UTILIZATION OF AIR CLEANING EQUIPMENT IN EXHAUST AIR RECIRCULATION SYSTEMS

John T. Talty, P.E.*

Abstract

The energy crisis is providing an incentive for industry in the United States to conserve fuel. A major consideration is the recirculation of industrial exhaust air to reduce energy consumption in heating or cooling workplace air. Air cleaning equipment is an essential component of recirculation systems that must be designed to prevent occupational health problems.

Although there is a history of literature on the subject, meaningful design criteria for recirculation systems are very limited. Primary system components are air cleaning equipment and monitoring/alarm equipment. Monitoring equipment requires significant development work in order to assist in safeguarding recirculation systems.

It is very important to evaluate each case on its merits to determine the feasibility of recirculation. If feasibility is established, air cleaning equipment must be selected to properly remove specific contaminants. Air cleaning equipment (ACE) is normally designed for the removal of particulates or gases and vapors. The following ACE is considered to have potential for recirculation system design:

1. *absorbers/wet collectors,*
2. *adsorbers,*
3. *electrostatic precipitators (ESP), and*
4. *fabric filters.*

Each of these types of equipment is reviewed from the standpoint of collection mechanism, equipment configuration, performance capability, and applicability to recirculation. Cost data from 1969 for particulate collectors are also summarized.

A general approach to design of ACE is presented with the following major factors requiring in-depth study as part of the design process:

1. *characterization of air stream and contaminants,*
2. *collection required,*
3. *equipment capability,*
4. *residue disposal,*

*Chief, Control Technology Research Branch, DPSE, NIOSH, Cincinnati, Ohio.

5. *costs, and*
6. *operation and maintenance requirements.*

Options must be evaluated to arrive at a specific design approach. Current studies to improve design criteria for recirculation systems are discussed.

Research needs are discussed relating to the following subjects:

1. *ACE performance in recirculation systems,*
2. *ESP,*
3. *fabric filtration, and*
4. *wet scrubbing.*

Conclusions are presented concerning the use of commercial air cleaning equipment and an engineering design approach for recirculation systems.

INTRODUCTION

The energy crisis that has developed in the United States is a major problem facing both the public and private sectors of our nation. As we search for solutions to the problem it is evident that two approaches are necessary--conserve usage and increase the supply of energy resources. As industry searches for methods to conserve the use of energy resources, increasing attention is being given to the concept of recirculating exhaust air so as to conserve the use of energy in heating or cooling air used in the workplace.

In order to prevent the development of major occupational health problems as a result of recirculating air, it is obvious that air cleaning equipment will be a necessary component of systems designed for this purpose.

The purpose of this paper is to review the concept of air recirculation, the applicability of air cleaning equipment (ACE), and design approaches that are appropriate. A discussion of ACE research needs will also be presented. Finally, an attempt will be made to put available information in perspective and to identify certain conclusions reached.

RECIRCULATION OF EXHAUST AIR

The general concept of industrial air recirculation has been briefly discussed in the literature for many years. A literature search on the subject using the "Compendex," "Pollution," and "Bert" (NIOSH) data bases was performed resulting in 119 citations of which 7 were relevant. The earliest reference found dates back to 1952, which included a specific discussion of the "Recirculation of Cleaned Air from Dust Collectors" (ref. 1). Additional literature considered significant to the subject is identified in references 2, 3, 4, and 5. Although literature does exist on the subject, actual documented industrial experience is very limited, and technical design criteria for recirculation systems have not been developed in sufficient detail.

It should be made clear that the applicability of air recirculation is limited in consideration to air that would otherwise be discharged through an exhaust system to the atmosphere from a ventilation system. An exhaust system is defined to include hoods, ducts, fans, air cleaners, and necessary monitoring equipment. The concept is not intended to apply to industrial process air, from a furnace for example, which would normally be discharged to the atmosphere through a stack. The basic concept is to return cleaned air to the workplace to reduce the use of energy to heat or cool makeup air. The recirculated air must not produce excessive contamination of the workplace. Established occupational health standards for contaminants provide minimum design criteria that a recirculation system must be able to achieve (ref. 6).

The primary control equipment that must be designed as integral components of a recirculation system are suitable air cleaner and monitoring/alarm equipment. Air cleaners, the primary subject of this report, are discussed in detail in the following sections of this paper.

The basic purposes of contaminant monitoring in a recirculation system are to provide documentation of contaminant levels at specific points in the system and to trigger an alarm mechanism and remedial action if system failure occurs. Failure is defined as discharge of recirculated air to the workplace, which would result in worker exposure to contaminants at levels that exceed Occupational Safety and Health Administration (OSHA) standards. Monitoring equipment capability is considered to be a weak link in the technology for recirculation systems requiring significant development work (ref. 7).

AIR CLEANING EQUIPMENT

This discussion of air cleaning equipment (ACE) will cover the types of contaminants that are considered recirculatable and that require removal, the basic types of cleaning equipment, the expected performance and limitations of cleaning equipment, and cost data. The discussion will be focused on use of ACE for primary collection of contaminants, recognizing that precleaning and postcleaning may also be necessary for specific systems.

A basic premise that should underly consideration of the utilization of ACE in recirculation systems is that only those substances for which safe air quality levels have been established or that are known with confidence to be nonhazardous to workers health should be considered recirculatable. In the context of this paper, a safe level is equivalent to an OSHA standard air concentration for particular contaminants or mixtures (ref. 6). A review of 541 single substances has been performed by Southwest Research Institute and it was concluded that 158 contaminants should not be considered for recirculation (ref. 8). The specific criteria for exclusion are quite complex and are presented in the referenced report. The point of this information is that considerable discretion must be used in making a judgment as to whether recirculation should be considered in a particular plant, in advance of attempting to select ACE capable of removing specific contaminants. Once this judgment to recirculate has been made, it is then essential to select or search for ACE that is capable of sufficient contaminant removal.

Air contaminants may be classified as gases and vapors or particulates and may occur singly or in mixtures. This classification also provides a useful basis for discussion of the basic types of ACE available.

Table 1. Major types of ACE in use in industry.

Types of cleaning equipment	Primary contaminant collected: Gases and Vapors	Particulates
Absorbers	X	-
Adsorbers	X	-
Incinerators	X	-
Electrostatic precipitators	-	X
Fabric filters	-	X
Mechanical collectors	-	X
Wet collectors	-	X

It is also true that gases and vapors may also be combined with particulates in a particular exhaust airstream and the overall cleaning problem increases in complexity. Recognizing the potential complexities, the basic types of ACE will now be discussed including a description of the capability associated with each. Combinations of ACE in a particular plant may indeed be necessary to properly cope with the airstream contaminants of concern.

As shown in table 1, ACE includes seven basic types of equipment. Although incineration is an effective mechanism for oxidation of organic gases and most odorous materials, the equipment cost and large fuel requirements eliminate it as a realistic technique for recirculation for energy conservation (ref. 9). Mechanical collectors have very poor collection efficiency for smaller particles and are also not considered applicable to recirculation systems (ref. 9). Seven sources were used as basic references in developing the following discussion of equipment that does have potential application to recirculation system design (refs. 10, 11, 12, 13, 14, 15, and 16).

It should be noted that there is a wide variety of ACE that is commercially available. Based on a 1977 Product Guide review (ref. 17) the information in table 2 was obtained to place the subject in perspective.

Gas and Vapor Collection

Absorbers--
Gas absorption is a mechanism by which constituents are removed from a gas stream by dissolving them in a selective liquid solvent. Absorption equipment is designed to provide thorough contact between the gas and liquid solvent, to allow interphase diffusion of materials. The contact can be achieved by dispersing gas in a liquid solvent or liquid solvent in a gas. Absorbers that use liquid dispersion include packed towers, spray towers or spray chambers,

Table 2. Emission control equipment.

Type	Item having largest no. of manufacturers	No. of manufacturers-
Inertial separators	Cyclone separators	65
Scrubbers and washers	Mechanical scrubbers	64
Fabric and filter collectors	Complete baghouses	65
Other equipment	Direct flame fume incinerator	56
Fans and blowers	-	40

and venturi absorbers. Equipment that uses gas dispersion includes plate towers and vessels with sparging equipment.

Packed towers are commonly filled with plastic shapes which, when wetted by the solvent, present a large area of liquid film for gas contact. Usual flow conditions are countercurrent with the liquid introduced at the bottom flowing upward. This equipment is usually preferred for smaller installations with the preferred tower diameter less than 2 ft.

Spray towers and chambers achieve interphase contact by dispensing the solvent as a spray and passing the gas through it. This equipment is preferred when pressure drop is a major concern and where solid particles exist in the gas stream.

Venturi absorbers achieve interphase contact by means of the differences between the gas velocity and liquid velocity, and the turbulence in the throat. This equipment obtains good liquid-gas mixing but has the disadvantage of short contact time and high pressure drop.

In contrast to packed towers, plate towers employ stepwise contact by means of a number of plates arranged so the gas is dispersed through a liquid layer on each plate. Plate towers are usually selected in larger sizes and where the solvent liquid contains suspended solids that tend to plug packed towers.

A simple method of dispersing gas in a liquid is by injection of the gas through a perforated pipe into a vessel filled with the solvent liquid. This is sparging.

In general, absorber removal efficiencies would require upgrading to achieve acceptable in-plant air quality levels. Exit air from absorbers is close to saturation and would also present a potential water vapor problem in the plant. Absorbers would have limited application in recirculation system design.

Adsorbers--

Gas adsorption is the phenomenon by which molecules of a fluid contact and adhere to the surface of a solid material. By this process, gases at very small concentrations can be selectively removed from airstreams by specific materials called adsorbents. The constituent adsorbed is called the adsorbate. The most important characteristics of adsorbents are their large surface-to-volume ratios and preferential affinity for individual constituents. The adsorptive power of any adsorbent may vary significantly with the method by which it is prepared as well as the nature of the gas or vapor adsorbed. In most adsorption processes, three steps are involved. First, the adsorbent is contacted with the fluid, and a separation by adsorption results. Second, the unadsorbed portion of the fluid is separated from the adsorbent. Third, the adsorbate is removed from the adsorbent, which thereby regenerates the adsorbent.

Solids possessing good adsorptive properties are numerous. Activated carbon, silica gel, alumina, bauxite, and molecular sieves are some of the widely used adsorbents for gas cleaning.

Adsorption systems are generally of the cyclic, fixed-bed type or the fluidized- and moving-bed type. Most systems are of the fixed-bed design based on a permissible airflow rate and breakthrough of the adsorption zone. The pressure drop in fixed-bed units is higher than fluidized units due to the gas flow through the entire bed, rather than just the adsorption zone. Fixed-bed design requires prediction of the length of adsorption and the desorption cycle. Fluidized beds operate by countercurrent contact of gas and solids. They offer the advantage that for a given pressure drop and cross-sectional area, high gas rates may be used.

Since adsorption efficiency is reduced as retention capacity is approached, monitoring to identify breakthrough is essential in adsorption systems that would be used in recirculation systems. Also, the presence of particulates in the gas stream contaminates adsorbent materials and would necessitate frequent regeneration of the adsorbent. Adsorbents should have wide application in recirculation system design as primary equipment for the collection of gases and vapors.

Particulate Collection

Electrostatic Precipitators--

Electrostatic precipitation (ESP) is a process which utilizes forces on electrically charged particles in the presence of an electric field to effect the separation of particles from a gas stream. The principal functions of the process are as follows:

1. generation of corona,
2. particle charging,
3. particle collection, and
4. particle removal.

Corona is a gas discharge phenomenon associated with the ionization of gas molecules by electron collision in regions of high electric field strength. The process requires a nonuniform electric field which is obtained by the use of a small diameter wire as one electrode and a plate or cylinder as the other electrode. The corona is positive if the wire electrode is positive, and negative if the wire electrode is negative. Negative corona permits operation at higher voltage and is used for most industrial applications.

Recent literature has reported results of laboratory studies that indicate that both ozone and oxides of nitrogen may be produced in the corona discharge of ESP (refs. 18 and 19). Both contaminants are hazardous to health at low concentrations and must be considered a disadvantage in considering the applicability of ESP in air recirculation systems. The following design procedures have been identified to minimize the production of contaminants in an air atmosphere:

1. use a positive corona,
2. select a corona wire of the smallest possible diameter, and
3. heat the corona wire.

The forces acting on a charged particle in a precipitator are gravitational, inertial, electrical, and aerodynamic. The latter two are the principal collection forces in ESP. The collection of a particle depends upon the probability that it will enter the region where the electrical force will result in its deposition on the collection surface. Gas flow is generally turbulent in ESP and this flow determines the trajectory of dust particles in the interelectrode region. The particle velocity due to electrical force is significant only in the region adjacent to the collection electrode. The following equation expresses the theoretical collection efficiency in ESP (ref. 13):

$$\eta = 1 - \exp - \frac{A}{Q} w \qquad (1)$$

where η is the efficiency, A is the collection surface area, Q is the gas flow rate, and w is the precipitation rate parameter or effective migration velocity of a particle. In order to obtain an overall collection efficiency, an integration of the above equation for the specific dust particle size distribution range would be necessary.

Once collected at the electrode, the particles must be removed from the ESP. This can be accomplished by means of a liquid flowing down the electrode to wash down the particles or by rapping the electrodes to dislodge the particles. The advantages of wet removal are the minimization of dust reentrainment and elimination of dust resistivity. Some wet removal problems include corrosion, scaling, and slurry disposal. The principal problem with dry removal methods, rapping, is dust reentrainment. Rapping frequency and intensity require close attention in order to minimize reentrainment.

Dust resistivity is one of the major factors limiting ESP performance. If the collected dust is of high resistivity, the current density will be limited by breakdown of the interstitial gases in the dust layer. The two principal methods of overcoming dust resistivity problems are by means of operation at temperatures that will produce a desirable resistivity and the addition of chemical conditioning agents to the gas. The low temperatures prevalent in most exhaust systems should present minimal dust resistivity problems.

The design of ESP equipment is normally based on collection efficiencies ranging from 90 to 99 percent, including small particles. Design is based on equation (1) with the precipitation rate parameter, w, being the most important consideration. In practice, the selection of w is made taking into account reentrainment, uniformity of gas flow, electrical sectionalization, and other factors. ESP with positive corona may have applicability to recirculation system design.

Fabric Filters--

Fabric filters capture and retain particles by means of simple sieving for large particles, and by means of inertial impaction, diffusion, gravitational settling, and electrostatic attraction. Once a mat or cake of dust particles is accumulated, additional small particle collection is achieved by sieving, as well as by the above mechanisms. Fabric filters are made of woven or felted textile materials in the shape of a cylindrical tubular bag or flat, supported envelope bag. Some commonly used fabrics are cotton, wool, nylon, acrylics, and glass. The filter material is retained in a metal housing with inlet and outlet gas connections, dust storage hopper, and a mechanism for periodic cleaning of the fabric.

The operation cycle of the fabric filter includes two phases. The first is the filtration phase when particles are being deposited and accumulate on the fabric as the pressure drop across the dust deposit increases and airflow decreases. The second phase is the cleaning operation for dust removal with no filtration flow. The two phases also serve as a basis for classification of filters with regard to filtration and cleaning mechanisms.

Both tubular and envelope filter elements are usually installed vertically, allowing dust to fall to a collection point for disposal. Gas is usually introduced at the bottom of a compartment with upward flow. Another major variable is whether the dust will collect on the inside or outside of the filter element.

The cleaning process may be manual or automatic. The most common cleaning methods are by shaking or reversing the flow through the filter cloth. Shaking methods include the following:

1. horizontal or vertical shaking of one end or all of the filter element,
2. vibrating or rapping,
3. fluttering with air currents,
4. snapping with a compressed air pulse, and
5. sonic cleaning.

Flow reversal methods include the following:

1. forcing the cake off by back pressure,
2. collapsing the cloth resulting in flexure and cracking of the cake,
3. snapping with a compressed air pulse, and
4. blowing the cake off with a jet of air.

Although filtration theory has been developed in depth, it is difficult to relate collection efficiency and pressure drop to the actual operation of fabric filters. Most industrial design is therefore based on past experience and industry practice. The primary design parameters are as follows:

1. air-to-cloth ratio (airflow/cloth area) or filtering velocity,
2. fabric and dust resistance,
3. selection of fabric material, and
4. selection of cleaning method.

Basic equations are available to estimate resistance, or pressure drop. The total pressure drop is the sum of the basic fabric resistance plus the dust resistance. The following equations express this relationship (ref. 10):

$$\Delta P_f = K_f \times V_f, \quad (2)$$

$$\Delta P_d = K_d \times V_f \times C_d, \text{ and} \quad (3)$$

$$\Delta P_{total} = \Delta P_f + \Delta P_d \quad (4)$$

where

ΔP_f = fabric/residual dust resistance, in. of H_2O

K_f = fabric resistance factor, in. of H_2O/ft/min

V_f = filtering velocity, ft/min

ΔP_d = dust cake resistance, in. of H_2O

K_d = dust resistance coefficient, in. of H_2O/ft/min/grains/ft^3.

C_d = dust loading, grains/ft^3.

Fabric filters provide very high collection efficiencies, exceeding 99 percent, including small particles, with pressure drops of 4 to 6 in. of H_2O. Some potential disadvantages of filters are that liquids can cause failure and some dusts can present a fabric fire or explosion hazard. Fabric filters are considered to have extensive applicability to the design of recirculation systems.

It should be noted that fiber filters, commonly used in air conditioning systems, may also have application for small installations with very light dust loadings.

Wet Collectors--

Wet collection is accomplished by the mechanisms of inertial impaction, impingement or interception, diffusion, thermal gradients, and electrostatic attraction. Particle wetting characteristics, condensation of moisture, and liquid evaporation also have an impact on collection of particles. Generally, inertial impaction and interception are the predominant mechanisms for particle collection in wet collectors. Inertial impaction occurs when a particle in the gas approaching a droplet separates from the path of its gas streamline around the droplet and continues on to collide with the droplet. When a particle follows the path of the streamline around the droplet, and a streamline carrying a particle passes within $d_p/2$ from the droplet surface, where d_p = the particle diameter, interception occurs.

There are some 15 categories of wet collectors or scrubbers and from 20 to 30 design variations in each category. Wet collectors may be broadly classified as low- or high-energy scrubbers. Low-energy scrubbers with 1- to 6-in. water gauge pressure drop include simple spray towers, packed towers, and impingement plate towers. High-energy scrubbers with pressure drops of 10 to 35 in. water gauge include the venturi type. Scrubbers may also be categorized on the basis of principle of operation as follows:

1. gravity spray,
2. centrifugal or wet cyclone,
3. self-induced spray,
4. impingement plate,
5. packed bed.
6. venturi, and
7. mechanically induced spray.

Discussion of the details of each of these types of equipment is beyond the scope of this paper but may be found in other sources (refs. 11 and 14).

The following equation expresses the collection efficiency for wet scrubbers (ref. 11):

$$\eta = 1 - \exp(-N_t) \tag{5}$$

where η is the efficiency and N_t is the dimensionless transfer unit that describes the gas-liquid contacting power. Equations to determine the value of N_t have been developed for various types of wet scrubbers (ref. 11).

The collection efficiency of wet collection devices is related to the energy input to the equipment. The high operating cost of high-energy scrubbers can result in total costs as high as high-temperature fabric filters and ESP. The high-energy scrubbers can achieve collection efficiences from 90 to 99 percent for small particles and may have applicability to recirculation system design. Low-energy scrubbers have much lower collection efficiencies for small particles, from 40 to 80 percent, and would have very limited applicability to recirculation systems.

Cost Data

Cost data on ACE can be found in a number of sources. However, data are scarce regarding absorbers and adsorbers, most likely because each installation is assumed to be unique and often proprietary. With regard to particulate collectors two primary sources have been identified (refs. 5, and 16). Cost data, dating from 1969, are summarized in table 3 for three types of particulate collection equipment (ref. 16).

Of note in this summary are the generally higher installation costs of fabric filters over ESP equipment, and the high operating cost of wet collectors. It should also be noted that all of the data are not presented on a comparable basis.

Table 3. Cost data for particulate collection equipment.

Type of collector + gas flow extremes	Installed cost range ($1,000)	Annualized operating cost range ($1,000)
Wet collector @ 5,000 acfm	3 - 20	1 - 10
Wet collector @ 350,000 acfm	60 - 400	60 - 400
High voltage ESP @ 20,000 acfm	35 - 100	5 - 15
High voltage ESP @ 1,000,000 acfm	500 - 1,200	90 - 200
Low voltage ESP @ 5,000 acfm	10 - 25	2 - 3
Low voltage ESP @ 100,000 acfm	150 - 350	20 - 50
Fabric filter @ 10,000 acfm	10 - 35	3 - 6
Fabric filter @ 1,000,000 acfm	600 - 1,800	200 - 300

It should be noted that variation in ACE cost, especially on an installed basis, is difficult to estimate, and the use of comparative figures is to be done only with caution. Some factors that are variable and make useful cost data difficult to obtain are price variability with volume capacity, accessories included, installation costs, and special construction.

DESIGN APPROACH

The design of air cleaning equipment as components of recirculation systems does not involve a single approach. Many parameters must be identified and interrelationships must be understood as the first step of the design process. There are six general areas that must be evaluated in order to proceed with design:

1. Characterization and variability of airstream and contaminants to be recirculated:
   a. gas properties,
   b. contaminant properties,
   c. mass flow rate, and
   d. buildup of contaminants;
2. Collection required:
   a. gas removal,
   b. particulate removal, and
   c. allowable exhaust and work area concentrations;
3. Equipment capability, limitations, and reliability:
   a. wet or dry system, and
   b. efficiency;

4. Residue disposal:
   a. liquid waste, and
   b. solid waste;
5. Costs:
   a. purchase,
   b. installation, and
   c. operating; and
6. Operation and maintenance requirements.

Characterization is a very important consideration and should include determination of gas volume, temperature, and moisture content; particle size distribution, density, explosiveness, and concentration; and gas and vapor concentrations.

The selection of a particular piece of air cleaning equipment is based on the degree of contaminant removal that is required. In recirculation systems it must be recognized that monitoring equipment must also be built into the system to help insure proper performance. The general capability and limitations of existing ACE have been previously reviewed in this paper. However, each design must be approached with the objective of acquiring current equipment performance data in order to make the best selection possible.

The disposal of ACE residue is a very important consideration, whether the residue is in the liquid or solid state. This operation must be recognized as an integral component of the cleaning process requiring design attention and cost.

Meaningful cost data are very hard to obtain and use with confidence. Again, each design must include a specific effort to obtain the best available cost figures to form a basis for achieving the best performance for the least cost.

Poor maintenance and improper operation of ACE must be prevented since such practices could result in the return of highly contaminated air to the breathing zone of workers. The proper time to initially address operation and maintenance (O & M) requirements is during the design phase. A specific O & M plan should be developed as a major element of each design.

The design process is not complete without the analysis, in some depth, of alternative solutions to the problem. The viable options should be identified early in the design process and examined in terms of design configuration, performance, and cost.

Initial efforts have been performed to develop design criteria for recirculation systems including analytical models to predict system performance (ref. 8). Contractual studies sponsored by the National Institute for Occupational Safety and Health are underway to further develop design criteria, and conduct criteria validation studies, including pilot studies of air cleaning/monitoring equipment installations. It is expected that the results of these studies will aid in the establishment of a firm basis for the design of ACE in recirculation systems in the future.

RESEARCH AND DEVELOPMENT NEEDS

The identification of research and development (R & D) needs is not an easy task, regardless of the technical subject of concern. This is true with regard to the cleaning of exhaust air for industrial recirculation systems. The following discussion will be focused on such needs based on this paper and literature sources. Although there are apparent research needs associated with gas and vapor absorption and adsorption cleaning equipment, literature sources do not generally address such research needs. Therefore, those needs will not be discussed in this paper. The general areas to be discussed include:

1. performance of cleaning equipment in air recirculation systems,
2. electrostatic precipitation,
3. fabric filtration, and
4. wet scrubbing.

In general, there is a clear need for the development of valid design criteria and the generation of performance data related to the design and operation of air cleaning equipment, both primary and secondary, as components of industrial exhaust air recirculation systems. Engineering laboratory and field research is needed to verify both the design criteria and performance data for common industrial operations where energy conservation needs are likely to result in firm incentives to recirculate. Data are lacking at the present time to determine exactly how ACE will perform in the context of air recirculation systems. For particulate collection the data must be obtained on the basis of establishing in-duct particle size distribution and determining the fractional efficiency of collection equipment utilized.

It should be noted that existing test methods and performance data have been established in the context of domestic and commercial air filtration applications. Testing methods and performance data for industrial applications must be developed and published in order to advance the state-of-the-art and the use of ACE with confidence in recirculation systems.

ESP research needs have been comprehensively addressed in a report completed in 1970 (ref. 13). Although nearly 7 years have passed, the needs generally remain valid and the relevant needs are specified below:

1. Refine the system model developed in the report.
2. Determine the role of turbulence and electric wind on precipitator performance.
3. Conduct fundamental studies of spark propagation to define voltage and current relationships.
4. Develop quantitative data to relate reentrainment to dust resistivity.
5. Determine the effect of dust layers on corona generation.
6. Develop improved techniques for collection of small particles.
7. Develop techniques for the collection of high resistivity dust.
8. Conduct research on the application of ESP to the following industries:
    a. pulp and paper,

   b. metallurgy, and
   c. cement.
9. Develop improved methods for specifying equipment and contracting to provide adequate assurance of proper performance.

An additional area of ESP research is to develop techniques to prevent the generation of gaseous contaminants from the corona discharge (refs. 18 and 19).

Fabric filter research needs were also developed in a report issued in 1970 (ref. 5). The basic needs that are relevant to this paper and remain valid are as follows:

1. Develop basic data relating particle properties to operating performance and cost.
2. Develop basic data on performance and cost of available fabric media and their surfaces.
3. Determine how improved fibers can be developed for use in filtration systems.
4. Develop improved techniques for system design.
5. Identify and evaluate new fabric filter applications.

Wet scrubbing research needs were documented in a report issued in 1972 (ref. 14). The basic needs identified are as follows:

1. Investigate the basic concepts of collection to improve the basis for design.
2. Develop basic data to better define physiochemical parameters.
3. Develop improved equipment incorporating the results of items 1 and 2.
4. Develop improved methods of engineering design and optimization of systems.
5. Develop improved monitoring instruments and evaluate the dynamic response to upsets.

A number of the needs identified above are not unique to a particular type of air cleaner. Specifically, item 9 under the ESP needs, items 1 and 4 under the fabric filter needs, and each of the items under the wet scrubber needs have general application to ACE.

The control equipment industry is a key factor in attempts to fill the above research gaps. In particular, the industry needs to address the need for ACE designed for use in industrial air recirculation systems. This is not to say that existing equipment is not adaptable; however, both airflows and contaminant concentrations in exhaust air systems can differ considerably from those encountered in process effluent airstreams. A recent technical journal article implies that the long-term outlook for control equipment is totally directed to developing equipment to meet air pollution control requirements (ref. 20). Such trends are encouraging, but other applications must not be overlooked, such as recirculation systems.

SUMMARY AND CONCLUSIONS

The energy crisis is providing an incentive for industry in the United States to conserve fuel. A major consideration is the recirculation of exhaust air to reduce energy consumption in heating or cooling workplace air. Air cleaning equipment is an essential component of recirculation systems that must be designed to prevent occupational health problems.

Although there is a history of literature on the subject, meaningful design criteria for recirculation systems are very limited. Primary system components are air cleaning equipment and monitoring/alarm equipment. Monitoring equipment requires significant development work in order to assist in safeguarding recirculation systems.

It is very important to evaluate each case on its merits to determine the feasibility of recirculation. If feasibility is established, air cleaning equipment must then be selected to properly remove specific contaminants. ACE is normally designed for the removal of particulates or gases and vapors. Subject to the limitations previously discussed, absorbers, adsorbers, electrostatic precipitators, fabric filters, and wet collectors are considered to be applicable to recirculation system design.

Each of these types of equipment has been reviewed from the standpoint of collection mechanism, equipment configuration, performance capability, and applicability to recirculation. Cost data from 1969 for particulate collectors have been summarized.

A general approach to design of ACE is presented with the following major factors requiring in-depth study as part of the design process:

1. characterization of airstream and contaminants,
2. collection required,
3. equipment capability,
4. residue disposal,
5. costs, and
6. operation and maintenance.

Options must be evaluated to arrive at a specific design approach. Current studies to improve design criteria for recirculation systems are discussed.

Research needs are discussed relating to ACE performance in recirculation systems, ESP, fabric filtration, and wet scrubbing.

The following are the major conclusions that have been reached in this paper.

1. There is a growing interest in the recirculation of industrial exhaust air.
2. Valid design criteria and performance data are badly needed to provide a sound basis for design of recirculation systems.
3. Reliable monitoring/alarm equipment needs to be developed to function in conjunction with air cleaning equipment and aid in safeguarding recirculation systems.

4. There is a wide variety of air cleaning equipment commercially available that has potential application in recirculation systems, including absorbers, adsorbers, electrostatic precipitators, fabric filters, and wet collectors.
5. A comprehensive engineering design approach must be rigorously applied to air cleaning equipment in recirculation systems to insure optimum performance and worker protection.
6. Major R & D for air cleaning equipment is needed to improve the overall capability of the equipment. Laboratory and particularly field investigations are needed to evaluate the performance of such equipment in the context of recirculation systems. The control equipment industry is a key factor in attempts to fill research gaps. Both test procedures and performance data need to be established to define the capability of ACE in industrial applications.

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DISCUSSION

MR. JOHN ASHE (American Air Filter Co., Louisville, Kentucky): The ESP does exhibit a very low operating resistance or pressure drop. I believe that is why the chart showed the low voltage ESP as a low operating cost device. As a point of clarification, there are two types of electrostatic precipitators, low and high voltage. Very definitely, speaking for the industry, the high voltage type ESP is not recommended for recirculation systems while the low voltage type is.

Ozone emission from the high voltage ESP could be a problem. The low voltage type, however, was specifically designed to minimize ozone emission and has been used for commercial heating, ventilating, and air conditioning systems since the mid 1930's. Gaseous particulate emission, especially ozone, has been a subject of concern to the industry for years. ESP's have been traditionally used for commercial ACT systems, and through modification of design and applicability internal R & D learned where it was generated, and it has been a subject of general control. In fact, in some of our field tests we've found that the outside level has exceeded that given off by ESP. In certain laboratory applications where absolute control is desired, a two-stage approach is used where ESP is followed by an absorber, specifically activated carbon, and solved it. However, the normal emission level is significantly low with respect to TLV, according to our tests.

MR. TALTY: I don't think I disagree with anything you said. I think I was pointing out the fact that such contaminants can be generated.

MR. WILLIAM CHENEY (United Air Specialists, Cincinnati, Ohio): The problem is that for years this has been mentioned and never been put to rest. I'm not acquainted with the test that he referred to. I'm acquainted with some of our own, and the ozone production is well below TLV. Honeywell had a test run on their residential air cleaner, and again the internal air going through the ESP was much below the ozone level present outside, and I would like to see if anyone has evidence that the ozone produced by ESP exceeds that TLV for factory air. The State of Pennsylvania for years had a ruling that ESPs could not be used for recirculation of air because of the deadly ozone condition.

MR. TALTY: I think there are data available as to what the generation rate is. You're saying that the gas is generated at a concentration less than the TLV for ozone?

MR. CHENEY: I'm saying factory air in any normal ESP application is well below it.

MR. TALTY: I don't have data at hand that would contradict or support that, and it would be good to cite the data if you can make it available.

MR. CHENEY: I would be glad to give it to you. The question comes up so often I would like to have it clear at some authoritative level. I think it is erroneous.

THE RECIRCULATION OF INDUSTRIAL EXHAUST AIR

Symposium Proceedings

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NIOSH Project Officer: Alfred A. Amendola
Principal Investigator: Franklin A. Ayer

FOREWORD

These proceedings of the symposium on "The Recirculation of Industrial Exhaust Air" are submitted under Contract No. 210-77-0056 to the National Institute for Occupational Safety and Health of the U.S. Department of Health, Education, and Welfare. The symposium was held in Cincinnati, Ohio, on 6-7 October 1977.

The objective of this symposium was to discuss the development of technical criteria for the recirculation of industrial exhaust air. With emphasis on the protection of the worker's health, technical subject matter discussed included: (1) decision logic for determining recirculation feasibility; (2) design and performance guidelines for recirculation systems; (3) availability of air cleaning and monitoring systems; and (4) maintenance guidelines.

Mr. Robert T. Hughes, Chemical Agents Control Section, Control Technology Research Branch, Division of Physical Sciences and Engineering, National Institute for Occupational Safety and Health, Cincinnati, Ohio, was the Symposium General Chairman.

Mr. Alfred A. Amendola, Control Technology Research Branch, Division of Physical Sciences and Engineering, National Institute for Occupational Safety and Health, Cincinnati, Ohio, was the Symposium Vice-Chairman and Project Officer.

Mr. Franklin A. Ayer, Manager, Technology and Resource Management Department, Center for Technology Applications, Research Triangle Institute, Research Triangle Park, North Carolina, was the Symposium Coordinator and Compiler of the proceedings.