



Evaluation of Methods to Reduce Exhaust Penetration into School Buses

Dennis R. Fitz, David V. Pankratz

College of Engineering-Center for Environmental Research and Technology
University of California, Riverside

Kathleen Kozawa, Eduardo Behrentz, and Arthur M. Winer

Department of Environmental Health Sciences
School of Public Health, University of California, Los Angeles

Scott A. Fruin

California Air Resources Board (presently University of Southern California)

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Introduction

- Children are especially susceptible to air pollutants
- Many children spend significant time commuting in diesel-powered school buses in California
- Diesel exhaust has been designated a toxic air contaminant by the ARB
- Exposure due to exhaust from self-pollution or from following another diesel-powered vehicle has been shown to be significant
- While 2007 and future diesel engines have reduced emissions, many older buses are still in use



Overall Objective

Develop and evaluate methods to minimize exposure to diesel exhaust while commuting on school buses



Approach

- Identify mitigation methods
- Evaluate effectiveness of mitigation methods using tracer gases in the exhaust while
 - Stationary
 - On a test route



Mitigation Methods Evaluated

- Identify and repair exhaust leaks
- Measure and lower the bus air leak rate
- Raise the exhaust release point
- Power ventilate the bus
- Combine the last two methods



Exhaust Leak Identification

- Tracer Method
 - Added dimethyl sulfide to fuel
 - Probed exhaust manifolds and pipes with the inlet of a flame photometric real-time total sulfur analyzer
 - “Calibrated” by monitoring near an “artificial leak” created by flowing gas at expected exhaust SO₂ concentration
 - One bus sampled
- Back Pressure Method
 - Placed stopper with orifice into exhaust pipe
 - Measured pressure before and after orifice
 - Seventeen buses sampled

Probing for Leaks with Sulfur Tracer





Sulfur Tracer Probing Results (1 bus)

- Three leaks found in the 50ml/min range
- Less than 0.01% of the exhaust
- Insignificant

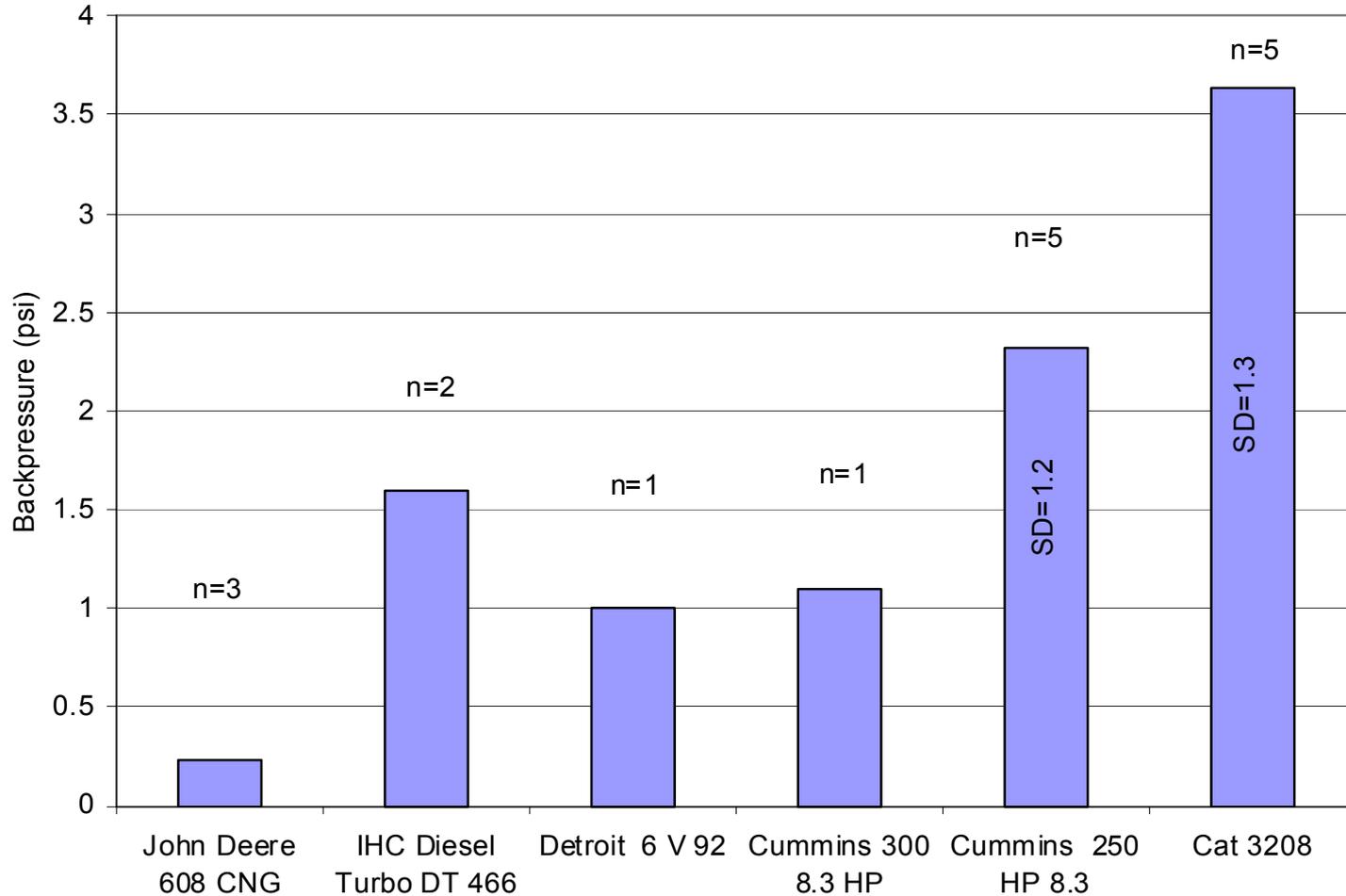


Back Pressure Leak Detection





Back Pressure Leak Detection





Measurement of Bus Cabin Leak Rate

- “Blower door” method
 - Used extensively for buildings
 - Pressurize with a blower of known flow rate (1200 cfm)
 - Measure pressure drop between inside and outside
- Seventeen buses sampled

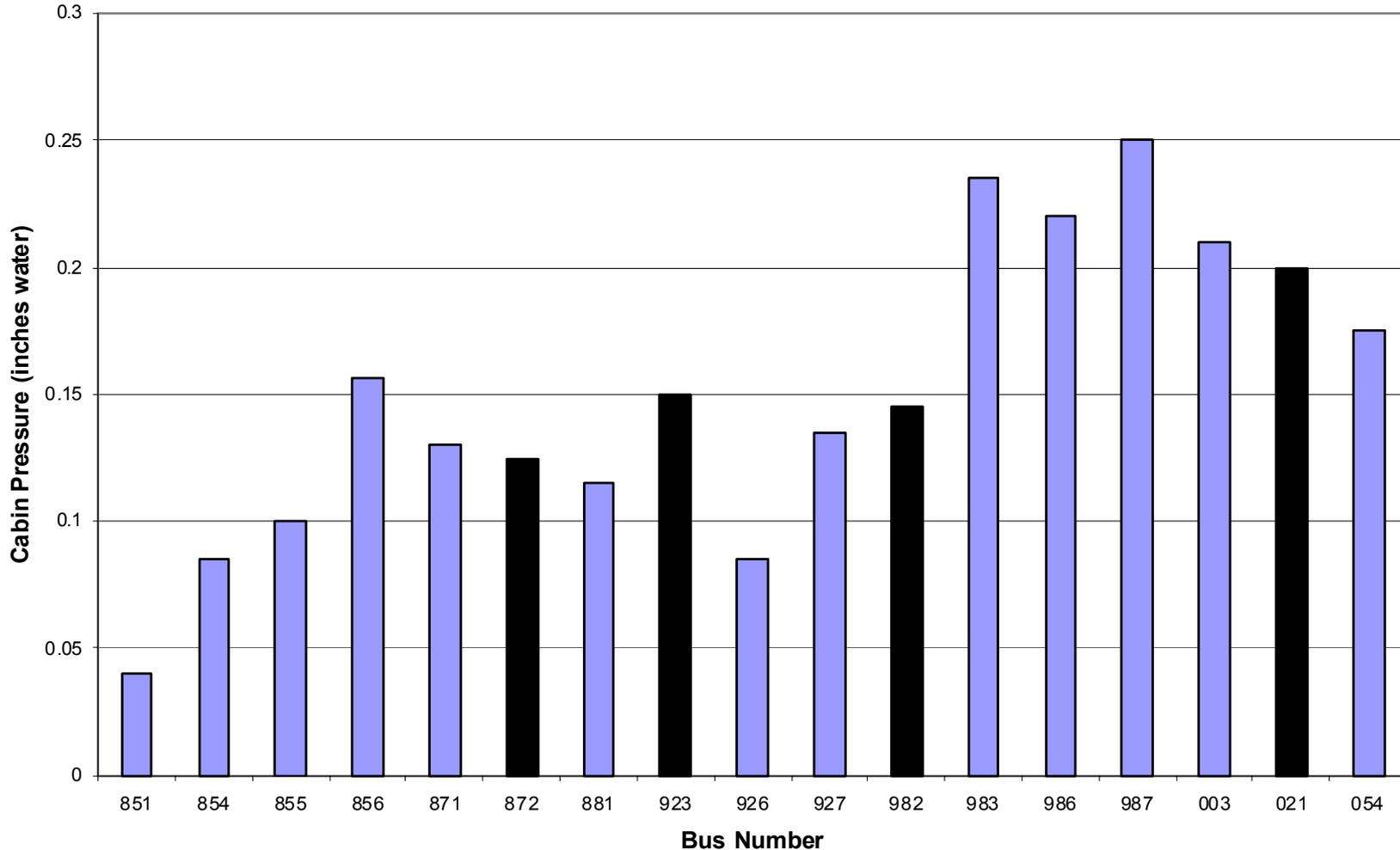


Blower Door Method



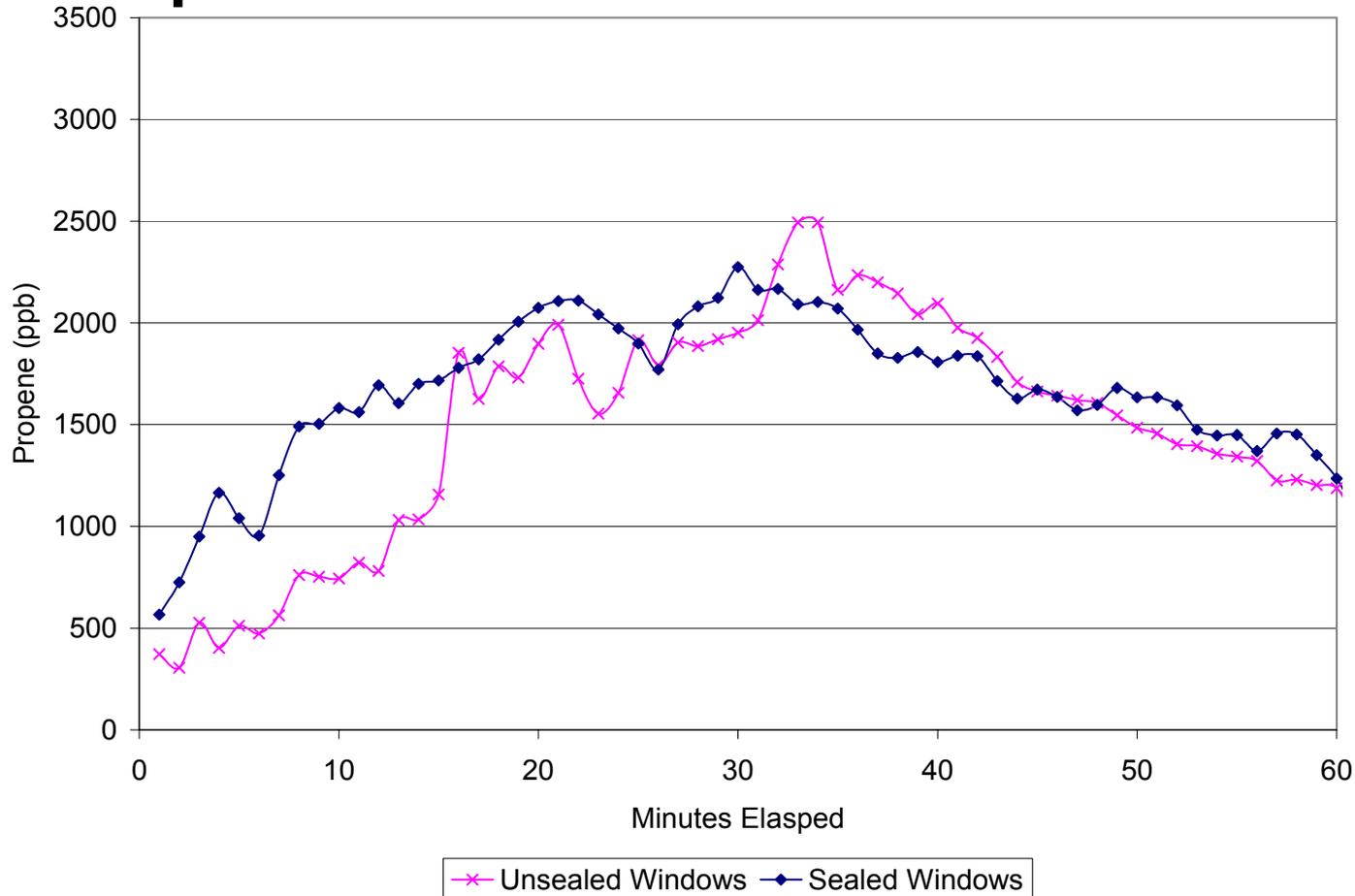


Blower Door Results





Window Sealing Evaluation using Propene Exhaust Tracer Gas





Raised Exhaust Evaluation

- Four representative buses used
- Tracer gases (SF_6 and propene) at each height
 - Propene measured by photoionization
 - SF_6 measured by electron capture
- Tracer flow rate was controlled by a data logger to maintain constant concentration with engine speed
- Four operational modes
 - Stationary self-pollution
 - Stationary leader-pollution (tracers released from leader)
 - Mobile self-pollution
 - Mobile leader-pollution (tracers released from leader)

Raised Exhaust



Original exhaust pipe location

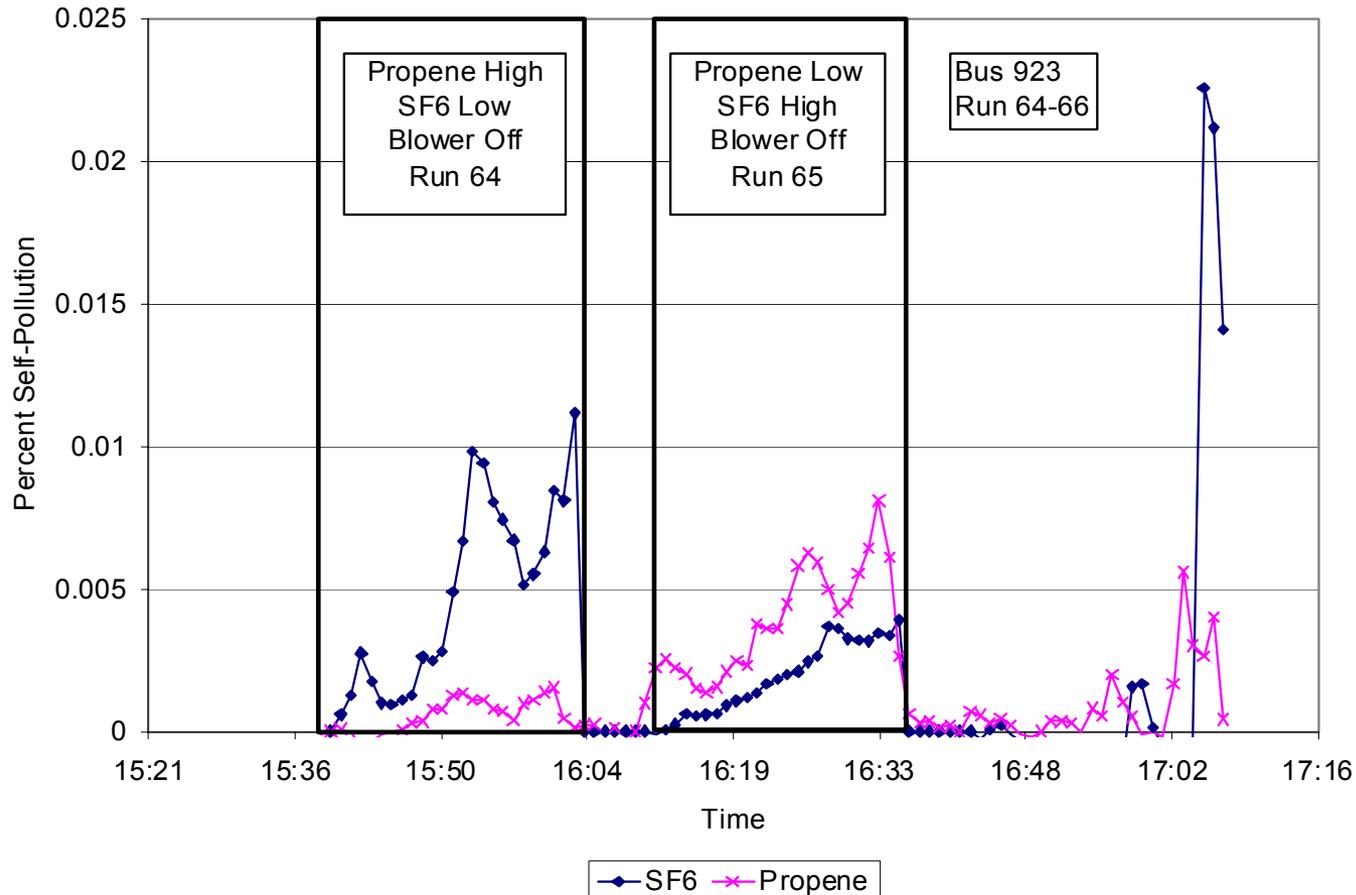


Tracer Study Data Analysis

- Calculated the percentage of air in the cabin that can be attributed to the exhaust as the ratio of tracer concentration in the cabin to tracer concentration in the exhaust (i.e. percent “self-pollution” or percent “leader intrusion”)

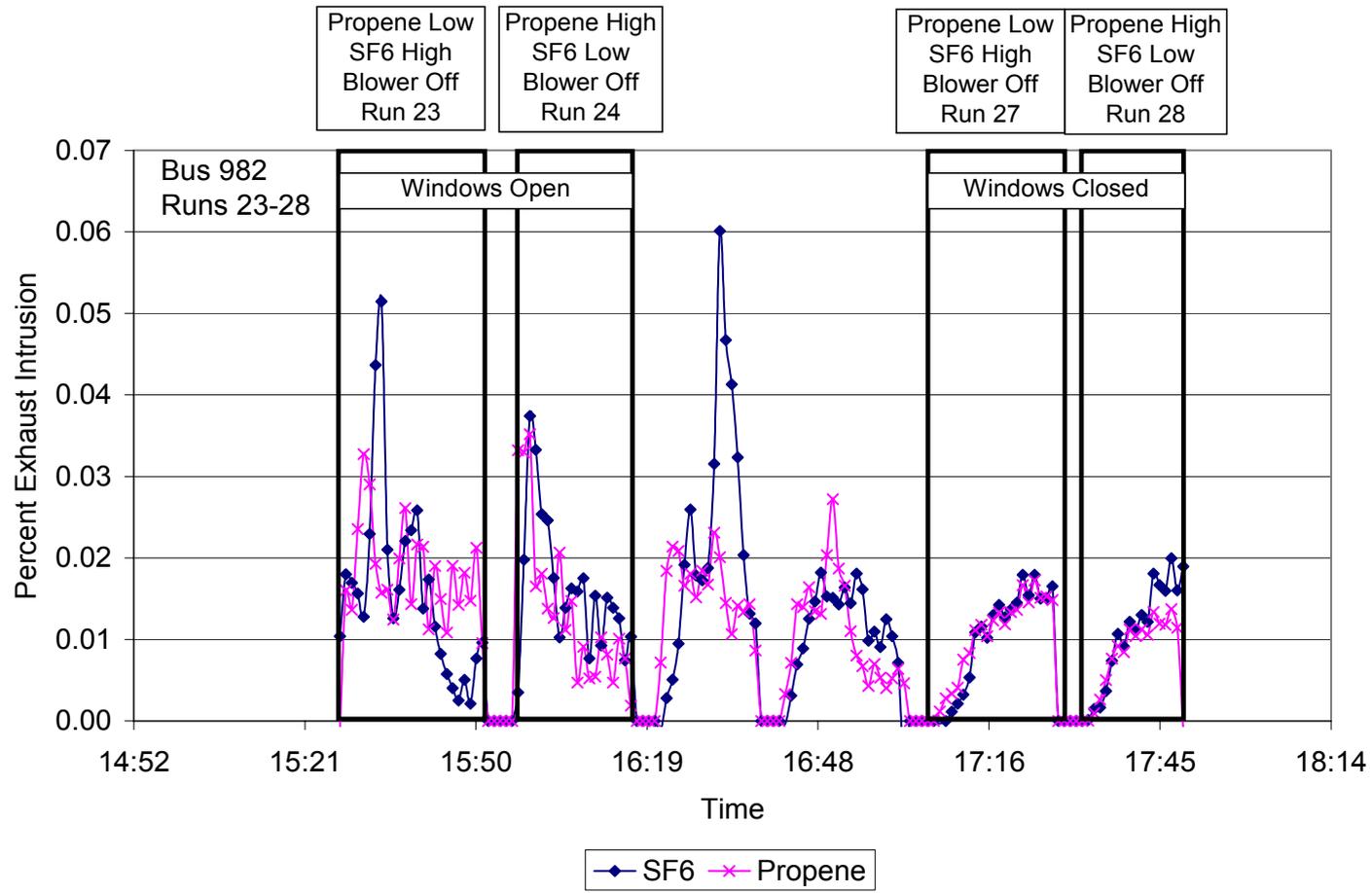


High/Low Exhaust Typical Results: Mobile Self-Pollution





High/Low Exhaust Typical Results: Mobile Leader-Pollution





Powered Ventilation

- Constant speed blower used inside the bus at 1200 cfm
- Air inlet at top of bus or at window
- Air outlet near the rear of the bus
- Four modes of operation (windows closed)
 - Stationary self-pollution high/low exhaust
 - Mobile self-pollution high/low exhaust
 - Stationary leader-pollution high/low exhaust
 - Mobile leader-pollution high/low exhaust

Powered Ventilation

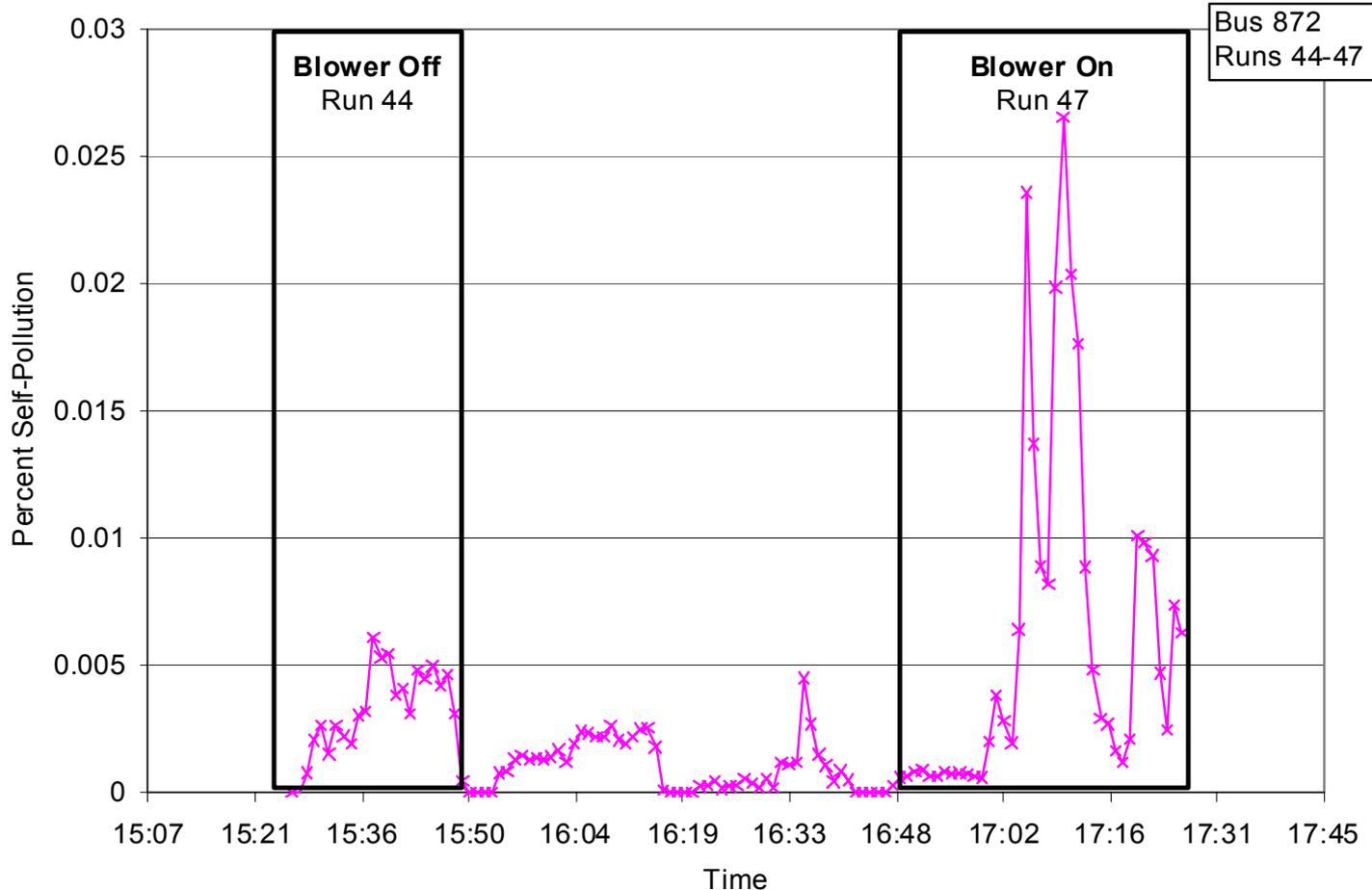


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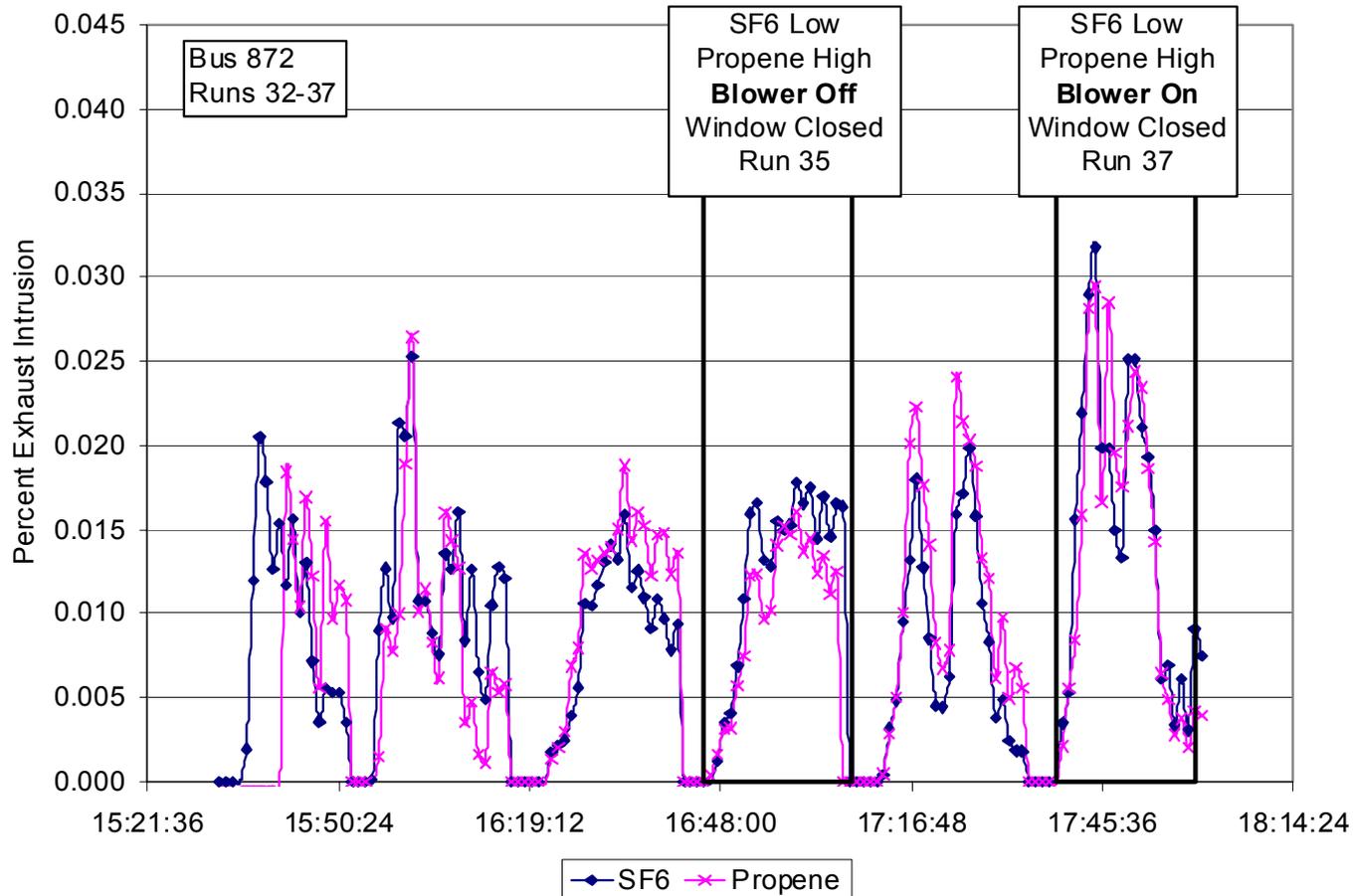


Powered Ventilation Typical Results: Mobile Self-Pollution





Powered Ventilation Typical Results: Mobile Leader-Pollution





Summary Results of Combined High-Low Exhaust and Powered Ventilation

MITIGATION METHOD	Exhaust High vs. Low	Blower On vs. Off	
	Blower Off	Exhaust Low	Exhaust High
RUN TYPE			
Self-Pollution, Mobile	++/-	++	+/--
Self-Pollution, Stationary	++/-	+/--	+/--
Leader-Follower, Mobile	+	+/-	-
Leader-Follower, Stationary	++	+/--	--



Conclusions

- Exhaust system leaks are minimal in a well-maintained bus
- Bus cabin leak rates varied significantly, but it was not clear that reducing leaks would significantly reduce exposure to exhaust
- Power ventilation reduced exposure in some cases but increased it in others
- Raising the exhaust was the most effective mitigation method
- Leader-pollution was approximately twice self-pollution



Acknowledgements

- California Air Resources Board
- Hemet Unified School District
- UCR Transportation Services



For More Information

- Final report to the California Air Resources Board: arb.ca.gov/research/apr/past/03-343.pdf