CONTAINMENT VS. DILUTION VENTILATION:

WHICH IS THE SAFEST SYSTEM?

Introduction

In OSHA's *Occupational Exposures to Hazardous Chemicals in Laboratories; Final Rule* (*Federal Register*, Vol. 55, No. 21, Wednesday 31, 1990, Rules and Regulations, pps. 3300 and 3334), a NIOSH's presentation of the evidence of risk associated with chemicals in laboratory operations was cited. NIOSH evaluated employee exposure and health hazards associated with xylene, formaldehyde, chloroform, toluene, and methyl methacrylate. The results of these investigations showed that in some instances employees exposed to these substances were at risk. This document stated:

> "Major contributions to the hazardous conditions included ***ineffective exhaust ventilation*** and ***poor workplace practices***," (p. 3004)

and

> "Studies on ethylene oxide, for example, indicate a significant risk to workers at ***levels as low at 1 part per million*** over the worker's lifetime." (p. 3004)

In the final rule making standard, a research chemist with the Center for Disease Control, U.S. Department of Health and Human Services is quoted as follows:

> "First, exposure to toxic agents in the laboratory can have severe consequences including death; second, these injuries can occur in any type of laboratory where toxic chemicals are handled; and third and most important most or all of these injuries are preventable." (p. 3004)

Clearly the presence of materials, most commonly in a vapor form and though dilute in concentration, are often present in laboratory workplace environments. In some instances, known or unknown to a lab worker, these chemicals can be hazardous to the laboratory worker, even at dilute concentrations . The questions are: (1) how do these materials migrate into the room's environment, assuming from a fume hood; and (2) can this migration be stopped by properly engineered laboratory air flow control systems, improved fume hoods, properly placed air supply outlets and other engineered features that maximizes the containment ventilation? Our engineering testing and development efforts tell us yes.

Historical Perspective

A wartime effort in the 1940s signaled the beginning of the atomic energy era (ca 1942 -1955). This era and the creation of the atomic bomb dictated an accelerated learning and developmental effort that was directed at maximizing containment ventilation (Note: maximizing containment ventilation considerations include the laboratory air flow and control system; laboratory elements such as the sizing and placement of supply outlets; the fume hood complete with rounded air foil openings, a continuous slot type discharge baffle and other aerodynamic containment enhancements; and all other design features having the goal of maximum containment within the fume hood). Many lives were lost in laboratories at that time because all the factors associated with containment ventilation systems were not understood and exposure to toxic and radioactive chemicals occurred. And, while there were tragedies, there were also significant containment safety ventilation systems, device, and application lessons learned that advanced the state of the art concerning ventilation system performance. Engineers and others concerned with proper containment ventilation worked side by side with scientists; and if containment was not present, both suffered.

Engineers initially developed laboratory air flow systems that depended only upon the operation of hood exhaust fan for motive power. These containment ventilation systems relied upon a "pull" through type airflow system concept (see John Weber, Jr., Disclosure, United States Atomic Energy Commission paper, AECD-2380, *A Mechanism for Automatic and Manual Control of the Air Velocity at the Window Opening of Fume Hoods*). Labs built in Los Alamos, New Mexico and Oak Ridge, Tennessee did not utilize "refrigerated air" (air conditioning) and were absent any devices for forced ventilation that "pushed" air into the work space. These early laboratories were typically designed with a center hallway where the air was "pulled" into the building, typically through a louvered opening above an outside entrance door through a unit heater. The air flow was then down the hallway, into a lab through another louver installed in a laboratory door; and it was then "pulled" through the fume hood, on through the exhaust duct work, and then through the exhaust fan, followed then by discharge to the ambient air, outside the building.

In the early 1950s, about the time of the start of the chemical era in the United States (ca 1952-1975), engineers started installing "refrigerated air" systems into laboratory buildings for occupant comfort. At that time, the hazards of long-term chemical exposure on human health hazards, such as chronic health problems, were often not understood nor identified for many chemicals now in common usage. Unfortunately, ventilation containment systems that depended upon capturing fugitive emissions liberated or generated in some type of fume hood or other enclosure were greatly impaired by the action of the "pushed," or forced, air supply systems. (See *Proceeding Laboratory Design for Handling Radioactive Material*, National Research Council, Building Research Advisory Board, Research Conference Report No. 3, November 27, 1951: for air flow considerations see pps. 13, 23-39; for hoods see pps 10, 26 and 47; for face velocity control and experience-gained concerning desirable face velocity see pp. 26-27, 37-39, and 47). Designers simply did not have the controls at that time that could slave room supply flow to hood and room exhaust flow and that could perform with sufficient accuracy, precision, and speed of response on a sustained maintenance-free basis to allow effective "push-pull" system incorporation into design. Moreover it was difficult if not impossible to apply and effectively utilize **Weber's** "pull" only mechanical linkage control concept to throttle hood exhaust flow with hood sash opening and concurrently control room supply with a mechanical linkage.

Control system difficulties associated with the mechanical linkage concept gave rise to the acceptance of using constant volume supply and exhaust air flow systems. With these systems, hood face velocity was supposedly maintained constant by allowing hood make up air intake to pass either thought the hood sash opening or through a dampered bypass opening integral to the hood but above the sash opening. With this arrangement, as the sash opening area increased by moving it upward, the upper end of the sash at the same time proportionally blocked off the bypass section above the hood sash opening. In another case, bypass was accomplished via an opening into the exhaust duct between the discharge of the hood and the intake of the fan, with bypass flow throttled via a mechanical link connecting the sash to the bypass damper. Unfortunately, constant face velocity with sash position can not be achieved with either of these two arrangements and attempts to maintain the face velocity constant at all sash openings is not possible with this arrangement. This arrangement represented, however, the first of many compromises in air flow systems; this arrangement also foretold the subtle and unrecognized shift from containment ventilation as a goal to dilution ventilation.

Other factors contributing to loss of containment within the fume hood include:

- non-airfoil inlet sections on the faces of hoods (i.e., square and beveled edges vs. rounded);
- poor baffling within the hood, especially at the top of the hood;
- use of a round or square duct for exhaust connection to the hood rather than a slot type hood exhaust pick up across the back of the hood;
- use of outside make air bonnets installed on the hood with discharge that produces a shear flow that is normal to the plane of the hood sash opening;
- poor supply air register placement that resulted in disruptive supply terminal velocity and drafts and eddy currents pulled into the plane of the hood sash opening;
- and numerous other factors that disturbed the uniform, laminar like air flow into the hood that produces maximum containment within the hood.

Eddy currents and disruptive drafts in the room cause havoc in the air flow patterns with "push-pull" lead to air system that induce fugitive emissions to escape from the hood. Though dilute, the emission becomes mixed in the air in the laboratory workspace. The opportunity for emission to become mixed with room air is far greater with a push-pull system than with a pull- only system, especially when controlled as suggested by **Weber**.

Ventilation Problems Today

Problems associated with push-pull systems exist today in most laboratory installations. These faults, coupled with the fact that these early air conditioning systems were designed largely by engineers concerned with tempering the air supplied into a lab and not with the air quality in the room, was further complicated by the lack of designer's appreciation of the impact that the supply system had on containment ventilation. These design flaws have been perpetuated and remain to complicate ensuing designs because of the tendency of designers to copy layout arrangement from previous jobs. Also a lack of metered performance data has allowed designers to relish in a false sense of satisfactory accomplishment concerning the effectiveness of past jobs. This situation is further complicated by the fact that the person representing the owner is normally concerned only with keeping costs below budget rather than ending up with a properly performing and safe laboratory, and this owner's representative, having delegated design authority to the lab designer, has only a scant understanding of the technical aspects of the project and how it is to preform.

The impact of push type ventilation make up air delivery into a laboratory area is simply most often not appreciated, understood, or even thought about as it impacts containment performance within the fume hood and its abilities to contain the material generated or liberated within it. Also, since the chronic health impact that was associated with many chemicals was unknown and most often not considered until the past decade, the escape of fugitive emissions from a hood, in dilute concentrations, into the work place was, and most often still is, given little consideration.

In summary, ventilation difficulties inherent in a "push-pull" systems coupled with the in-abilities of designers to overcome problems associated with this type of system because of lack of maintenance free air flow controls suited for this purpose gave rise to the dilution ventilation system design concept now most widely used in laboratories. And clearly, while dilution ventilation systems simply do not perform as well as the containment ventilation systems of the early 1940s, design convenience has caused a compromised in containment performance, especially with materials that are toxic in the parts per million range. Finally, those designers associated with the evolving chemical industry one or more decades ago simply did not recognize the dangers associated with each and every particular situation where chemicals were used in hoods. In the atomic labs, the illnesses were acute and most often fatal and directly attributable to the lack of ventilation containment. In contrast, in the chemical labs the exposure health problems are much more difficult to identify and are often long delayed in the chronic health impacts that occur from exposure, especially at low concentration. Complicating this issue is the fact that labs typically employ multiple chemicals, and isolating an individual chemical as the cause of a particular health problem in most cases is difficult, if not impossible, to link.

With the evolution of containment ventilation to dilution ventilation, the design and laboratory safety mission went backwards in time. **Fume Hoods and Laboratory Air Flow Systems: Lessons, Features and Improvements from the "Old Saints" of the Atomic Energy Era Through Today** discusses some of these factors

Containment Ventilation: A Superior Solution

The goal of all laboratory ventilation systems should be to contain hazardous materials. Containment ventilation systems are specifically designed to keep hazardous materials within fume hoods, or other similar devices. For optimum performance:

- the ventilation system must be properly designed;
- the system's equipment (such as hoods, ductwork, fans, etc.) should be chosen based upon past performance;
- the system should be placed within the laboratory considering the location of hoods, doors, supply grills, aisle ways, and more to optimize containment; and
- supply air flow into the room must continuously be drawn toward and into the fume hood sash opening, thus purging the room. This will prevent breathing air laced with chemical emissions.

If the above criteria are met, emission from the hood not only will be minimal, but any

emissions will be captured and contained by the air flow as it continuously flushes the room.