4731 (RP-1191)

# Overview of Existing Guidance and Ventilation Approaches for Control of Diesel Exhaust Inside Locomotive Facilities

**Chadwick C. Rasmussen**

**Amy Musser, Ph.D., P.E.**
*Associate Member ASHRAE*

**Kimberly Bunz**
*Student Member ASHRAE*

**Matthew Radik**
*Student Member ASHRAE*

## ABSTRACT

*This paper provides an overview of existing guidance, regulations, and design approaches to control diesel exhaust from locomotives operating in buildings. First, design guidance and standards for exposure to major components of diesel exhaust are reviewed. Next, issues regarding engine design, fuel composition, and outdoor emissions control strategies and their potential impact on current and future indoor emissions are discussed. Ventilation approaches that have been implemented in existing facilities are also presented. The review highlights both approaches and information that will be useful to designers planning or retrofitting this type of facility.*

## INTRODUCTION

The design of ventilation systems for buildings in which locomotives operate requires consideration of contaminant sources that are not easily defined and contaminant targets that are continuously updated. Design approaches have been developed, but no studies targeted specifically to ventilation systems have been performed to measure their success or to provide research-based guidelines for their implementation.

The purpose of this review was to investigate the technical literature and talk with practitioners to identify current issues, problems, and approaches to ventilating these types of buildings. The flow and heat removal conditions for tunnels present different challenges and are not addressed by this review. First, the review seeks to define the design problem by identifying contaminants for which exposure limits are recommended and those that may be monitored in the near future. Next, the vast amount of published information on engine performance and emissions is reviewed to identify data relevant to the indoor design problem. Possible future developments in fuel characteristics and engine design are also identified and discussed in the context of impact on low load, cold start, and indoor operation. Finally, some design approaches are discussed, with information on what is effective and areas in which new technology may be helpful.

## DESIGN CRITERIA

### Current Design Guidance

Several sources provide design and operations guidance relevant to ventilation of railroad facilities. The ventilation rate procedure of *ASHRAE Standard 62-1999, Ventilation for Acceptable Indoor Air Quality*, specifies 1.5 cfm/ft$^2$ (7.5 l/s per m$^2$) to maintain acceptable indoor air quality in auto repair rooms, which is the closest listed occupancy (ASHRAE 1999a). This limit is based in large part on carbon monoxide present in auto repair facilities, not the different mix of contaminants present in diesel locomotive facilities. Also, locomotive facilities tend to have high ceilings and larger volumes, so the *2003 ASHRAE Handbook—Applications* recommends that a volumetric model instead be used to calculate the design ventilation rate (ASHRAE 2003). Both the *2003 ASHRAE Handbook—Applications* and the American Railway Engineering and Maintenance-of-Way Association's (AREMA) *Manual for Railway Engineering* currently suggest 6 air changes per hour when dilution ventilation is used (AREMA 2001). The authors know of no cases in which this guideline has failed to produce compliance with the current contaminant limits, although tightening of these limits may require this guideline to be revisited in the future.

The American Conference of Governmental and Industrial Hygienists suggests a source-based method of sizing

---

**Chad Rasmussen** is a Ph.D. candidate in aerospace engineering at the University of Michigan, Ann Arbor, Mich. **Amy Musser** is an assistant professor, **Kim Bunz** is a candidate for an MAE, and **Matt Radik** is an undergraduate student in the Department of Architectural Engineering, University of Nebraska, Lincoln, Neb.

ventilation systems for facilities where diesel engines are in operation. They recommend 100 cfm (47 l/s) per operating horsepower of the engine (NJDHSS 1994). A locomotive engine idling with no head end power (HEP) operates at less than 100 hp (75 kW) and the ventilation system would be sized for 10,000 cfm (4720 l/s) based on this guideline. However, the ventilation system designer must also check this against the requirements for heat removal when sizing a system. Most design references also suggest the use of localized exhaust to reduce energy use.

## Standards for Exposure

The Occupational Safety and Health Administration (OSHA 2001a) sets legally enforceable exposure limits for workplace contaminants in the U.S. Most states follow these federal limits, but a few states may set more restrictive requirements. The OSHA standards specify maximum contaminant concentrations called permissible exposure limits (PEL) that are allowed in the workplace. When determining its standards, OSHA takes into consideration the table of threshold limit values (TLV) for chemical substances and physical agents published by the American Conference of Governmental Industrial Hygienists (ACGIH). The TLVs provided by the ACGIH are recommendations or guideline values for use in industrial hygiene and are not legally enforceable. Also in the U.S., the National Institute for Occupational Safety and Health is the federal agency responsible for conducting research on potential workplace hazards and publishes recommended exposure levels (REL) based on this research. Finally, the Mine Safety and Health Administration (MSHA) also publishes legally enforceable limits that apply only to workers in the mining industry.

A PEL can be given as a time-weighted average (TWA), short-term exposure limit (STEL), or a ceiling value. The TWA is a time-weighted average of the varying concentrations of a contaminant in an eight-hour workday, which cannot be exceeded during the work shift. The STEL value is usually a 15-minute time-weighted average, and a ceiling value is a maximum limit that cannot be exceeded at any time (Lewis 1996).

OSHA does not currently regulate diesel exhaust specifically, although many substances found in diesel exhaust are regulated. OSHA (OSHA 2001b) identifies carbon dioxide ($CO_2$), carbon monoxide (CO), nitrogen dioxide ($NO_2$), nitric oxide (NO), diesel particulate matter (DPM), and sulfur dioxide ($SO_2$) as major components of diesel exhaust. Thirty-one additional substances are identified as minor components, with seventeen of these being polycyclic aromatic hydrocarbons (PAH). These minor components are elements of DPM.

Countries outside the U.S. legislate their own contaminant limits, though these may draw heavily from the ACGIH and other U.S. publications. Table 1 compares various

**Table 1. Contaminant Exposure Limits for Major Diesel Exhaust Components**

| Entity | $NO_2$ (ppm) | | | NO (ppm) | | CO (ppm) | | | $SO_2$ (ppm) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 8 h | 15 min | ceil | 8 h | 15 min | 8 h | 15 min | ceil | 8 h | 15 min |
| OSHA – USA (PEL) | | | 5 | 25 | | 50 | | | 5 | |
| ACGIH – USA (TLV) | 3 | 5 | | 25 | | 25 | | | 2 | 5 |
| NIOSH – USA (REL) | | 1 | | 25 | | 35 | | 200 | 2 | 5 |
| Australia | 3 | 5 | | 25 | | 50 | 400 | | 2 | 5 |
| Belgium | 3 | 5 | | 25 | | 50 | 400 | | 2 | 5 |
| Denmark | 3 | 5 | | 25 | | 35 | | | 2 | |
| Finland | 3 | 6 | | 25 | | 20 | | | 2 | 5 |
| France | | 3 | | 25 | | 50 | | | 2 | 5 |
| Germany | | | 5 | 25 | | 30 | | | | 2 |
| Japan | | | | | | 50 | | | | |
| Sweden | 1* | | | 25 | 50 | 35 | 100 | | 2 | 5 |
| Switzerland | 3 | 6 | | 25 | | 30 | 60 | | 2 | 4 |
| United Kingdom | 3 | 5 | | 25 | 35 | 50 | 300 | | 2 | 5 |
| China | | | 2.6 | | | | | 26 | | 6 |

* Limit specifically for $NO_2$ from exhaust fumes.

published exposure limits in parts per million (ppm). OSHA requirements shown are the federal limits, and a few states may set more restrictive requirements. All OSHA, ACGIH, and NIOSH limits are current as of February 2003 or newer. Other limits are taken primarily from an international database of participating countries (ILO 2003; Lu 1993).

Currently, for most jurisdictions, nitrogen dioxide ($NO_2$) is present in exhaust emissions at the highest levels relative to its published limits. This makes it the "critical contaminant" for design. If it is assumed that all exhaust contaminants are diluted or removed in the same way, the critical contaminant has the highest emissions per required limit. In this case, nitrogen dioxide has a much higher emissions to limit ratio, and ventilation systems designed to control nitrogen dioxide will maintain other contaminants well below their respective limits. However, the reader should be aware that as more becomes known about other compounds—particularly diesel particulate matter (discussed below)—the limits for these compounds may become more critical.

OSHA does not currently distinguish DPM from other particulates. The PEL for particulates not otherwise regulated (free of asbestos and less than 1% silica) is 15 mg/m$^3$ TWA. The ACGIH has targeted DPM in its Notice of Intended Changes since 1995. In the 2001 notice, a limit of 0.02 mg/m$^3$ for DPM measured as elemental carbon was proposed (ACGIH 2001). It has been shown that DPM levels can be accurately determined by measuring elemental carbon in railroad environments (Liukonen 2002). A recent ACGIH press release confirms the addition of diesel exhaust to the 2003 published TLVs, which will be released later in 2003 (ACGIH 2003).

The increasing emphasis on diesel particulate is evident in new laws enacted by MSHA in January 2001 to protect mine workers from diesel particulates. These rules will establish an interim maximum eight-hour "full shift" DPM concentration limit of 0.4 mg/m$^3$ for metal and non-metal mines, which is required by law as of July 2002. This limit will be reduced to 0.16 mg/m$^3$ over the following five years. The intent of these rules will be applied to coal mines by requiring reduced emissions from diesel equipment, since the presence of coal particulate interferes with the measurement protocol for diesel particulate (MSHA 2001).

Outside the U.S., the German "Chemicals Act" specifies maximum concentrations for no adverse effect on worker health (MAK) or concentrations achievable using technically available measures (TRK). These regulations currently limit elemental carbon to 0.1 mg/m$^3$ in diesel environments and 0.3 mg/m$^3$ in non-coal mines and tunneling (DieselNet 2001).

## POLLUTANT SOURCE ISSUES

Indoor emissions are influenced by many factors, including engine design, operation, and fuel quality. Therefore, an understanding of these effects is a necessary context for applying published emissions data and to begin to anticipate future trends and changes. It may also be helpful in addressing emissions issues specific to a particular facility.

### Diesel Exhaust Characterization

Pollutants that have been specifically targeted by diesel emissions research include oxides of nitrogen ($NO_x$), sulfur dioxide, DPM, carbon monoxide, and unburned hydrocarbons. A detailed knowledge of combustion processes is needed to quantify the generation of each contaminant in a diesel engine. Designers cannot be expected to become experts in the subject of engine design, but some identified relationships between fuel composition, environment, and operating conditions provide some insight into the nature of emissions generation and trends that impact the indoor environment.

DPM emissions are primarily a result of the inability of some fuel to adequately interact with oxygen. This is most likely a result of a locally rich fuel-air mixture (Barry et al. 1985). Increasing the combustion temperature has been shown to reduce the amount of particulate emissions, and engine design parameters such as swirl can also affect their formation. The particles themselves contain cores of elemental carbon or unburned fuel that accrue other substances such as hydrocarbons, sulfates, PAHs, nitro-PAHs, nitroarenes, and metals on the outer surface (MECA 2001). Diesel particulate matter emissions are "reasonably anticipated to be a human carcinogen" by the U.S. Department of Health and Human Services (U.S. DHHS 2001).

The health effects of the major gaseous pollutants, such as nitrogen dioxide and carbon monoxide, are relatively well understood. However, the health risks associated with many compounds found in DPM are less clear. Ongoing research is adding to our understanding of the components of DPM and their potential health effects. Therefore, future DPM regulations are likely and may continue to develop to reflect ongoing and future research that better quantifies the health effects of the many substances found in DPM. Design guidance should be flexible enough to respond to tightening restrictions in a timely manner. Ventilation systems that are easily adapted, updated, or retrofitted may be of value to owners as well.

Sulfur has been targeted by emissions standards because of its role in DPM formation and associated adverse health effects. Inhalation of $SO_2$ contributes to respiratory side effects such as lung and throat irritation and shortness of breath (ATSDR 2001). Sulfur dioxide is prone to oxidize during combustion to form sulfates. These sulfates are emitted as DPM (U.S. DOE 1999), and increased amounts of sulfur in diesel fuel have been shown to correlate to increased DPM emissions (Barry et al. 1985; U.S. DOE 1999).

Diesel combustion processes readily form oxides of nitrogen because of the lean conditions under which combustion typically occurs. As a result, excess oxygen is present in the cylinder and may react with nitrogen in the air to form $NO_x$. Increasing temperature will result in formation of larger amounts of $NO_x$ (Chevron 1998). Nitrogen dioxide exposure can cause negative health effects such as shortness of breath, as well as eye, nose, and throat irritation (U.S. EPA 2001).