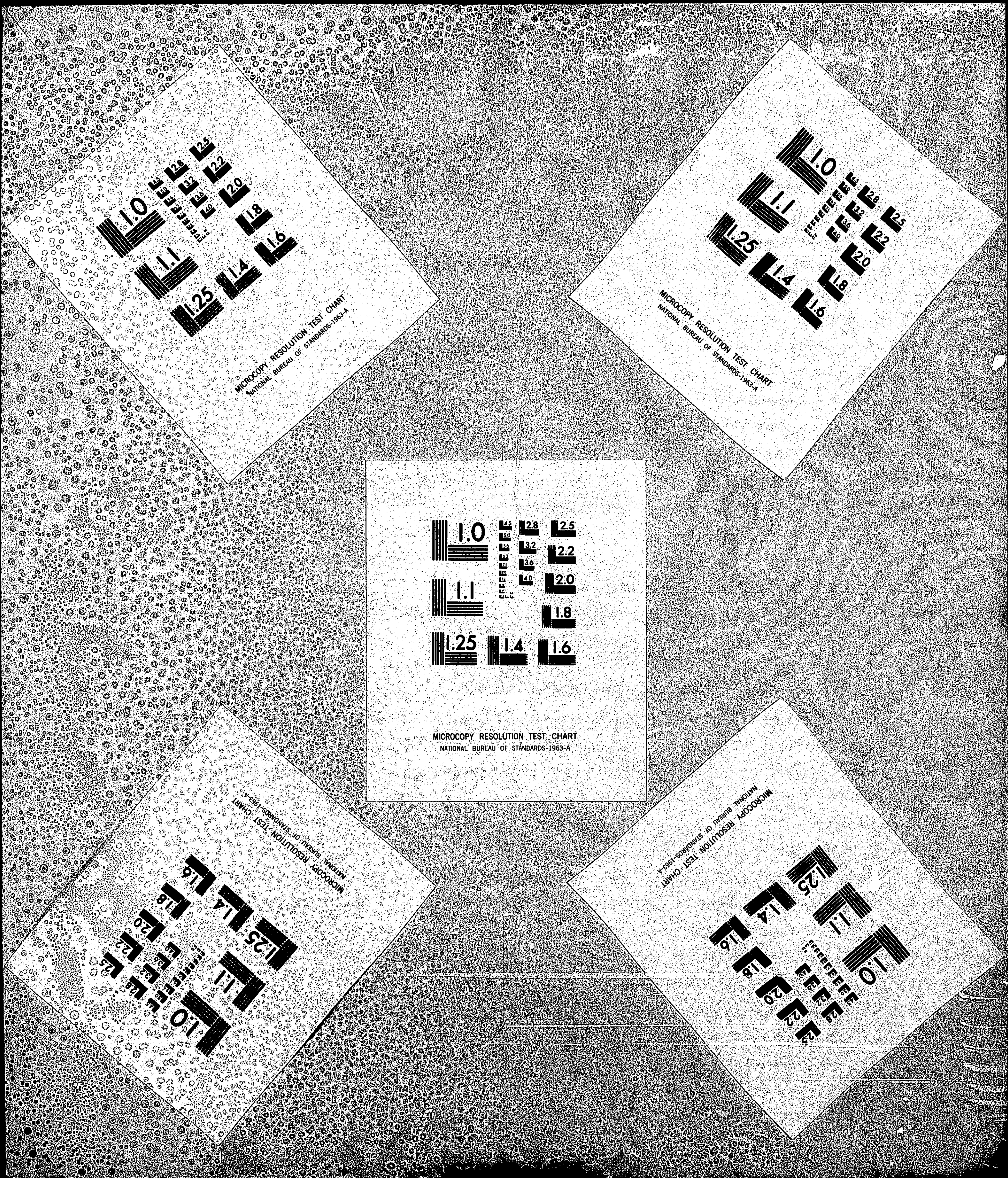
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AIR CLEANING DEVICES FOR RECIRCULATION OF EXHAUST AIR

John M. Kane*

Abstract

There is a substantial backlog of experience with industrial particulate collectors used to recirculate cleaned air. Applications have been concentrated in systems where particulates are mechanically generated and are relatively inert or nontoxic. The fabric dust collector will be the usual cleaning device, although wet dust collectors have been used for a limited number of applications. Atmospheric air cleaners seldom have dust-holding capacity for particulate removal even from general ventilation exhaust systems used in industrial operations.

Where the contaminant is a gas or vapor, recirculation has seldom been applied. The cost/benefit relationship will be least favorable where a collector is not required except to achieve recirculation benefits.

Monitoring of the workspace rather than the effluent air from the air cleaner has certain advantages and compensates for in-plant relationships of infiltration, additional exhaust ventilation, building cubical content, volume of recirculated air, and its distribution.

The design and utilization of air cleaning devices will be dependent on factors such as contaminant concentration; particle size distribution, if particulate; the degree of removal required; and conveying gas characteristics including volumes, temperature, and water vapor content. In some systems, the fire or explosion hazard will influence collector selection. With wet-scrubbing devices, corrosive characteristics affect choice, and contaminant removal from the scrubbing circuit will require evaluation. Designs for particulate removal will seldom be used for contaminants in the gas or vapor state and vice versa.

PARTICULATE COLLECTOR TYPES AND CHARACTERISTICS

Particulate collectors fall into two basic groups: 1) industrial air cleaners for removal of the heavy concentration of particulates common to industrial exhaust systems, and 2) atmospheric air cleaners for removal of the very light concentration of atmospheric suspensions.

Industrial Air Cleaners These devices are designed to remove the heavy concentrations common to local exhaust of industrial operations where concentrations are generally in the range of 0.1 to 20.0 grains per cubic foot of conveying airstream (0.23 to 46.0 grams per cubic meter). There are four basic types of air cleaners grouped by their major separation mechanisms of 1) dry centrifugal, 2) wet scrubbing, 3) fabric filtration, and 4) high-voltage electrostatic precipitator.

Of these, the dry centrifugal and the electrostatic will seldom have application for systems recirculating cleaned air back to the workspace. Collection efficiency of dry centrifugals is insignificant and practically nonexistent on the particles measuring -5 μm, so significant where recirculation

*Industrial Consultant, Louisville, Kentucky.

is considered. Ozone generation and the types of applications (high-temperature combustion, calcinning, and metallurgical stack gas cleaning) nearly rule out the high-voltage precipitator.

The design with the greatest capability for recirculation and the one with substantial application experience is the fabric arrester, known also as the fabric filter, cloth collector, and baghouse. Collection efficiency on small particulates is excellent--in fact, the highest of the mechanisms available for particulate removal. Although the collector is normally located outdoors because of its size, temperature loss is quite modest because of the limited surface available for heat transfer when compared to the pounds of exhaust system airflow. As most such systems operate in the range of 10" to 12" of water static pressure (SP), fan heat of compression produces a 5° to 6° F regain.

There has been limited application of wet particulate collectors for recirculation to the work area. Collectors are usually of the medium-pressure-drop (4" to 6" SP) range and preferably have low humidifying efficiency. Evaporation of water with the consequent increase in relative humidity can be a limiting factor in wet collector recirculation. Also, the lower collection efficiency on small particulates restricts application potential to ones of low concentration and/or larger particle size ranges. Examples would be dust from metal finishing operations and mist or droplets from plating tanks. Applications normally involve those for which fabric collectors cannot be used because of fire hazard, or adherence to or blinding characteristics to the cloth media.

Atmospheric Air Cleaners Because there are frequent attempts to use atmospheric particulate collectors ("air filters") for industrial exhaust applications, a brief discussion of this group of devices is pertinent. Collection mechanisms include dry centrifugal; viscous impingement; wet scrubbing, usually with oil as the medium; fabric filtration, including paper, cloth, and glass fibers; and low-voltage electrostatic precipitation, where ozone generation can be minimized. Devices are designed for the collection of the small-size particulates found in atmospheric suspensions, with good to excellent particulate removal ability.

Such devices are designed, however, to collect the light, invisible particulate loadings typical of outdoor air where concentrations are in the range of $0.05 \cdot 10^{-3}$ grains per cubic foot (115 micrograms per cubic meter). Because particulate loadings in local exhaust ventilation systems are seldom less than 0.1 grain per cubic foot or 2,000 times that of usual atmospheric concentrations, air filters can seldom be used for industrial exhaust air cleaning, because of their limited dust holding capacity. They do find occasional application as final cleaners after dry centrifugals on metalworking application where particle sizes are large and concentrations low. Removal of oil mist from machining operations is another example. Here the continuous draining of the collected oil drops from the collector surfaces produces a self-cleaning action.

Air filters cannot be used readily as a backup or fail-safe device downstream from a high-efficiency particulate collector without excessive maintenance costs. With a 5-grain inlet loading and a fabric collector removal efficiency of 99.9 percent, the escapement would be 0.005 grains per cubic foot of exhaust air or 100 times the usual application range for an atmospheric air cleaner.

There have been periodic efforts also to use such devices to remove the smokes, fumes, and other fine particulates that can accumulate and form visible haze in the roof truss area. Again, these concentrations are many times those of atmospheric loadings which result in excessive maintenance and replacement costs.

GAS AND VAPOR COLLECTOR TYPES AND CHARACTERISTICS

For the removal of gases or vapors from an industrial exhaust system, control devices usually employ the removal mechanisms of incineration, adsorption, or absorption.

Incineration High-temperature incineration is an effective mechanism for oxidation of organic gases, aerosols, and most odorous materials. For direct flame designs, usual temperatures are 1,200° F or higher, the retention time is 0.3 seconds or longer, and there is a turbulent gas flow. The fuel cost is substantial since most industrial exhaust systems are "lean," both because the contaminant provides little fuel value and because exhaust volumes involve so much air (10,000 cfm equal 22.5 tons per hour), generally at low to moderate temperatures.

Fuel consumption can be reduced by catalytic incineration in many systems with air entering temperatures in the range of 500° to 850° F, sufficient to sustain catalytic combustion. Gases must be relatively free of inorganic dust that would coat the exposed catalytic surfaces; free from metallics such as arsenic, lead, mercury, and zinc, which would inactivate ("poison") the surfaces; and free from gas suppressants such as halogen gases and SO_2.

Because of the high exit temperature and the gases of combustion, recirculation would be impossible except by means of an indirect heat exchanger. Indirect heat exchangers can have application to both the direct flame and the catalytic designs, although reclaimed heat is normally used to preheat the incoming gases rather than for makeup air systems.

Cost of incineration equipment and the high fuel requirements make the installation of incineration equipment impractical where air conservation is the only objective.

Absorption Wet scrubbing is the usual device for gaseous absorption. The gas flows in frequent and close contact with surfaces wetted by water often containing a reactive alkali or in some cases an acid. Packings that provide the wetted surface are usually plastic shapes with control dimensions in the 1" to 3" range. While gas flow can be horizontal (crossflow), the vertical counterflow tower is the more frequent selection for gas scrubbing applications. To provide the necessary mass transfer, beds can be 16 or more feet high with approach velocities of 300 to 400 fpm and pressure drops of 5" to 10" wg or more.

Normally, efficiencies of absorbers are tailored to meet atmospheric air quality standards and would have to be upgraded at considerable cost and power to assure in-plant air quality. Exit air is very close to saturation, making the problem of water vapor content another obstacle to recirculation.

Adsorption Where molecular weights exceed about 45, an adsorbent, usually activated carbon, will selectively capture and remove gases and vapors from an airstream. Air temperatures should not exceed 100° F, and presence of particulate matter and liquid mists contaminate the adsorbent, requiring more frequent regeneration.

Because adsorptive efficiency is reduced as retentive capacity is reached, monitoring to detect this "break point" will be essential where recirculation from an exhaust system is employed. Where more than one contaminant is involved, the one having the higher boiling point will displace the lower boiling point contaminant, requiring more frequent regeneration to maintain adsorption efficiency.

Carbon beds are quite large with airflow through the bed in the 50- to 100-fpm range. For most industrial exhaust system applications, regeneration in space using live steam will be needed along with equipment to condense and store the dislodged contaminant.

FACTORS INFLUENCING RECIRCULATION

Recirculation from exhaust ventilation systems has the potential for the savings in fuel or energy that would be expended if exhaust air were replaced with conditioned outside air. Also saved would be the capital, operating, and maintenance costs of the makeup air equipment.

There are also special situations, as when using unit collectors for small-volume applications, where the cost of expensive ducting to the atmosphere is eliminated or where movement of the contaminant-producing operation makes such a connection difficult.

Salvage Value The savings from recirculated air from exhaust systems will be a function of exhaust volume, plant location, and operating hours. It will take a substantial air volume, probably in excess of 30,000 cfm on an 8-hour-day cycle, to justify the added costs where monitoring, bypass dampers, and return air ducts offset fuel savings. Larger air volumes would be indicated where air cleaning devices have to be added or upgraded.

The fuel savings will be a function of local outdoor temperatures, usual length of the work day, and the required temperature of the incoming air. For many industrial plants, heat generated within the plant will permit a 55° F air supply temperature rather than the traditional 65° F. The impact inlet temperature and plant location on heat savings can be observed from the comparisons reported in table 1.

Note that the degree days in table 1 assume 24-hour days and 7-day weeks. For a 40-hour week, the number would be reduced by 40/168, reducing each 1,000 degree days to 238. A volume of 10,000 cfm exhausted 40 hours each week involves for each 1,000 degree days in table 1:

$$\begin{aligned}\text{BTU loss} &= 10{,}000 \text{ cfm} \cdot .075 \cdot .24 \cdot 60 \text{ minutes}\\ &= 10{,}800 \text{ Btu/hr/degree F}\\ &= 10{,}800 \cdot 24 \text{ hr} \cdot 1{,}000 \text{ degree days} \cdot \frac{40 \text{ hours operation}}{168 \text{ hr/wk}}\\ &= 61{,}714{,}000 \text{ Btu/heating season}\end{aligned}$$

($.075$ lb/ft^3 for air; specific heat = .24)

$$\text{Fuel equivalent} = \frac{61{,}714{,}000 \text{ Btu}}{140{,}000 \text{ Btu/gal} \cdot .90 \text{ boiler efficiency}} = 397 \text{ gal fuel oil.}$$

Table 1. Degree days per heating season (based on 24-hour day, 7-day week)

Air supply temperature		55° F	65° F
Degree days in:	Chicago	3,743	6,315
	Indianapolis	2,829	5,297
	Louisville	2,294	4,180
	Memphis	1,284	2,950

Table 2. Fuel savings
(gal. oil/10,000 cfm recirculated air/40-hr workweek)

Replacement air supply temperature	55° F	65° F
Gallons of fuel oil saved in:		
Chicago	1,486	2,507
Indianapolis	1,123	2,103
Louisville	911	1,660
Memphis	510	1,171

For the locations reported in table 1, the resulting fuel savings are shown in table 2. In those industries for which summer cooling requires mechanical refrigeration, similar energy savings calculations will indicate conservation potential.

Monitoring For inert or nontoxic substances (generally those where large TLV's apply), monitoring of the cleaned airstream has seldom been practical or deemed necessary for recirculated systems. For more critical contaminants, monitoring of the workroom air in strategic locations has a number of advantages over monitoring collector outlet. The impact of abnormal contaminant concentrations in the recycled air will have a variable effect on the workroom air quality, dependent on:

a. the contaminant, its concentration, and duration of the abnormal release,
b. the exhaust volume recirculated related to room volume; amount of other exhaust ventilation; the quantity of infiltrated air, and
c. the location of recirculated air release.

Impact will be minimal where recirculated air is discharged in an area where substantial exhaust of nonrecirculated air occurs, and maximum where recirculated air represents the major source of air supply.

For particulates, sampling of cleaned air effluent in the recirculated duct systems is difficult and expensive. It is hardly practical with present techniques for such monitoring duty. On the other hand, use of respiratory air samplers located at selected spots within the workspace can be readily obtained at reasonable cost. Samples could be taken daily, weekly, or less frequently depending on the contaminant, with the recognition that any short-term increase above TLV values has no "catastrophic" effect. Instead, this monitoring approach reflects and evaluates the other variables influencing air quality.

For gases and vapors, monitoring of the effluent air is technologically more practical. However, monitoring of workroom area would have the same advantages discussed for particulates. The rate of generation of most industrial contaminants is far from uniform, so monitors must gather a sample over a relatively long time interval to prevent triggering an alarm during a short-term surge.

Failsafe Protection In no case would the failure of a recirculation component introduce greater concentrations to the workspace than a component failure of the exhaust system portion used to confine and convey the contaminant from the building. Yet backup of prime mover or other system components has seldom been found necessary, and indeed would be a rarity in present-day exhaust ventilation practice.

Likewise, it is difficult to visualize an air balance situation where air bleed-in would be required to compensate for bypassing to the atmosphere the air quantities designed to be recirculated. (Dampers in the building walls would be of little help; standby wall fans or tempered makeup air units would be indicated.) Industrial buildings are far from gas-tight vessels, and infiltration will repair any unbalance caused by bypassing the recirculation leg of an exhaust system during a malfunction.

FEASIBILITY OF RECIRCULATION

1. The area of greatest appeal will be the recirculation from existing particulate collectors, where the dust is mechanically generated (by crushing, screening, conveying, mixing, packaging, etc.). Mechanically generated dusts are relatively large in particle size and most readily collected. The collection efficiency of many of the connected dust collectors, especially those of the fabric type, is ample and would require no upgrading.

2. Recirculation from the above type of systems has greatest appeal for inert or relatively nontoxic materials having a high TLV value. For more toxic materials, fuel savings can be offset by cost of necessary monitoring and the potential for employee liability litigation (see item 7).

3. Recirculation of collectors removing fumes or smoke from local exhaust systems would be questionable. The size of the particles makes collection more difficult and the potential for significant release to the workroom more probable.

4. Fuel conservation for exhaust systems where contaminants are incinerated can best be obtained by indirect heat exchangers.

5. Recirculation from local exhaust systems employing absorption or adsorption types of collectors will require system-by-system evaluation due to lack of application experience and the multitude of complex compounds involved.

6. General exhaust ventilation for removal of stray or fugitive contaminants not confined by local exhaust systems is an area where potential for recirculation does exist, because of the low contaminant concentration. Since air-cleaning-device cost is a function more of air volume than contaminant concentration, cost benefits of recirculation will be offset to varying degrees by capital, operating, and maintenance costs of the control system.

7. There can be intangible or legal drawbacks to extensive use of recirculation. Factors to be evaluated could be:

    a) employee attitudes and relationships;
    b) the current trend toward drastic reduction in established TLV values;
    c) liability for unnecessary degradation of the workroom atmosphere. This concept, used so successfully regarding external air pollution, could readily spill over into in-plant environment. The basis could be the unnecessary increase of contaminant level with the only justification being that of monetary savings to the employer.

CONCLUSIONS

Where climatic conditions indicate, recirculation of exhaust-system-cleaned air offers a substantial energy savings mechanism. Cost benefits will be greatest for local exhaust systems handling mechanically generated dusts for which high-efficiency air cleaning devices are required for external air pollution control. Recirculation from local exhaust systems handling fumes, smokes, vapors, or gases will be the least practical.

Substantial air volumes handled by means of general exhaust ventilation through roof or wall fans, usually containing dilute contaminant concentrations, deserve study of their potential for cleaning and recirculation. The first step, however, would be an appraisal of needs. There appear to be many such systems where exhaust could be eliminated or drastically reduced. Both the low cost of air movers and the small horsepower involved are conducive to oversize selection and generous application of such general ventilation units.

DISCUSSION

MR. JAMES C. WOODLING (Goodyear Tire and Rubber Company, Akron, Ohio): We have the balloons, we have the blimp. Mr. Kane, would you perhaps make a comment to those who suggested that if redundant systems are required, that filters or air cleaning devices should be series, opposed to parallel.

MR. KANE: To place a backup collector in series introduces substantial added pressure loss and horsepower consumption that it is hard to justify. In the case of fabric collectors, the pressure loss on the downstream filter will build up to significant values, because reconditioning by any of the cleaning mechanisms is quite ineffective until a dust cake or mat of considerable thickness has been accumulated.

To place one in parallel on a standby basis, if the objective is the ability to recirculate the air during a malfunction of the initial collector, would in my opinion involve an investment that could not be economically justified.

MR. KNOWLTON J. CAPLAN (Industrial Health Engineering Associates, Inc., Hopkins, Minnesota): When you're pointing out your bit about the 8-hour day on the degree days, John, if it is a one-shift operation (which it probably would be--8 hours a day) take a close look at your temperature data. The degree days of course include 24 hours a day. It's always colder at night than it is at daytime, so that you get an even additional edge or break on figuring your eating during your daytime only, and this would push the economics against the value of recirculation.

MR. KANE: Right. The difference in the temperature on a 24-hour-a-day basis is pronounced. However there are so many other variables in a heat loss calculation that few designers attempt to refine the 24-hour data. Interestingly, it appears that the degree day average for either single-shift or two-shift 16-hour day is about the same.

MR. CAPLAN: The point I want to argue with you about is that we keep overlooking the fact that with a recirculating system we have the potential for a major advantage to the health of the worker. You can handle greater volumes of air and keep the workroom atmosphere cleaner, especially if it is the kind of job where you can't get an enclosing hood. I have worked with such a one. We didn't do it both ways, of course. I hate to tell you this, but it involves lead; we used 40,000 cfm instead of what you would pick out of the handbook (25,000) because of the difficulties of capture in the first place.

MR. KANE: But Cap, wouldn't 40,000 cfm makeup air exhausted to the atmosphere do a better job?

MR. CAPLAN: That's right, but it would cost too much.

MR. KANE: There is no such thing as too much cost when it comes to protection of labor, is there?

MR. CAPLAN: I was a little bit astounded to hear you add lead to your list of no-no's. That is a time-weighted average problem.

MR. KANE: If you're doing that, you would certainly want to monitor a lot more carefully than you would if it were limestone dust.

MR. CAPLAN: Certainly.

MR. DON R. SCARBROUGH (Nordson Corporation, Amherst, Ohio): I would like to take an adverse position, come back to the tandem filter arrangement, and raise a point--that you may be dealing with a combustible dust. Now, even though the TLV may be technically acceptable in the effluent from the collector, and you may have a very breathable concentration, you cannot tolerate the accumulation of sedimented combustible dust within the factory--you're building a bomb. In this case you'll want to run a very-high-efficiency, very fine filter serially with the dust collector to polish the effluent, and then install some system between the two filters to measure an increase in pressure, should the primary filter start failing, (start leaking) and loading the secondary filter. Having interlocked the sensing device, you should shut the whole mess down before you rupture the secondary filter.

MR. KANE: Okay.

MR. JOHN T. TALTY (NIOSH, Cincinnati, Ohio): About cleaning, you didn't mention too much about cleaning devices for gases, but how would you assess the state-of-the-art there? Is it advancing, as far as application to what we are talking about?

MR. KANE: My exposure to gas cleaning installations is not frequent enough for me to be quoted. In the plants that I visit, I see no efforts at recirculation for adsorption or absorption systems. Heat recovery from incineration has attracted substantial interest although the heat is generally used to preheat the incoming gases.

MR. GUY CUSUMANO (Hoffman Dust Control, Manalpan, New Jersey): John, does not serial redundancy (our experience would bear us out in terms not blinding) work with buildup on the second filter only if the first filter is not adequately sized? Where the first filter has been adequately sized, the second one is seeing maybe .005 grains at the top level and it just never does get around to building up. It serves as a backstop or last resort, you might say, when the bag breaks.

MR. SCARBROUGH: Exactly.

MR. KANE: You mean because you can never build up a dust mat?

MR. CUSUMANO: It never builds up a dust mat. It never builds up any additional resistance over and beyond what you are already paying for in the way of initial resistance in the safety factor.

MR. SCARBROUGH: Until you tear a bag in the primary filter.

MR. CUSUMANO: Right. And we have had this experience both with pulse collectors and shaker collectors, but very good shaker collectors. Manual shaker collectors I can't speak about because I'm not involved with them.

MR. JAMES C. BARRETT (Department of Public Health, Lansing, Michigan): John, would you say a word about low-voltage electrostatic precipitators? Otherwise we will be out checking for ozones.

MR. KANE: Low-voltage electrostatic air filters do not have the ozone generation characteristic of the high-voltage industrial design. Ionizer wires are of very small diameter, which reduced the arc over potential; and because the collector plates are so closely spaced (a fraction of an inch), the voltages involved are much lower--14,000 volts as opposed to 40,000 to 60,000 volts.

MR. CAPLAN: I wanted to add a note to this discussion about what goes through a fabric filter and what you can use after it. It's kind of ironic, but the fabric filters for so many years were regarded as so good that nobody did much in the way of measuring what came through, or else they were satisfied with just the concentration. GCA Corporation has been doing quite a bit of research for EPA on this topic as it related to atmospheric pollution. They find in general that the particle size distribution of the material that comes through a fabric filter on industrial dust loadings is usually about the same size distribution as the inlet. I have noted the same phenomenon in laboratory tests that I did, even though it sounds reasonable that you get only the fines through. But if you did get only the fines through, you would have trouble with blinding on the second filter. However, I believe the leakage from a properly operating fabric filter is probably not just blown through with the airstream; it's probably a mechanical or physical migration. And it comes out the same mix as it went in; there is just less of it.

MR. MAURICE W. WEI (Aluminum Company of America, Pittsburgh, Pennsylvania): I wanted to mention something with regard to the ozone generation. In the industrial and domestic type precipitators, the manufacturers generally make the discharge electrode positive, and that way you minimize the ozone production.

MR. KANE: It is my understanding that the lack of significant ozone generation in the low-voltage precipitator results from the wire diameter and the voltage. I can recall numerous discussions between air filter engineers about the influence of positive- or negative-charged ionizer wires, but they referred to collection efficiency potential.

The extensive use of low-voltage precipitators in residential and commercial air conditioning systems indicates, in any case, that ozone concentrations have been held to an acceptable range for air supply, whether makeup or recirculated.