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Air Contaminant Movement and Dilution in the Atmosphere

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The trajectory of a cannonball can be described by Newton's equations of motion. These equations of motion can also be used to characterize the arc of a basketball in flight, the path of a horseshoe thrown at a picnic, and the shifting movement of loose objects in a car as it rounds a corner. We have an instinctual understanding about some of these movements, and the degree of our appreciation allows some individuals to make a thirty-foot jump shot, and others to miss the backstop altogether.

The movement of air contaminants and gases released into the air, on the other hand, is less intuitive for most of us, and potentially more difficult to describe. The parameters that affect the movement of gases, or affect the dilution of gases in air, are multi-fold. When carbon monoxide, for example, is released into a building, its path and dilution may mean death for some exposed individuals and no harm for others. The following article discusses some of the considerations and concerns, from an industrial hygiene perspective, in describing the motion and dilution of gases in the near environment, such as the release and dilution of carbon monoxide in and around buildings.

A pressurized gas release may have a high initial velocity. That velocity, at moderate pressures, is proportional to: the area of the release opening, the shape of the opening that the gas is released from, and the pressure drop. It is expressed by the following proportionality:

$$V_{init} \sim (\text{Area})\ (\text{Release Opening Factor})\ (P_1 - P_2)^{0.5}$$

Knowing the initial velocity parameters may allow calculation of the height or the length of the path of the pressurized release. This height or distance may be important in determining if the gas from a ruptured pressurized line will escape the immediate area of the release or if it will remain in the release area.

While the exhaust flow of carbon monoxide from an engine's tailpipe may change by an order of magnitude, the maximum horizontal separation distance of the exhaust from the pipe based on its exit velocity may be relatively small. The distance traversed by this flow is limited, because flowing gases have little momentum to carry them forward, and have significant drag forces to slow their movement through otherwise stationary air. This drag force, is in part, described as:

$$\text{Drag} \sim (\text{Shape Constant})(\text{Velocity})^{x}$$

The velocities associated with suction (the opposite of exhaust) are further constrained, and that is one reason why you can forcefully exhale and feel your breath at arm's length, but cannot inhale and feel air movement over the same distance.

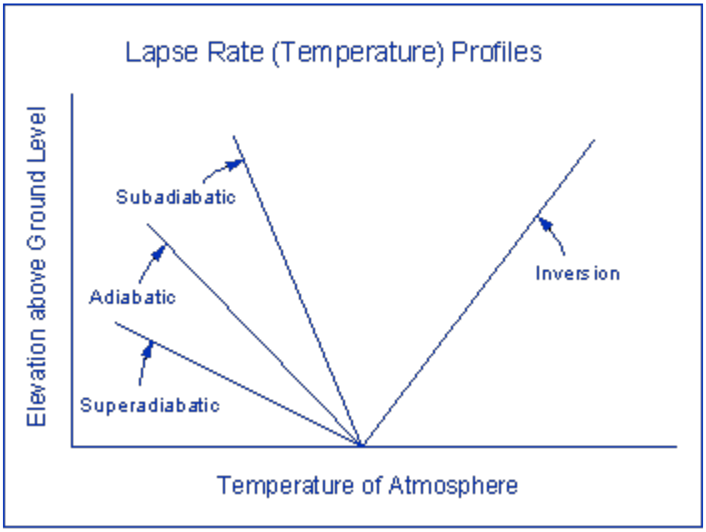

Figure 1

A vertically-positioned exhaust pipe from an engine or a combustion flue from a furnace may enhance the vertical distribution of the gas due to thermally induced buoyant forces within the gas. While the exit temperature, specific heat capacity, and heat losses of the exhaust stream and ambient air control the potential height attained, the atmospheric temperature profile may limit or enhance the actual vertical profile of the gas. The vertical temperature profile of the atmosphere is called the lapse rate and is a controlling factor in inversion conditions where gases are trapped and prevented from attaining their normal vertical distribution. Figure 1 shows the atmospheric profiles for various lapse rates which encourage and discourage vertical mixing.

The non-pressurized release of a contaminant gas into a calm atmosphere, below or approaching the few percent range, often is assumed to cause a stratification of the contaminant based upon the density differences of the gas and the local atmosphere. Some may assume that if the released gaseous contaminant is heavier than air, then it must flow downward and concentrate at the floor level. Comparing the settling velocity based on density differences (see equation below) to the normal air movement velocities for calm air refutes this general notion at low concentration levels and indicates that this will not always occur.

$$\text{Vel} = \left(\frac{(2)(\text{Gravity Constant})(\text{Height})(\text{Density Difference})}{(\text{Density of Mixture})} \right)^{0.5}$$

Certainly, if a gas is released into a moving air stream, or that formed from a ventilation system (e.g. into the wind or induced draft), it will tend to be carried along with it and will attain the local air stream's velocity. At the same time it will have forces acting on it due to concentration gradients which will tend to spread the contaminant in all directions and cause it to be diluted. Various boundary conditions, or constraints, may influence this spreading effect. For example, there may be a setting where a constant source of carbon monoxide is released and moves through a hallway toward an open window. The concentration of the contaminant at various times and positions would be expressed by;

$$\text{Concentration} = \frac{\text{Initial Concentration (ERFC [Position])}}{(2)\,[(\text{Diffusion})(\text{Time})]^{0.5}}$$

Lateral movement is generally caused by concentration-driven effects, but it may also be influenced by air turbulence, the lapse rate in the atmosphere, thermal buoyancy effects, and, if inside of a structure, air infiltration effects. The American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) has established not only forced ventilation requirements for various locations within buildings, but it has developed means to estimate air infiltration rates into buildings. This "leakage" or infiltration can act to move and significantly reduce airborne concentrations of contaminants within buildings.

Collectively, all of these variables may or may not be present at a particular location. Proper appreciation of the controlling parameters can allow correct modeling and estimates of airborne contaminants.

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