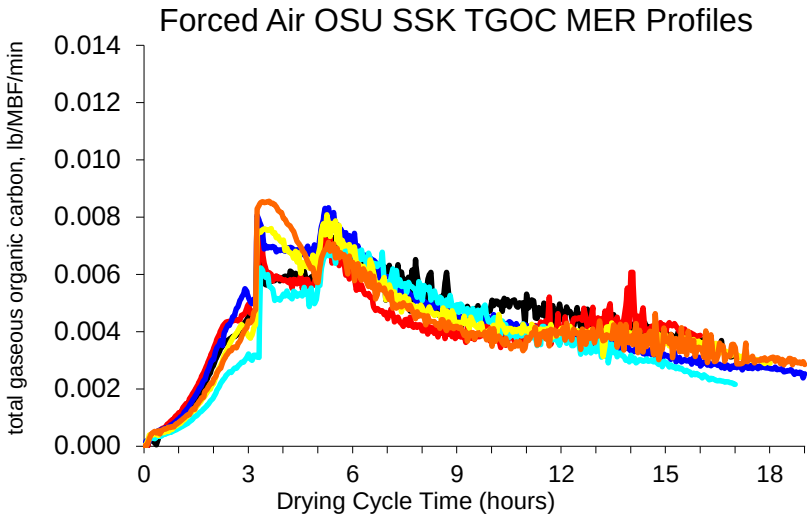
2016 NCASI Lumber Kiln Test Effort

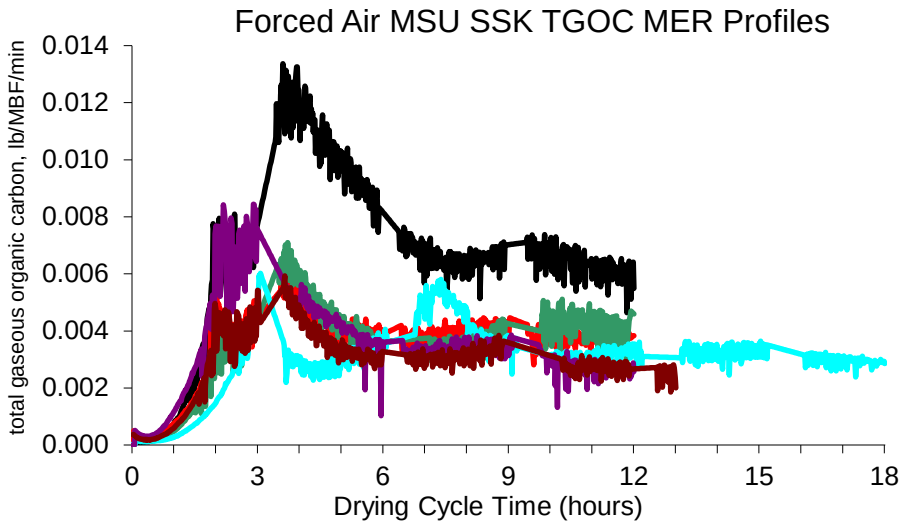
- Pollutants
  - Total gaseous organic carbon (TGOC) via Method 25A
  - Total HAPs via the BHA Method
  - Filterable $PM_{2.5}$ via modified Method 201A
    - Heated in-stack cyclone
    - Out of stack $PM_{2.5}$ filter
    - Single cyclone and filter for entire kiln cycle
  - Condensable PM vis Method 202
    - Changed out after each fan reversal

Historical TGOC MER Profiles for FSK & SSK

(indirect-fired lumber kiln tests for Southern pine; data from NCASI TB 845)

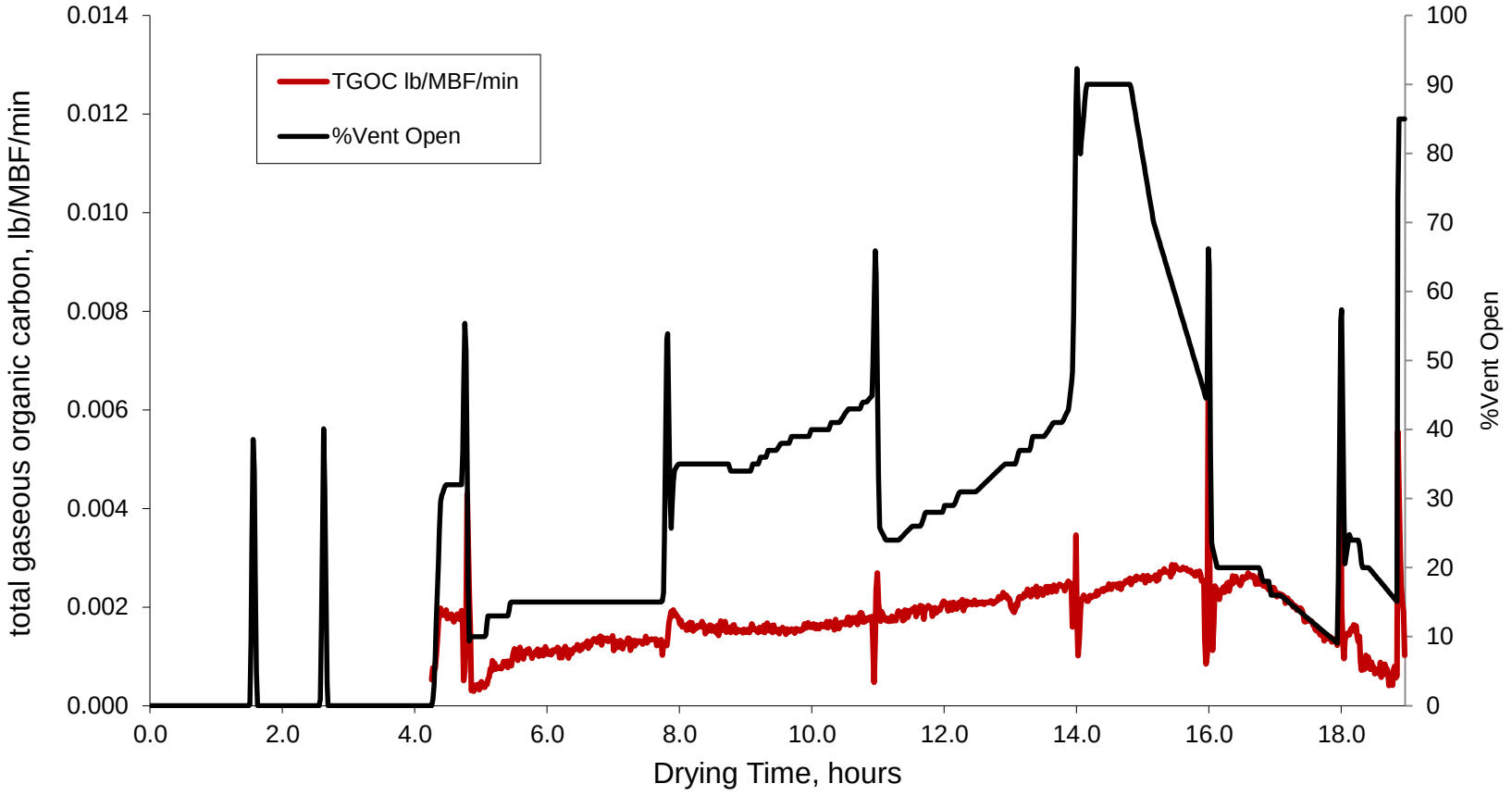






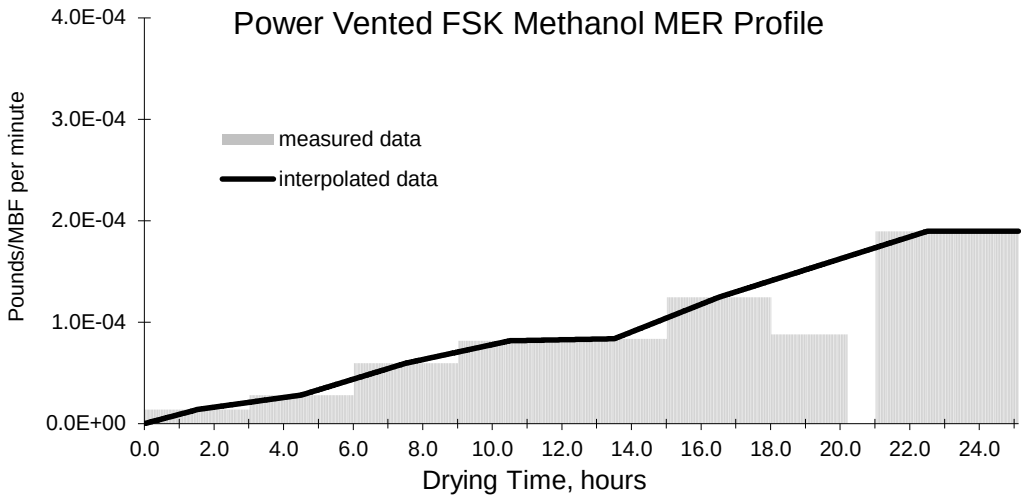
TGOC MER = total gaseous organic carbon mass emission rate; FSK = full-scale lumber kiln; SSK = small-scale lumber kiln; MBF = 1000 board feet

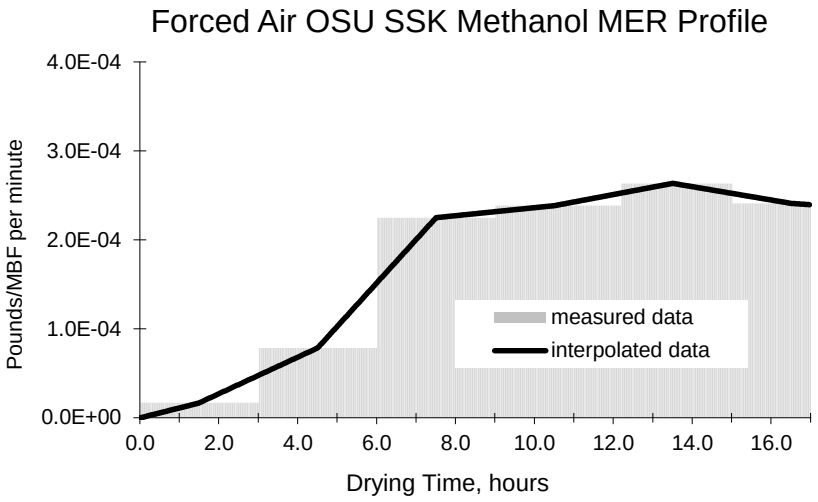
TGOC MER Profile for the 2016 NPV-FSK NCASI Test Effort[1]

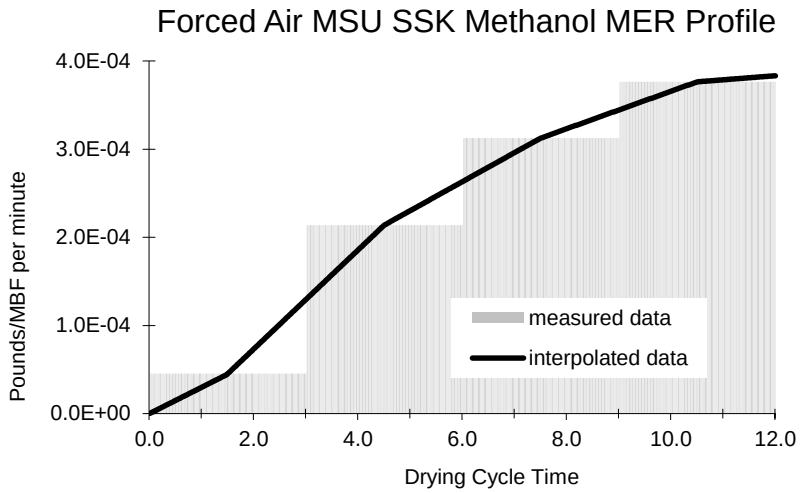


1. TGOC MER = total gaseous organic carbon mass emission rate; NPV-FSK = non-power vented full-scale lumber kiln; MBF = 1000 board feet

Methanol MER Profiles for the PV-FSK & FA-SSKs (indirect-fired lumber kiln tests for Southern pine; data from NCASI TB 845)

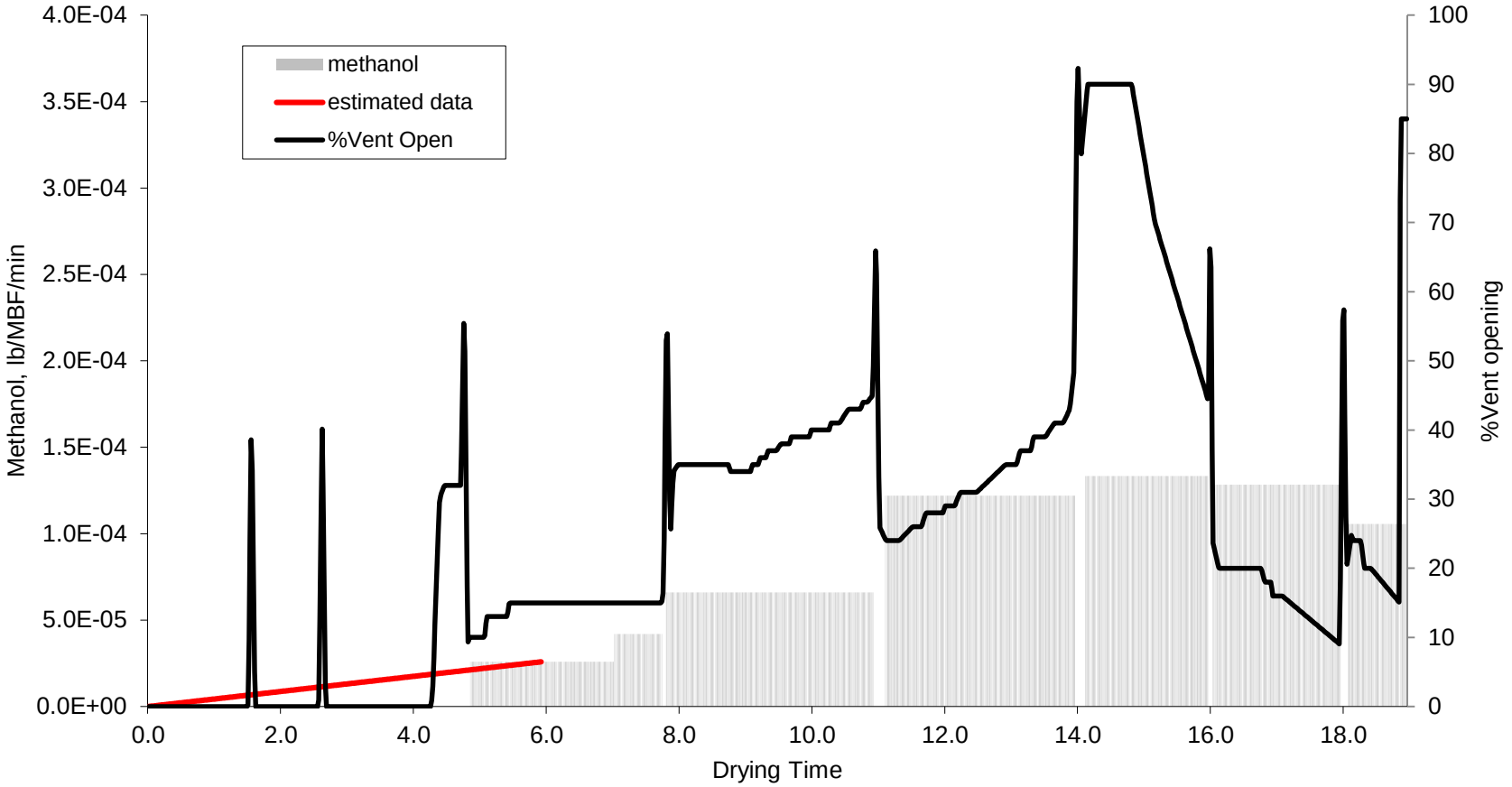






PV-FSK = power vented full-scale lumber kiln; FA-SSK = forced air small-scale lumber kiln; MBF = 1000 board feet

Methanol MER Profile for the 2016 NPV-FSK NCASI Test Effort



MER = mass emission rate; NPV-FSK = non-power vented full-scale lumber kiln; MBF = 1000 board feet

Summary of Continuous Profile Data for Power Vented, Forced Air, and Non-Power Vented Kilns

- Exhaust flow rate profiles different for power vented and non-power vented kilns
- TGOC MER profiles for non-power vented kiln different than power vented and forced air kilns
- Methanol MER profiles similar for all three kiln types

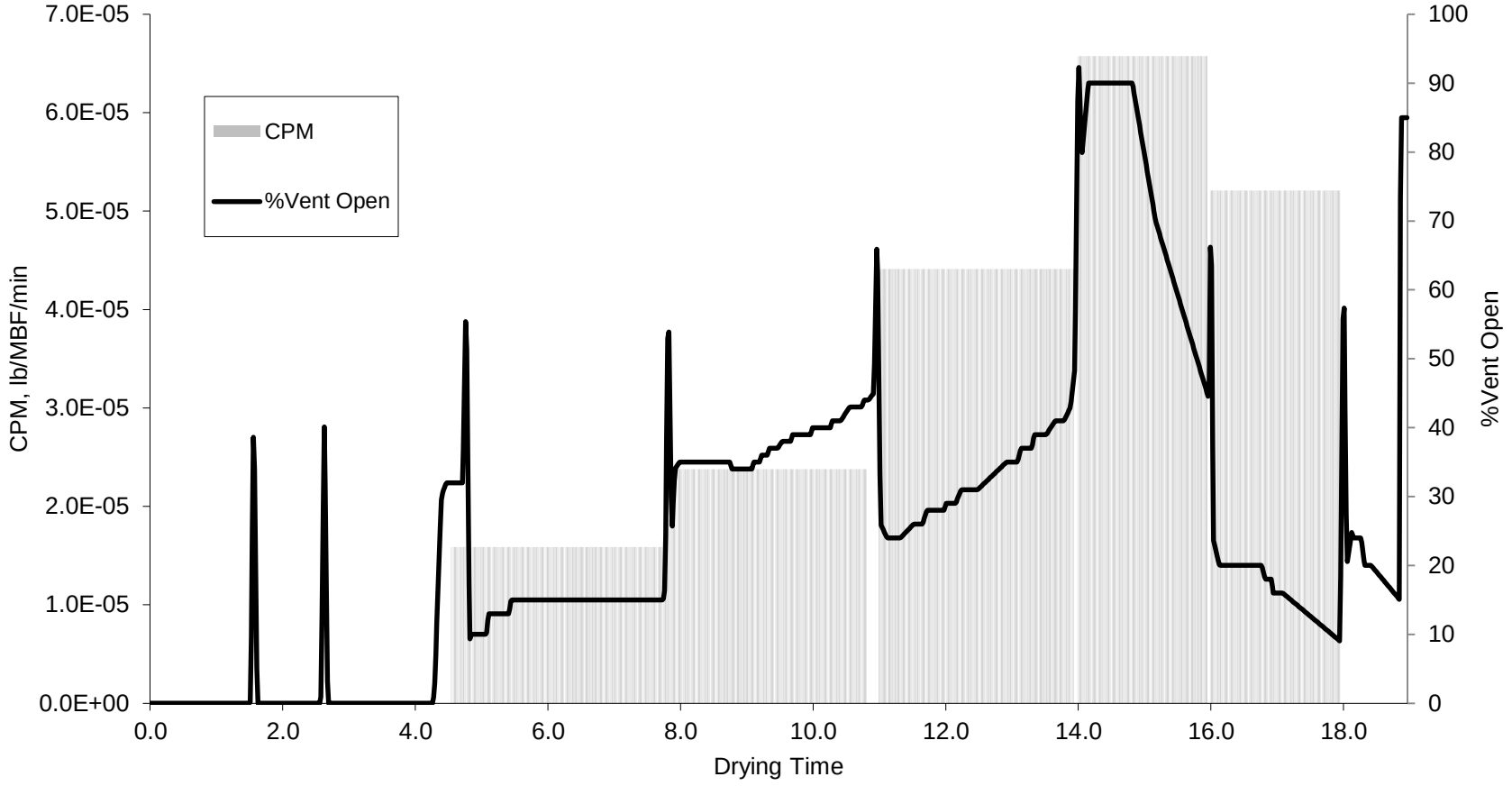
Summary of Mass Emission Rate data

- While there are some differences in the profile data, the overall TGOC and total HAP MERs were found to be in agreement with historical data
- Thus, the $PM_{2.5}$ data should be representative

Reported MBF	135.17	lb/MBF from 4 Stacks		NCASI Database Values for lb/MBF	
Filterable PM (Method 201A)		0.0028			
Filterable PM2.5 (Method 201A)		0.0024	4%		
Total Condensable PM (Method 202)		0.0583	96%		
Direct PM2.5		0.0606			
				Full-scale kiln	Small-scale kiln
Method 25A total gaseous organic carbon		3.13		3.38	3.20
acetaldehyde		0.016		0.042	0.052
acrolein		0.0033		0.0060	0.0037
formaldehyde		0.011		0.015	0.012
methanol		0.15		0.19	0.13
phenol		ND		0.010[1]	0.013[1]
propionaldehyde		0.0011		0.0029	0.0016

1. NCASI database shows phenol as a detect for FSKs and SSKs which appears to be an error; values show appear to be the detection level and, therefore, the database should indicate non-detect.

CPM MER Profile for the 2016 NPV-FSK NCASI Test Effort



Impact of Fugitive Emissions on the NCASI 2016 NPV-FSK MER Data

- Water balance can be used to estimate the impact from fugitive emissions
  - 1) Estimated parameters
    - Wood density = 2.1 lb/BF for Southern pine
    - Kiln condensate loss = 15% of total water extracted
    - Ending moisture content of charge = 15%-dry
    - Starting moisture content of charge = 100%/90%-dry for lumber harvested in the spring
  - 2) Calculated parameters
    - Oven-dry weight of entire lumber charge, amount of water extracted from the lumber charge, and amount water loss to kiln condensate
    - Amount of water exhausted from stacks

Impact of Fugitive Emissions on the NCASI 2016 NPV-FSK MER Data

- Results from water balance indicate fugitives had minimal impact

		BF	lb wood/BF	lb wood	kiln condensate estimate
		135,168	2.1	283,853	15%

dry std cubic feet exhausted	wet std cubic feet exhausted	cubic feet of water vapor	lb water exhausted from 2 stacks	lb water exhausted from 4 stacks	**%of water exiting the stacks**
2,262,046	4,214,208	1,959,364	98,159	196,318	

		lb water	
If starting MC-%dry =	100%	283,853	
ending MC %dry =	15%	42,578	
amount of water expected to be extracted from the kiln charge ==>		241,275	
remaining water after deduction for kiln condensate est. at 15% of total water ==>		205,084	96%
If starting MC-%dry =	90%	255,468	
ending MC %dry =	15%	42,578	
amount of water expected to be extracted from the kiln charge ==>		212,890	
remaining water after deduction for kiln condensate est. at 15% of total water ==>		180,956	108%
If starting MC-%dry =	80%	227,082	
ending MC %dry =	15%	42,578	
amount of water expected to be extracted from the kiln charge ==>		184,504	
remaining water after deduction for kiln condensate est. at 15% of total water ==>		156,829	125%

Summary

- Lumber kilns (batch and continuous) present significant testing challenges
- Intent of the 2016 NCASI lumber kiln test effort was fill the data gap for a direct-$PM_{2.5}$ emission factor
- Water balance estimate indicates fugitive emissions had minimal impact on MERs
- Continuous flow and TGOC MER profiles appear to be different for PV vs NPV kilns while continuous HAP MER profiles appear to be similar
- The co-sampled data for TGOC and total HAP indicate that the direct-$PM_{2.5}$ results should be representative of drying Southern pine lumber in an indirectly heated lumber kiln

QUESTIONS?