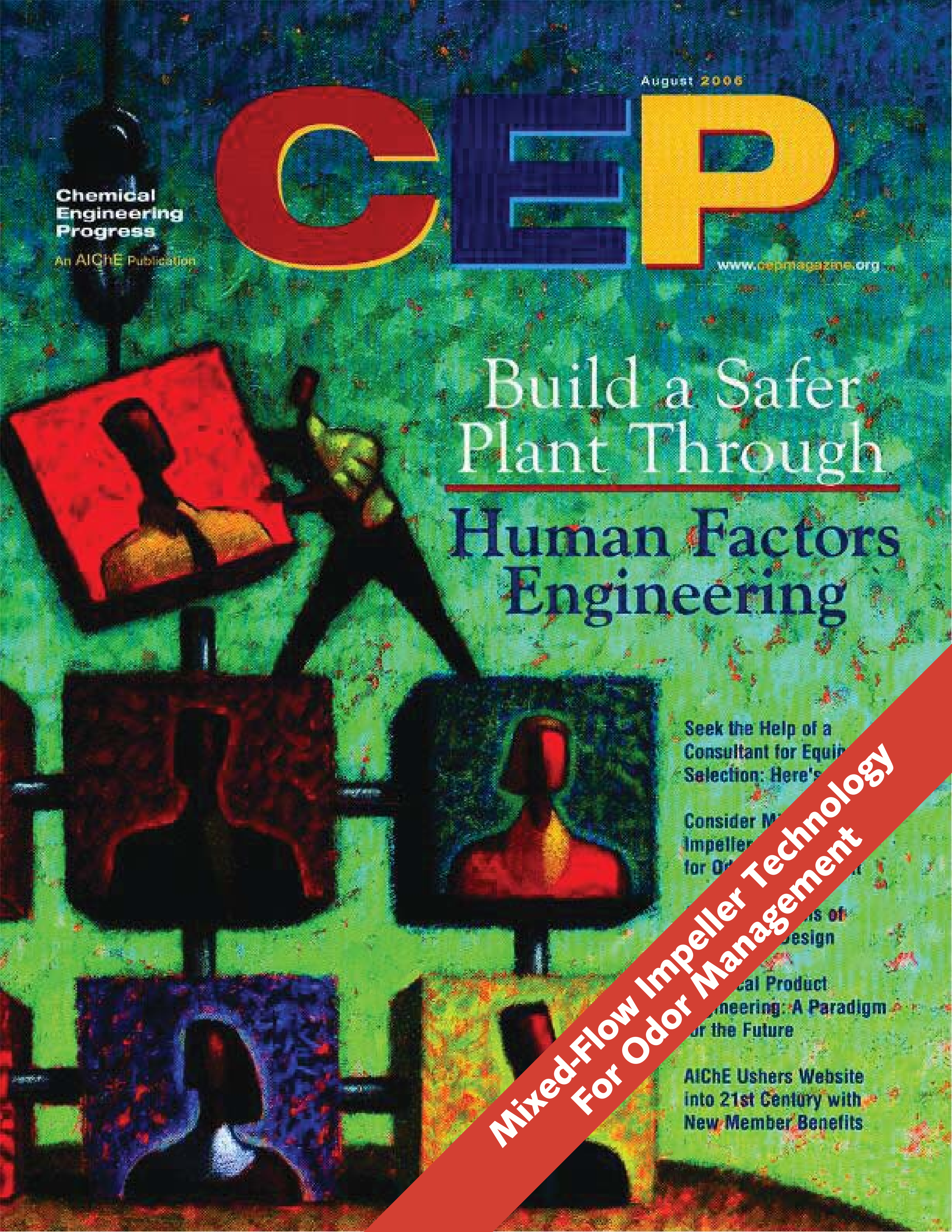

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Consider Mixed-Flow Impeller Technology for Odor Management

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Propelling an odorous exhaust stream high into the air at a high velocity is often an effective way to eliminate odors.

It used to be that discussing unpleasant odors emanating from chemical process industries (CPI) facilities was like discussing the weather — everybody talked about it, but no one did anything about it. There hasn't been much progress toward influencing the weather, but progress has been made in managing unpleasant odors. While there are almost as many odors as there are chemicals, there are also quite a few methods available to manage them.

One such technology is a mixed-flow impeller system, consisting of low-profile roof exhaust fans, which dilutes odorous exhaust gases with ambient air above the roofline prior to atmospheric discharge. Mixed-flow impeller fans are commonly used in university, hospital, government, commercial, independent research, and other types of laboratories, as well as in food processing, industrial solvent handling, semiconductor manufacturing, pulp and paper mills, and wastewater treatment applications. However, they are less well known throughout the traditional CPI. This article explains the technology and how it works.

Odor perception varies

The ability to detect odor varies widely among different people. The concentrations at which two individuals can detect a particular odor may vary by several orders of magnitude.

Dilution eliminates the *perception* of odor. In many cases, the perception of odor is the only way to measure an odor. In other words, if an odor is perceived (whether or not it is annoying), the odor exists.

Consider an airstream containing methyl ethyl ketone (MEK). The safe concentration for exposure of humans to MEK is 600 mg/m^3, but the odor threshold for MEK is only 30 mg/m^3. So, even though a concentration that is an order of magnitude lower than the safe exposure limit does not represent a health hazard, the presence of MEK is detectable.

Odors emanating from CPI facilities, whether unpleasant or even pleasant, can be either toxic or nontoxic. Toxic emissions are regulated by the U.S. Environmental Protection Agency (EPA) and other government agencies. Short-term exposure limits (STELs) for 15-min periods and time-weighted averages (TWAs) for longer periods of exposure are expressed as concentrations of the odor-causing compound in parts per million or billion (ppm or ppb), or the amount of material in a volume of air (mg/m^3). Emissions of nontoxic substances are generally considered safe in the amounts likely to be generated, although there may be limits beyond which their concentrations are regulated.

Because odor is based on perception, it is sometimes hard to quantify its removal from an exhaust stream. Most odor-control technologies, such as chemical scrubbing and/or bio-scrubbing, thermal or catalytic oxidation, charcoal filtration, precipitation, etc., can be characterized with regard to their effectiveness at removing and/or destroying one or more pollutants, because manufacturers usually can predict with accuracy the amount of these compounds that will be removed from an exhaust stream. When an odorous exhaust stream is diluted, it can be difficult to quantify the odor.

The dilution solution

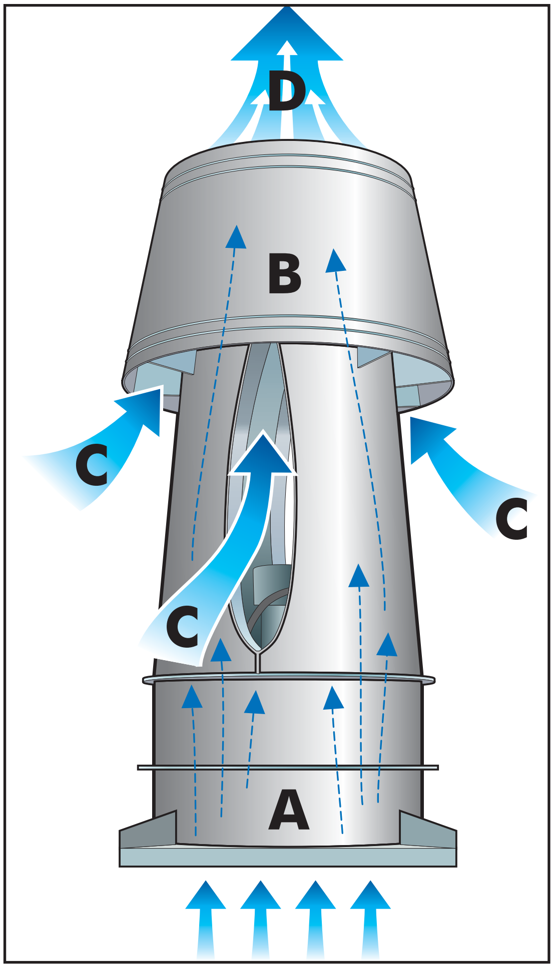
The theory behind dilution is simple: To control odor by dilution, fresh air is mixed with the odorous exhaust air until a suitable concentration (ppm or mg/m³) is reached and the odor is no longer perceptible or objectionable.

Dilution levels will vary depending on the specific chemical causing the odor. For instance, mercaptan and hydrogen sulfide odors (which smell like rotten eggs and are irritating even at extremely low concentrations) will require substantially more dilution than less-noxious chemicals, such as butyl acetate, ethyl butyrate, octyl acetate, methyl salicylate, ethyl methanoate, and others.

An exhaust stream containing 900 mg/m³ of MEK (whose odor threshold is 30 mg/m³) could be mixed with equal parts of fresh air to render it safe, but requires dilution with 30 volumes of fresh air to make it non-detectable. Wind-tunnel modeling of a rooftop exhaust at a typical CPI facility determined that a dilution ratio of 500:1 was needed to reduce a 1,500-ppm concentration of an odorous chemical in a 10,000-cfm airstream to below the concentration required to avoid detection, which was 3 ppm. Exhaust from chemical laboratory fume hoods might need to be diluted as much as 5,000 times, while exhaust from diesel motors or emergency generators might require 10,000:1 dilution in order to eliminate odor perception and complaints.

Indirect dilution occurs when the plume of air leaving the exhaust fan is dispersed and diluted by the atmosphere before it reaches the property line, air intakes to ventilation systems, doors or windows, pedestrian walkways, or other inhabited areas. Dilution can also be achieved directly, by diluting the exhaust stream before it leaves the fan.

Mixed-flow impeller fans (Figure 1) operate on the direct-dilution principle. 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, unconditioned outside air is drawn into the exhaust fan and mixed with the odorous chemical exhaust (a). The diluted process air is accelerated through a discharge nozzle/windband (b), where nearly twice as much additional fresh air is drawn into the exhaust plume before leaving the fan assembly (c). The windband creates a protective envelope around the emerging discharge plume and keeps the surrounding air stationary to improve entrainment.



■ Figure 1. Mixed-flow impeller fans reduce odors through direct dilution.

More fresh air is entrained into the exhaust plume after it leaves the fan assembly through natural aspiration (d). The combination of added mass and high discharge velocity minimizes the risk of contaminated exhaust being re-entrained into buildings' fresh-air intakes, doors, windows or other openings.

Direct dilution is most effective when the resulting mixture of odorous exhaust and outside air is ejected upward at a high velocity, which induces large amounts of additional fresh air to be pulled into the plume. This stream is sent high into the atmosphere, where it undergoes further, indirect, dilution.

Wind tunnel studies have shown that direct dilution is most effective when the diluted airstream is projected upward at velocities in excess of 3,000 ft/min, the minimum specified by the ANSI Z9.5 standard for laboratory ventilation.

A mixed-flow fan moving 80,000 cfm of combined building and bypass air at an exit velocity of 6,300 ft/min can send an exhaust-air jet plume up to 120 ft high in a 10-mph crosswind. A typical centrifugal fan used for the same application might require a stack as tall as 100 ft to achieve the same results. The cost and complexity of such a structure, and the unsightliness of that structure, are major drawbacks.

Direct dilution, which occurs as the various airstreams are mixed in the exhaust fan. is easy to measure. Velocity traverses, which employ pitot tubes or other instruments to measure air velocity at various points across the ductwork, indicate the flowrates of fresh outside air that is induced into the fan's outlet before ejection and that is drawn into the fan's suction at the inlet. The indirect dilution is then determined

■ Figure 2. Mixed-flow impeller fans have a low profile, typically measuring about 15 ft high.

■ Figure 3. There you see it, here you don't. To comply with local ordinances governing roofline aesthetics, the mixed-flow impeller systems are mounted inside the building of this pharmaceutical manufacturer.

using methods approved by the American Society of Heating. Refrigeration, and Air Conditioning Engineers (ASHRAE) *(1)* or computer programs such as the EPA's SCREEN3, AERMOD or ISCST3/ISCPRIME models (www.epa.gov).

Design considerations

Because odor perception can be widely subjective and there is no accurate means of quantifying an odor's removal, it is necessary to match the fan to the application for effective odor control.

The high-velocity, low-profile fans employed in mixed-flow impeller technology are designed to reduce the concentration of discharged gases to levels well below the gases' odor thresholds. Although the concepts are relatively simple, several key design parameters must be optimized to ensure proper operation:

- outlet velocity and effective stack height — determined based on the site's physical dimensions and characteristics, and meteorological conditions
- mechanical efficiency and energy consumption— evaluated by comparing the various models available
- maintenance requirements and sustainability — costs of maintaining the equipment versus other models, and whether the models can be adapted or expanded to meet future requirements
- sound generation — noise levels must comply with local ordinances and U.S. Occupational Safety and Health Administration (OSHA) requirements.

Several factors affect an exhaust plume's characteristics in the environment, many of which cannot be influenced by the system designer, such as the building's shape, the topography of the surrounding terrain, and meteorological conditions. Wind is a critical component. Not only does it influence the direction and discharge of a plume, but it also creates wake areas that can greatly reduce plume height and, in some cases, trap the plume. This could lead to high concentrations of exhaust gases in these zones. Indoor air quality (IAQ) problems might result if the building's supply fans are located in these zones.

Rectangular buildings can be evaluated using a simple geometric method. However, this technique is not suitable for non-rectangular buildings, and it does not consider the topography surrounding the building. These factors result in a more complex model.

Atmospheric stability, temperature gradients and local turbulence are also important considerations. A strong, stable atmosphere creates a boundary layer, or inversion, which can keep the exhaust plume from penetrating the atmosphere or, instead, direct it back toward the exhaust point. Topography also affects the wind profile gradient. For example, level rural areas will typically experience higher winds at lower elevations than urban areas. Issues such as ambient air temperature and humidity are also factors in the selection of an odor-control technology.

A Gaussian dispersion model, such as the EPA models mentioned previously, can be developed to predict the behavior of an exhaust plume. These mathematical models take into account the stability of the atmosphere, and generate concentration levels at various distances from the source. They are ideal for determining ground-level concentrations. The models also take into account the angle of the plume at the location where it reaches ground level, at which point there is an increase in concentration due to part of the plume reflecting off the ground.

With regard to stack height, when retrofitting or designing new rooftop exhaust systems, most organizations consider aesthetics. Clearly, the lowest possible profile (Figure 2) eliminates the "smoke stack" look and its negative connotations. In some jurisdictions, low stacks — or no stacks, as in Figure 3— may be required in order to comply with applicable ordinances. Some communities restrict total building height, which limits the height of exposed stacks and other rooftop equipment. Elimination of tall, unsightly stacks, whether because they are prohibited by code or simply because they are undesirable, is a worthwhile goal.

Operational factors

Mixed-flow impeller technology capitalizes on the performance benefits offered by axial, radial and centrifugal flow technologies by combining them into a unique fan-blade geometry (*i.e.*, camber and twist). The airflow, and thus load, on both sides of the blade are equal, regardless of air volume.

As a result, as shown in Figure 4, the performance curve is perfectly stable, with no stall or unstable sections. This provides stable performance with lower vibration than is possible with comparable centrifugal-type fans.

Inherently lower in vibration, a properly designed mixed-flow impeller is well-suited to take advantage of the higher reliability of a direct-drive configuration. A direct-drive system has one potential point of failure— the motor — whereas a typical belt-drive system has five potential failure points — the belts, motor, shaft, pillow block bearings, and flexible duct connections. Fewer moving parts result in fewer breakdowns.

Under normal conditions, mixed-flow impeller fans are designed to operate continuously for years with minimum maintenance. Direct-drive motor bearings have typical lifetimes of L_{10} = 100,000 h. (The term L_{10} refers to the life expectancy within which the bearings of 10% of a sample would fail.) This is significantly higher than traditional belt-drive systems, whose motor bearing lifetimes are roughly L_{10}= 40,000 h.

Direct-drive motors are also more energy-efficient than belt-driven motors, which are subject to transmission losses. Even the most efficient belt-driven centrifugal fans typically lose up to 10% of their energy. In most cases, actual losses are higher because of improper alignment of shafts, pulleys, pillow blocks, and motors. The table compares typical direct-drive and belt-driven fans in various types of odor control systems.

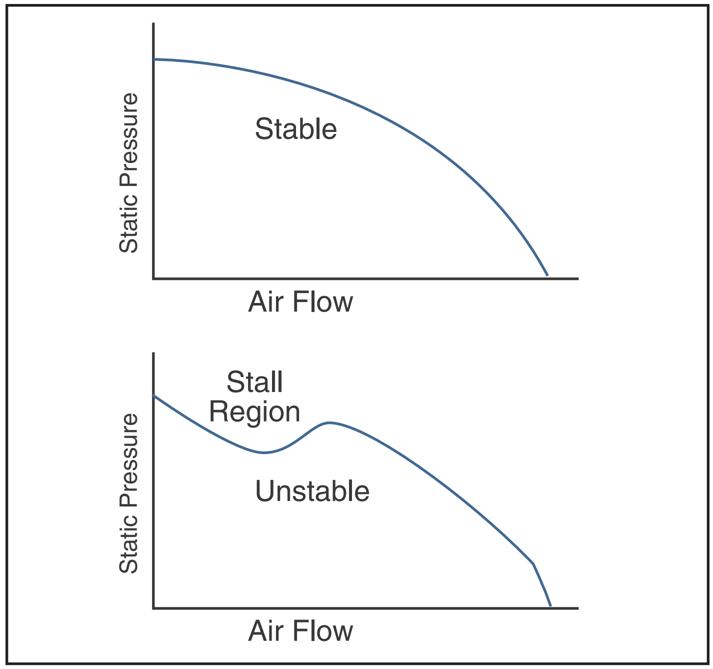


Figure 4. The mixed-flow fan's performance curve has no stall or unstable sections.

Another advantage of dilution is lower maintenance costs. Dilution fans do not require filter change-outs or expensive chemicals for scrubbing, avoiding the labor costs associated with this maintenance. The use of direct-drive mixed-flow impeller fans eliminates the need for the weekly belt inspections that belt-driven fans require.

Noise Reduction

Odor isn't the only problem that can lead to unhappy neighbors — sound matters as well. Although sound, unlike odor, can be measured, its perception, like odor, is important with regard to neighbor complaints. The distance between the equipment and the property line needs to be considered because noise dissipates over distance. For instance, if the noise measures 80 dBa at the source, it would register about 34 dBa at the property line 300 ft away. This is based on a free-field calculation, which does not consider sound reflection. Some of the same factors that influence the dispersion of exhaust, such as the shape of the building and the topography of the terrain also affect noise dissipation, and these need to be factored into the design as well. A simple approach to reducing noise is attenuation at the source. Most fan manufacturers offer attenuation equipment with their products, such as a discharge silencer added onto the stack. While this may solve the sound problem, the silencer's appearance may generate negative perceptions in the community. Most mixed-flow impeller systems are available with integrated sound

Table. Annual operating costs for direct-drive vs. belt-drive systems.*

	Pressure, in. w.g.	Direct Drive	Belt Drive	Additional Costs
Dilution	2	$2,796	$3,107	$311
Filtration	8	$9,357	$10,397	$1,040
Scrubber	20	$22,478	$24,978	$2,500

* Based on continuous operation 24/7/52 and electricity @ $0.10/kWh

attenuators that don't increase their overall height. This may be an advantage, particularly in communities with building height restrictions.

Care should be taken to use the lowest possible static pressure for a mixed-flow impeller fan system. The higher the static pressure requirements, the higher the blade tip speed and, therefore, the higher the noise levels generated by the fan. Blade tip speed is a function of the fan diameter and fan speed. To generate higher pressures, many manufacturers may use larger-diameter blades in order to maintain the same, slower speeds as lower-pressure-developing fans. For this reason, it is important to consider tip speed as well as fan speed (rpm) when configuring a fan.

Other advantages of mixed-flow designs

Mixed-flow impeller fans, which measure about 15 ft high, are significantly shorter than centrifugal fan assemblies with their tall, often unsightly stacks. In addition, these low-profile fans do not require structural reinforcements on the roof, nor complex, expensive mounting/stabilizing hardware, such as elbows, connectors, guy wires or spring vibration isolators, as centrifugal fans do. Their simplicity can reduce installation time and costs substantially.

Furthermore, mixed-flow impeller fans are Underwriters Laboratory listed and conform to all applicable American National Standards Institute/AIHA Z9.5 laboratory ventilation guidelines, as well as to ASHRAE and National Fire Protection Association standards.

Because mixed-flow impeller fans can consume roughly 25% less energy than centrifugal fans, they offer faster payback. A typical energy reduction is $0.44 per ft^3/min at $0.10/kWh, which translates to an approximately 2-yr return on investment.

A one-two punch

In most cases, mixed-flow impeller technology is quite effective at eliminating odor problems in a neighborhood. Others situations, though, require a combination of control methods, depending on the application and the materials being handled. Pulp and paper mills, for instance, may require additional treatment of the exhaust stream when pollutant concentrations are significantly above the odor thresholds.

Certain pollutants with lower odor thresholds might not be dispersed effectively by dilution alone. The addition of chemicals such as potassium permanganate, sodium hypochlorite or chlorine could help dilute and/or diminish an odor by reacting with the exhaust and, in effect, scrubbing the air before it is exhausted. For example, a wastewater treatment facility might take this approach to reduce s odors at a pumping station.

Considerations such as ambient air temperature and a humidity also come into play during the selection of odor control technologies, because certain odors are perceived more easily than others under a given set of atmospheric conditions, such as higher temperatures and/or humidity levels.

Final thoughts

While most traditional odor-control technologies are satisfactory for managing the odors emanating from CPI plants, some leave room for improvement in areas such as capital expenditure, maintenance, energy consumption and overall efficiency. By necessity, certain odors must be managed by specific technologies.

Other odor-control protocols may allow for some discretion. In many of these cases, dilution provides a practical, cost-effective solution, while eliminating the need for multiple, maintenance-intensive, and more-expensive odor-management systems. In fact, over the past few years, dilution has been gaining popularity as an odor-control alternative, and is worthy of further investigation.

Literature Cited

1. American Society of Heating, Refrigerating and Air-Conditioning Engineers, "ASHRAE Handbook — HVAC Applications," Ch. 44, Building Air Intake and Exhaust Design, ASHRAE, Atlanta, GA (2003).

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