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AIR QUALITY IMPLICATIONS OF RECIRCULATION FROM INDUSTRIAL DUST COLLECTORS

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ABSTRACT

ASHRAE Research Project RP-531 has demonstrated the feasibility of recirculation from industrial dust collectors to reduce energy requirements of ventilation systems.

This paper expands the mathematical modeling work of RP-531 to show how recirculation affects both particulate and gas phases.

The results signal that air quality problems can very readily be encountered when collector air, adequately cleaned of particulate, is recirculated.

INTRODUCTION

The problem of indoor air quality in the office environment has been of considerable interest to ASHRAE since reductions in outdoor air ventilation rates and tight buildings have been instituted in the marketplace to conserve energy. Indeed, since 1986, ASHRAE has been holding major indoor air quality conferences each spring (ASHRAE 1986, 1987, 1988, 1989b).

In the office environment, the subtleties of air freshness and the percentage of persons finding the air quality acceptable, plus the physiological effects of the presence of many constituents in very low concentrations, are all of interest.

Poor air quality can produce headaches, dizziness, drowsiness, fatigue, nausea, and eye and respiratory irritation. In addition to discomfort these symptoms may indicate the presence of agents producing serious long-term health effects.

The problems of the industrial environment are considerably different from those of the office. While the office environment often consists of a variety of low-level contaminants, not all of which may be known, the industrial environment, owing to the nature of either the process or operation, has had obvious and identifiable contaminants. These are regulated via the Occupational Safety and Health Administration (OSHA) to standards promulgated by the National Institute for Occupational Safety and Health (NIOSH) and the American Conference of Governmental Industrial Hygienists (ACGIH). Concentration limits, or threshold limit values (TLV), are broadly divided into three kinds: time-weighted averages (TWA), short-term exposure limits (STEL), or ceiling values (C). (For discussion, see ACGIH 1988.) Thus, if one monitors the identifiable contaminants and controls them to established guidelines, there is assumed to be safety in the workplace.

Recirculation from industrial dust collectors poses the threat of greatly increased concentrations of previously unknown or unsuspected harmful agents, particularly in the gas phases.

This paper reviews the fundamental ventilation mass balances of RP-531 and recasts them in ratios that are applicable to both the particulate and gas phases.

DISCUSSION

Modeling of Factory Floor

For purposes of illustration, Figure 1 shows a somewhat simplified model of a factory floor space.

Ventilation effectiveness and contaminant stratification are not addressed, although it is recognized that in large factory spaces these are a major concern. What is considered, however, is local control capture efficiency for the removal of dust and process off-gassing.

To calculate the contaminant concentration in a working space where contaminant is being generated, removed, or added by hood and air flows (i.e., supply air, return air, and outdoor air makeup), it is necessary to consider the mass balance of a model factory floor, as shown schematically in Figure 1. The rate of change

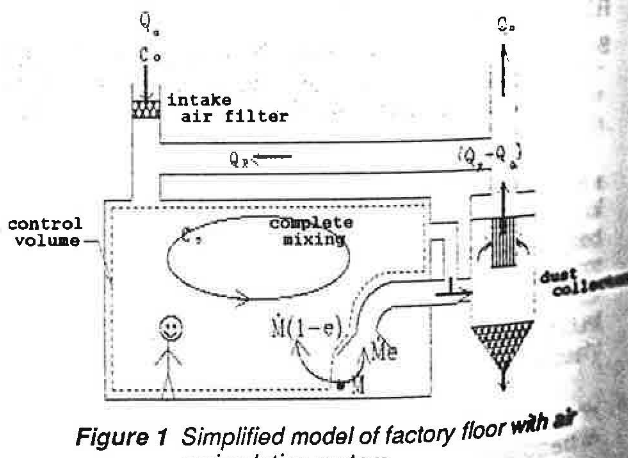

Figure 1 Simplified model of factory floor with air recirculating system

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The total mass of contaminant in the control volume, V (shown by the dotted line in Figure 1), is then

$$V\frac{dC}{dt} = \dot{M}_{generated} + \dot{M}_{introduced} - \dot{M}_{removed} \qquad (1)$$

or

$$V\frac{dC}{dt} = \dot{M}(1-\varepsilon) + \left\{ Q_oC_o(1-E_o) + \frac{Q_R}{Q_o + Q_R}(1-E)\left[C(Q_o+Q_R)+\dot{M}\varepsilon\right]\right\} - C(Q_o+Q_R) \qquad (2)$$

where

C_o = outdoor air contaminant concentration
C = room contaminant concentration
V = room volume
Q_o = outdoor air supply flow rate
Q_R = recirculated airflow rate
E = system filter efficiency (for gas phase or aerosol)
 = $E_1 + E_2 - E_1 \times E_2$
E_1 = primary filter efficiency
E_2 = safety filter efficiency
E_o = outdoor supply air filter efficiency
$\dot{M}$ = contaminant generation rate
t = time
ε = hood capture efficiency

Rearrangement and integration of Equation 2, a first order ordinary differential equation, with initial contaminant concentration of C_i, results in the following:

$$C(t) = C_s + (C_i - C_s)\, e^{(-t/T)} \qquad (3)$$

or

$$\frac{C(t)-C_s}{C_i-C_s} = e^{(-t/T)} \qquad (4)$$

where

$$C_s = \frac{\dot{M}\left[(1-\varepsilon)+\varepsilon(1-E)\frac{(Q_R)}{(Q_o+Q_R)}\right]+C_o\,Q_o(1-E_o)}{Q_o+EQ_R} \qquad (5)$$

$$T = \frac{V}{Q_o + EQ_R} \qquad (6)$$

T = time constant, the time required to reach 63% of steady state from any change in contaminant emission rate due to the change in production process or intermittent operation.

The steady-state contaminant concentration, as expressed by Equation 5, can be considered as the ratio of total contaminant entering the space and the total effective dilution air. Similarly, the time constant, T, is the ratio of the total system volume to the total effective dilution air and is a measure of the responsiveness of the designed recirculation system to the change in the plant operations.

The above equations, and other forms of them adapted for specific ventilation systems and filter placement, have had wide publication in air quality papers; Table E-1 of ASHRAE Standard 62-1989, "Ventilation for Acceptable Indoor Air Quality," being one of them (ASHRAE 1989a).

Equations 5 and 6 can be evaluated for various contaminants (gases or various size fractions of aerosols). Other items, such as settling of large particles, diffusional loss of small aerosols to the walls, or ventilation effectiveness, can be added but, for trend analysis, it is preferable to work with Equation 5.

Equation 5 may be simplified to examine problem boundaries (0% hood capture efficiency, 100% recirculation filter efficiency, etc.). This has been done in Table 1.

TABLE 1
Bounding Expressions for Workspace Concentrations from Equation 5

A. 100% efficient filtration in recirculation air loop (perfect filter):

$$C_{s,E=1} = \frac{\dot{M}(1-\varepsilon) + Q_oC_o(1-E_o)}{Q_o + Q_R}$$

B. 0% efficient filtration in recirculation air loop:

$$C_{s,E=0} = \frac{\dot{M}\left[(1-\varepsilon) + \varepsilon\frac{Q_R}{Q_o + Q_R}\right] + Q_oC_o(1-E_o)}{Q_o}$$

C. 100% hood capture efficiency (perfect hood):

$$C_{s,\varepsilon=1} = \frac{\dot{M}\,(1-E)\frac{Q_R}{Q_o + Q_R} + Q_oC_o(1-E_o)}{Q_o + EQ_R}$$

D. 0% hood capture efficiency:

$$C_{s,\varepsilon=0} = \frac{\dot{M} + Q_oC_o(1-E_o)}{Q_o + EQ_R}$$

E. Negligible outside air contribution:

$$C_{s,C_o(1-E_o)=0} = \frac{\dot{M}\left[(1-\varepsilon) + \varepsilon(1-E)\frac{Q_R}{(Q_o + Q_R)}\right]}{Q_o + EQ_R}$$

F. Recirculation prohibited (toxic gas or aerosol):

$$C_{s,Q_R=0} = \frac{\dot{M}(1-\varepsilon) + Q_oC_o(1-E_o)}{Q_o}$$

The principal concern of this paper is what happens to low concentrations of gas-phase contaminants when recirculation is accomplished with a very efficient particulate collector.

TABLE 2

Threshold Limit Values for a Few Typical Contaminants

Contaminants	Threshold Limit Value CTH, TWA	Agency
Welding fumes:		
aluminum	*5000 µg/m³	OSHA
copper	100 *	OSHA
Silica, crystalline	50-100 * (there are 4 types)	OSHA
Beryllium	2.0 *	OSHA
Arsenic (organic compound)	500 * (ceiling)	OSHA
Carbon black	3500 *	OSHA
Antimony compound (asSb)	500 *	OSHA
Lead	under court remand	OSHA
Cadmium fume	100 * (in rulemaking)	OSHA
Chromium	500 *	OSHA
Copper fume	100 *	OSHA
Oil mist (mineral)	5000 *	OSHA
Cotton dust	100 µg/m³	OSHA
Ammonia (transitional limit)	50 ppm	OSHA
Benzene	10 *	OSHA
Chlorine dioxide	0.1 *	OSHA
Fluorine	0.1 *	OSHA
Formaldehyde	3 *	OSHA
Hydrogen cyanide	10 *	OSHA
Hydrogen sulfide	20 *	OSHA
Nickel carbonyl	0.001 *	OSHA
Nitrogen dioxide (ceiling)	5 *	OSHA
Sulfur dioxide	5 *	OSHA
Toluene	100 ppm	OSHA

*As determined from breathing zone air samples.

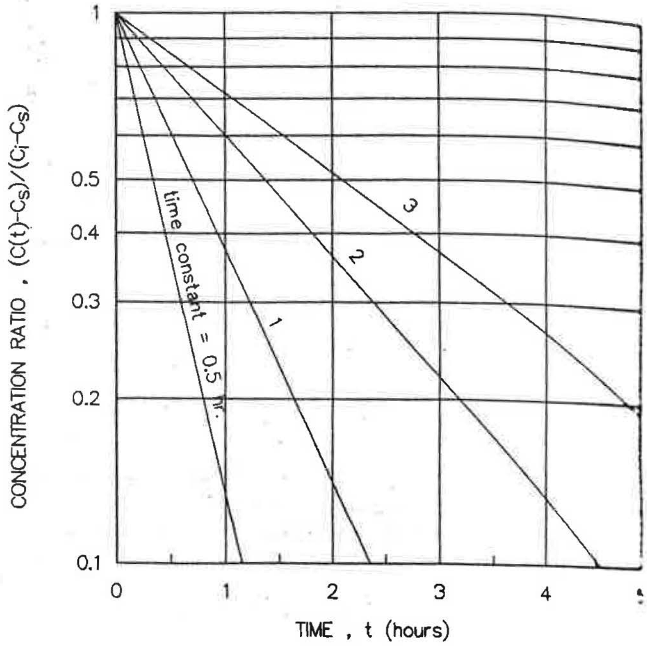

***Figure 8** System response time*

efficiency actually increases the factor, multiplying existing shop floor gas concentrations in the recirculating system.

In the industrial working environment, acceptable contaminant levels on the shop floor have been established by various government agencies (OSHA, NIOSH, ACGIH). Therefore, the work space contaminant levels, C_s, should be compared against whatever threshold values, C_{th}, are set by these agencies for the specific contaminant involved. To this end, Equation 9 is rewritten as

$$\frac{C_s}{C_{th}} = \frac{\dot{M}}{C_{th}(Q_o + Q_R)} \frac{1 + Q_R/Q_o}{1 + EQ_R/Q_o} \cdot \left[(1-\varepsilon) + \varepsilon(1-E)\frac{Q_R/Q_o}{1 + Q_R/Q_o}\right] \qquad (15)$$

The value as expressed by Equation 15 can be determined for the system with known hood capture efficiency and filter efficiency for many species of contaminants with different threshold limit values. Equation 15 is calculated for typical assumed system filter and hood capture efficiencies in Figure 7. As long as C_s/C_{th} is less than 1, the plant's working environment is in compliance with government regulations for the specific contaminant generation rate in the figure.

Some of the threshold values are listed in Table 2 for illustration. For example, for a plant designed with makeup air and recirculated air flows of 1000 cfm and 5000 cfm and system filter and hood capture efficiencies of 99.9% and 90%, respectively, the maximum total contaminant generation rate allowable in the plant for the specific contaminant with a threshold value of 3.5 µg/m³ is 6 mg/min (= 0.001 × [1000 + 5000], from Figure 7). At a higher generation rate, shop floor concentration of the contaminant will exceed the threshold limit value (i.e., $C_s/C_{th} > 1.0$).

In many industrial plants, the production processes are intermittent and the contaminant generation rate is not constant. In order to evaluate the responsiveness of the control system in cleaning up a sudden release of the contaminant, Equation 4 is plotted in Figure 8. For any system, the time constant can be calculated and the time needed to lower the shop floor contaminant level below safe levels may be estimated from the figure.

CONCLUSIONS

1. If the existing hood capture efficiency is high before the installation of an air recirculation system, the gas-phase contaminants on the shop floor may increase by several orders of magnitude after installation of an air recirculation system with a high-efficiency dust collector.

If there is no hood prior to the installation of an air recirculation system with a dust collector, the gas-phase contaminant level on the shop floor will go up by a factor equal to the ratio of the air recirculation rate and the fresh outdoor air supply rate plus one (i.e., $Q_R/Q_o + 1$).

2. Good hood design is important for improving the shop floor environment. However, if system efficiency (either for particulate or gas-phase contaminants) is very low, the improvement in hood capture efficiency will not result in a better working environment

3. For a perfect collector (e.g., efficiency > 99%), the recirculation rate is immaterial (i.e., for any Q_R/Q_o ratio), but the working environment can be improved by several orders of magnitude by improving the hood capture efficiency.

4. In general, the shop floor contaminant level can be expressed by the ratio of the net contaminant addition to the shop floor environment and the net effective clean dilution air. Since the efficiencies of the hood and filter vary with different species of contaminants (gaseous or particulate size fractions), the overall performance of the installed air recirculation system can be obtained by weighted summation or integration of all the contaminants involved.

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DISCUSSION

M. Belovicz, Principal Mechanical Engineer, Metropolitan Water Reclamation District of Greater Chicago, IL: Would the concentrations of smaller particles tend to increase?

R.R. Raber: Collector efficiencies at smaller particle sizes in the respirable range (~ .035 microns) tend to be low until a cake is built. Thus concentrations of respirable sizes will increase more than the larger sizes, even for the same filter.