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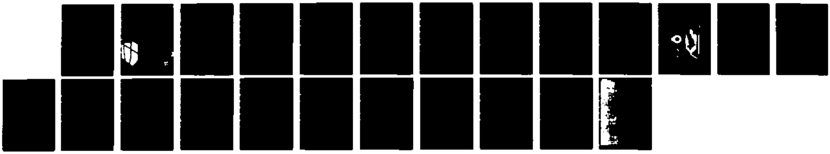

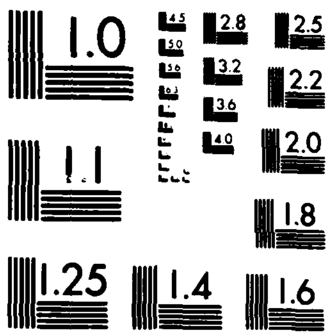

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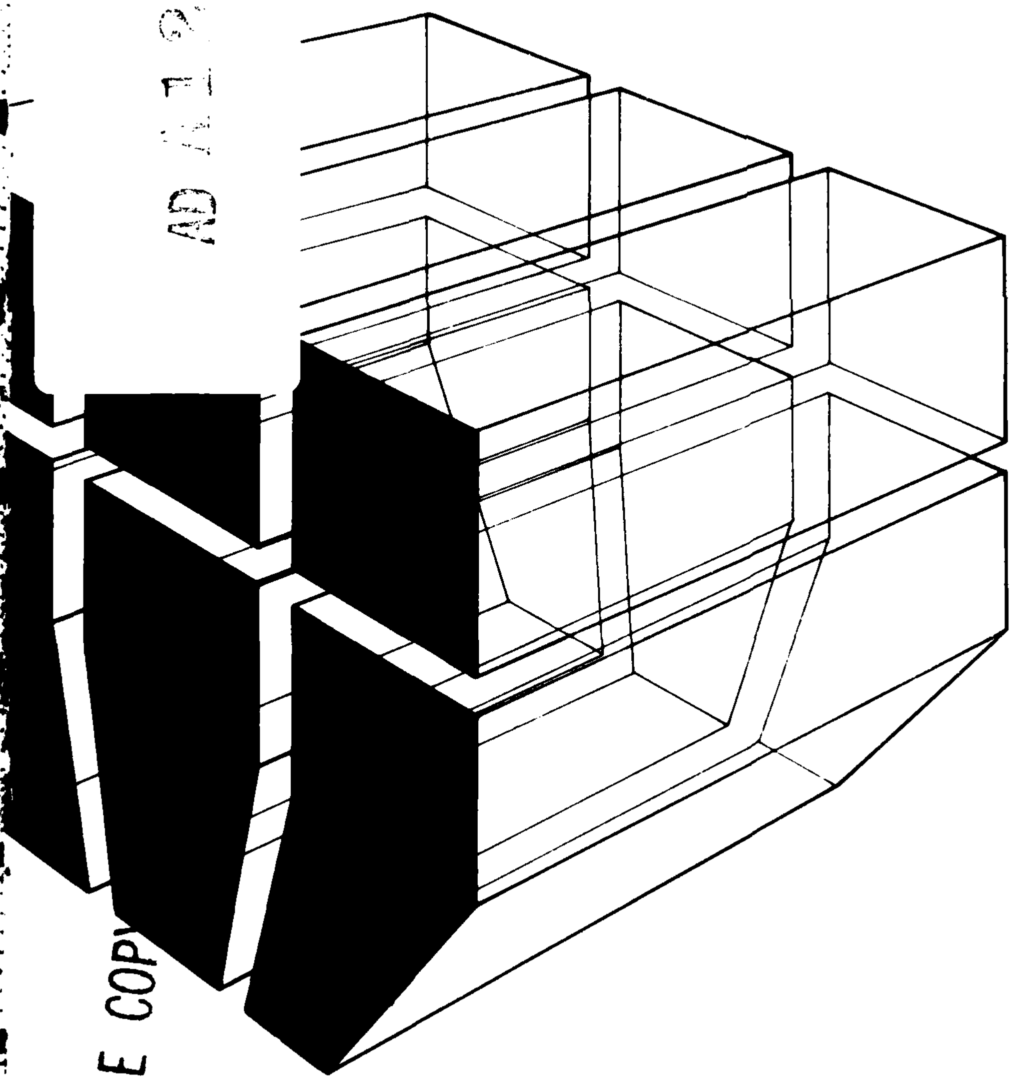
TECHNICAL REPORT N-140
March 1983
Design and Operational Guidance for Applying Air Pollution Control Devices

PARTICULATE AIR POLLUTION CONTROL FOR ARMY COAL-FIRED BOILER PLANTS



by
Walter J. Mikucki

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The Army has several coal-fired boiler plants and, in accordance with its Solid Fuel Conversion Program, will have many more in the future. Particulate emissions from such plants are strictly regulated by state agencies. The current coal-fired plants use various particulate-control technologies, with mixed success. This study examined these technologies and determined several design deficiencies which could contribute to the uneven performance of existing Army air pollution control devices. This study also identifies

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three new particulate control technologies with possible application to Army installations and industrial facilities, and gives recommendations for the operation and maintenance of the Army's existing technologies.

FOREWORD

This investigation was conducted for the Assistant Chief of Engineers under Project 4A7162720A896, "Environmental Quality Technology"; Task B, "Environmental Design and Construction Strategy"; Work Unit 042, "Design and Operational Guidance for Applying Air Pollution Control Devices." The Technical Monitor was Mr. Bernard Wasserman, DAEN-ZCF-U.

This investigation was performed by the Environmental (EN) Division of the U.S. Army Construction Engineering Research Laboratory (CERL). Dr. R. K. Jain is Chief of CERL-EN.

Special application is given to Mr. Donald Ekstrom, DRCIS-RI-IU, for data and help regarding U.S. Army Development and Readiness Command (DARCOM) plants.

COL Louis J. Circeo is Commander and Director of CERL, and Dr. L. R. Shaffer is Technical Director.

CONTENTS

PARTICULATE AIR POLLUTION CONTROL FOR ARMY COAL-FIRED BOILER PLANTS

1 INTRODUCTION

Background

For several years, the Army has very actively attempted to comply with the provisions of the Clean Air Act,[1] while still meeting its responsibility for providing a strong national defense. One of the most significant activities related to the Act's provisions at Army installations and industrial facilities is the combustion of fossil fuel to produce heat or process steam. Of the fossil fuels used by the Army today, the one with the most potential for creating air quality problems is coal.

When the Clean Air Act established national air quality goals, it mandated the U.S. Environmental Protection Agency to write and enforce regulations to achieve those goals; of particular importance to the Army were the Act's goals for the control of particulate emissions, sulfur oxide, and nitrogen oxide produced by the combustion of fossil fuels.

The Act also assessed air quality in different parts of the United States to determine to what extent various regions of the country complied with its air-quality goals. This assessment was vital because air movement knows no boundaries, and air-pollution implications of activities in one state may only be apparent several states away. Using certain climatologic and physical geographic features which were known to affect air movement, "airsheds" were defined to describe geographic areas subject to the consequences of air pollution activities within those areas.

The concepts of airsheds and status of compliance with the air quality goals as described in the Clean Air Act's National Ambient Air Quality Standards (NAAQS) are important, since they are the factors used to determine whether a region of the country is classed as an "attainment" or "nonattainment" area.

Attainment Area

Airsheds in which the ambient air is of quality equal to or better than the NAAQS are called attainment areas. In attainment areas, existing sources are regulated only so far as needed to maintain the status quo. Industrial growth is permitted within what is known as Prevention of Significant Deterioration (PSD) increments. This means that a region in an attainment area cannot use up all of the difference between the current emissions and the NAAQS levels. Thus, only a portion of the difference can be used to accommodate industry growth. But if a new industry moves into the region, or an existing industry expands or renews production after long inactivity, the PSD increments might be exceeded. If such growth is to be allowed, other sources contributing to the air quality in that region must be controlled more stringently. It is usually the burden of the new or expanding industry to pay not only the capital cost, but also the operation and maintenance (O&M) costs of control devices placed on other sources to ensure the region's total emissions do not exceed the PSD increment.

Nonattainment Area

Airsheds in which the ambient air quality does not meet the minimum NAAQS are called nonattainment areas. Emissions restrictions are more severe than those in attainment areas, with the objective to improve the region's air quality until it meets the NAAQS.

New Source Performance Standards

The Army will soon have to meet new source performance standards (NSPS) for industrial-sized boilers at its military and industrial installations. The NSPS combined with existing Clean Air Act provisions means that installation Directorates of Engineering and Housing (DEHs) and their supporting Corps of Engineers districts will face a complex web of coordination and regulation requirements when undertaking any project which could impact air quality.

Objective

The objective of this study was to (1) collect information on performance problems associated with current Army particulate-control devices and data on new particulate-control technology, and (2) develop recommendations for the operation and maintenance (O&M) of existing Army air pollution control devices.

Mode of Technology Transfer

It is recommended that the information in this report be abstracted in an Engineer Technical Note and be used to update Army Technical Manual 5-815-1, *Air Pollution Control Systems for Boilers and Incinerators.*

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[1]Clean Air Act of 1970, Public Law 91-604, 87 Stat 1676-1713 (as amended).

2 ARMY PARTICULATE CONTROL EXPERIENCE

History

In the early days following passage of the Clean Air Act, the Army tried to solve its short-term emissions problems by switching to the "clean" fossil fuels like oil and natural gas. However, the energy crises of the mid and late 1970s substantially increased the price of these fuels, with further increases predicted. This economic factor, coupled with a growing dependence on foreign fuel sources, caused military and Governmental planners to seek a better way to exploit fuels which were not subject to interdiction. This led to the Army's current Solid Fuels Conversion program.

Not all Army boilers were switched from coal during the energy crisis. Instead, air pollution control devices were designed and built for many of the Army's operating coal-fired plants. Table 1 summarizes the Army's existing air pollution control systems.

Lessons Learned

Applying air pollution control technology to old boilers used mainly for heating (without a base load) was not without its share of problems. As with most new applications of technology, critical design factors developed for Air Pollution Control for large utility-sized boilers do not necessarily scale down in size equally.

Conveyance of Flue Gas

When air pollution control devices were retrofit to existing boilers in congested areas, they often required contorted ducting runs to convey the flue gases. Considerable care must be taken to convey the particle-laden gases to the collector. Changes in direction should be armored to counter the abrasion of the duct by the conveyed material. Also, access must be provided so the ductwork can be inspected periodically (where feasible) during boiler outages to determine if corrosion, particulate sedimentation, or abrasion are occurring.

Baghouse Fires

The Department of Defense (DOD) has suffered several baghouse fires at non-Army facilities. The cause of the fires, which can be fierce enough to result in structural damage, is the subject of much speculation. A baghouse's combustible material is captured flyash. An analysis of the flyash from an Army bag-

Table 1
Army Air Pollution Control Devices

Installation	Stoker Type	Air Pollution Control Device	Status
Lexington/Bluegrass Army Depot	Spreader	Baghouse	Operating
Pueblo Army Depot	Spreader	Baghouse	Operating
Rock Island Arsenal	Spreader	Baghouse	Operating
Holston Army Ammunition Plant	Pulverized	Electrostatic	Not operating
Holston Army Ammunition Plant	Spreader	Electrostatic	Operating
Radford Army Ammunition Plant	Pulverized	Electrostatic	Operating
Red River Army Depot	Biomass	Baghouse	Under construction
Tobyhanna Army Depot	Chain grate	Hopper evacuation/ multicyclone	Under construction
Fort Benjamin Harrison	Spreader	Baghouse	Operating
Mississippi Army Ammunition Plant	Chain grate	Electrostatic/ Double Alkali Flue Gas Desulfurization	Under construction

house revealed a heating value in the range of 7500 to 8500 Btu/lb (17 408 to 19 729 kJ/kg). This is approximately two-thirds the heating value of raw coal.

There are two theories about the probable causes of baghouse fires. One theory ascribes ignition to the carryover of firebrands or "sparklers" from the combustion chamber. These could pass through the convection passes of the boiler and any mechanical collector in the system into the baghouse to ignite the collected flyash. The other theory suggests that the flue gas stream conveying the particulates is hot enough (temperatures around 500°F [257°C]) to cause the flyash particles to glow if enough oxygen is present to support combustion. This condition does exist in many Army boilers which operate at high excess air levels (i.e., in the range of 100 to 200 percent of theoretical). Yet, not all baghouses burn. The true cause remains to be discovered.

Bag Blinding

Another baghouse problem is bag blinding. This happens if hydrocarbon or other vapor materials condense when the baghouse is at the dewpoint of the flue gas. The condensed material usually is sticky and traps the flyash on the bag, where it clings tenaciously enough to resist the cleaning mechanism designed to keep the baghouse online. During a baghouse's initial startup, this problem can be alleviated by "seeding" particulate material into the ductwork upstream of the baghouse before combustion in the boiler begins. This "seeded" particulate material, which can be previously captured flyash, powdered limestone, or some other suitable material, coats the bags. Usually this coating is deep enough to capture any deposits of "baghouse condensibles" on the seed cake, instead of the bag material, when the boiler is brought up to operating conditions (passing through the hydrocarbon dewpoint on the way). The seed material is then removed by the normal cleaning process after the boiler has come to operating level.

Corrosion

Corrosion is another problem common to retrofit air pollution control devices. While good engineering should take the effects of corrosion into account, several DOD facilities have had problems with corrosion. In one case, intermittent boiler operation caused an electrostatic precipitator (ESP) to spend considerable time offline. This meant there was no way to keep the ESP temperature above the flue gas dewpoint or to purge the combustion gases from the device. In another case, an ESP was retrofit to a boiler by placing a tee into the ductwork connecting the boiler with the existing stack. The existing stack was then fitted with a cap which would normally be closed, but which could be opened to permit bypass of the ESP. Apparently the caps did not seal properly, because cold air was drawn down the old stack by the action of the induced draft fan downstream of the ESP. This caused the flue gas to drop below the acid dewpoint, condensing sulfurous and carbonic acids on the metal interior of the device.

3 AVAILABLE NEW TECHNOLOGY

Watching for new or emerging air pollution control devices is an ongoing part of applied research. Often, technologies developed in one industrial segment can be adapted to solve problems in another segment. Technology surveillance also gives an insight into the problems encountered during a technology's early application, allowing the designer to avoid these same problems when using that technology for Army emissions control. Of the current new technologies, the dry granular media scrubber and hopper evacuation technologies have the best potential for helping solve the Army's coal-fired emission control problems.

Dry Granular Media Scrubber Technology

The dry granular media scrubber consists mainly of three concentric cylinders (Figure 1). The annular space between the outermost and middle cylinders serves as the dirty-gas inlet distributor. The middle and inner cylinders are perforated, and act as a containment vessel for the filtration medium, a pea gravel which ranges from 1/8 to 1/4 in. (3.1 to 6.3 mm) in size. Particulates in the flue gas are captured when they directly impact the gravel.

The flue gas follows a tortuous path as it flows radially through the gravel-filled annulus. To increase the probability of impact, an electric grid operating in the 15 to 20 kV range is used to create a field in which particles of the same sign are attracted. Particles of the opposite sign are repelled. But whether the force attracts or repels, the influence of the field on particles which otherwise might pass through the device in the streamline of the gas flow is strong enough to cause a movement from the streamline and increase the probability of capture. The operating voltage is considerably less than that of an ESP, since no attempt is made to impart a charge to the particles. (This saves

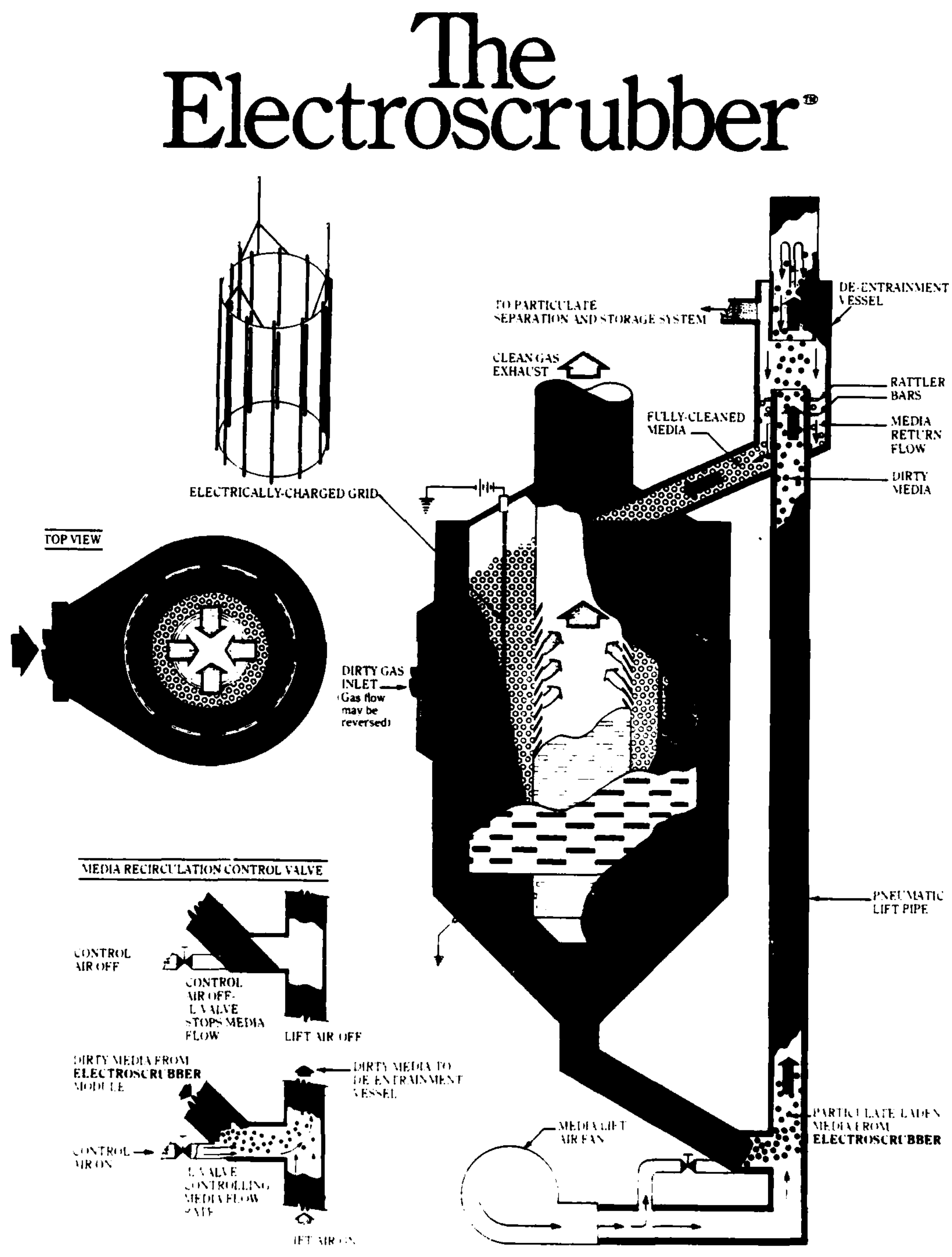

Figure 1. Dry granu... n dia ubber (Electroscrubber). (Reprinted with permission of Combustion Power Company, ın..., 1346 Willow Road, Menlo Park, CA 94025.)

electric power and means the device can operate with a smaller power supply than an ESP.) The medium passes vertically downward, perpendicular to the gas flow. The particle-laden medium is removed from the bottom of the device, then cleaned and transported pneumatically to the top of the device.

This technology was first used on boilers fueled by wood wastes. They have been performing satisfactorily in this application for several years. Its first coal-fired boiler application was on a pulverized coal unit. The device was originally comprised of the gravel-filled annulus, then retrofit with the electric grid. The gravel was cleaned by a vibrating screen, and the medium was conveyed to the top of the scrubber by bucket elevator. Table 2 summarizes the performance of the unit with and without electrostatic enhancement.

The pulverized coal operation encountered several problems. Most notable was the dislocation of the electric grid, with accompanying arcing to the cylindrical portion of the device. Power supply problems, noisy medium-cleaning and transport devices, and bucket elevator problems have also plagued the operation.

Later, a coal combustion application of this technology was used which more nearly matches the conditions of existing Army operations. In this application, a chain-grate stoker on an industrial plant, the device was designed as an Electroscrubber* (i.e., with the grid installed). It used the screen/bucket elevator method of gravel cleaning and transport. This device has satisfied the emissions regulations of the state in which it is located, and the plant owner seems pleased with the device's performance and simplicity. It is recognized that the chain-grate stoker is a cleaner combustion technology than that used at most Army coal-burning installations. However, the application to a boiler whose main demand is for space heating more closely approaches the Army's application.

Several features make the Electroscrubber attractive. First, the rock medium cannot burn; it is continuously cleaning and represents a thermal mass sufficient to prevent flue gas condensation during short shutdowns. On the negative side, the device is heavy compared to other particulate removal devices. Thus, special attention must be paid to foundation design. Also, roof-mounting such devices in a congested area would be prohibitively expensive. The device has not yet been applied to a spreader/stoker-fired boiler of the design common in the Army, nor has it yet become satisfactorily operational with the pneumatically cleaned and conveyed rock on a coal-fired boiler.

*Electroscrubber is a Trademark of the Combusti^n Power Company, Inc., 1346 Willow Road, Menlo Park, CA 9.J25.

Hopper Evacuation Technology

The second technology attracting interest for application to Army boilers is the so-called hopper evacuation technology (Figure 2). This technology maximizes the collection efficiency of the type of multicyclone mechanical collector found on many Army coal-fired boilers. It attacks one basic cause of poor performance in multicyclones: gas flow in the collection hopper. This gas flow occurs because the poor flow pattern of incoming flue gas causes a disproportionate share of the gas to be processed by the cyclone tubes closest to the dirty gas inlet. The ultimate result is a pressure differential near the particulate exit points of the cyclone tubes; i.e., between the tubes closest to and farthest from the gas inlet. This pressure differential causes gas flow in the hopper area, which intercepts and entrains particulate material which has been removed by the intervening tubes. Hopper evacuation technology seeks to eliminate this undesirable gas flow by inducing a positive downflow in all tubes. This is done by removing a small fraction of the inlet gas flow to the multicyclone through penetrations in the collection hopper immediately below the dirty-gas tube sheet. This small side stream is then routed through a small baghouse and reintroduced into the stack, where it rejoins the bulk of the mechanically cleaned gas.

Table 2
Electroscrubber Performance
(Pulverized Coal Boiler)

Typical Data	Dry Scrubber*	Electroscrubber
Inlet, gr/acf** (gr/am^3)	0.45 (1.02)	0.46 (1.05)
Outlet, gr/acf (gr/am^3)	0.134 (0.306)	0.023 (0.052)
Removal efficiency	70%	95%

*Dry Scrubber is a Trademark of the Combustion Power Company, Inc., 1346 Willow Road, Menlo Park, CA 94025.

**Grains per actual cubic foot.

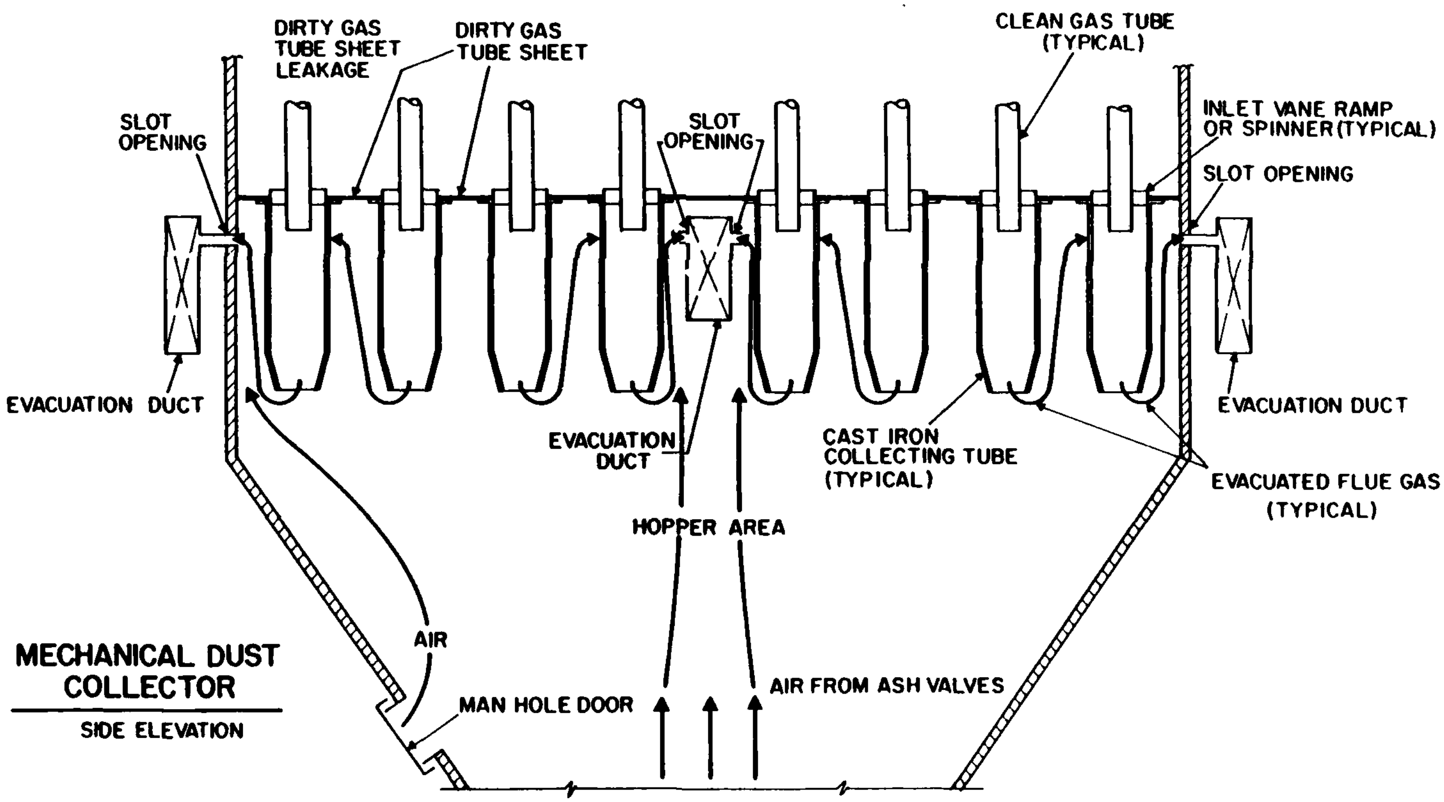

Figure 2. Hopper evacuation technology.

The advantages of this technology are many:

1. It capitalizes on existing equipment. Thus, the capital cost of application is small.

2. It has the basic simplicity of the multicyclone system. Its O&M is much less complex than more sophisticated devices.

3. The system's operating costs are lower than competing technologies.

On the negative side, it lacks substantial operating experience; neither its sensitivity to coal composition nor the size range of particle capture have been established. This technology also depends on a tight (non-air-leaking) boiler and the longevity of the tightness with only normal maintenance has yet to be determined. Hopper evacuation technology has undergone short-term tests at two Army installations. At both installations, it improved the emissions quality beyond that needed to comply with state emissions regulations. Performance test data are shown in Table 3.

Studies are underway to determine the capabilities and limitations of this technology and to develop design criteria to permit its application to Army facilities.

Electrostatically Enhanced Fabric Filtration Technology

Electrostatically enhanced fabric filtration technology is in the developmental stages. It attempts to combine the particle-capture properties of the ESP and baghouse. Pilot test claims include a lower pressure drop and easier and more thorough cleaning. Further development of this technology is being sponsored by the U.S. Navy. Obviously, if this technology is successful, it will give Army designers an additional option for controlling particulate emissions.

Table 3
Hopper Evacuation Performance Tests

Parameter	Installation A lb/mm Btu (mg/kJ)	Installation B lb/mm Btu (mg/kJ)
Outlet (no HE)*	0.296 (0.127)	0.249 (0.107)
Outlet (10% HE)	0.098 (0.042)	0.164 (0.071)

*HE denotes Hopper Evacuation. The percentage refers to the fraction of incoming flow removed through the Hopper Evacuation system.

4 DESIGN CONSIDERATIONS

TM 5-815-1 provides a good *fundamental* basis for the design of air pollution control devices for Army boilers,[2] but does not address certain vital design issues such as how to decide between two competing alternative particulate control techniques like the ESP and the baghouse.

ESP vs Baghouse

In many cases, the emissions allowed by a regulatory agency require removal levels beyond those achievable by unaugmented mechanical collectors. However, two proven technologies can achieve removals greater than 90 percent: the ESP and the baghouse. Often, the choice between the two is not clear. Perhaps the most important consideration when choosing is the life-cycle cost of the two technologies. Often the first cost of a baghouse is lower than an ESP. However, when the cost of periodic (2 years or less) rebagging is added to the cost of increased fan power consumption caused by the baghouse's larger pressure drop, this cost advantage may diminish. Cost estimation for these two competing technologies is somewhat complex. The latest available data are given in a serialized report appearing in *Chemical Engineering* magazine.[3] These data can provide basic information on the cost estimates for these devices. Obviously, the costs must be further modified in accordance with AR 415-17 methods to give a more correct picture.[4]

[2] *Air Pollution Control Systems for Boilers and Incinerators*, TM 5-815-1 (Departments of the Army, Navy, and Air Force, November 1980).

[3] "Cost File, Part IV: Estimating the Size and Cost of Ductwork," *Chemical Engineering* (December 1980), pp 71-73; "Cost File, Part V: Estimating the Size and Cost of Gas Conditioners," *Chemical Engineering* (January 1981), pp 127-132; "Cost File, Part VI: Estimating Costs of Dust-Removal and Water-Handling Equipment," *Chemical Engineering* (March 1981), pp 223-228; "Cost File, Part VII: Estimating Costs of Fans and Accessories," *Chemical Engineering* (May 1981), pp 171-177; "Cost File, Part VIII: Estimating Costs of Exhaust Stacks," *Chemical Engineering* (June 1981), pp 129-130; "Cost File, Part IX: Costs of Electrostatic Precipitators," *Chemical Engineering* (September 1981), pp 139-140; and "Cost File, Part XI: Estimating the Size and Cost of Baghouses," *Chemical Engineering* (March 1982), pp 153-158.

[4] *Cost Estimating for Military Programming*, AR 415-17 (Department of the Army, 15 March 1980).

Other factors to consider when choosing between a baghouse and an ESP are:

1. The nature and size of the particles to be collected.

2. In the case of an ESP, the resistivity of the particle.

3. In the case of a baghouse, the degree of flue gas temperature control.

Resistivity is a measure of the charge-carrying capacity of the flue gas particulates, i.e., of how "collectible" the particles are by an ESP. This factor is sensitive to coal composition. Thus, specifying the acceptable range or resistivity for which the ESP was designed should become an integral part of the coal contract in the same manner as Btu content, percentage ash, and percentage sulfur. Another consideration in the use of an ESP is that its O&M requires some skill levels not usually present in Army boiler-houses. The ESP operates on the basis of imparting an electrical charge to a particle and then collecting the particle on an oppositely charged collector plate. To impart the charge, high voltages are applied to the electrodes in the device. These voltages are supplied from high-voltage DC power supplies. A high-voltage electrician would have to service this portion of the device.

Flue gas temperature control is an important factor in the application of baghouses to flue gas particulate control. Bag manufacturers specify maximum operating temperatures for their various bag materials (usually $< 550°F$ [$< 284°C$]). To assure these temperatures are not exceeded, various schemes including air-to-air heat exchangers, heat exchanger wheels, air preheaters, and spray-tempering chambers have to be used.

Choosing a Baghouse Air Filter Fabric

A major consideration for baghouse designs is the material used for fabric filtration. Choosing from among many construction materials between woven or nonwoven material and choosing a weave type and fiber coating material is as important to the ultimate user as to the original designer. Often the material specification is left to the designer or equipment supplier, with only such gross specifications as air-to-cloth ratio and operating temperature.

The type of bag chosen for the fabric filter depends on the material to be removed and the operating conditions to be encountered, not only during steady-state operations, but also during swings, startup, and shutdown. The physical characteristics of the bag material are important measures of its ability to withstand the operating environment.

Most filter fabrics have permeability ratings, i.e., a measure of their ability to pass air in cubic feet/minute/square foot of fabric at 0.5 in. (12.7 mm) of water pressure drop. Bags are also rated on a parameter called the "Mullen Burst Pressure." This is a measure of the pressure necessary to rupture a secured fabric specimen (usually expressed in pounds of force per square inch). This parameter is one indicator of how durable the fabric will be when it is flexed or abraded. Tables 4 and 5 list properties of many popular bag materials.

O&M Considerations

If an air pollution control device fails to perform well, it may be a result of design deficiency, be symptomatic of changed boiler operating conditions, or caused by poor O&M.

Design Deficiencies

The design deficiencies that most often plague air pollution devices are related to the mode of gas distribution to the device. Often, in both new and retrofit applications, the location of the air pollution control device is made a matter of convenience. The location of other components is given the prime consideration. This often results in the particle-laden gas being forced to follow a tortuous path to reach the device. Two complications arise from this condition:

1. A drastically increased pressure drop associated with changes in direction.

2. A maldistribution of gas velocities because fully developed flow profiles cannot occur.

Since the particles in the gas have mass, they become unevenly distributed across the cross-section of the inlet duct. This causes portions of the air pollution control device to work harder than other portions. As noted in the case of multicyclones (Chapter 3), this is the prime cause of cross-hopper ventilation. To remedy this condition, both the designer and the design reviewer must pay strict attention to gas dynamics and be mindful that the gas is carrying particulate material. Special consideration should be given, where practical, to providing a sufficiently long, straight inlet run of

Table 4
Bag Material Properties

Fabric	Melting Temperature** °F (°C)	Maximum Operating Temperature** °F (°C)	Physical Resistance*					Chemical Resistance*				
			Dry Heat	Moist Heat	Abrasion	Shaking	Flexing	Mineral Acids	Organic Acids	Alkalies	Oxidizing Agents	Solvents
Cotton	302 (148) (decomposes)	180 (81)	Good	Good	Fair	Good	Good	Poor	Good	Fair	Excellent	Excellent
Polypropylene	333 (165)	200 (92)	Good	Fair	Excellent	Excellent	Good	Excellent	Excellent	Excellent	Good	Good
Nylon	480 (246)	—	Good	Good	Excellent	Excellent	Excellent	Poor	Fair	Good	Fair	Excellent
Acrylic	—	—										
Polyester	—	—										
Nomex	675 (354)	425 (216)	Excellent	Excellent	Excellent	Excellent	Excellent	Poor to Fair	Excellent	Good	Good	Excellent
Teflon	750 (395) (decomposes)	500+(257)	Excellent	Excellent	Poor to Fair	Good	Good	Excellent	Excellent	Excellent	Excellent	Excellent
Fiberglass	1470 (791)	550 (285)	Excellent	Excellent	Poor	Poor to Fair	Fair	Excellent	Excellent	Good	Excellent	Excellent

*"Fabric Filter Installation for Flue Gas Fly Ash Control," Status Report, *Technology*, 18 (1977), pp 79-110.
**R. P. Bundy, et al., *Handbook for the Operation and Maintenance of Air Pollution Control Equipment* (1975).
+Emits toxic gases at 450°F (230°C).

Table 5
Performance Properties of Various Types of Fabrics*

Fabric	Rating
Collection Efficiency	
Nonwoven fabrics (felts)	Most Efficient
Woolen system fabrics	↓
Cotton system fabrics	↓
Texturized filament fabrics	↓
Multifilament fabrics	↓
Monofilament fabrics	Least Efficient
Cleanability	
Monofilament fabrics	Least Difficult to Clean
Multifilament fabrics	↓
Textured fabrics	↓
Cotton system fabrics	↓
Woolen system fabrics	↓
Nonwoven fabrics	Most Difficult to Clean
Flexibility	
Nonwoven fabric	Most Flexible
Woolen system fabric	↓
Cotton system fabric	↓
Texturized filament fabric	↓
Multifilament fabric	↓
Monofilament fabric	Least Flexible

*From *Fabric Filter Manual,* Volume 1, Chapter 3 (McIlvaine Company, April 1978).

duct work connecting the air pollution control device to the emitter. Changes in direction should be of the long radius type. Where warranted, the inner face of the elbow at the point of impaction should be armored, either by using specially designed elbows or replaceable impaction plates.

In all cases where wear is expected, consideration should be given to installing access ports so the condition of the elbow or armor plate can be inspected. Often the inlet duct size is different from the inlet flange of the pollution control device, requiring a transition piece. While the temptation exists to leave the design of the transition to the duct fabricator, the designer and design reviewer must assure that the flow regime is maintained, and that the transition piece minimizes the introduction of flow disturbances which would affect the distribution of particles reaching the control device.

Boiler Operating Condition

Air pollution control devices are usually designed to control emissions resulting from a maximum load of the emitter(s) under specified fuel characteristics and gas-flow conditions. The prudent designer allows some safety factor in his or her design to account for variations in operating conditions. However, a broad enough range of operating conditions to handle all eventualities usually leads to an inefficient design and may even result in unsatisfactory performance. Where the range of operating conditions varies significantly and where the specific control device is sensitive to these fluctuations, consideration should be given to modularizing the control device so modules can be isolated during periods in which they are not needed. While automatic isolation might be best, dampers and poppet valves for the isolation of gas flow have proven to be less than totally effective. Consideration should be given to manual, blast-gate isolation.

When the performance of a device declines, it may result from changes in the emitter. One of the first considerations in the case of a coal-fired boiler is the fuel. Of particular concern is the percentage of ash in the fuel and the percentage of "fines." Both of these conditions can load the control device with more particulates than it was designed to handle.

Another fuel consideration is specific to performance of ESPs. As mentioned in Chapter 3, the resistivity of the particulate is an important fuel characteristic. Indeed, resistivity can be specified in the coal contract if the performance of the ESP is sensitive to that factor.

A third fuel-related parameter is coal size distribution. Too many fines may cause an excessive suspension of incompletely burned particulates leaving the boiler. Also, fines segregation in the storage bunker, larry, and feed hopper may result in uneven fuel distribution on the grate of a spreader stoker or, in the case of a traveling grate, in holes in the fuel bed. Either condition causes unstable combustion and an excessive particulate loading to the control device.

Where fuel is the suspected culprit in a device's failure to perform well, special surveillance of the delivered quality is in order. Sieve analysis, ash determination, and in the case of an ESP, resistivity determination should be performed on samples taken at the feed hopper, in the weigh larry, in the overhead fuel storage bunker, and in the coal pile. This will not only indicate if the delivered fuel is meeting specifications, but also if the fuel is undergoing any adverse change during the handling and storage process that precedes combustion. Where the current sampling and analysis program is considered inadequate, commercial testing laboratories or the Environmental Division of the U.S. Army Construction Engineering Research Laboratory (CERL) should be consulted.

A final consideration in the operation of the emitter is leakage. Most boilers operate at an internal negative pressure because of the induced draft fan. Efficient combustion dictates that the minimum amount of excess air needed for complete combustion be introduced into the boiler. That is, the amount of air to the boiler must be controlled. As the boiler ages, control often deteriorates, since leaks in the boiler setting, stoker seals, duct joints and other places develop with time. A leaky boiler affects the performance of an air pollution control device in several ways:

1. Excess air introduces gas volumes and consequent gas velocities which may exceed the design range.

2. Large volumes of infiltrating air may lower overall gas temperature and density far enough to influence the principle upon which the device depends for particle capture.

3. If the flue gas is cooled below temperatures corresponding to either the hydrocarbon or acid dewpoints, sticky or corrosive materials may be deposited on the internal surfaces of the control device. This can lead to particulate buildup or corrosion of the construction materials.

Device Inspection and Maintenance

Virtually no air pollution control device in existence today can operate continually in a "set and forget" mode. This is a factor which escapes many boilerhouse operators and is especially true of the primary particulate control technology common in the Army today, the multicyclone. Because the multicyclone's operating principle is simple and because it has no moving parts, it often does not get the attention it needs to keep it operating properly. Multicyclones require periodic inspection to determine whether erosion, corrosion, plugged turning vane, plugged clean gas tube, or plugged down tube conditions exist. Turning vanes located below or flush with the dirty gas tube sheet are more susceptible to plugging than designs in which the vanes protrude a small distance above the tube sheet. Raising the vanes may be possible; however, the device manufacturer should be consulted. Down tubes usually become plugged when collected ash builds up in the storage hopper until it covers the exit of the down tube, causing ash to back up into the down tube. Ash in the down tube will bridge and remain, plugging the down tube long after the high-ash level in the hopper has been remedied. This can be avoided by increasing the frequency of ash pulling, thus keeping the hopper more nearly empty, or by installing a level indicator and alarm system on the hopper to warn of high-ash conditions.

Baghouses are more complex control devices than multicyclones for many reasons. First, the device uses relatively fragile filter bags as the mode of control. These bags must be inspected periodically to determine whether pinholes, tears, or bag burning has occurred. In cases where damage is to only a few bags in the module, the offending bags may be removed and the inlet ports to these bags blanked off without degrading the device's performance enough to cause an air pollution violation. Where damage is more widespread, the bags must be replaced so the remaining bags in the module will not be subject to filtration velocities in excess of their design. Manufacturers' recommendations on bag replacement procedures should be followed.

A second complicating factor in the operation of the baghouse is the variable pressure drop resulting from dust cake buildup. This pressure drop is important both because it increases the power consumption of the induced draft fan and because (in extreme cases) it can affect the completeness of fuel combustion, since the induced draft is in part responsible for inducing turbulence above the fuel bed. A properly designed baghouse system has a cleaning cycle which is initiated by pressure drop. Regardless of the cleaning mode, the cleaning cycle duration should be periodically monitored to verify that the controller is working properly. Also, for cycles initiated by pressure drop, the operation of the pressure drop sensor should be verified by installing a manometer. (For baghouses subjected to freezing conditions, the manometer fluid should be chosen based on the conditions listed above.)

A last factor is the number of moving parts in the baghouse which must be inspected for proper operation: the cleaning mechanism (where mechanical) and ash-removal mechanisms, including ash valves, isolation dampers, and poppet valves. The supplier's maintenance directions should be followed faithfully, and, where special conditions or failures dictate, the inspection schedule and list should be augmented.

ESPs also require special care. The proper DC voltages and currents must be maintained to assure efficient collection. Fluctuations in these parameters may be symptomatic of power supply failures, or of a failure in the particle charging or collection mechanisms. This device has the same problems with ash level and properly operating ash-removal mechanisms as multicyclones. It must be maintained with full attention to the fact it is a high-voltage device. It must not be entered without properly locking out the power supply and sealing the inlet duct. Failsafe devices and power interlocks must ***never*** be turned off to "save time." The collection chamber should be inspected before the device is cleaned, since the dust patterns on the charging wires and on the collection plates may give a clue to improper operation. Conditions like arcing, inadequate collection voltage, inadequate cleaning during previous cycles, and material buildup indicate problems. More obvious conditions like corrosion, broken wires, and warped collection plates are easy to spot during an inspection. ESP power supplies are usually located in a chamber on top of the device; this chamber should be inspected for cracked or broken insulators and evidence of dust infiltration and corrosion. These latter two conditions are symptomatic of flue gas leaks into the chamber, a condition which is supposed to be prevented by maintaining a positive pressure on the power supply chamber. The device supplier's recommendations are the best source of information on inspection and maintenance procedures and schedules.

5 CONCLUSIONS

This report described the performance problems of the particulate-control devices now used by the Army and suggested new particulate control technologies that the Army can consider to solve those problems. Recommendations were also given for the O&M of the Army's existing air pollution control devices.

In particular, it was concluded that:

1. The Army's commitment to reconvert its boilers to burn coal and the forthcoming New Source Performance Standards has increased its need for simple, cost-effective particulate control technologies.

2. Three promising technologies deserving continued surveillance are the Electroscrubber, the Electrostatically Enhanced Fabric Filter, and Hopper Evacuation.

3. Performance failure of air pollution control devices can result from design deficiencies or from inadequate O&M procedures.

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