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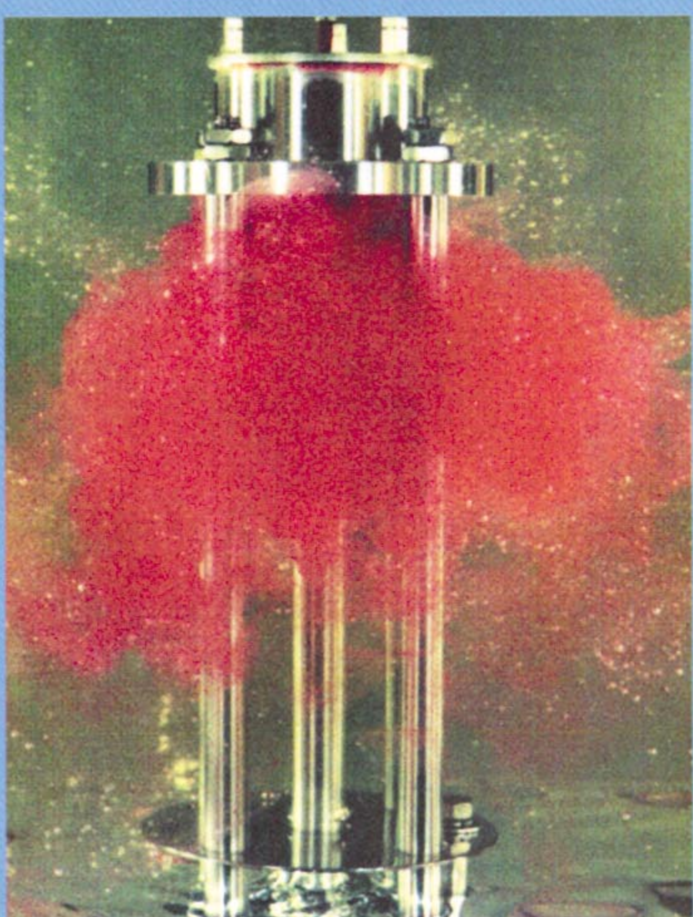

**Dilution for Odor Control**

# Consider Dilution for Odor Control

*Mixing an exhaust stream with fresh air may be enough to eliminate an odor problem.*

**Victor A. Neuman,**
Strobic Air Corp.

In the past, communities have been tolerant about the odors associated with chemical process industries (CPI) activities. An odor from a plant or oil refinery was referred to as "the smell of money," and it was accepted because of jobs and other economic benefits. And, communities accepted the concept of "grandfathering" — if an odor-producing business had been onsite for a long time, it was given more leeway, since its neighbors moved in knowing that there was some odor associated with the facility that was there first.

Both of these concepts are increasingly coming under attack. Today, neighbors (even new neighbors to existing plants and businesses) are much more likely to complain about the health risks to their children than to tolerate what they consider to be a nuisance or a menace. Complicating the situation is the fact that individuals' perception of odors can vary by more than 10,000 times, according to the American Industrial Hygiene Association *(1)*.

Previous *CEP* articles *(2, 3)* have discussed various technologies for odor control and how to choose among them, as well as how to develop an overall odor control program. This article looks at one technique that has not received as much recognition as the others — dilution. It explains how dilution achieves odor control, illustrates the basic dilution ratio calculations, and offers guidelines for implementing dilution.

## The nature of odors

Odors can be either toxic or nontoxic. Toxic odors are those that are regulated by the Environmental Protection Agency (EPA), Occupational Safety and Health Administration (OSHA), and other government agencies. Nontoxic odors are either completely safe, or safe in the amounts that are likely to be generated. (Even "safe" materials, though, may have limits beyond which their emissions would be regulated.)

Tolerance for toxic odors has also sharply decreased in recent years. Government agencies are continually establishing more stringent standards; allowable exposure limits are dropping to lower and lower levels. These allowable exposure limits are expressed as short-term exposure limits (STELs) for 15-min periods and time-weighted averages (TWAs) for longer periods of time. The actual measurement will usually be in parts per million (ppm) of odor-causing compound or the amount of the material in a volume of air ($mg/m^3$).

## Dilution - the basics

Dilution is an efficient method of odor control, but it hasn't quite received the recognition it deserves. One reason for that may be because other methods (such as wet scrubbing, charcoal filtration, and thermal oxidation) can accurately predict the amount of chemical materials that will be removed from an exhaust stream, while odor control by dilution is harder to predict quantitatively.

The theory of operation is simple: To

control odor by dilution, fresh air is mixed in with the chemical-laden air until a suitable concentration (ppm or mg/rn$^3$) is reached and the odor is no longer perceptible or objectionable.

For example, consider an air stream with an acetone concentration of 2,000 mg/m$^3$. The safe concentration of acetone for exposure to humans is 1,780 mg/m$^3$. To render the acetone-laden air safe, it needs to be mixed in equal parts with fresh air to lower the concentration to 1,000 mg/m$^3$. The odor threshold for acetone, however, is only 40 mg/m$^3$; to dilute the acetone to below detectable levels, 50 volumes of fresh air would have to be added.

Dilution has also been used for analyzing an objectionable chemical odor. A panel of judges with better-than-average noses is convened in a laboratory. A sample of the chemical-laden air is taken, and then it is introduced into tubes in random sequence and mixed (diluted) with increasing amounts of fresh air until the odor is either not objectionable or is not detectable by the panel of judges when they sniff the tubes. This level of detectability of chemical odor determines the concentration allowed at the property line or at the intake of ventilation equipment. When comparing the concentration of the original sample with the concentration needed to avoid odor detection, a dilution level is calculated. For example, an exhaust containing chemical odors might need to be diluted 100:1, 1,000:1, or even more before being acceptable.

Dilution can be achieved directly by diluting the exhaust air before it leaves the exhaust fan. Or, it can be achieved indirectly, where the stream of air leaving the exhaust fan (the plume) is diluted by the atmosphere after it leaves the fan and before it reaches the property line or nearby air intakes to doors, windows, air conditioners, or pedestrian walkways.

The most efficient and cost-effective method of dilution is direct dilution using an exhaust fan that is specially designed for this purpose. The fan draws the odor-laden exhaust into a ductwork system and carries it to the highest point of the building's roof. At the roof, fresh air is drawn into the exhaust fan to mix with and dilute the odiferous chemical exhaust. This technique is most effective when the resulting mixture

## One Approach to Eliminating Odor Problems in the Neighborhood

Industrial facilities are often located in residential neighborhoods, sometimes as a result of outdated zoning laws. Such companies must make every attempt to eliminate offensive odors that could lead to complaints from nearby residents. Here's how one firm solved its problem.

Borden Decorative Products, a division of Borden, Inc., is a rotogravure printing firm that produces decorative surfaces for home floors, walls, kitchen cabinets, furniture, and recreational vehicle floors. It also extrudes polyvinyl chloride films for print stock used in its printing processes, and plastic films for many specialty products. The facility is located within an industrial park situated in a residential area in Crestwood, MO, a suburb of St. Louis. It borders a historic home site and city-operated tea house restaurant. Borden management became concerned when they received occasional odor complaints from nearby residents and site visitors.

The company had always been considered as a good neighbor, and had been using electrostatic precipitators (ESPs) on its extrusion lines to eliminate odorous particulate and oil mist emissions. The ESPs were mounted between the exhaust hoods and outside exhaust stacks. Each ESP contained prefilters, electrostatic precipitator cells, a belt-driven furnace-type blower, and a charcoal filter section served by an inlet and outlet plenum.

An environmental consultant determined that two problems existed with the odor exhaust system. The odor problem was caused by two extrusion lines and individual exhaust stacks nearest the residential area and restaurant site. Odiferous mercaptans in the effluent were penetrating the charcoal filters in the precipitators. Even though there was no re-entrainment of odors back into the plant extrusion exhaust fumes were not exiting the stack at sufficient height or velocity to overcome changes in wind direction due to local weather effects. This caused the fumes to blow toward the neighbors, and prompted the complaints.

The company did not want to lose the exhaust cleaning advantage of the ESPs, but they needed a more-effective means of diluting and dispersing the odorous effluent away from the residential area and the tea house. Noise pollution was another critical issue, since they did not want to replace an odor problem with a noise problem.

The solution involved connecting a roof exhaust system to the existing ESPs. In this way, the plant was able to retain elements of the original system with only minor modifications and was able to eliminate its odor problems. To further relieve neighbors of the odor problem, the fans were installed on 35-ft-high towers, the local legal maximum stack height

Approval from the Air Quality Control Section for St. Louis County was needed to modify permitted control equipment. Company management met several times with the St. Louis County Board of Aldermen, the mayor, the chief engineer of Crestwood, and concerned citizens. They explained the project, answered questions, showed a videotape from the equipment manufacturer that demonstrated how quietly the system operates, and displayed an architectural rendering of the proposed 35-ft stack towers to show that they would be unobtrusive. The agency approved the installation on a conditional basis.

Since the system was installed, the plant hasn't received any more extrusion odor complaints. Although the company is using a bit more energy (each exhaust fan is 10 hp, whereas the original centrifugal blowers were 2 and 5 hp), the added energy costs are easily justified by significantly more-efficient operation and virtually no maintenance costs.

of odorous exhaust and outside air is ejected from the exhaust fan upwards at high velocity.

Wind tunnel studies *(4, 5)* have shown that direct dilution is most effective when the diluted air stream is projected upward at velocities in excess of 3,000 ft/min. A typical exhaust system to ensure dilution might use a steel stack as tall as 100 ft to disperse the plume of odor from the fan. However, the cost and complexity of such a structure, and its unsightliness, work against it. Also, for retrofit situations where employees or neighbors have previously complained of the odor, a tall stack is a daily reminder of the presence of the odor.

An alternative solution is to use a high-velocity fan that draws in nearly twice the amount of fresh air as exhaust air into the fan's exhaust and results in a 5,000 ft/min exit velocity. The jet velocity at the fan's exit induces large amounts of air to be drawn into the plume. This injection of fresh air causes immediate relief of odor perception by dilution, and sends the odor-laden air high into the atmosphere. Often the use of such a system is enough to solve an odor problem on its own. If it isn't, combining dilution with one or more of the other available odor-control methods should be considered.

Engineers should be aware of chemical exhaust fans with small air flows. Fans with flows less than 2,000 cfm of air have difficulty pushing through the turbulent flow of air on a building's roof. Whenever possible, fans bearing chemical-laden air should be chosen with final flows in excess of 2,000 cfm; the larger the final flow the better for dilution purposes. Also, final exit velocities from the fan should be in excess of 3,000 ft/min. This exit velocity will prevent exhaust downflow to the roof level (with possible contamination of outside air intakes) at wind velocities up to 22 mph.

Direct dilution is easy to measure as the various air streams are mixed in the exhaust fan. Velocity traverses with pitot tubes or other instruments in the ductwork connected to the exhaust fan will indicate the flow of fresh outside air that is induced into the exhaust fan outlet before ejection or that is drawn into the fan's suction at inlet. The indirect dilution is then calculated using methods approved by the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) *(5)*.

***Required dilution levels will vary for different mixtures of chemicals***

## How much dilution?

To help determine whether dilution would be effective for a specific application, one can analyze how much dilution is necessary. ASHRAE conducted more than 10 years of fundamental wind tunnel research to provide engineers with the calculation tools that they needed *(5)*. These simple hand calculations can be extended when more accuracy is needed by using computer calculation methods such as the EPA's computer model SCREEN3. (See Ref. 6 for information on this and other similar programs.) The following example (from Ref. 7) illustrates the dilution calculations.

Extensive wind tunnel research was conducted at a typical CPI facility where the chemical process is exhausted through a fan on the roof. The duct carries a volume of 10,000 cfm of chemical-laden air as it leaves the process. The exhaust fan was selected based upon an upward air exit velocity of 3,000 ft/min to meet odor criteria standards at the property line 100 ft away. The chemical is present at a concentration of 1,500 ppm, and it has been determined that the maximum allowable concentration to avoid detection is 3 ppm. For both direct and indirect dilution, a dilution ratio of 500:1 is needed.

The worst-case wind speed for a zero-height fan, $U_{crit,0}$, is calculated as:

$$U_{crit,0} = 3.6(V_e/S)(A_e/B_1)^{1/2} \qquad (1)$$

where $V_e$ is the fan exit velocity = 3,000 ft/min, $A_e$ is the fan exit area = 10,000 cfm/3,000 ft/min, $B_1$ is the air entrainment parameter (a constant) = 0.059, and S is the stretched-string distance from the exhaust to the nearest intake.

So, $U_{crit,0}$ = 3.6(3,000/150) x [(l0,000/3,000)/0.059]$^{1/2}$ = 811 ft/min = 9.2 mph for a stack flush with the facility's roof.

The worst-case dilution for a flush roof stack, $D_{crit,0}$, is:

$$D_{crit,0} = \frac{\left(1+26\dfrac{V_e}{U_{crit,0}}\right)^2}{\left(1+13\dfrac{V_e}{U_{crit,0}}\right)} \qquad (2)$$

Plugging in $V_e$ = 3,000 ft/min and $U_{crit,0}$ = 811 ft/min gives $D_{crit,0}$ = 192:1, which is less than the desired 500:1 dilution ratio.

Equations 1 and 2 are solved by trial and error until an acceptable solution emerges. In this case, the exhaust can be diluted further with fresh air at the fan inlet or outlet, or the stack height can be increased to give better dilution. Refs. 5 and 7 give further information.

## Dilution levels

Required dilution levels will vary for different mixtures of chemicals.

Exhausts from chemical laboratory hoods might have to be diluted 1,000 to 5,000 times, while exhausts from diesel motors or emergency generators might have to be diluted 10,000:1 in order to eliminate odor complaints.

Of particular interest are mercaptan and hydrogen sulfide odors, which are irritating even in extremely low concentrations. The engineer dealing with these substances, which smell like rotten eggs, must be prepared to provide large amounts of dilution, possibly coupled with other air treatment methods.

## Implementing dilution

When evaluating dilution, either along or combined with another odor-control technology, consider these basic guidelines:

• Odor-laden air must be pointed upward with rain protection that prevents downward flow (no rain caps, goosenecks, or flapper dampers).

• Use as high a stack exit velocity as possible (at least 3,000 ft/min).

• Locate exhaust fans on the highest usable roof with regard to duct connections.

• Use a combination of extra fresh air from the roof into the stack flow along with stack height to achieve desired odor detection levels at the property line or supply-air intakes.

Keep in mind that dilution applies to the control of odor problems that are not subject to further regulatory requirements, such as standards for volatile organic compounds (VOCs) or hazardous air pollutants (HAPs). The costs for some types of control equipment depend on airflow rates (cfm). Thus, if additional controls are required, dilution could result in higher costs unless the other system is placed upstream of the dilution fan.

Other methods of odor control include:

• prevention - eliminating the source of the odor or substituting a non-odor-causing material;

• minimization — reducing the amount of odor-causing material or causing it to evaporate at a slower rate; and

• masking — adding a pleasant odor to the air to hide or mask the objectionable odor.

Masking is usually too costly to be used very often in CPI facilities. Some specific prevention and minimization strategies include eliminating the source of the pollution, changing raw materials and/or fuels, modifying process operation, recycling exhaust rather than venting it to the atmosphere, minimizing entrainment of pollutants into the gas stream, reducing the number of points in the system where materials can become airborne, recycling a portion of process gas, and designing hoods to exhaust the minimum quantity of air necessary to ensure odiferous pollutant capture.

Selecting an odor-control technology depends on the compounds causing the odors and their concentrations, as well as the air stream flow rate, moisture content, and variability (2). Ref. 2 is a comprehensive article on odor control from CPI facilities that includes descriptions of many other common methods of odor control.

While a variety of literature exists with regard to CPI exhaust odor problems, their identification, and remedial actions, the concept of dilution is a relatively new approach to solving the problem. When individual methods of odor control either fail or don't provide the operating efficiency desired, consider dilution, either by itself or in combination with another technique. CEP

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### Related Web Sites

www.aiha.org — American Industrial Hygiene Association

www.ashrae.org — American Society of Heating, Refrigerating, and Air Conditioning Engineers


**V.A. NEUMAN, P.E.,** is a regional sales manager at Strobic Air Corp., San Diego, CA (888) SAC-FANS; Fax: (619) 284-5170; E-mail: tristack@strobicair.com; www.strobicair.com), a subsidiary of Met-Pro Corp., Harleysville,PA (www.met-pro.com). His responsibilities include supporting engineers and facility managers in design and evaluation of new and existing ventilation systems. He has been involved in laboratory ventilation and odor control applications for more than 15 years, having designed laboratory fume hood controls and room pressurization controls for many research facilities, as well as plumbing and mechanical systems for more than 100 university and corporate laboratories. He graduated from San Diego State Univ. with an MS in mechanical engineering, and is a registered mechanical engineer. He is active in industry task forces involved in updating related codes and standards, is a past vice chair of the ASHRAE Technical Committee on Laboratories, and is a coauthor of the ANSI/AIHA Z9.5 Laboratory Ventilation Standard.

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