

Specifying Exhaust and Intake Systems

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Entrained Air Exhausts

Entrained air exhaust manufacturers often quote an effective stack height for their system, which many designers consider when choosing the appropriate system. The effective stack height specification is based on a mathematical equation that predicts the height of the centerline of the emitted exhaust stream versus downwind distance. The effective stack height that is often presented is, in reality, the maximum height of the exhaust plume centerline at some large distance (say, 100-200') downwind of the stack and is *not* an effective stack height. What the manufacturers should supply as a specification is the "effective stack height improvement" over a conventional exhaust system. The stated improvement may not be as great as might be expected. Effective stack height specification is misleading and manufacturers should be encouraged to delete this specification and add the specification of the "effective stack height improvement" over a conventional system.

Recommended Analysis Approach

The Basic Approach

The recommended approach to evaluating the air quality aspects of exhaust stack is to perform dispersion modeling to demonstrate that expected concentrations do not exceed health limits or odor thresholds. The design recommendations and standards discussed earlier can be helpful in the design process, but they do not guarantee adequate air quality.

The air quality acceptability question can be written as:

(1) $C_{max} < C_{health}$? and (2) $C_{max} < C_{odor}$? where C_{max} is the maximum concentration expected at a sensitive location (air intakes, operable windows, pedestrian areas), C_{health} is the health limit concentration and C_{odor} is the odor threshold concentration of any emitted chemical.

When a large number of potential chemicals are emitted from a building, a variety of mass emission rates, health limits and odor

thresholds are examined. It then becomes operationally simpler to recast the acceptability question by normalizing (dividing) Equations 1 and 2 by the mass emission rate, m :

$$\left(\frac{C}{m} \right)_{max} < \left(\frac{C}{m} \right)_{health} ? \quad (3)$$

and

$$\left(\frac{C}{m} \right)_{max} < \left(\frac{C}{m} \right)_{odor} ? \quad (4)$$

The left side of each equation $(C/m)_{max}$, is only dependent on external factors such as stack design, receptor location, and atmospheric conditions. The right side of each equation is related to the emissions and is defined as the ratio of the health limit or odor threshold to the emission rate. Therefore, a highly toxic chemical with a low emission rate may be of less concern than a less toxic chemical emitted at a very high rate.

In practice, a chemical inventory for each exhaust type is examined to determine the appropriate values of $(C/m)_{health}$ and $(C/m)_{odor}$ for any released chemicals. Dispersion modeling is performed to determine $(C/m)_{max}$ for all stack designs studied. Those designs that yield concentrations lower than the design goal, i.e., $(C/m)_{max} < (C/m)_{goal}$, are the recommended exhaust stack designs.

Formulating a Concentration Design Goal

Three types of information are needed to develop normalized health limits and odor thresholds: 1) a listing of the toxic or odorous substances that may be emitted, 2) health limits and odor thresholds for each emitted substance, and 3) the maximum potential emission rate for each substance.

Substances Emitted. A list of toxic and odorous chemicals is usually obtained from the building owners. The list may be a chemical inventory or a list prepared to meet environmental regulations. Storage amounts are useful for obtaining an upper-bound estimate of the largest amount released.

Health Limits. Recommended health

limits, C_{health} , are based on the ANSI/AIHA Standard Z9.5 for Laboratory Ventilation, which specified air intake concentrations no higher than 20% of acceptable indoor concentrations. Acceptable indoor concentrations are taken to be the minimum short-term exposure limits (STEL) from the American Conference of Governmental Industrial Hygienist (ACGIH), the Occupational Safety and Health Administration (OSHA), and the National Institute of Occupational Safety and Health (NIOSH), as listed in ACGIH.

Odor Thresholds. ACGIH provides a good source for odor thresholds, C_{odor} . ACGIH critically reviews previous experimental data and lists geometric means of accepted data. For chemicals not listed in ACGIH, geometric means of high and low values provided in Ruth, 1986 are recommended.

Emission Rates. For laboratories, the emission rates are typically based on small-scale accidental releases, either liquid spills or emptying of a lecture bottle of compressed gas. The actual emission rates from experimental procedures are difficult to quantify, especially at large laboratories with diverse research. Small accidental releases have two advantages: 1) they can be considered to be the upper limit of the largely unknown release rates occurring in laboratories; and 2) they can be quantified. Evaporation from liquid spills is computed from EPA equations based on a worst-case spill within a fume hood. Typically, the worst-case spill is defined as they complete evacuation of a 0.26 gallon beaker over a 11 ft² area. Appropriate adjustments to the worst-case spill volume can be made to account for maximum storage quantities less than 0.26 gallon and for fume hood counter surface areas that are less than or greater than 11 ft².

Compressed gas leaks typically assume the emptying of a fractured lecture bottle in one minute. For other sources, such as emergency generators, boilers, vehicles, chemical emissions rates are often available from the manufacturer.

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Concentration Design Goal Selection.

Once the information on chemical usage, health limits, odor thresholds, and emission rates is gathered, the normalized health and odor limits $(C/m)_{\text{health}}$ and $(C/m)_{\text{odor}}$ are computed. The concentration design goal, $(C/m)_{\text{goal}}$, for the stack/receptor design will ideally be the minimum value of these limits for all of the chemicals. As new processes and chemicals are used in the laboratory, the quantities $(C/m)_{\text{health}}$ and $(C/m)_{\text{odor}}$ can be evaluated for each chemical added to the inventory. If these values are less than $(C/m)_{\text{goal}}$, air quality problems may arise, and usage or emission controls may be warranted.

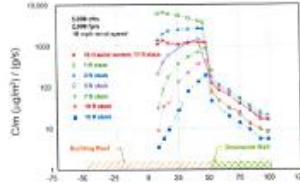
Often for a facility with intensive chemical usage, the minimum normalized concentration value is below the minimum normalized concentration achievable with a reasonable stack design. Usage controls can reduce the worst-case emission rates, m , and raise the concentration design goal to achievable levels. Such usage controls can include diluted mixtures, smaller liquid storage quantities or smaller gas bottles.

Wind-Tunnel Modeling

In the recommended approach, wind-tunnel modeling is used to predict maximum concentrations, normalized by emission rate (C/m) , for the stack designs and locations of interest. ASHRAE provides more information on scale modeling simulation and testing methods. Wind tunnel modeling is recommended because it provides the most accurate estimates of concentration levels in complex building environments.

As part of ASHRAE research project RP-805, a simple rectangular building 50' high, 50' wide and 100' long was modeled and positioned in a boundary layer wind tunnel with a simulated suburban approach wind condition. A tracer gas mixture was released from a stack installed on the roof of the model building at the building center. The simulated parameters were: 5,000 cfm volume flow rate, 2,000 fpm exit velocity, stack height varying from 1' to 12', with a 16 mph wind speed at 33'. Concentration

levels were measured on the building roof and sidewall for each condition. One test was run with a 10' solid screen positioned around an 11' stack. All other tests had an unobstructed roof.



The above figure shows the normalized concentrations (C/m) on the building roof and sidewall for the various configurations. It should be noted that string distances between 0' and 50' are on the building roof, and string distanced between 5 and 100' are on the sidewall. The figure shows the expected trend that as stack height increases, the concentrations on the roof decrease with the point of maximum C/m moving farther away from the stack location. Concentrations on the building sidewall are much lower than those on the roof for each configuration evaluated, which shows the advantage of locating air intakes on building sidewalls versus the roof.

The results in the figure can be used to assess the adequacy of the ASHRAE mathematical method. A 13' stack is recommended when the air intake is 50' from a 5,000 cfm exhaust with 3,000 fpm exit velocity. A 10' stack would be adequate to meet the $400 \mu\text{g}/\text{m}^3$ per g/s ASHRAE design criterion with a 2,000 fpm exit velocity. If the air intake is on the sidewall, there is presently no reliable mathematical method to account for the concentration decrease. Thus a conservative approach would have to be taken, which would result in a 13' stack. A 1' stack would meet the ASHRAE criterion if the air intake were on the building sidewall.

With a 10' solid screen positioned around an 11' stack, the concentrations on the roof are similar to those for a 5' stack without a screen present. Hence, the solid screen has reduced the effective

stack height by a factor of 0.4. This result illustrates the adverse effect on rooftop features, which are often not accounted for using the simplified methods discussed previously. Hence, stack heights can be specified that are not tall enough to ensure acceptable air quality.

Discussions and Conclusions

The article has provided general information regarding the need for good stack design and discusses issued that should be considered when specifying exhaust and intakes. No matter what type of exhaust system is used, the important parameters are the physical stack height, volume flow rate, exit velocity, expected pollutant emission rates and concentration levels at sensitive locations. Whether conventional or entrained air exhaust systems are used, the overall performance should be evaluated using the appropriate criterion, i.e., ensuring acceptable concentrations at sensitive locations. Selecting an exhaust system based on an effective stack height alone is not sufficient to ensure an adequate exhaust system design.

The article also presented a quantitative approach to evaluate the air quality aspects of exhaust stack design. The approach includes dispersion modeling, specifically wind-tunnel modeling, to predict maximum concentrations at sensitive locations such as air intakes, operable windows, and pedestrian areas. Concentration goals for acceptability are based on health limits, odor thresholds and emission rates of chemicals likely to be used at the facility. Using the approach for a simple building geometry demonstrated that the mathematical methods tend to give unnecessarily tall stacks heights for an unobstructed roof and give stacks that are not tall enough for a roof with obstructions.

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