CONTROL OF SALT-LADEN PARTICULATE EMISSIONS FROM HOGGED FUEL BOILERS

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ABSTRACT

This report presents results of an evaluation of salt emissions from hogged fuel boilers, and defines the technical problems, compliance prospects, and costs of various control systems. The control measures considered are fuel pretreatment, combustion modifications, use of conventional control devices (electrostatic precipitators, fabric filters, and scrubbers), and several novel particulate control devices.

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SUMMARY AND RECOMMENDATIONS

Although the data base is small, test operations have demonstrated that salt-laden particulate emissions from hogged fuel* boilers can be controlled to comply with stringent particulate and opacity regulations by application of currently available control technology. Whether this technology should be applied to each affected hogged fuel fired boiler should be determined on a case-by-case basis. The following information summarizes salient aspects of this report and the conclusions drawn therefrom. Recommendations are given for further study of reducing salt emissions.

SIGNIFICANCE OF THE SALT EMISSION PROBLEM

Salt emissions from hogged fuel boilers are a significant problem, principally because the salt portion of the particulate is primarily submicron in size. Particles larger than 5 μm are deposited in the nasal cavity or naso-pharnyx. The smaller particles, however, are deposited in the lungs, including over 50 percent of the particles from 0.01 to 0.1 μm diameter that penetrate the pulmonary compartment. The tendency of particulates to penetrate the respiratory systems and be captured is mainly a function of their geometry rather than their chemical properties.

Health effects of the captured fine particles depend largely on their chemical or toxic qualities, except for long fibrous materials, whose physical qualities also provide potential for

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* A term derived from the machine that processes the mixture of wood and bark before it is burned and that is called "a hog" or "hogger".

irritation of tissue. Because of the many unknown factors, it is unwise to generalize concerning health effects of fine salt particulates from hogged fuel boilers.

The other important aspect of the problem is that salt-laden particulate emissions, after passing through a conventional mechanical collector, are usually in violation of both particulate emission and opacity regulations. A plume from these operations is often highly visible and aesthetically objectionable in the community.

DEFINITION OF THE SALT EMISSION PROBLEM

The salt concentration in hogged fuel varies widely, and the salt content of wood fuel or flue gas can be expressed in several ways: as NaCl, equivalent chloride, or total sea salt. No standard method of analysis is in use, and the method of analysis often is not reported. The need is apparent for a consistent method of collecting, storing, and analyzing salt samples from wood fuel or flue gas.

To evaluate the effects of salt-laden particulate emissions on local ambient air quality, we analyzed data from three sites. At none of them were there violations of ambient air regulations for suspended particulates, during the period when mechanical collectors were used for particulate control. Secondary collectors have been installed at two of the sites, but data are not sufficient to indicate whether these installations have led to a measurable decrease in ambient particulate levels.

The absence of ambient air violations on a monthly or yearly basis does not mean that ambient particulate levels are not increased on a short-term basis. With low winds and inversion conditions, the plume from a salt-laden hogged fuel boiler equipped only with mechanical collector could significantly increase ambient salt levels over a short term. However, just one of the three sites analyzed in this study has shown violations of the 24 hour maximum average standard, and that was only in 1970.

An increase in corrosion due to salt emissions would be possible if the salt aerosol were present in sufficient quantities to deposit on surfaces. Tsang and Stubbs, however, found no deleterious corrosive effects in a 2-year period downwind of a boiler fired with salt-laden hogged fuel in a coastal environment.

CONTROL TECHNOLOGY TO REDUCE SALT EMISSIONS

Handling and Pretreatment of Fuel

Among various preventive methods for reducing salt particulate emissions from hogged fuel boilers, the most obvious is not to transport the logs via saltwater; in most cases this is not possible. Transport by flat rafting rather than in bundles will reduce the salt content of hogged fuel, as will reducing the duration of storage in salt water. About half of all salt absorbed in 6 months is absorbed in the first 2 or 3 weeks of contact with seawater.

Hydraulic debarking of logs with fresh water is reported to have reduced salt content in one instance but not in another.

Bark pressing can reduce moisture content by 50 percent and remove substantial quantities of salt in the process. This can result in lower opacity and particulate emissions because of increased boiler efficiency and fewer fine particles of salt. The disadvantage, however, is serious water pollution from the bark pressate wastewater.

Other methods of predrying fuel do not reduce the salt content, but do reduce combustible emissions by improving boiler efficiency.

Combustion Modifications

Combustion modifications can increase boiler efficiency and thereby reduce total particulate emissions, but do not reduce salt emissions because salt is not combustible.

About 65 to 85 percent of the salt in bark passes out of the chimney as particulate emissions; the remainder is retained in the boiler, on the grates, or on boiler surfaces, reducing efficiency of the boiler and disrupting uniform air flow through the fuel beds. Plant engineers therefore should try to reduce both the salt and moisture content of the bark at reasonable cost. The resulting improvement in fuel quality will reduce consumption of auxiliary fuel and boiler cleaning requirements. Additional research is needed into ways to slow the quenching effect on vaporized salt leaving the combustion zone in hogged fuel boilers. This would generate large particles of salt that would be more easily collected by a secondary control device. In most operations, however, additional control measures will be necessary to reduce salt-laden particulate emissions to acceptable levels.

Conventional Secondary Collectors

Secondary conventional collectors operating on salt-laden emissions are fabric filters and wet scrubbers. Electrostatic precipitators (ESP's) are not used because the manufacturer's guarantee will cover outlet emission levels and in-stack opacity, but not visible opacity. The dry scrubber has not been successful on a full-scale boiler burning salt-laden hogged fuel.

Performance data show that the best available control system is a mechanical collector followed by a fabric filter. This is as expected, in view of the variation in salt content of wood fuels and the fine-particle collection capability of the fabric filter. Operation of a fabric filter is not affected by changes in salt content to the same extent as wet scrubbers and presumably ESP's, which should be designed for the worst-case condition. For the scrubber, the design must provide for a higher pressure drop to account for increases in fines when the salt content of the wood fuel increases. This then entails higher operating costs due to power consumption and component wear. For the ESP, the design must provide enough collection plate area to compensate for the reduction in corona current at a given voltage because of space charge phenomena caused by high fines content. This disadvantage is compensated for somewhat by the low resistivity (and unburned carbon) of the bark ash, which causes higher power inputs; however, the low resistivity also can cause severe reentrainment problems. The cost of additional collection plate area may make the ESP noncompetitive with the fabric filter.

Although no fractional efficiency data are available from the presently operating fabric filter and wet scrubber installations, the low opacity (<5%) and low outlet loading (0.02 g/m^3 or 0.01 gr/dscf) of the Simpson Timber Co. fabric filter indicate that it is very effective in removing the salt fines. The scrubber installation at Crown Zellerbach's Port Townsend Mill generates an estimated opacity of 35 percent and cannot meet the emission regulation of 0.23 g/m^3 (0.10 gr/dscf), when the salt content of the fuel is greater than 1 percent, because pressure drop is limited to 51 cm (20 in.) of water. Performance at these two installations is consistent with test data on fabric filters and wet scrubbers in other applications. ESP's have potential for efficient removal of fines, but are less effective than fabric filters.

Performance of a pilot ESP on a boiler fired with salt-laden hogged fuel at Victoria Sawmill Division of B.C. Forest Products, Ltd., ranged from excellent to poor, with outlet loadings of 0.11 to 0.42 g/m^3 (0.05 to 0.20 gr/dscf). Salt particles were removed to an acceptable level as long as the ESP was maintained and operated within precise limits; otherwise, performance deteriorated markedly.

The disposal of salt-laden ash from secondary collectors is a problem sometimes overlooked in evaluating the salt emissions problem. Landfilling of the ash is complicated by the presence of salt, which presents a potential leachate problem. Return of a slurry containing salt and ash to a bay or ocean is unacceptable because of the ash content, and the ash cannot be sold for cement or asphalt production because of the salt.

Acceptable disposal practices include providing an impermeable liner for an ash pond or diluting the salt concentration by mixing the ash slurry with other plant wastewater streams or with municipal wastewater and processing the ash slurry by conventional wastewater treatment. Wet treatment seems to be more effective in terms of efficiency and economy. Either method, however, increases capital and operating costs.

Novel Devices

Devices that combine the principles of an ESP and a wet scrubber offer potential for effective control of salt-laden particulate emissions from hogged fuel boilers.

A full scale test of one of these devices, the University of Washington electrostatic scrubber, was recently performed on a salt-laden hogged fuel boiler in the Pacific Northwest. The exact location is unknown and test details are sketchy, but reports cite emission levels of 0.114 g/sdm^3 (0.05 gr/dscf) and 20 percent opacity. Data from pilot tests of the Ceilcote ionized wet scrubber and the A.P.S. electrotube show outlet loadings of 0.09 g/m^3 (0.044 gr/dscf) and lower.

Performance of the various types of electrostatic scrubbers indicates that these units should be tested further in full-scale applications.

COSTS

Cost information on application of conventional control devices to boilers burning salt-laden hogged fuel is minimal. Weyerhauser Co. has developed cost estimates that allow comparison of a fabric filter and ESP at a level where the fabric filter would comply with opacity regulations (40 percent), but the ESP would not [0.42 g/m^3 (0.2 gr/dscf)]. For an installation with throughput of 5042 m^3/min (180,000 acfm), the capital cost of the fabric filter at $372 per m^3/min ($11.72/acfm) is approximately 18 percent higher than that of an ESP. Increasing the plate area for the ESP to comply with the opacity regulation of 40 percent would probably increase its cost over that of a fabric filter. The capital cost for a comparable venturi scrubber is somewhat less at $241 per m^3/min ($6.74/acfm).

Estimates of annual costs for the same installations show that the fabric filter would be more costly to operate than the ESP, mainly because of bag replacements. Annual costs of operating the venturi scrubber are still higher because of the high power requirement of the fan.

The actual capital costs of the Simpson Timber Company's fabric filter and Crown Zellerbach's venturi scrubber, when escalated at 7.5 percent per year, agree well with the Weyerhauser estimates, which are in 1978 dollars. Actual operating costs for Simpson Timber's fabric filter, however, are considerably lower than the Weyerhauser estimates, which do not include costs of ash disposal.

RECOMMENDATIONS FOR EVALUATION OF AFFECTED FACILITIES

The following are recommendations for evaluation of the boilers burning salt-laden hogged fuel in EPA Region X and currently violating applicable particulate emission and opacity regulations.

(1) Analyze each plant on an individual basis. Contact the affected companies to determine their plans for reducing salt emissions to achieve compliance with regulations.

(2) If the company has no plan for compliance, visit the site to evaluate the situation. Perform a detailed assessment of plant fuel handling practices and combustion techniques to determine whether improvements could reduce emissions of salt and ash. Determine the amount of space available at the site and difficulty of retrofitting a secondary control device.

(3) Estimate costs of preventive measures and of installing secondary collection equipment; develop a construction schedule for installation of the equipment. Concurrently, conduct an economic feasibility study of the affected company to determine

whether it can afford to install the needed pollution control equipment.

4) If the company is financially unable to install the equipment, consider other alternatives such as closing the facility and evaluate the impacts of such alternatives on the employment situation in the local community. If the plant is not violating local ambient air quality standards and citizen complaints are not numerous, investigate the possibility of a variance or some other compromise, such as partial treatment of the flue gas.

If the affected facility is in an area where further degradation of air quality is not permitted, approach other companies wishing to establish plants that would cause additional local pollution with respect to providing some or all of the money needed to install pollution equipment on the affected hogged fuel facility. Such an approach could reduce both emissions and ambient pollutant levels while encouraging industrial growth.

SECTION 1

INTRODUCTION

In some areas of the country, wood fuel that is fired in industrial boilers comes from logs that have been transported or stored in sea water, from which the bark may absorb substantial amounts of salt. When the fuel is burned, the noncombustible salt particles, which are primarily submicron in size, contribute to opacity and particulate emissions. Most hogged fuel boilers are controlled only with mechanical collectors, which are not efficient in collecting fine particulate; the emissions therefore usually violate state and local regulations of particulates and opacity.

Excessive salt emissions from hogged fuel boilers occur almost exclusively in the coastal states of the Pacific Northwest. There are 16 salt-emitting installations in Washington, Oregon, and Alaska. This study deals only with those boilers, which together account for 4 percent of the total hogged fuel boilers in these three states, as shown in Table 1-1. Additional information on these boilers is given in Appendix A.

Depending on the salt fraction of the fuel and the type of control device used, salt particles can constitute 30 to 90 percent of stack emissions from these boilers. Firing of oil concurrently with the hogged fuel can also contribute to stack opacity. Although emissions from these boilers violate regulations set forth in the State Implementation Plans (SIP's) and local regulations, available ambient air data obtained near several of these plants have not shown violations of ambient air quality standards.

In responding to the salt emissions problem, some companies have cited potentially high costs and technical problems

TABLE 1-1. HOGGED FUEL BOILERS WITH EXCESSIVE SALT EMISSIONS

	Total no. of hogged fuel boilers	No. of boilers emitting salt	% of total	Approximate heat input of boilers emitting salt, 10^6 J/h (10^6 Btu/h)
Washington	98	10	10	1,050,700 (995)
Oregon	318	2	0.6	362,210 (343)
Alaska	10	4	40	785,660 (744)
Total	426	16	4	2,198,570 (2082)

associated with control of these emissions with secondary control equipment. The smaller companies, particularly, regard control of salt emissions as a financial burden.

SCOPE OF THIS STUDY

The purpose of this study is to examine the salt emissions problem, and to define the technical problems, compliance prospects, and costs of various control techniques.

Section 2 presents background information on the distribution of hogged fuel boilers. It describes some characteristics of hogged fuel, including the range of salt concentrations, and methods used to measure salt content. It outlines methods for pretreatment and storage of hogged fuel, types of furnaces and combustion techniques, characteristics of the resulting flue gas, and the effects of salt particle size distribution on opacity.

Section 3 reviews the control technology available for reducing salt emissions from hogged fuel boilers, considering both preventive measures, such as fuel pretreatment and combustion modifications, and remedial measures, such as use of conventional or novel particulate control equipment. Basic design parameters are presented for each conventional control device, along with evaluation of its applicability for control of submicron salt particles. Common operation and maintenance problems associated with each control device are reviewed, with emphasis on those problems that are aggravated by the salt particles. Techniques for disposal of the salt-laden particulate are also discussed. Section 3 continues with a discussion of novel control devices and their potential for control of salt emissions from hogged fuel boilers.

Section 4 summarizes cost information available in the literature on conventional control devices, giving actual and estimated capital and annual costs.

Appendix A lists the hogged fuel boilers in Washington, Oregon, and Alaska, with excessive salt emissions.

Appendix B describes the types of furnaces in which hogged fuel is burned.

Appendix C presents two case histories of application of secondary control devices to salt-laden particulate from hogged fuel boilers.

Appendix D describes some novel control devices that have been tested on salt-laden particulate emissions from hogged fuel boilers, giving test results; it also provides information on commercial availability and cost of these devices.

SECTION 2

DEFINITION OF THE SALT EMISSIONS PROBLEM

CURRENT USAGE AND GEOGRAPHIC DISTRIBUTION OF HOGGED FUEL BOILERS

The greatest use of wood residue and bark as fuel is by the industries that generate the wood wastes:[1] lumber and plywood mills, paper mills, and particle board and hardboard mills. These industries originally burned wood residue as a fuel out of necessity. Today these industries can use this relatively low-cost fuel to generate electricity and process steam. In some cases, they can generate a surplus of electricity for sale to an electric utility or for use in the electric system of the "company town." In the Pacific Northwest and other areas, the forest products industry has been rapidly installing new wood-burning boilers to replace those that burn oil and gas.

Since oil prices have increased, wood fuel has become so desirable that wood products industries are saving it for their own use rather than selling it on the open market. One utility in Oregon that uses wood wastes to generate electricity, the Eugene Water and Electric Board, had to forego expansion because local wood product industries, in a period of about a year, completely reevaluated the wood fuel situation and chose to use this fuel themselves rather than sell it.

Figure 2-1 summarizes the basic ways of using wood fuels directly to generate energy in the form of electricity, process steam, or hot gases. The uses for process steam are summarized in Table 2-1.

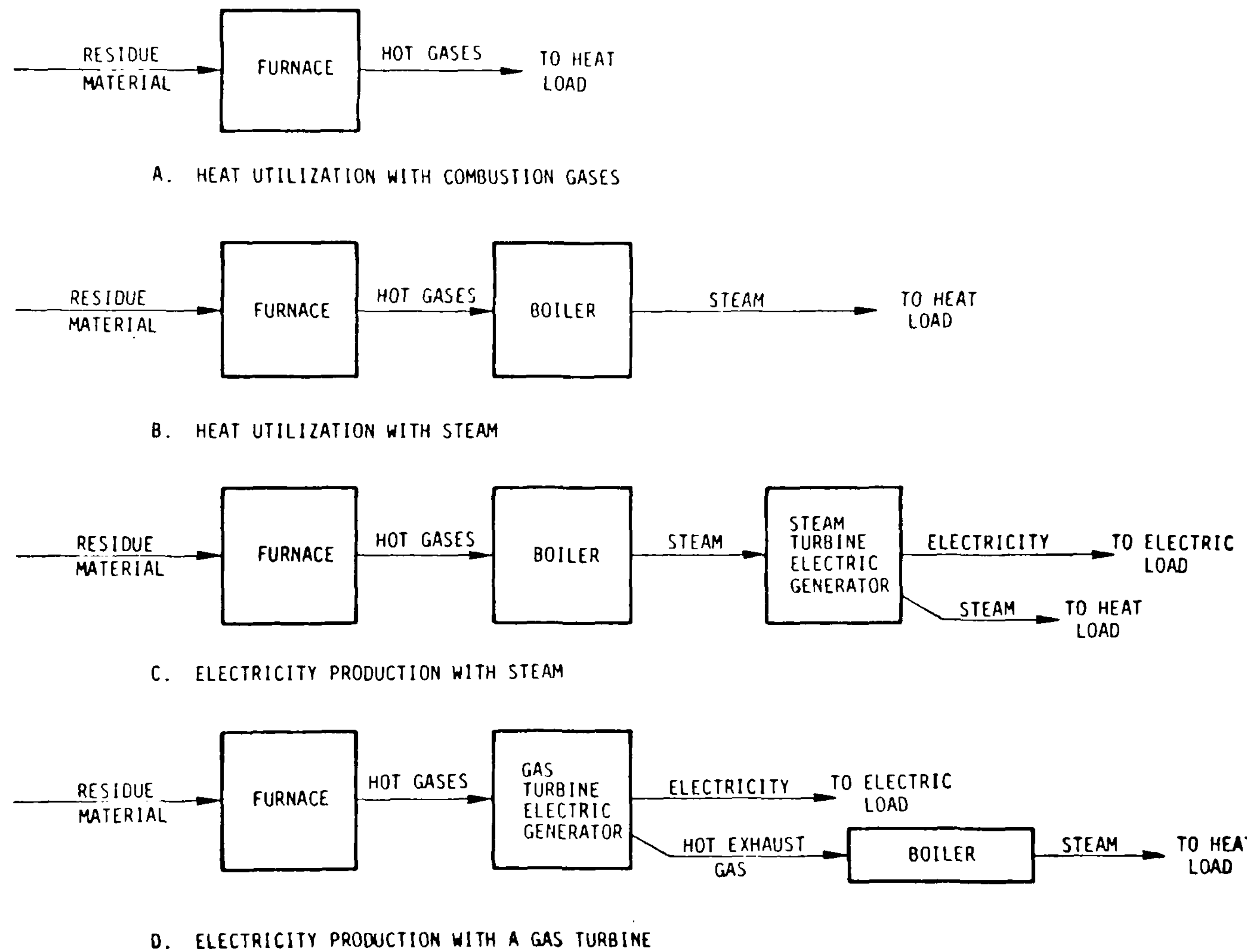

Figure 2-1. Some methods of energy conversion using direct combustion of residue materials.[1]

TABLE 2-1. USES OF PROCESS STEAM IN FOREST PRODUCT MANUFACTURING PLANTS[1]

Type of plant or operation	Use of steam from wood-fired boilers[a]
Dimension lumber	Kiln for drying lumber and "Shotgun carriage" (old, but still used)
Plywood mill	Veneer dryer and hot press
Particle board and hardboard	Steam-heated particle dryer and hot press
Paper mill	Digester and paper machine dryer
Furniture manufacture	Hot press and wood steaming system

[a]It is assumed that all facilities use wood fuel to supply heat and hot water for plant and offices.

Hot flue gases can be used directly for drying of wood, veneer, or particles. The hot gas may be generated directly by a wood-fired furnace without a boiler; or boiler flue gas can be used instead of exhausting it through a stack.

Because wood-fired boilers are traditionally located near the fuel source, most are in the states with large forest products industries. Figure 2-2 indicates the number of boilers and weight of wood residue consumed in those boilers in each state. Boubel[1] obtained the data for Figure 2-2 in a mail survey of state air pollution control agencies. For states not replying, he estimated the number of boilers by a linear regression equation based on replies received and on wood usage as reported by Suprenant.[2] In spite of discrepancies in the data, he believes that they are probably as reliable as any that can be obtained. For example, although reference 5 states that no wood is burned industrially or commercially in Arizona or Michigan, the agency in Arizona reported 14 wood-fired boilers and that in Michigan listed 27.

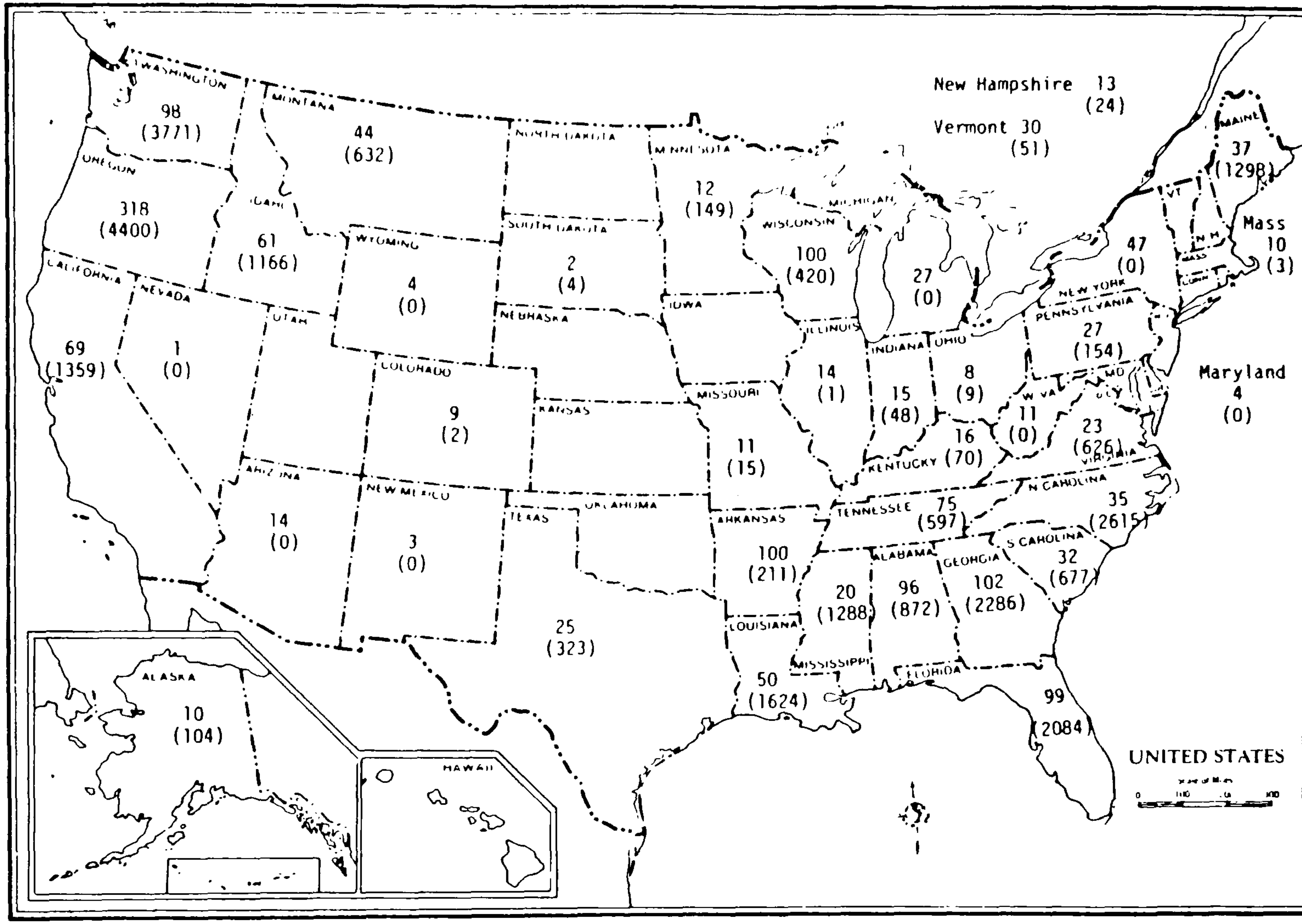

Figure 2-2. Number of wood-fired boilers by state.[1] (Values in parentheses indicate annual wood consumption in thousands of tons; 1 ton ≈ 0.907 Mg.)

It is predicted that conversion of wood residue to energy will increase by 60 percent by 1985;[2] if this occurs, most of the growth probably will occur in a few states having wood resources that are not utilized today, such as Oregon, Washington, Idaho, and California. Although some of the other states may increase the use of wood for fuel, they do not have enough unused resources to double their usage in 10 years.[1]

CHARACTERISTICS OF HOGGED FUEL

The properties of wood residues and bark fuels can vary so widely that no standard specification is possible. The differences should be recognized and accounted for in the engineering and operation of wood-fueled systems.[1]

Many species of wood can be used as fuel, but some are better than others. Wet cedar bark, for example, is stringy and difficult to reduce in size. By comparison, dry Douglas fir bark is considered a very desirable fuel.[1] Table 2-2 summarizes the analyses of several wood species used as fuel.

Other types of wood fuel are used to supplement the hogged fuel. Among these are sawdust, wood chips and shavings, wood waste material, and sanderdust. Sludges and spent liquors from wastewater treatment processes are burned occasionally, more as a means of disposal than for any advantageous fuel characteristics. At some installations where downtime of the hogged fuel boiler is critical to plant operations, the system incorporates provisions for the burning of an alternative fuel, such as No. 6 fuel oil.

The supplemental fuels are used in various quantities and combinations depending largely upon the function and design of the plant. Except for sludge and spent liquors, the supplemental fuels have more desirable burning characteristics (e.g., lower moisture content and higher heating value per equivalent mass) than does the hogged fuel. The supplies of hogged fuel, however,

TABLE 2-2. ANALYSES[a] OF SELECTED WOOD REFUSE BURNED AS FUEL[1]

Item	Jack pine	Birch	Maple	Western hemlock
Proximate analysis, percent				
Ash	2.1	2.0	4.3	2.5
Volatile	74.3	78.5	76.1	72.0
Fixed carbon	23.6	19.2	19.6	25.5
Ultimate analysis, percent				
Carbon	53.4	57.4	50.4	53.6
Hydrogen	5.9	6.7	5.9	5.8
Sulfur	0	0	0	0
Nitrogen	0.1	0.3	0.5	0.2
Ash	2.0	1.8	4.1	2.5
Oxygen (by difference)	38.6	33.8	39.1	37.9
Heat value (bone dry), J/g (Btu/lb)	20,718 (8930)	20,578 (8870)	19,000 (8190)	20,613 (8885)
Ash analysis, ppm				
SiO_2	16.0	3.0	9.9	10.0
Al_2O_3	6.3	0	3.8	2.1
Fe_2O_3	5.0	2.9	1.7	1.3
CaO	51.6	58.2	55.5	53.6
$CaCO_3$	4.9	13.0	1.4	9.7
MgO	5.5	4.2	19.4	13.1
MnO	1.6	4.6	1.0	1.2
P_2O_5	2.8	2.9	1.1	2.1
K_2O	4.1	6.6	5.8	4.6
Na_2O	3.1	1.3	2.2	1.1
TiO_2	0.2	Trace	Trace	Trace
SO_3	2.6	3.2	1.4	1.4
Fusion point of ash, °C (°F)				
Initial	1343 (2450)	1488 (2710)	1454 (2650)	1516 (2760)
Softening	1510 (2750)	1493 (2720)	1549 (2820)	1521 (2770)
Fluid	1516 (2760)	1499 (2730)	1554 (2830)	1527 (2780)
Weight (bone dry), kg/m^3 (lb/ft^3)	46 (29)	59-70 (37-44)	50-67 (31-42)	42-46 (26-29)

[a] **Average moisture of about 50 percent as received at firing equipment. Adapted from information compiled by the Steam Power Committee of the Canadian Pulp and Paper Association.**

are usually more dependable; also, it is available in much larger quantities and at comparatively lower costs.

Salt Content of Hogged Fuel

In the northwest coastal areas of the United States, logs transported by water can be subjected to a salt or saline environment for long periods of time (sometimes weeks or months), especially if they are stored in saltwater. Such storage allows ample time for the deposition of the various salts and other chemicals present in seawater upon and in the bark of the logs.

Hogged fuel that is transported or stored in salt or saline waters and used in power boilers has been shown to contain anywhere from 0.09 to 2.2 weight percent salt (as sodium chloride, NaCl). The primary factors influencing salt content are length of time the logs remain in saltwater and concentration of salt in the water. These factors, in turn, are affected by plant location with respect to the wood source, log supply and demand, type of storage (i.e., dry or wet, fresh or salt water), and, in tidal estuaries or rivers, the amount of mixing of seawater with freshwater. MacLean and MacDonald[6] found that the average salt content of bark from hemlock after 6 months flotation was 1.44 to 3.13 percent, of which roughly half was absorbed in the first 3 weeks.

Since the concentrations and proportions of the various salt fractions in seawater vary greatly, it is difficult to predict the total emissions of particulate and salt from hogged fuel boilers. Table 2-3 lists the ranges of the principal salt compounds in seawater, with their respective boiling and melting points.

TABLE 2-3. MAJOR SALT COMPOUNDS IN SEAWATER[7]

Compound	Percent by weight	Melting point, °C (°F)	Boiling point, °C (°F)
NaCl	68.08	801 (1474)	1413 (2575)
$MgCl_2$	14.44	708 (1306)	1412 (2574)
Na_2SO_4	11.36		
$CaCl_2$	3.20	772 (1422)	1600 (2912)
Misc.	2.92		

The effect of mixing of fresh and salt waters can be seen by comparing the salinity at high and low tides in a coastal river. Salinity at low tide would tend to be lower because there is a greater flow of fresh water past a given point as the tide moves out. At high tide, the reverse is true. Typical values are 9800 ppm NaCl at low tide and 13,000 ppm at high tide.

Salt Measurement Techniques

Salt content of wood fuel or flue gas can be expressed as a percentage of NaCl, of equivalent chloride, or of total sea salt. This can lead to confusion in interpretation of data, since no standard method is consistently applied to determinations of salt content and the method of analysis often is not given. The amounts of salt reported as NaCl, all chloride salts, and total sea salts can differ significantly (recall Table 2-3).

In this regard the Council of Forest Industries of British Columbia has stated the following:[5]

> "The salt content of particulate matter is commonly expressed as equivalent sodium chloride. This value is obtained by multiplying the chloride ion concentration by 1.58, the factor representing the weighted average of the ratios of chloride salt molecular weight to the chloride content of the molecule. Actually, the value so obtained does not represent sodium chloride (which would be obtained by multiplying chloride by 1.66) but the total chloride salts. A further correction actually is required for

accuracy because chloride salts represent about 90 percent of sea salts and so the factor to get total sea salts from chloride content is 1.76. This latter correction rarely has been made."

This statement emphasizes the importance of identifying the basis upon which salt concentrations are presented and the need for a standard reference method. Table 2-4 lists the methods used at several facilities for measuring salt content of hogged fuel and boiler emissions.

Some procedures suggested by Boubel and Junge[7] for determining salt contents in wood fuels and flue gas emission samples are summarized below.

Because of the wide variation in salt content of fuel materials, it is important to obtain a good representative sample. In fuel supplies that appear to be fairly homogeneous, 10 or 12 samples should suffice. Where the fuel supplies show a wide variation, as many as 24 or 36 samples may be needed. Approximately 900 g (2 lb) of fuel should be collected for each sample.

Next, the fuel sample should be ground until the size of the particles is about 0.3 cm (1/8 in.) or less. Approximately 100 to 200 grams of the ground sample is then used, and the sodium and/or chloride portion is extracted by a standard technique for subsequent analysis.

The salt content of stack emissions is determined in a similar manner. After the fractional masses have been determined (using EPA Method 5), the individual fractions are subjected to a standard procedure for extraction of the sodium- and chloride-based salts. The total extracted sample is then ready for analysis.

FUEL STORAGE AND PRETREATMENT

Fuel Storage

Saltwater transport and storage of logs is common practice at forest products plants in the U.S. northwest coastal region. Typical storage by flat raft and bundle methods is shown in

TABLE 2-4. TECHNIQUES FOR MEASURING SALT CONTENT OF FUEL AND FLUE GAS FROM HOGGED FUEL BOILERS

Source	Measurement technique
Weyerhauser Co.	Total salt as NaCl; calculated by determining total chlorides of a water extract of the sample and assuming all chlorides in the form of NaCl (multiply Cl by 1.66)
Crown Zellerbach	Total salt as NaCl; calculated by determining total chlorides and assuming that all clorides are in the form of NaCl
Simpson Timber Co.	Total salt as NaCl; calculated by determining total chlorides and assuming all chlorides in the form of NaCl
Washington State Department of Ecology	Total salt as NaCl; calculated stoichiometrically by determining Na by atomic absorption and Cl by the mercuric nitrate method

Figure 2-3. The bundle type storage allows more salt to permeate the bark than flat raft storage because hydrostatic pressure holds portions of the bundle well below the water line.

Bark is generally removed with a hydraulic debarker, which is a high-pressure saltwater jet that peels the bark from the logs.

Most of the processed wood waste is stored outside the plant because covered storage space is limited. At the Simpson Timber Company, in Shelton, Washington, logs are stored by flat raft in Oakland Bay.[8] As shown in Figure 2-4, the log storage time in the Bay ranges from 1 to 10 months. The logs arrive by barge during spring and summer.

Plants that depend on one or more auxiliary fuels for continued operation provide separate storage facilities for auxiliary fuels.

Fuel Pretreatment

The fuel is usually uniformly sized before any further pretreatment. If the delivered fuel is not as uniform as required, additional sizing is done at the plant. The usual way to reduce the size of large chunks of wood and bark is with a hogging machine, shown in Figure 2-5. If still further size reduction is required, it is usually done with a hammermill, which also is often used to treat bark directly after the debarker.

All bark fuels contain grit, which should be removed prior to burning or be discharged from the burner with the hot gases. It is also possible to remove grit as a molten slag from the burner.[10]

Predrying Systems for Fuel[1]

Predrying is an important pretreatment for saltwater-borne hogged fuel. This treatment does not greatly reduce the salt content of the hogged fuel, but it improves the efficiency of combustion and reduces overall emissions from the stack. The following discussion of predrying is extracted in large part from Reference 1.

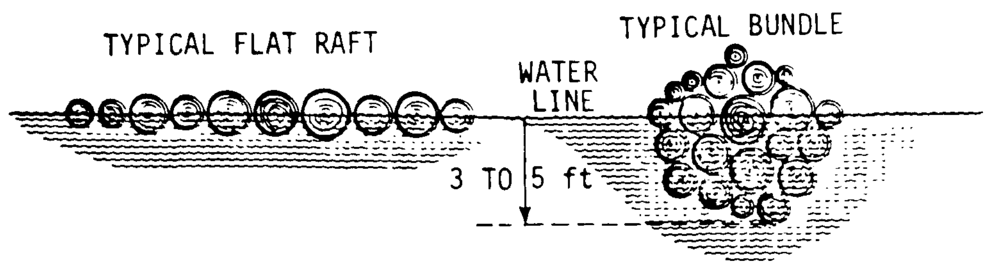

Figure 2-3. Storage of logs by flat raft and bundle.[8]

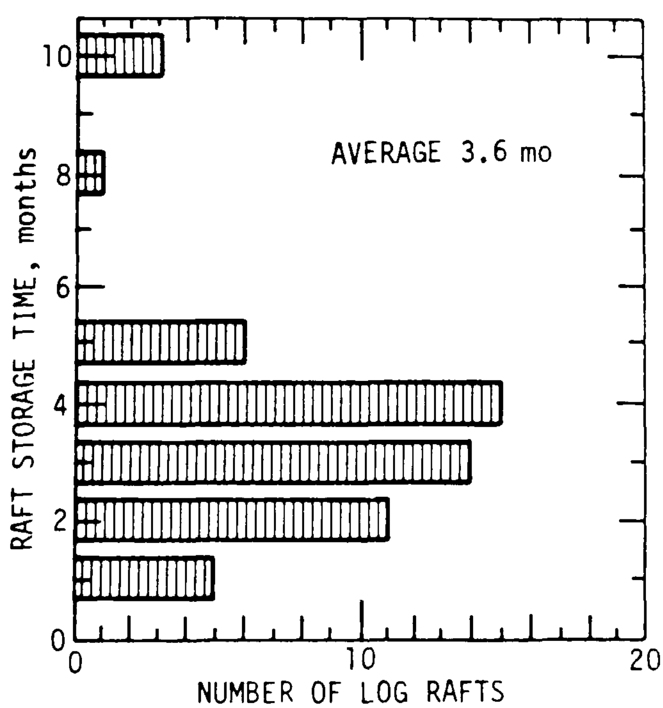

Figure 2-4. Log storage time in Oakland Bay for Simpson Timber Co.[8]

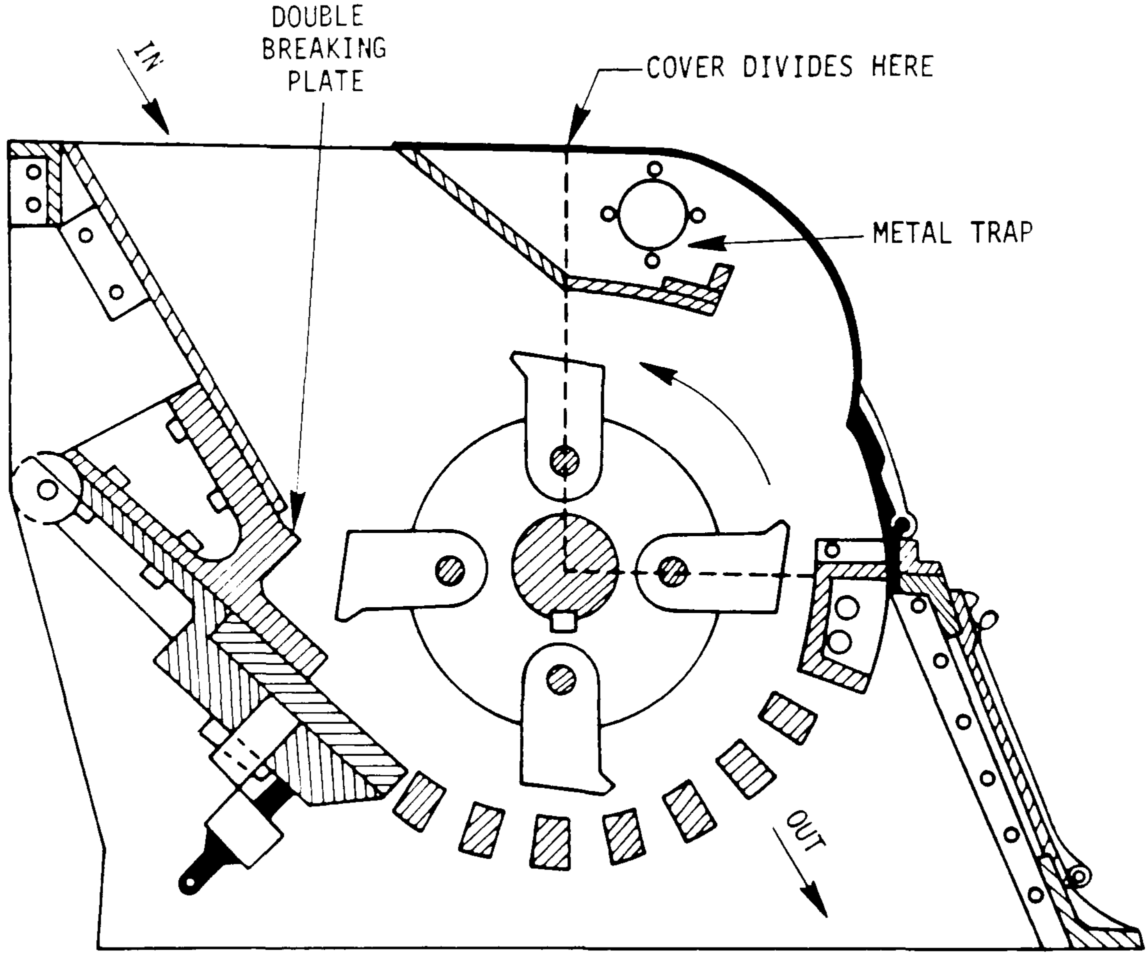

Figure 2-5. Cross-section of a typical hogging machine.[1]

Systems for predrying wood fuels are relatively new. They were developed to overcome two serious shortcomings related to moisture content. The first problem is the extreme variability in moisture content of hogged wood, sawdust, bark, and even other "dry" fuels. The moisture content is affected by species, handling, storage conditions, and similar factors. Drying the fuel outside the furnace allows both manufacturers and operators to deal with a more uniform fuel.

The second function of predrying is reduction of the moisture content. This increases both the thermal efficiency and the steam-generating capacity of the boiler. Figure 2-6 illustrates the effect of fuel moisture on steam production. The drier fuel can be ignited more readily, since the energy needed to evaporate water can go instead to volatilization of combustibles. The boiler responds more rapidly with drier fuel. Elimination of moisture from the flue gas reduces both the gas volume and the corresponding gas velocities. Thus, smaller fans can be used, and particulate carryover is reduced.

Fuel moisture may be controlled by several methods:[11]

1. Vibrate loose water off the fuel on a shaker screen.

2. Press out water mechanically.

3. Control the processes that generate the fuel to limit water addition.

4. Drive off moisture by heating the fuel in dryers.

Removal of water by vibration may be effective when the moisture content exceeds 55 percent. If the process that generates the wood adds large quantities of moisture (for example, hydraulic debarking), vibration can be an inexpensive and low-maintenance approach to control of surface moisture.

Presses can remove only limited amounts of moisture. With most hogged fuel, pressing can reduce moisture levels to 50 to 55 percent. Disposal of the bark pressate water is a serious problem, however; and the method is therefore not practical for

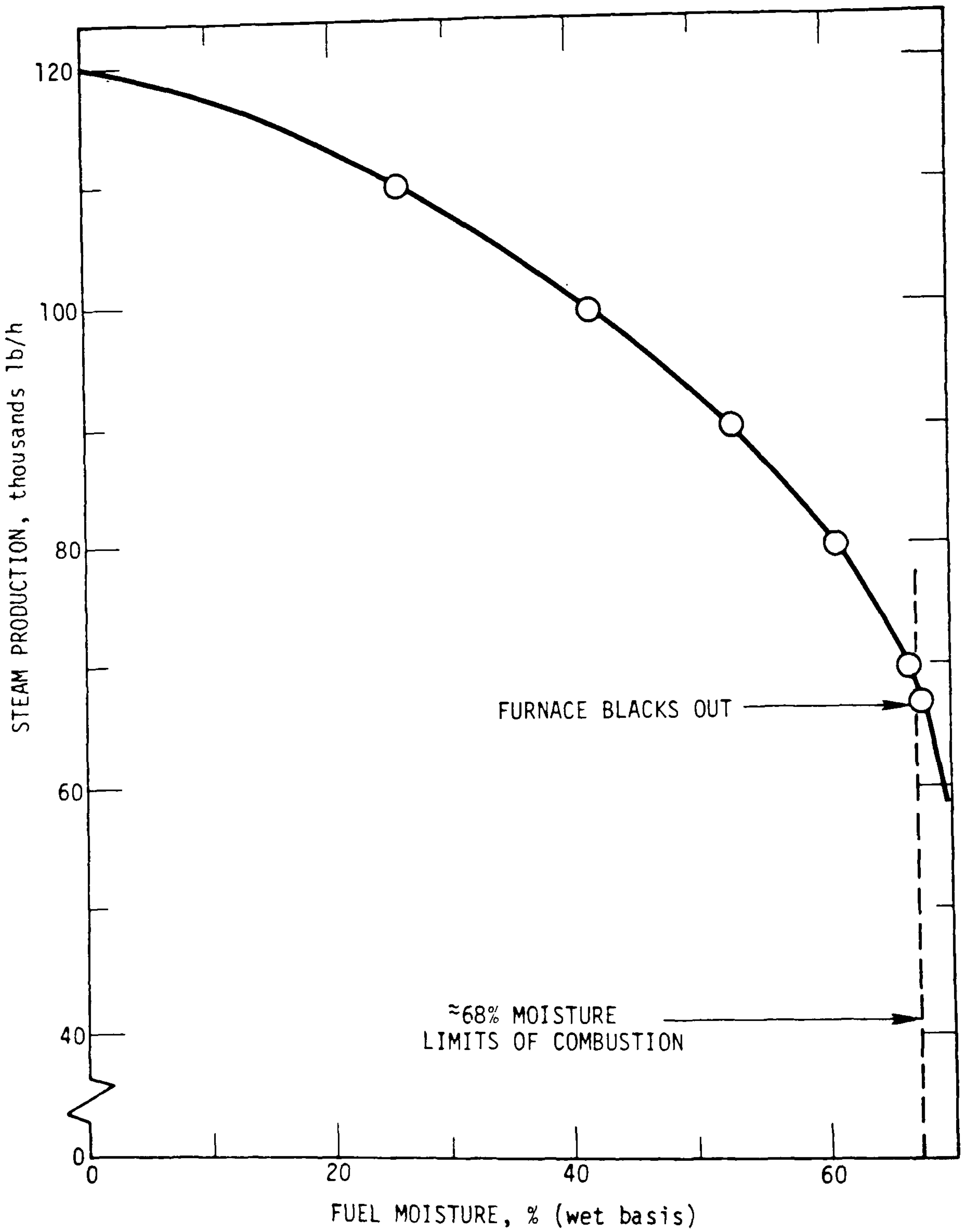

Figure 2-6. Effect of fuel moisture on steam production.[12]

removing moisture from salt-soaked hogged fuel. Control of water additions to fuel in production processes is usually difficult. For example, most plants cannot replace hydraulic debarkers with mechanical systems, and wood product plants have little control over the transport and storage of logs in salt water.

Heating the fuel can reduce its moisture content. Moisture levels in a range from 25 to 35 percent are usually adequate for good combustion. At levels below 20 percent, the dry fines can cause significant dust problems. Heating-type dryers, however, can generate pollutants of three types: if the wood fuel is overheated (above 300°F), the volatile organic material will evaporate and leave the dryer with the exhaust gas stream, which may condense in the atmosphere to form a visible plume; the dry fines may create dust; and, where the dryer is fired by a separate combustion system, the products from that system may become pollutants.

Three systems are currently being considered for drying fuel outside the furnace-boiler system: the hot hog, hot conveyor, and the rotary dryer.[13] These systems can be operated with separate burners (fired with sanderdust or other fines) or by directing boiler flue gases from the stack to the fuel dryer. Use of stack gases puts the drying system in series with the boiler. Thus a fuel dryer breakdown interrupts the feeding of dry fuel to the boiler, and a boiler breakdown shuts down the fuel dryer. These and many other factors must be considered with respect to external fuel drying. Table 2-5 summarizes advantages and disadvantages of the three major external drying systems.

COMBUSTION OF HOGGED FUEL

Because of the variable properties of saltwater-borne bark and wood residue, designing a furnace that will properly consume fuel to generate heat for the boiler with minimum particulate carryover is a difficult task. Some understanding of salt carryover in the flue gas is helpful in design of new boilers. Boubel

TABLE 2-5. ADVANTAGES AND DISADVANTAGES OF THREE MAJOR EXTERNAL DRYING SYSTEMS[14]

	Hot hog
Advantages:	Exposes more surface by grinding to dry quickly; can use boiler stack gas or separate heat source that burns wood fines
Disadvantages:	High energy requirements kW, (hp); high maintenance costs; limited moisture reduction
	Hot conveyor
Advantages:	Can utilize boiler stack gases
Disadvantages:	Low gas temperatures; low moisture release; high maintenance costs; low capacities
	Rotary drum drying
Advantages:	Can accept high inlet gas temperatures; can dry large quantities of high-moisture material; low energy requirements (kW, hp); low maintenance costs; high retention time
Disadvantages:	Requires space for installation

and Junge[7] provide an explanation of physical reactions of salt in boilers. They suggest that when the fuel burns, a portion of the entrained salt, being noncombustible, leaves the boiler as particulate matter in the flue gas. The remainder is deposited in the boilers. Although the mechanisms by which salt is converted to small aerosols in the boiler are not clearly defined, the physical characteristics of salt provide a guide to possible reactions. The major portion of the salt is sodium chloride (60 to 70%) and magnesium chloride (15%).

Since the combustion zone temperatures are typically above 1093°C (2000°F), sodium chloride is almost completely vaporized in the combustion zone. Magnesium chloride, having very similar melting and boiling points, is also vaporized. Condensation of the vaporized salts occurs as the gases are cooled in the convection passes of the boiler. It is hypothesized that rapid cooling or quenching of the vapors causes formation of very small particles. Slow cooling, conversely, leads to formation of larger particles. Since the rate of gas cooling is not constant and uniform throughout the boiler, the particles occur in different sizes. Temperatures of the gases leaving the combustion zone generally drops from the peak value to 316°C (600°F) in about 2 seconds. This quenching is rapid enough to create many fine particles of salt in the flue gases.

Salt-laden hogged fuels are burned in the same furnaces that burn other wood fuels. The design of such furnaces must be flexible enough to handle the fuel, with nonuniform moisture content, and still follow the steam load demand on the boiler. The furnace may be separate from the boiler or integral with it. If it is separate, the firing is outside the boiler; and the hot gases, which are probably still burning, are directed from the furnace to the boiler. If the furnace is integral with the boiler, the fuel is burned in the boiler, which is surrounded by a heat transfer surface. Both types are in use in the United States today.

Detailed descriptions of various furnace types are given in Appendix B. The following discussion from Corder[15] briefly summarizes these furnace types: Dutch oven, spreader stoker, inclined grate, suspension firing, cyclone, and direct firing.

Dutch Oven

This is a two-stage furnace, consisting of (1) a Dutch oven, in which moisture is evaporated and fuel gasified, and (2) a secondary furnace, in which combustion is completed. Fuel is fed by gravity through an opening in the Dutch oven and forms a conical fuel pile. The Dutch oven has been widely used in the past, but most new installations are using other systems.

Spreader Stoker

The spreader stoker is used on many new installations. Pneumatic or mechanical spreaders introduce fuel above the grates. Some of the fuel burns in suspension; and the rest falls on the grates, where burning is completed.

A modified form of the stoker furnace is the inclined-grate type, shown in Figure 2-7, in which the fuel is introduced in a continuous ribbon at the top of the grate. Moisture is removed in the upper section, and burning is completed in the lower section. Ash is removed from the lowest section of the grate.

Suspension Firing

This recent method for firing hogged fuel resembles a pulverized-coal-fired system. Hogged fuel of very small size is blown into the furnace alone or in combination with natural gas or oil.

Cyclone Furnace

Firing of a cyclone furnace can be either horizontal or vertical. The horizontal type is a version of the Babcock and Wilcox coal-fired cyclone furnace, and in fact it requires coal as the primary fuel for combustion with hogged fuel. The coal ash provides a slag coating to ensure proper burning of hogged

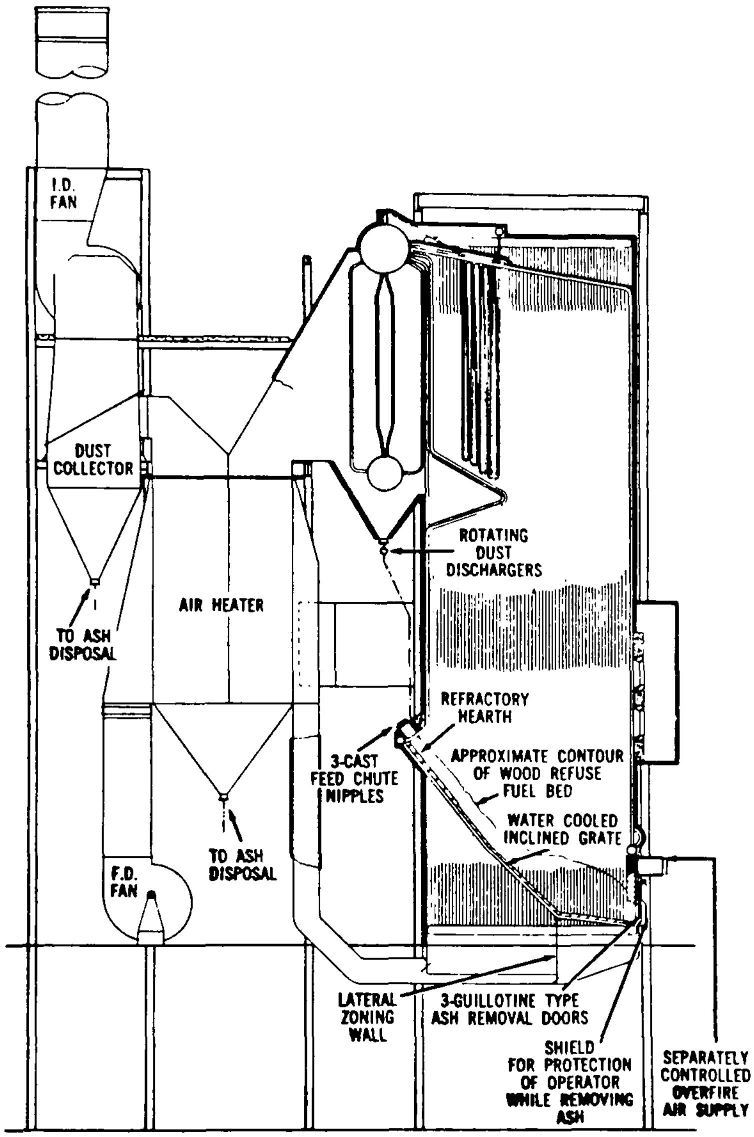

Figure 2-7. Inclined-grate stoker furnace at a paper and pulp mill in British Columbia.[15]

fuel, which cannot exceed 30 percent of the furnace heat input and must pass through a screen of 19-mm (3/4-in.) mesh.

The vertical cyclone furnace was developed in the sixties in Scandinavia especially for hogged fuel. It is a refractory-lined cylinder, in which an underfeed stoker pushes fuel up through the bottom grate to form a conical pile. Primary air under high pressure enters the furnace tangentially from below to provide cyclonic action (see Figure 2-8).

Direct Firing

Direct-fired systems use hot gases from hogged fuel burning as a supply of high-temperature gases for veneer dryers, lumber dry kilns, and dryers for wood and bark particles. The Energex system fires finely divided wood or bark fuel in a cyclonic burner. Hot gases from this system can be used in a rotary drum dryer for hogged fuel. A pile burning furnace has reportedly been used as a heat source for a veneer dryer,[16] and suspension burning of undried bark in a cylindrical annular combustion chamber on a laboratory basis has also been reported.[17]

PARTICLE SIZE DISTRIBUTION OF SALT EMISSIONS

The size distribution of the salt particles strongly affects the removal efficiency of control equipment. Particulate emissions from boilers burning hogged fuel with no salt can be handled adequately by conventional control devices. With salt-laden hogged fuel, however, the size range of the particulate emissions is much smaller; and the size fractions below 1 μm typically are composed of more than 50 percent salt.

In an analysis of the effect of salt (NaCl) on overall mean particle size in emissions from hogged fuel boilers, the salt fraction reduced the overall mean particle size by a factor of approximately 10 (see Figure 2-9).[18] As the figure shows, the mean particle size of the nonsalt fraction is about 17.5 μm. The mean particle size of the salt fraction is about 0.23 μm. The overall mean particle size, about 2.15 μm, indicates the

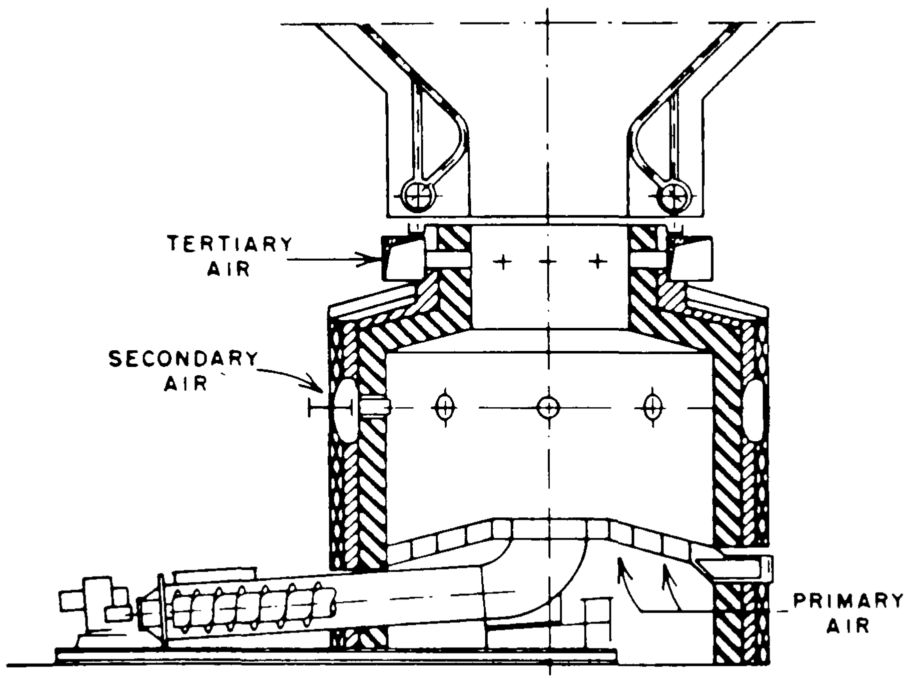

Figure 2-8. Bark-fired cyclone type furnace.[1]

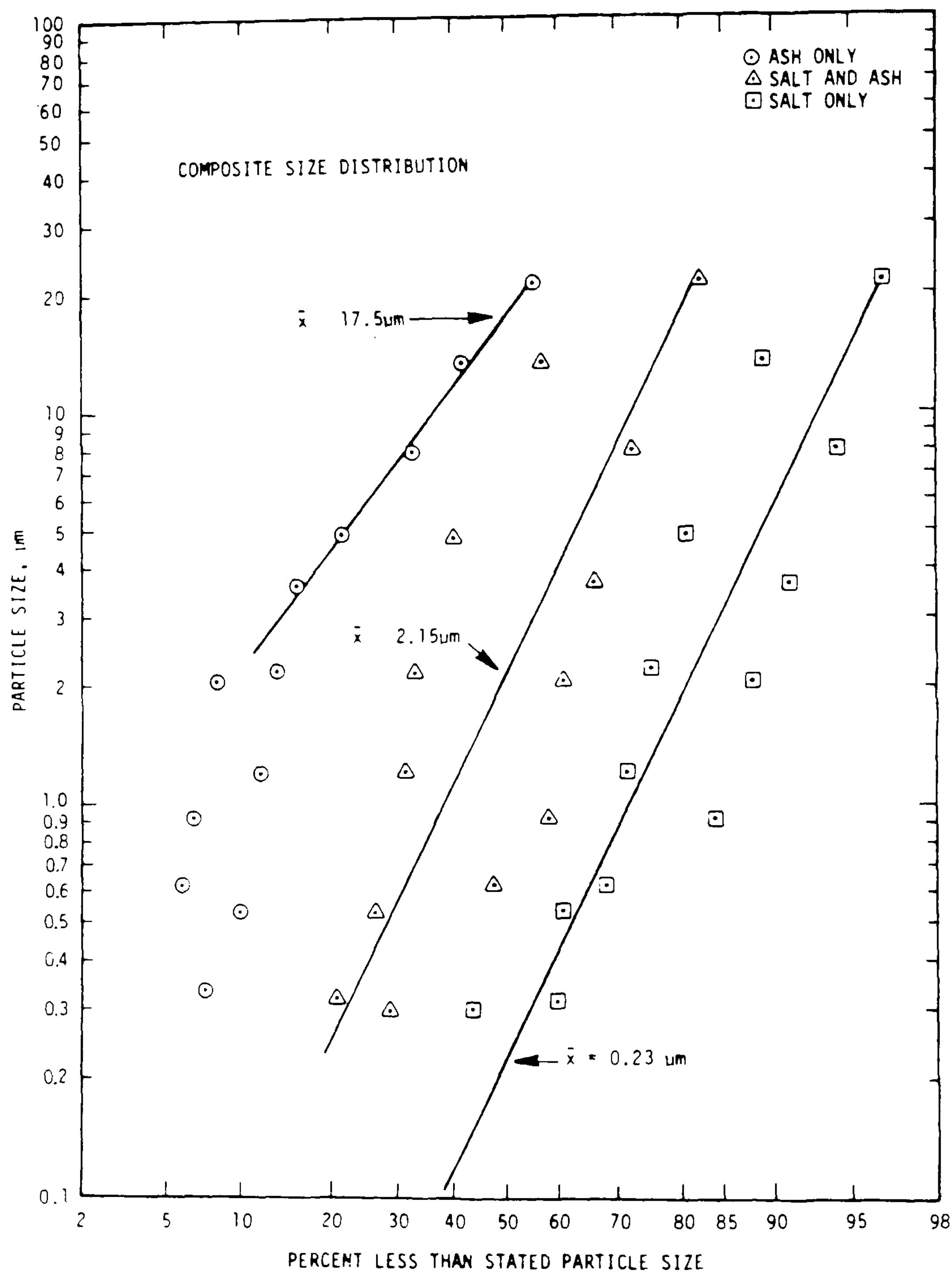

Figure 2-9. Particle size distribution at Weyerhauser Co., North Bend, Oregon, plant (composite from 11 tests).

extent of size reduction caused by salt in the emissions. Some data show that the overall mean particle size of the salt-laden particulate can be as low as 0.2 μm.

Comparison of particle size data from the Weyerhauser North Bend plant with data from Crown Zellerbach's Port Townsend plant and data from British Columbia verifies the reduction in mean particle size due to salt particles. Table 2-6 summarizes particle size data from various salt-laden hogged fuel boilers. All of these impactor measurements were taken at the outlet of a multiclone or cinder collector. The reduction in the overall mean particle size can result in dust even finer than the North Bend composite shown in Figure 2-9, depending on the size distribution of the nonsalt fraction of the dust.

EFFECTS OF SALT-LADEN HOGGED FUEL BOILER EMISSIONS ON AMBIENT AIR QUALITY

An important consideration in assessment of salt emissions from hogged fuel boilers is the effect of these emissions on ambient air quality in the vicinity of the boilers. This section summarizes data on ambient air quality near three facilities that fire salt-laden hogged fuel: (1) Simpson Timber Company's Shelton plant, which is controlled by a fabric filter, (2) Crown Zellerbach's Port Townsend plant, which is controlled by a venturi scrubber, and (3) Weyerhauser Company's North Bend plant, which is controlled only by multiclones. Federal and state standards for suspended ambient particulate matter and standards of Washington and Oregon are shown in Table 2-7.

TABLE 2-6. PARTICLE SIZE DATA FROM HOGGED FUEL BOILERS WITH EXCESSIVE SALT EMISSIONS[a]

Source	Salt in fuel, %	Particle size dist. Mean particle size ($\bar{x}$), µm	Particle size dist. Geometric deviation, σ_g	Reference
Weyerhauser North Bend, Oreg.	0.1 - 0.9 (0.48 avg.)	2.2[b]	≃10	18, 19
Crown Zellerbach Port Townsend, Wash.	0.3 - 1.8	0.35 - ~3.0	7.4 - ≃10	4,c
Simpson Timber Co. Shelton, Wash.	1.6 - 2.15 (dry basis)	85 to 95% less than 0.4 µm	NA	20,d
St. Regis Paper Co. Tacoma, Wash.	Not given	Salt 0.25, overall ~18	NA	21
Plant not specified, British Columbia	Low salt	3.2	≃7	5
	High salt	2.0	≃39	

[a] Measurements are after the multiclone or cinder collector unless otherwise noted.

[b] Composite of 11 tests.

[c] Personal communication with Mr. Alan Rosenfeld, Crown Zellerbach, Environmental Services.

[d] Personal communication with Mr. Robert Hoit, Simpson Timber Co.

NA - Not available.

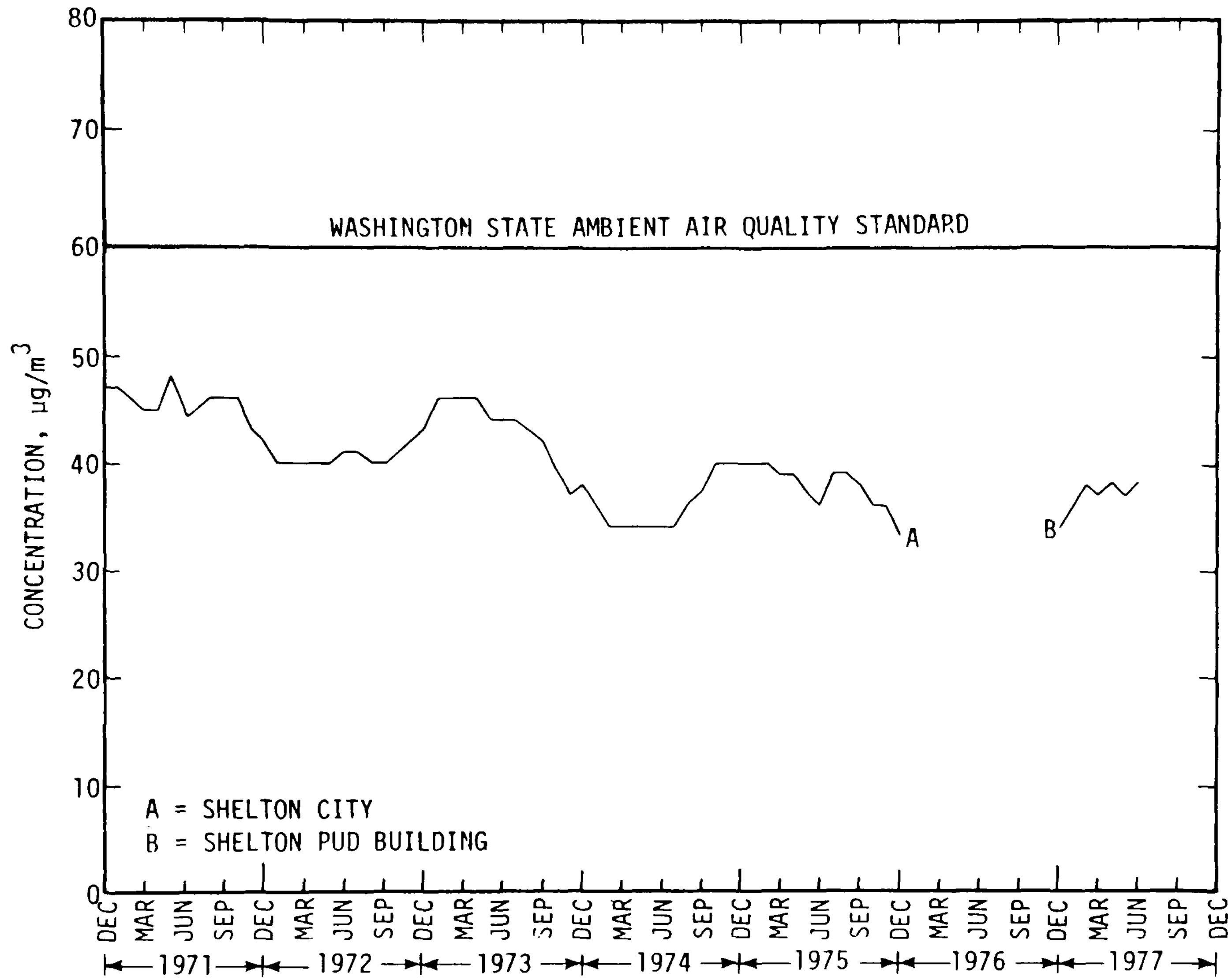

Figure 2-10. Suspended particulate data, Shelton, Washington, (12-month moving geometric means).[22]

TABLE 2-7. PARTICULATE AMBIENT AIR QUALITY STANDARDS ($\mu g/m^3$)

Averaging (time)	Federal		Washington	Oregon
	Primary (health)	Secondary (welfare)		
Annual geometric mean	75	60	60	60
24 hours	260	150	150	150
1 month				100

Simpson Timber Company, Shelton, Washington

Air monitoring has been done in Shelton since 1965, when the Washington State Department of Health established particle fallout stations within the city limits. Air monitoring by the Olympic Air Pollution Control Association (OAPCA) began in 1969. The measurements of suspended particulate are taken with high-volume (HV) air samplers. Values measured over a period of 5 years at two sites in the Shelton city limits are summarized in Table 2-8 and shown in Figure 2-10. These sites are located northwest of the Simpson Timber Company's plant, where fabric filters were installed on the salt-laden hogged fuel boilers in 1976. As these data show, the particulate air quality has been in compliance with standards on an annual basis since 1970. The installation of the baghouses on Simpson's hogged fuel boilers in 1976 apparently did not cause an appreciable improvement in the ambient air quality in the Shelton area. The data may have been affected, however, by relocation of the ambient air monitor to its present site in the same year.

TABLE 2-8. SUMMARY OF SUSPENDED PARTICULATE DATA, SHELTON, WASHINGTON[22] ($\mu g/m^3$ except as noted)

Sampler location	Year	Monthly Avg.		24-hr max.	No. ≥ 150	No. ≥ 260	Annual geometric mean
		Low	High				
Shelton City Hall	1970	23	108	194	3	0	47
	1971	23	92	132	0	0	42
	1972	19	104	155	1	0	43
	1973	23	68	103	0	0	38
	1974	24	79	171	1	0	40
	1975	20	65	99	0	0	33
Shelton-PUD	1976	19	72	132	0	0	34

Crown Zellerbach, Port Townsend, Washington

OAPCA began monitoring suspended particulate and particle fallout at the high school in Port Townsend in 1970. In 1973 the HV monitor was moved to its present location at the Port Townsend Fire Station. Both of these sites are located northwest of the Crown Zellerbach mill and its hogged fuel boiler. The mill is the major source of air pollution in the Port Townsend area.

Measurements of suspended particulate are summarized in Table 2-9 and shown graphically in Figure 2-11. The data show that both monitors have been in compliance with Federal and state ambient air regulations since 1971.

Crown Zellerbach installed a new hogged fuel boiler and venturi scrubber at the Port Townsend mill in September 1977. Because ambient air data are not available for 1977, it is not known whether the better control of the salt-laden particulate has yielded a measurable reduction in suspended particulate.

Weyerhauser, North Bend, Oregon

Boubel and Junge[7] have summarized ambient air data in the vicinity of Weyerhauser's North Bend plant. The Oregon Department of Environmental Quality has operated a total suspended particulate monitor on the roof of the Coos Bay City Hall since

TABLE 2-9. SUMMARY OF TOTAL SUSPENDED PARTICULATE DATA OBTAINED NEAR CROWN-ZELLERBACH BOILER[22]
($\mu g/m^3$ except as noted)

Sampler location	Period of record	Monthly avg. Low	Monthly avg. High	24-h max.	No. $\geq$ 150	No. $\geq$ 260	Annual geometric mean
Port Townsend High School	1-12/70	16	47	70	0	0	25
	1-12/71	15	51	80	0	0	25
	1-12/72	17	48	90	0	0	28
	1- 6/73	17	39	67	0	0	24
Port Townsend Fire Station	6-12/73	20	38	47	0	0	28
	1-12/74	25	61	170	1	0	35
	1-12/75	24	55	88	0	0	34
	1-12/76	22	46	68	0	0	31

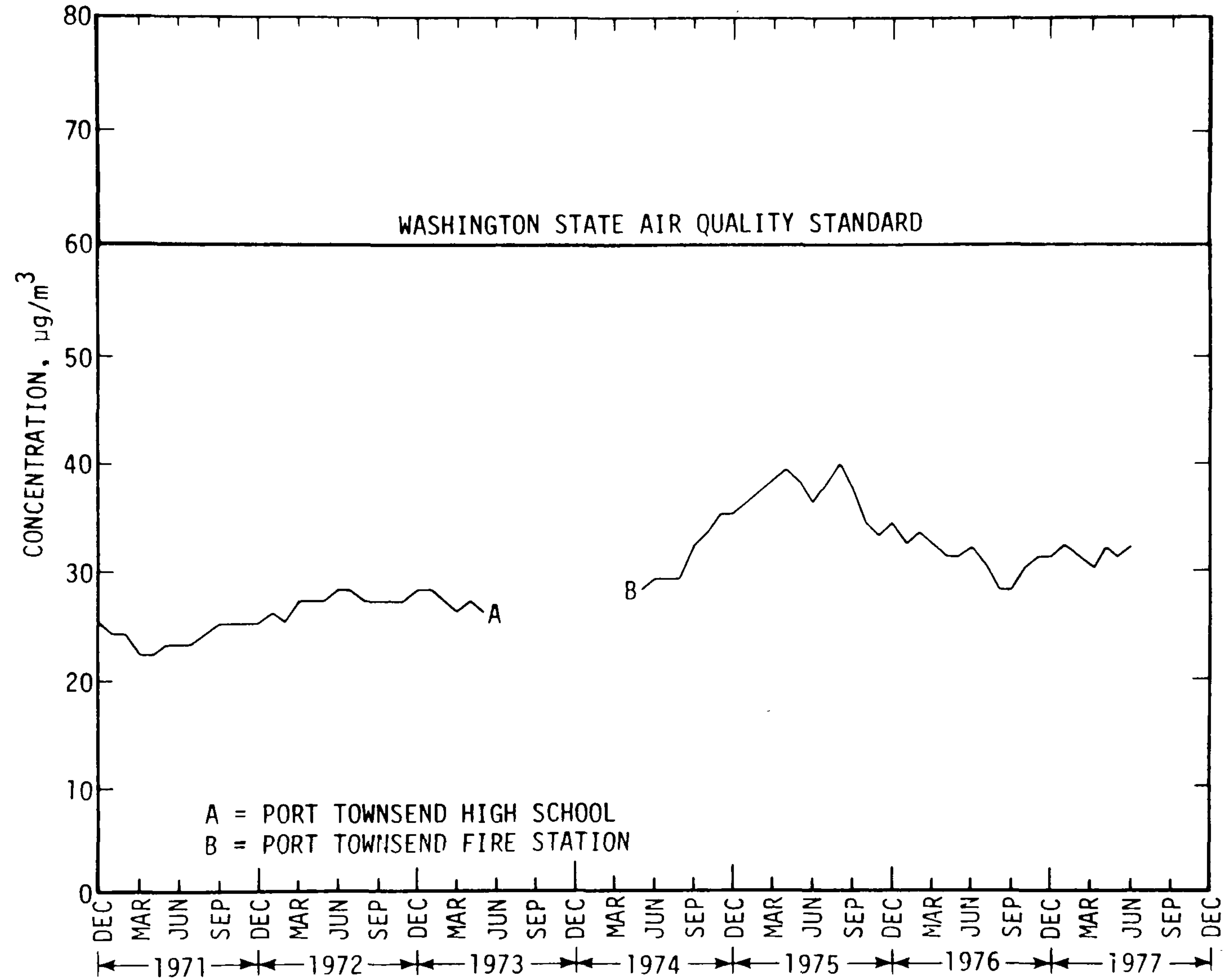

Figure 2-11. Suspended particulate data, Port Townsend, Washington, (12-month moving geometric means).[22]

1970. This site is approximately 3 miles south of the Weyerhauser North Bend stack. Figure 2-12 summarizes the geometric means of measurements for each month in 1976 and 1977, and Table 2-10 summarizes yearly data since 1970.

The total suspended particulate for the Coos Bay sampling station has been in compliance with Federal and state ambient air regulations since 1970. Weyerhauser's three hogged fuel boilers at the North Bend plant are equipped with multiclones for particulate control.

General

Since 1970, monitors near the hogged fuel boilers at Shelton, Port Townsend, and North Bend have shown compliance with annual suspended particulate standards, and only Shelton, in 1970 were there at violations of the 24-hour maximum average standard.

Not enough data are yet available after installation of secondary collectors at Port Townsend in 1977 and Shelton in 1976 to determine whether air quality has improved at the local monitoring sites.

The Council of Forest Industries of British Columbia[5] offers the following pertinent comment:

> The dispersion of salt from a hogged fuel boiler depends on meteorological conditions in the vicinity of a mill. With a high stack and reasonable wind velocities, the stack plume should be dispersed rapidly, and the salt should only add fractionally to that already in the air (coastal area). Locations with low wind velocity and inversion conditions, may cause the plume to linger in the vicinity of the mill and significantly increase ambient background salt levels.

EFFECTS OF SALT-LADEN PARTICULATE ON CORROSION RATES

Data on the effects of airborne salt on corrosion rates are minimal. Egan[23] states that such effects are very difficult to determine. Tsang and Stubbs,[24] reporting on a study of the effects of salt emissions from a hogged fuel boiler in a coastal

TABLE 2-10. SUMMARY OF TOTAL SUSPENDED PARTICULATE DATA, COOS BAY SAMPLING STATION[7]

Station number and location	Year	No. of samples	Days > 150	Days > 260	Particulate concentration, $\mu g/m^3$: Annual geometric mean	24-h avg.: Maximum	24-h avg.: 2nd highest
Coos Bay - 4th and Central (City Hall) 0607101	1970	89	1	0	51.7	152	137
	1971	49	1	0	53.6	185	137
	1972	81	0	0	44.9	108	103
	1973	56	1	0	50.4	164	123
	1974	52	0	0	47.9	127	111
	1975	59	0	0	37.1	95	93
	1976	54	0	0	40.6	110	110
	1977	56	1	0	43.3	220	130

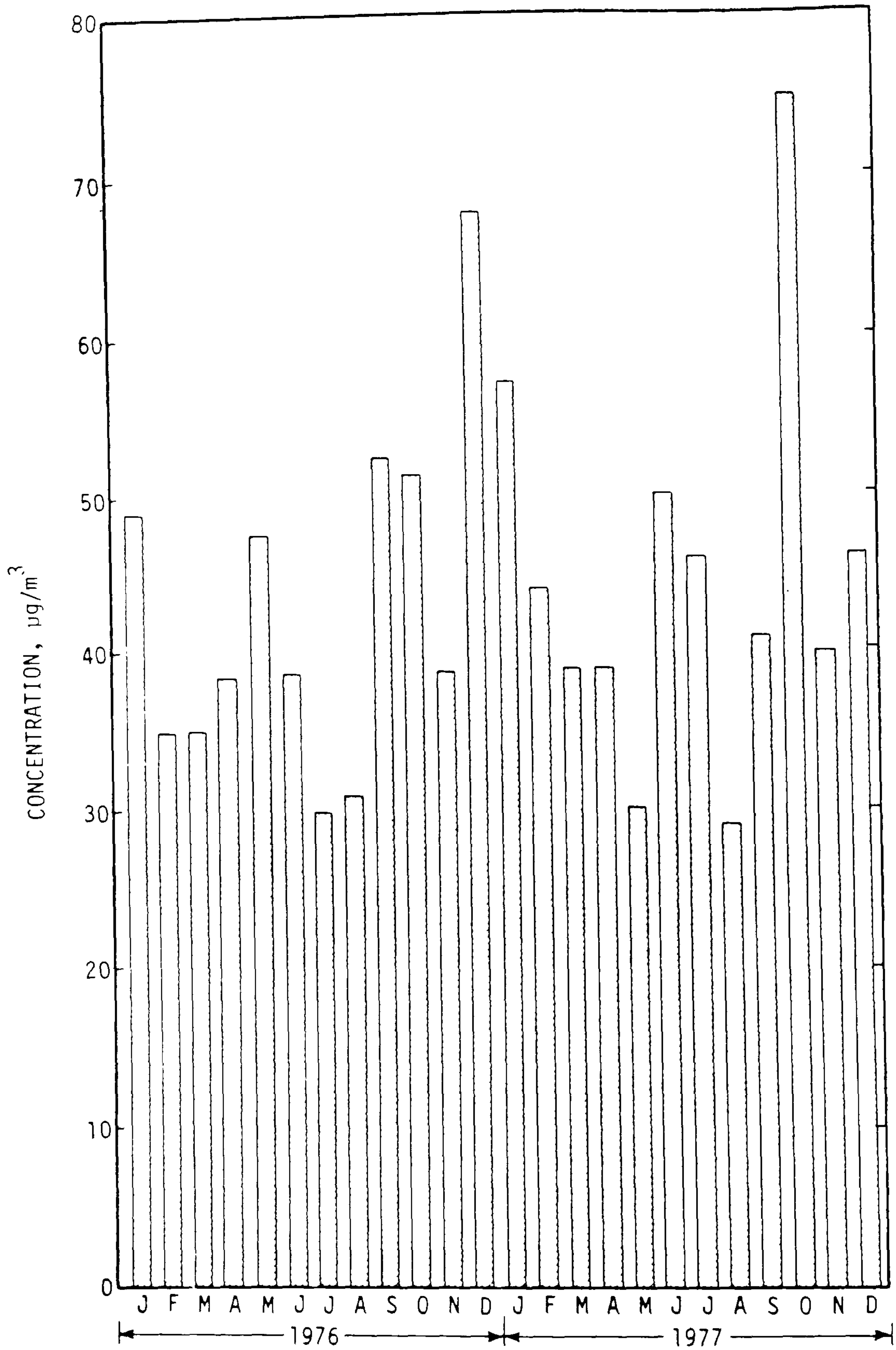

Figure 2-12. Suspended particulate data, Coos Bay, Oregon, (monthly geometric means).[7]

environment, state that although the sodium chloride levels in the surrounding environment increased measurably, the mill under study did not cause chloride corrosion to increase beyond natural background levels in the 1973 to 1975 study period. Apparently the salt deposition rate, an important factor in salt related corrosion, was not high enough to cause an increase in the corrosion rate.

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SECTION 3

CONTROL TECHNOLOGY TO REDUCE SALT EMISSIONS FROM HOGGED FUEL BOILERS

Among the several preventive and remedial ways of reducing salt-laden particulate emissions from hogged fuel boilers, the best preventive method is simply not to transport and store wood residue and bark in saltwater. Most often, however, this is not possible. Other preventive measures involve preparing the fuel in such a way as to maximize combustion efficiency and minimize stack emissions. Remedial solutions are to improve an existing control system or to install a more efficient secondary control device.

This section discusses the presently available technology for reducing salt emissions from hogged fuel boilers: fuel handling and pretreatment, combustion modifications, and use of conventional and novel particulate control devices.

FUEL HANDLING AND PRETREATMENT

Type and Duration of Storage

Water storage of logs as flat rafts or small-log bundles, as shown earlier in Figure 2-3, can affect salt emissions. In flat rafting of logs about 45 to 50 percent of each log remains out of water whereas in bundled logs only 10 to 20 percent of the logs are out of water. As a result the salt content of flat-rafted logs is lower than that of bundled logs, and the resultant salt emissions from the hogged fuel are lower also.

Storage time of logs in saltwater also governs the salt particulate emissions. Reducing the storage time from 3 to 4 months to about 5 days usually yields a significant decrease in salt emissions from the stack.[1] Figure 3-1 illustrates the

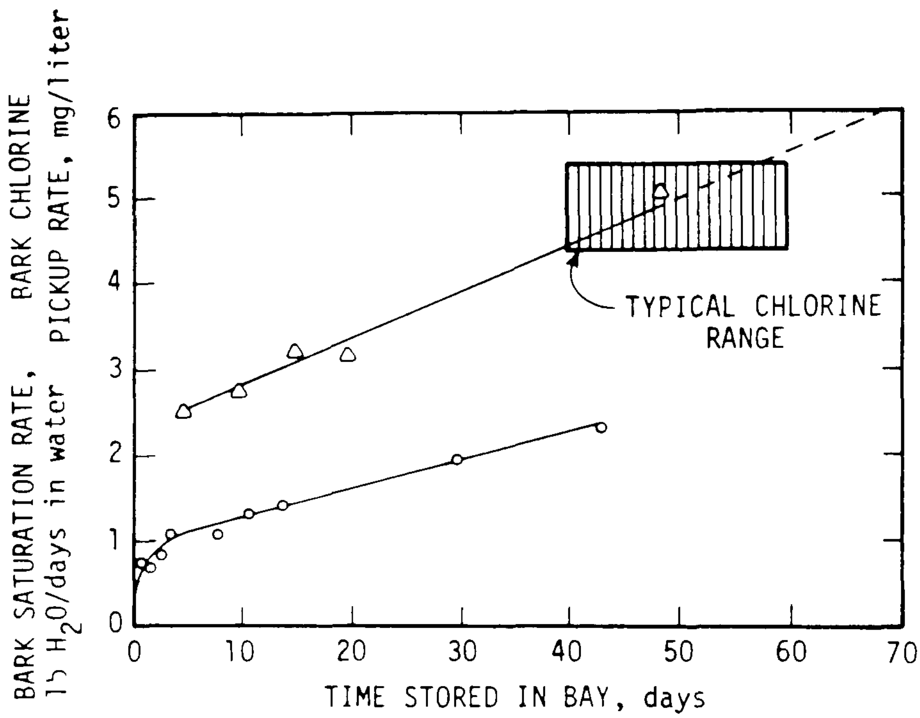

Figure 3-1. Relation of time in saltwater to absorption of water and salt.[1]

relation of time in saltwater to absorption of water and salt.[1] Another study[2] confirms this effect, indicating that approximately half of the total salt absorbed at 6 months is absorbed in the first 2 or 3 weeks of contact with seawater.

Fuel Pretreatment

Bark Pressing--

A well-engineered pressing operation reduces the moisture content of saltwater-soaked bark to about 50 percent wet basis.[3] The presses also remove substantial quantities of salt, and thus reduce plume opacity and salt particulate emissions when the bark is burned. The bark pressate water, however, is a "high-strength" wastewater that requires primary and secondary treatment plus deepwater outfall. Thus, although bark pressing does present an opportunity to substantially reduce opacity and particulate emissions by lowering salt content, this treatment creates a wastewater disposal problem.

Methods of Fuel Preparation--

As discussed earlier, boiler operators try to minimize the amounts of dirt and moisture in fuel and the size of fuel fed to the boiler. Rinsing bark with freshwater both reduces the salt content and cleans the fuel. This treatment prevents accumulation of excessive dirt in the boiler and reduces carryover of salt in the flue gas. Fuel size can be reduced by hogging and by hammermilling.

Moisture content of the saltwater-borne hogged fuel contributes significantly to the presence of combustible particulate matter in stack emissions.[4] Experiments have been done with fuels having different moisture contents. In one study, the opacity of stack emissions increased by 1/2 to 1 Ringelmann number when the moisture content increased from 57.4 to 61 percent.[1] The wetter the fuel, the more difficult it is to hold excess air at the desired low levels. Figure 3-2 shows why furnaces will black out or flame out with fuel having high moisture content. Temperatures shown are calculated theoretical

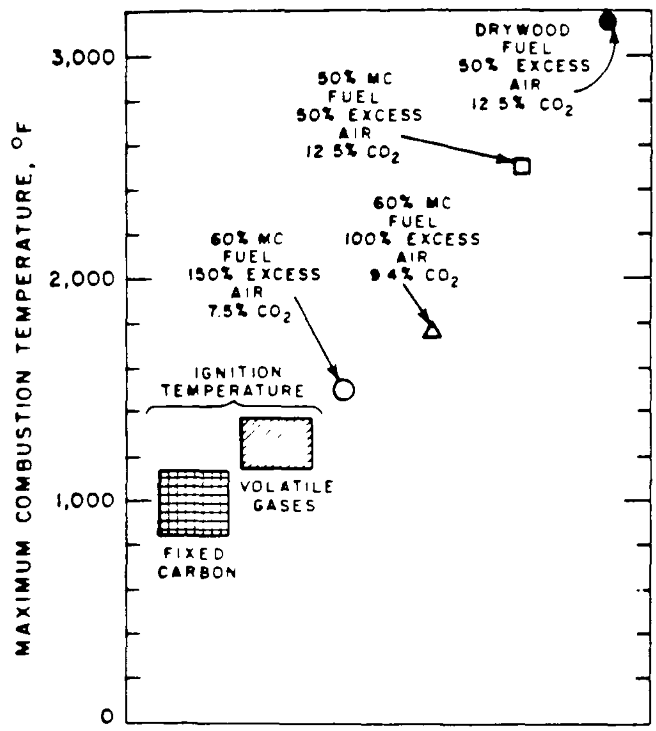

Figure 3-2. Maximum combustion temperatures of a mixture of Douglas fir and western hemlock fuel under four sets of conditions.[1]

maximums. Actual furnace temperatures are several hundred degrees lower, depending on waterwalls and other furnace design characteristics.[1]

Volatile gases represent 60 percent or more of the heating value of wood fuel. When furnace temperature drops below the ignition temperature of the volatile gas, the furnace blacks out and steam production is reduced drastically. Unburned hydrocarbons greatly increase the opacity of stack gas. The water-vapor contents measured in flue gases from hogged fuel boilers range from about 6 to 32 percent by volume. In burning hogged fuel with an average moisture content of 45 to 50 percent by weight, the water vapor content of the flue gas in the stack is about 20 percent by volume.[5] This value varies with moisture content of the fuel, relative humidity of the air, and the percentage of excess air. Higher water vapor content in the flue gas causes a white plume that does not violate opacity standards but does contribute to an increase in opacity of stack emissions.

The different systems of predrying to reduce the combustible matter in the stack gas are discussed in more detail in Section 2.

COMBUSTION MODIFICATIONS

Combustion modifications can maximize combustion of hogged fuel in the firing zone and thus attenuate opacity. The salt in the hogged fuel, which contributes to a major portion of the opacity, is noncombustible particulate matter. Hence an increase in rate of combustion will not reduce the carryover of salt particulates in the flue gas, but can lead to a significant reduction of other combustible particulate matter, which contributes to opacity and stack emissions.

Operating parameters that affect particle entrainment and combustion include initial fuel moisture content, furnace excess air levels, and steam generation rate.[6] Investigation of the influence of these parameters on carryover mechanisms could lead to changes in plant operation that would significantly reduce the emission of combustible particulate matter. Combustion model studies and furnace entrainment models of hogged fuel (without salt) show that an increase in initial fuel moisture reduces the burning rate and increases emissions in the flue gas.[6] An increase in excess air has the same effect but also reduces opacity. Increasing the steam generation rate increases both burning rate and furnace gas velocity.

A recent experimental study[7] of the problems associated with combustion of wood residue fuels illustrates that (1) combustion on the grate can be controlled to reduce particulate emissions, (2) increasing the fuel bed depth reduces particulate emissions, an effect that is more pronounced at higher combustion rates, and (3) in a spreader-stoker boiler with a bed of wood fuel thick enough to consume all of the oxygen in the underfire air, the flow rate of underfire air controls the rate of combustion.

With regard to control of noncombustible salt particles in flue gas, recall the hypothesis presented pn page 22. Additional work is needed on ways to slow the quenching effect on vaporized salt leaving the combustion zone. This would generate larger particles of salt that would be collected more easily by a conventional control system than are submicron salt particles.

Combustion control modifications to hog fuel boilers during combination firing with auxiliary fuels such as oil, natural gas, coal, or solid waste would reduce their consumption as well as carryover of combustible particulate in flue gas.[8]

Stack Diameter

A consideration that is not a control technique but affects visible opacity of particulate emissions is the stack diameter. The larger the diameter of the stack, the higher the apparent opacity, even though actual smoke density and emissions are constant (see Figure 3-3). This effect can be significant at large steam plants or where several boilers discharge into a

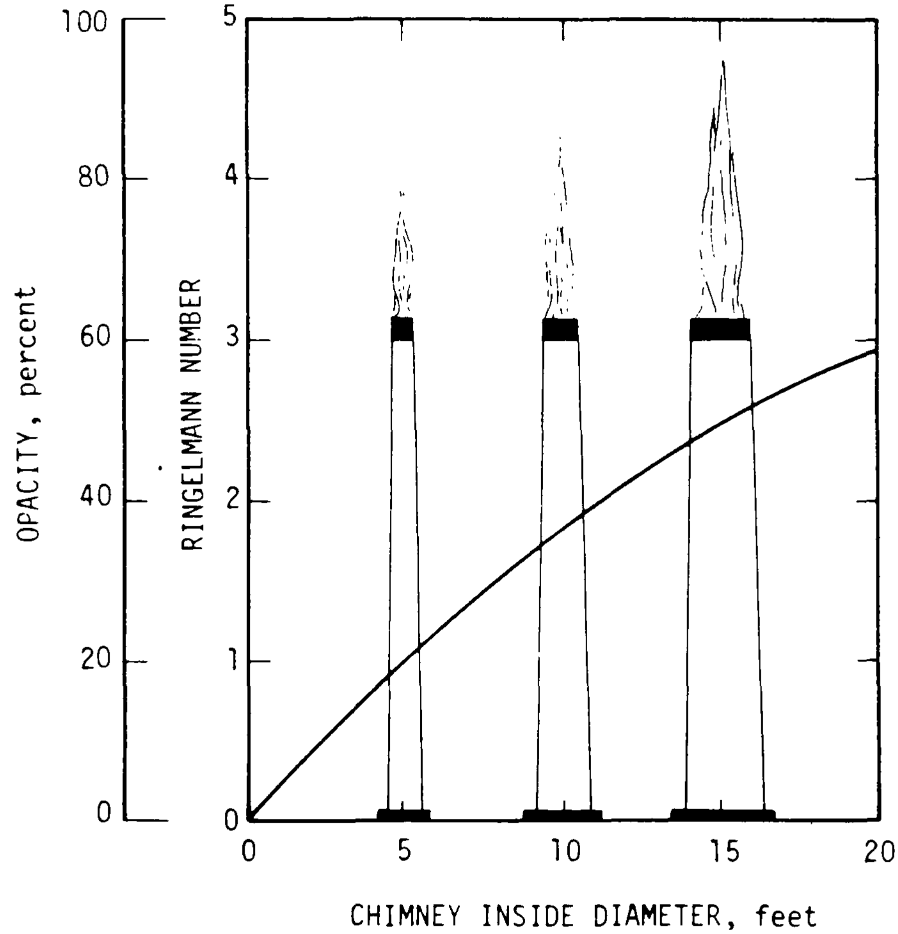

Figure 3-3. Increase in apparent density of smoke with increasing chimney diameter (actual density is constant).

common chimney. Smaller stack diameters that yield lower visible opacity readings should be considered in the design of new plants.

CONVENTIONAL PARTICULATE CONTROL DEVICES

Four types of conventional control devices are used to reduce particulate emissions from hogged fuel boilers: mechanical collectors, electrostatic precipitators (ESP's), wet scrubbers, and fabric filters. Only the latter three can remove submicron salt particles. Mechanical collectors, nonetheless, are used on salt-laden hogged fuel boilers and ESP's are not.

The following sections on each control device summarize basic design parameters, applicability for controlling salt emissions, performance on hogged fuel boilers (salt-free and salt-laden fuel), operation and maintenance problems, and disposal techniques for collecting salt/particulates. The best available method of collecting salt/particulates is also discussed. Case histories of a fabric filter and venturi scrubber operating on salt-laden hogged fuel boilers are presented in Appendix C.

Mechanical Collectors

General System Characteristics--

Particulate emissions from hogged fuel boilers have traditionally been controlled by mechanical collectors. Although mechanical collectors generally do not meet applicable emission regulations when controlling salt-laden particulate, discussion of system characteristics and design philosophy is included in this report because of the widespread use of mechanical collectors, and their importance as part of a total system of particulate control. Figure 3-4 shows a multiple cyclone (multiclone) collector, and Figure 3-5 illustrates gas flow through a single cyclone. These collectors are usually designed for dust loadings of 2 to 11 g/m^3 (1 to 5 gr/scf).[9] Particle size distribution of ash from combustion of nonsalt bark is normally 30 to 40 percent

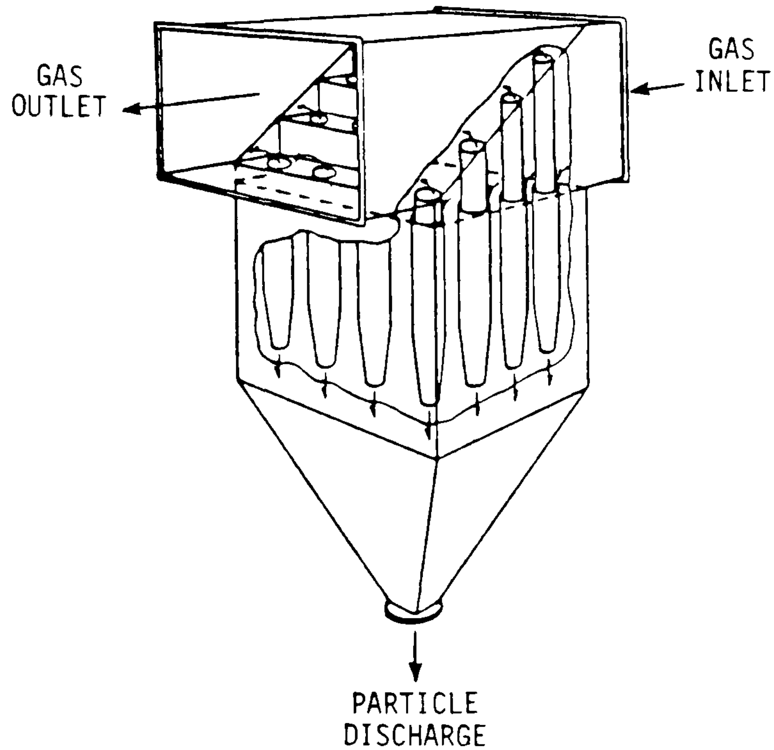

Figure 3-4. Simplified diagram of a multiple cyclone.[5]

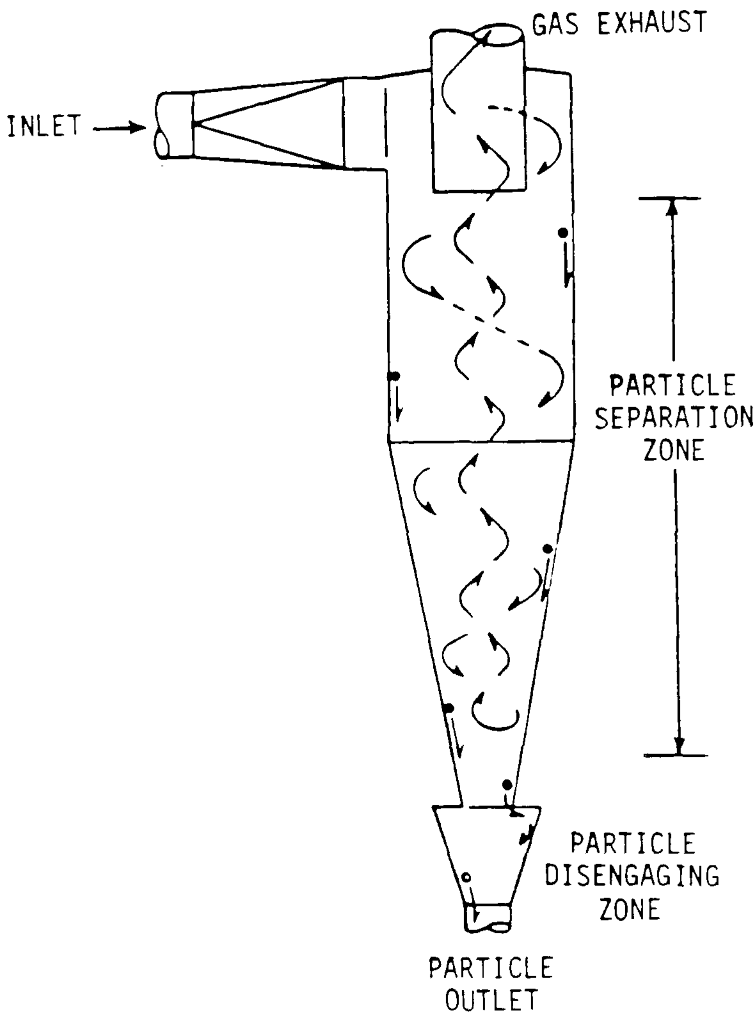

Figure 3-5. Cyclone collector for particles in flue gases.[5]

less than 10 micrometers. Pressure drop across the mechanical collector ranges from 3.8 to 6.4 cm (1.5 to 2.5 in. water) for best collection efficiency.[9]

With ash from salt-free bark, mechanical collectors can sometimes achieve collection efficiencies of 85 to 90 percent with outlet loadings of 172 to 258 kg/J (0.4 to 0.6 lb/10^6 Btu). A collection efficiency of 30 to 70 percent is a more realistic estimate. Even under optimum conditions opacity may be a problem, especially with stoker-fired boilers, which respond slowly to upset conditions. Opacity can be limited to 20 percent during normal operation, but may exceed 20 percent during boiler upsets.

The collection efficiency of a mechanical collector can be increased by adding a second stage, which is usually furnished with higher-efficiency vanes to collect the fine dust not caught in the first stage.[9] This second stage may add 5 percent to the collection efficiency.

Another method is to add a small multitubular collector, designed to remove 10 to 20 percent of the gas flow from near the top of the hopper housing of the main collector.[9] This collector removes fine and leafy char dust, which would normally be entrained and contribute greatly to stack opacity. Collection efficiency is improved by 2 to 3 percent.[9]

With salt-laden particulate, the collection efficiency of the mechanical collector is considerably lower because of the fineness of the salt particles; overall efficiencies of 30 to 50 percent would be expected. Test data from Weyerhauser's North Bend plant confirm this observation.[10]

Mechanical collectors would be less efficient on stoker boilers than on the Dutch-oven type because the stoker releases finer particulate. The Council of Forest Industries of British Columbia (CFIBC)[11] believes that the efficiency of mechanical collectors has been overstated and that they are not effective at particle sizes below 30 micrometers.

Design Factors--

The most important design parameters that affect cyclone efficiency are pressure drop, particle size distribution, inlet gas velocity, inlet dust loading, cyclone body, and diameter dimension ratios.[5,12,13]

Pressure drop--The pressure drop across a cyclone varies as the square of the gas volume and is directly proportional to the density of the dust-laden gas. The total pressure in a cyclone consists of separate losses in the inlet flue, the cyclone body, and the outlet duct.

Flow rates must be kept within the design range. If flow rates are too low, the centrifugal force is not great enough to separate the particles from the carrier gas. If flow rates are too high, energy is wasted in pressure drop across the unit and the return vortex configuration may be disrupted.[12]

Particle size--The size and density of particles control their settling velocity. It is the specific gravity of the particle, not the bulk density that is important. Small particles with low specific gravity and thus low settling velocity may not be able to reach the cyclone walls during the brief time the gas is in the cyclone.[12]

Figure 3-6 illustrates a typical efficiency curve as a function of particle size for both a conventional cyclone and a multiclone collector. With a single cyclone, collection efficiency falls off much more rapidly as particle size decreases, than with a multiclone collector. Because the diameter of the multiple cyclones is much smaller than that of the single large cyclone, the collection efficiency is greater, especially for fine particles.

Cyclone dimensions--A cyclone of higher efficiency and higher pressure drop could be designed by (1) increasing the length of the cyclone, (2) decreasing the inlet width, or (3) increasing the ratio of body diameter to outlet diameter, while

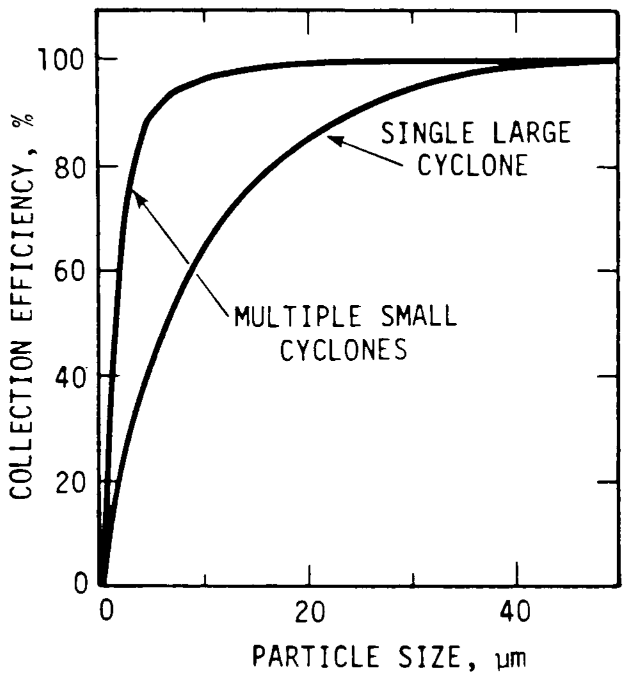

Figure 3-6. Relation of particle size to collection efficiency of cyclones.[5]

at the same time providing a smaller body diameter. An increase in the length of the cyclone body provides a longer residence time for gas in the cyclone and therefore more revolutions. An increase in body length minimizes the loss of efficiency due to reentrainment in the ascending vortex. Increasing the ratio of body diameter to the gas outlet diameter effects an increase in efficiency up to ratios of about 3 to 4, with relatively little gains above that. As the ratio increases, pressure drop also increases. Tables 3-1 and 3-2 summarize the effects of dimensional changes in a cyclone collector.

Operation and Maintenance Problems - Cyclones--

Operational and maintenance problems associated with cyclone systems removing particulates from flue gas of hogged fuel boilers are principally due to plugging, leakage of air into the system, and changes in gas flow to the cyclone.

Plugging of the cyclone tube(s) occurs often, especially when salt condenses on the collector surfaces. Erosion of the interior of the cyclone creates surfaces on which particles may become anchored. Particles continue to collect at this site until the tube becomes fully plugged. Plugging can also occur when the collection hoppers are overfilled. The particulate material must be removed from the hopper at the same rate that it enters or before the particulates can back up into the tube. Plugging can also be caused by caking of the particles on the tube walls because of particle size, adhesive properties of the particles, and condensed moisture in the system.

Cyclones can be operated as push-through or pull-through systems. Most hogged fuel boilers use a pull-through system to reduce abrasion on the induced-draft fan. Since this system operates essentially under vacuum conditions, there must be no leakage of air into the system. Leakage can cause reentrainment of particles, loss of removal efficiency and possibly fire.

The removal efficiency of cyclones is sensitive to changes in flow rates, which can be significant in the hogged fuel

TABLE 3-1. EFFECTS OF CYCLONE DIMENSIONS ON PERFORMANCE AND COST[13]

	Performance		
	Pressure loss	Efficiency	Cost
Increase cyclone size	Down	Down	Up
Lengthen cylinder	Slightly lower	Up	Up
Increase inlet area, maintain volume	Down	Down	No change
Increase inlet area, maintain velocity	Up	Down	Down
Lengthen cone	Slightly lower	Up	Up
Increase size of cone opening	Slightly lower	Up or down	No change
Decrease size of cone opening	Slightly higher	Up or down	No change
Lengthen clean gas outlet pipe internally	Up	Up and/or down	Up
Increase clean gas outlet pipe diameter	Down	Down	Up

TABLE 3-2. EFFECTS OF PHYSICAL PROPERTIES AND PROCESS VARIABLES ON EFFICIENCY[13]

	Pressure loss	Efficiency	Cost
Gas change			
Increase velocity	Up	Up	Initial cost down Operating cost up
Increase density	Up	Neg.	Slightly higher
Increase viscosity	Neg.	Down	Neg.
Increase temperature (maintain velocity)	Down	Down	Neg.
Dust change			
Increase specific gravity	Neg.	Up	Neg.
Increase particle size	Neg.	Up	Neg.
Increase loadings	Neg.	Up	Neg.

Neg. = Negligible.

boilers because steam demands are often highly variable. This, combined with the small particle size typical of salt-laden emissions can cause drastic reduction of removal efficiency.

Electrostatic Precipitators (ESP's)

General System Characteristics--

Although ESP's are used widely in controlling particulate emissions from combustion sources, they are rarely used on boilers fired with hogged fuel. Several successful installations on boilers that burn salt-free wood have been put into operation in the last 5 or 6 years. Figure 3-7 illustrates a typical ESP.

From the precipitation standpoint, ash from hogged fuel boilers poses two potential problems that must be accounted for in design:[5] (1) since it is carbonaceous, the ash has a lower resistivity than coal ash and tends to lose its charge quickly, and (2) the ash is prone to reentrainment because of its low density, coupled with flake-like particle shape. When the ash is salt-laden, the submicron salt particles require a conservative design, i.e., a larger collecting surface.

Performance of ESP's on boilers burning salt-free hogged fuel has reportedly been excellent. Where an ESP was retrofitted downstream of a cyclone at a paper mill, the average outlet loading was 0.04 g/m^3 (0.018 gr/acf); guarantee was 0.06 g/m^3 (0.025 gr/acf).[14]

The only reference to performance of an ESP on a boiler burning salt-laden hogged fuel comes from the Council of Forest Industries of British Columbia.[11] Test data from a pilot unit installed at the Victoria Sawmill Division of B.C. Forest Products, Ltd., showed that performance varied from excellent [0.05 g/m^3 (0.02 gr/dscf)] to poor [0.7 g/m^3 (0.3 gr/dscf)].[4] The program showed that the ESP could reduce salt fume to an acceptable level when it was maintained and operated within precise limits. When control of operation was not virtually perfect, however, the performance deteriorated markedly.

No full-scale ESP's have yet been installed on boilers

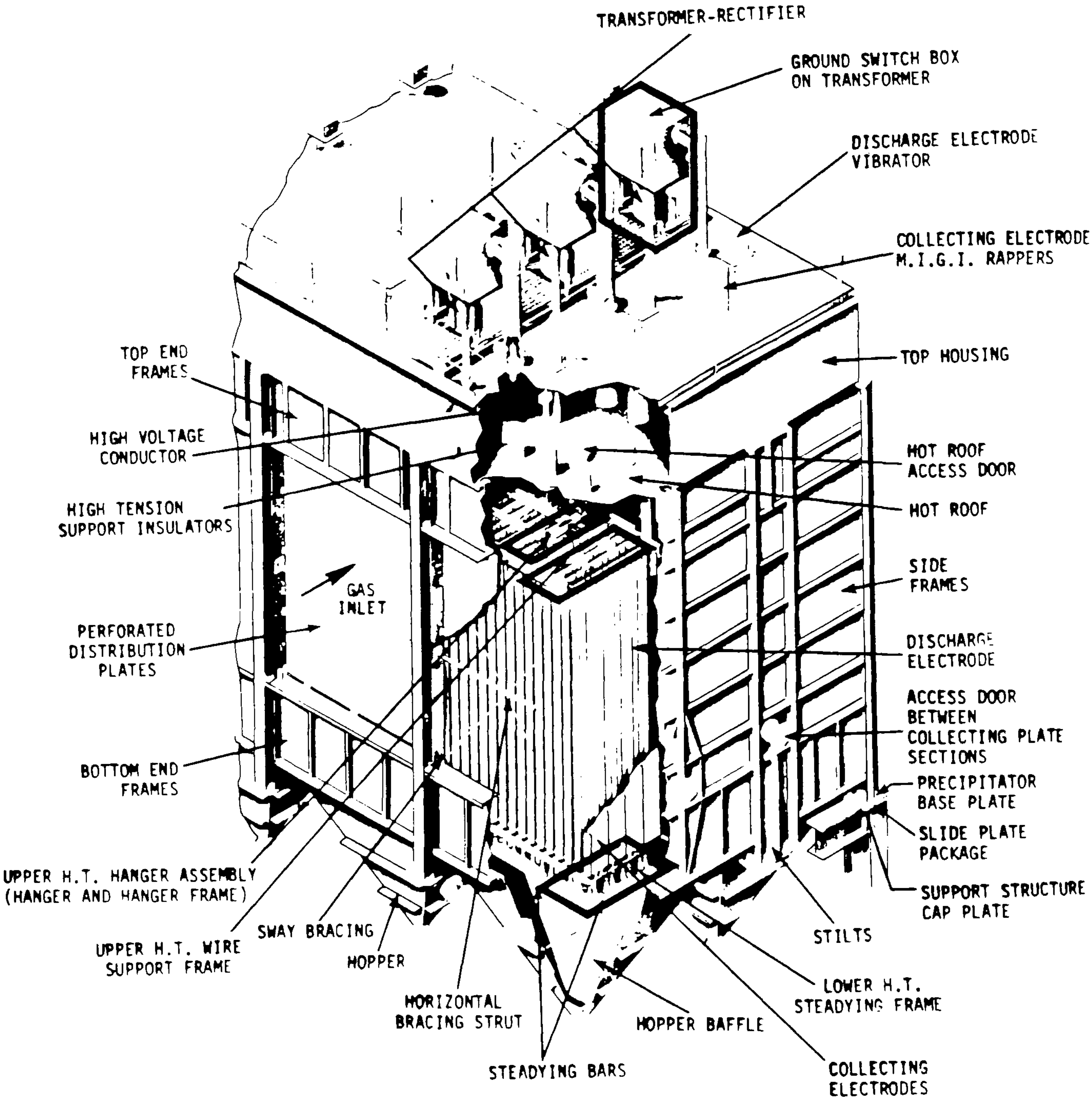

Figure 3-7. Typical electrostatic precipitator with top housing (courtesy of Research Cottrell, Inc.).

burning salt-laden hogged fuel. Weyerhauser Co.[15] has reported that ESP manufacturers will guarantee outlet grain loading but not visible opacity in these applications. Communication with a major ESP manufacturer indicates that the refusal to guarantee visible opacity is because salt content varies with season and the salt particles are difficult to control; in-stack opacity, however, would be guaranteed. This contact indicated that his company would guarantee visible opacity for an application with salt-free hogged fuel.

Design Factors--[16]

The three most important parameters that affect the design and subsequent performance of an ESP are (1) the gas volumetric throughput in m^3/min (acfm), the total plate collection area in m^2 (ft^2), and power density in watts/m^2 (watts/ft^2) of collecting area.

With knowledge of the total gas throughput, which is dictated by the boiler firing rate, and the specific collection area (SCA) in m^2/m^3 per s (ft^2/1000 acfm), one can determine the total area required for compliance with an emission standard. Equations for determining the required SCA are given below in English units:

$$SCA = \frac{16.67 \ln^2(1-n)}{w_k}$$

$$n = 1 - c_o/c_i$$

Where

n = Overall mass collection efficiency, percent

w_k = Modified migration velocity, ft/s

c_o = Allowable outlet grain loading gr/dscf

c_i = Inlet grain loading, gr/dscf

<u>Migration velocity</u>--The modified migration velocity is a function of electrical energization of the precipitator and of gas properties. It is often conveniently linked with resistivity level. A typical migration velocity range in boiler applications

with salt-free wood fuel is 0.6 to 1.5 cm/s (0.2 to 0.5 ft/s). With salt-laden fuel, the migration velocity would be in the lower portion of the range.

A digression is needed here to clarify the usage of w_k (modified migration velocity) in contrast to the effective migration velocity w, which is used in the conventional Deutsch-Anderson efficiency equation.[17] The effective migration velocity w is a function of several factors, including precipitator length, overall mass collection efficiency, and gas velocity. The variation in w within a given precipitator is caused by changing particle size distribution as precipitation proceeds in the direction of gas flow.

The modified migration velocity, w_k, as presented by Matts and Ohnfeldt,[18] can be treated essentially as a constant for any application. It is, of course, strongly dependent upon the inlet particle size distribution.

Power input--The third basic design parameter is power density required to establish the optimum voltage-current characteristics of the corona, given the dust entering the precipitator. Power density is a function of electrical resistivity, particle size characteristics and distribution, gas loading and composition, gas temperature, and gas pressure. It is often conveniently linked with resistivity, such that for a moderate resistivity of 10^9 ohm-cm, the value will be approximately 27 watts/m^2 (2.5 watts/ft^2). For boilers burning salt-free fuel the range of power input is 11 to 22 watts/m^2 (1 to 2 watts/ft^2). This power density range would not change significantly with salt-laden fuel.

The selection of power density is often conveniently based on resistivity of the dust. Table 3-3 illustrates a general correlation between power density and dust resistivity; this relationship would also apply to fly ash from coal firing.

TABLE 3-3. DESIGN POWER DENSITY

Resistivity, ohm-cm	Power density, watts/m^2 (watts/ft^2) of collecting plate
10^{4-7}	43 (4.0)
10^{7-8}	32 (3.0)
10^{9-10}	27 (2.5)
10^{+11}	22 (2.0)
10^{+12}	16 (1.5)
$>10^{+13}$	< 11 (< 1.0)

Field voltages and current densities for salt-free hogged fuel boilers range from 40 to 45 kV and 0.22 to 0.65 mA/m^2 (0.02 to 0.06 mA/ft^2), respectively. These values are not constant for each point in the precipitator. At the inlet section where the dust loading is greatest, the voltage-current characteristics differ significantly from those at the outlet.

Although it appears that resistivity plays a significant role in selection of w_k and power density, there is no precise or universally applied method for predicting resistivity on the basis of the material entering the furnace.

Operation and Maintenance Problems - ESP's--

Only a few ESP's are applied to hogged fuel boilers, and none have been installed on boilers burning salt-laden hogged fuel. Data on operating problems are sparse. One possible problem is the possibility of fire from "char" on precipitator walls (buildings) and especially in the hoppers. The fire hazard can be minimized by installing trough-type hoppers to remove dust continuously. Elimination of in-leakage will decrease the availability of air for combustion.

Reentrainment is also a problem with bark ash because of its low resistivity.

Specific design parameters for application of an ESP to hogged fuel firing are presented in Table 3-4.

Wet Scrubbers

General System Characteristics--

Wet scrubbers are applied to a number of hogged fuel boilers to control particulate emissions. Most are installed downstream of a multiple cyclone collector. In salt-free applications under normal operating conditions the outlet loadings range from 0.05 to 0.14 g/m^3 (0.02 to 0.06 gr/scf) at pressure drops of 15 to 38 cm (6 to 15 in.) water.[19]

Only one boiler fired with salt-laden hogged fuel is currently equipped with a venturi scrubber, Crown Zellerbach, Port Townsend plant; this scrubber is installed downstream of a multiclone. The reported outlet loadings are 0.16 to 41 g/m^3 (0.07 to 0.18 gr/scf), depending on the salt content of the fuel. A salt concentration greater than 1 percent will limit the performance of this venturi scrubber, which operates at a pressure drop of 38 to 51 cm (15 to 20 in.) water. The salt content of particulate emissions from the scrubber is reported to be 50 to 70 percent or more. Opacity of the stack effluent is estimated at 35 percent. This scrubber would require a pressure drop greater than 51 cm (20 in.) water to achieve the roughly 80 percent efficiency needed to meet the 0.23 g/m^3 (0.10 gr/dscf) particulate emission regulation, assumming a typical inlet concentration of 1.14 g/m^3 (0.50 gr/dscf), and greater than 1 percent salt in the fuel.

Design Factors--

This discussion is limited to venturi scrubbers since they can remove greater amounts of fine particles than other types of scrubbers when pressure drops are high enough. This is a prime consideration in removal of submicron salt particles from hogged fuel boilers.

In conventional terminology, the venturi scrubber is categorized as a gas atomized spray scrubber. A flooded disc type of venturi scrubber is illustrated in Figure 3-8. The collection process relies mainly on the acceleration of the gas stream to

TABLE 3-4. DESIGN PARAMETERS AND DESIGN CATEGORIES FOR ELECTROSTATIC PRECIPITATORS[16]

Dust composition

NaCl
C (Char)
Sand
Fly ash

Precipitator capacity

No. of precipitators
No. of chambers (units)/precipitator
No. of ducts/chamber (unit)
Duct spacing
Plate height
Treatment length
Section lengths and total number of each (per precipitator)
Collecting area
No. of electrical sections parallel to gas flow (per precipitator)
No. of electrical sections across gas flow (per precipitator)
No. of hoppers parallel to gas flow (per precipitator)
No. of hoppers across flow (per precipitator)

Rapping, electrodes, etc.

Type discharge electrode
Meter (feet) discharge electrode/vibrator or rapper
Type discharge electrode vibrator or rapper
Type collecting electrode
Square meter (square feet) collecting electrode/rapper
Type collecting electrode rapper

Electrical energization (of each electrical section)

Watts/m^2 (watts/ft^2) of collecting electrode
Square meter (square feet) of collecting electrode/T-R
Mode (switching)
Corona kilovolts
Milliamperes/1000 m^2 (mA/1000 ft^2) of collecting electrode
Milliamperes/T-R set

Performance-related parameters

Gas flow	Overall mass collection efficiency
Gas temperature	Fractional mass collection efficiency
Gas (treatment) velocity	Inlet grain loading
SCA	Outlet grain loading

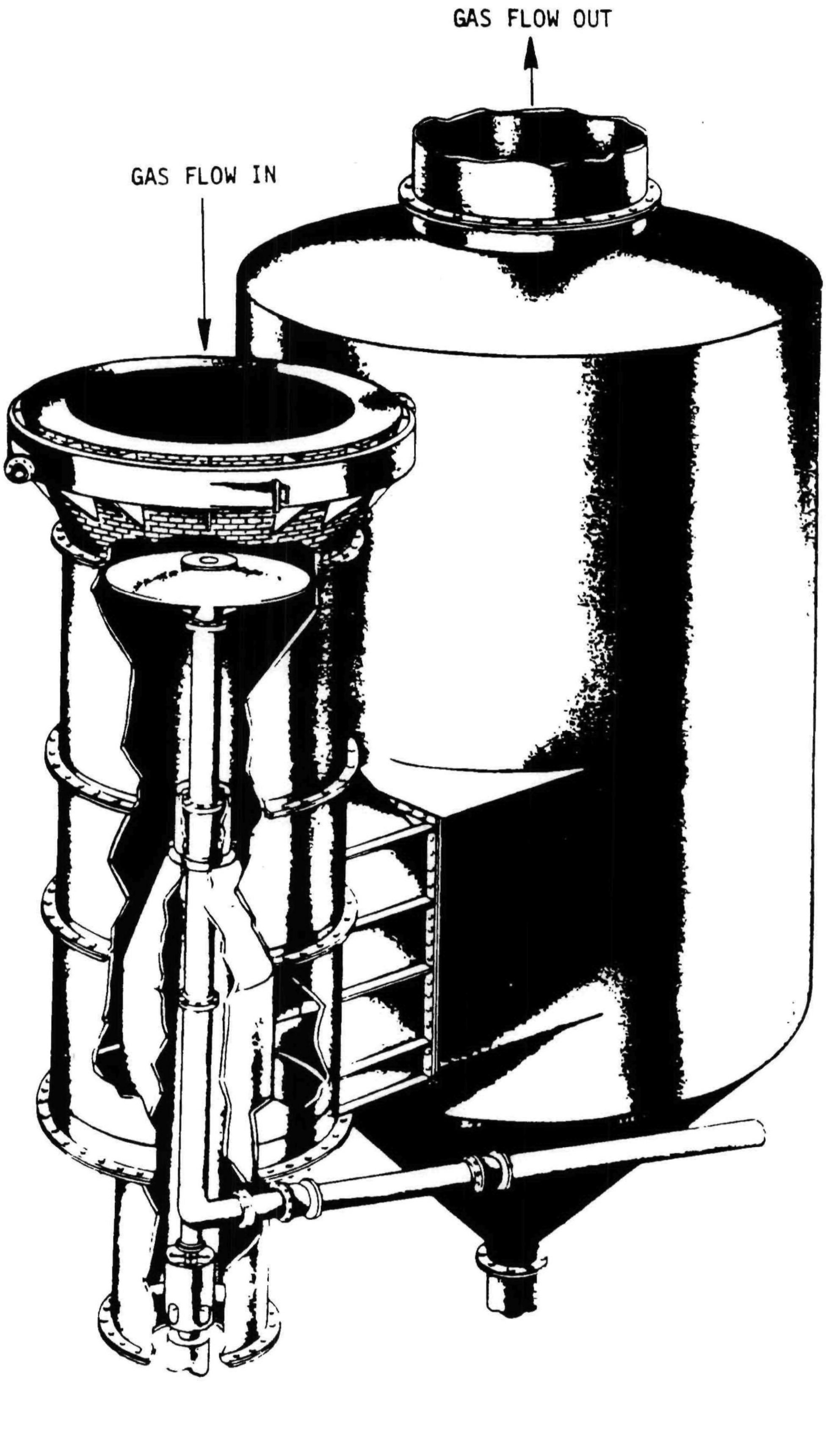

Figure 3-8. Research-Cottrell flooded disc venturi scrubber.

provide impaction and intimate contact between the particulates and fine liquid droplets generated as a result of gas atomization. This is a high-energy-consuming device designed for substantial particulate removal. A pressure drop of 51 cm (20 in.), or greater is required for salt-laden particulate removal, based on current operating data. The collection efficiency of venturi scrubbers increases with increasing pressure drop and liquid-to-gas (L/G) circulation rate. There is, however, an optimum L/G ratio above which additional liquid is not effective at a given pressure drop. The pressure drop can be increased by increasing the gas velocity.

In the design of venturi scrubbers, the follow key parameters affect particulate collection:

(a) Gas velocities and gas flow rates

(b) Particle size distribution

(c) Pressure drop

(d) Liquid-to-gas ratio.

The following information is also required to justify the choice of such equipment.

(a) Gas handling capacity per module

(b) Total number of modules required

(c) Capital investment

(d) Annual costs

(e) Water requirement; water recirculation

(f) Availability of the equipment or necessary downtime

(g) Indication of fractional collection efficiency of the device

(h) Total power consumption as a fraction of the generated power.

Velocity/gas flow rate--Sizing a venturi scrubber is often based on the velocity and flow rate of the inlet gas. Usually, the inlet gas velocity is about 18 m/s (60 ft/s), and the inlet flow rate depends on the boiler size. Typical scrubber diameters are under 3 m (10 ft). If the gas flow rate is too high for one scrubber, several scrubbers should be used.

Liquid-to-gas (L/G) ratio--The L/G ratio typically ranges from 0.13 to 2 $m^3/1000\ m^3$ (1 to 15 gal/1000 acf) and is basically a function of inlet gas temperature, inlet solids content, and method of water introduction.[14] At higher inlet gas temperatures, evaporation of the scrubbing liquor may occur at the point of contact. Where the inlet dust loading is heavy, the L/G ratio should be increased to minimized buildup of solids and plugging of drains. Although pressure drop across the venturi is essentially independent of a specific design, the less efficient methods of water introduction will require additional scrubbing liquor to meet efficiency requirements.

Pressure drop--The scrubber design for a given application requires careful selection of the throat velocity and L/G ratio to achieve the maximum collection efficiency for the energy spent. The energy spent is often indicated by the gas pressure drop across the scrubber, which ranges typically from 25 to 51 cm (10 to 20 in.) of water for venturi scrubbers on hogged fuel boilers.[21] To achieve a given pressure drop, numerous relationships between throat velocity and L/G ratio can be used. Only one set of conditions will yield the maximum efficiency for the energy spent. That one set of conditions is the only one that creates maximum droplet surface with minimum L/G ratio during atomization.

Particle size distribution--The particle size distribution in the inlet gas stream is a key factor in scrubber design. However, the particle size distribution in effluent from a hogged fuel boiler often varies with the percentage of salt in the fuel and with boiler operating conditions. Although the efficiency of particulate collection increases with increasing pressure drop, the inlet particle size distribution will determine the gas and liquid velocities required to achieve the desired overall mass collection efficiency.

Data on fractional collection efficiency for submicron particles is particularly difficult to obtain. When one is speaking of greater collection efficiencies, it should be clear that this refers to fractional collection efficiencies in the submicron particle size range.

Materials selection--Firing of salt-laden fuel with supplemental oil-firing can cause corrosion by abrasive solids. Suitable construction materials such as stainless steel must be selected. Where abrasion-resistance requirements exceed the limits of stainless steel, fiberglass-reinforced plastic (FRP, or polyester) may be used. Abrasion-resistant liners are also needed to withstand high temperature.

Mist eliminator--Mist eliminators are needed to control undesirable emissions of liquid droplets from scrubbers caused by atomization and carryover of liquid. Because of the solids in the scrubber liquor, the entrainment of water droplets can cause operating problems and liquid losses. Suspended or dissolved particles can cause buildup of solids, and suspended solids can cause erosion. Among the many problems caused by buildup is the increase in pressure drop.

Operation and Maintenance Problems - Venturi Scrubbers--

Common maintenance problems for venturi scrubbers include plugging of lines, nozzles, and pumps and erosion/corrosion and scaling of internal components. In operation of Georgia-Pacific Corp. wet scrubbers on salt-free hogged fuel boilers,[18] the problems are similar to those in other applications. High suspended solids content due to inadequately sized clarifers has led to deposition in horizontal transfer lines, drain weirs, and quiescent areas of the scrubber. The abrasive solids have accelerated the wear of pump impellers and spray nozzles.

Evaporation plus leaching of mineral salts (calcium, iron, and other compounds) from entrained particulate has caused buildup of dissolved solids in the recycled scrubber water, with resultant scaling and sludge problems.

Unexplainable changes in pH have caused corrosion of mild steel.

Operators of some Georgia Pacific plants have also cited foam generation as an operational problem, especially with venturi scrubbers.

Where such problems are not caused by inadequate design, they have been overcome by changes in operation and by maintaining the quality of water used in the scrubber within narrow limits.

Crown Zellerbach's Port Townsend venturi scrubber is the only one installed on a boiler burning salt-laden hogged fuel. Plant engineers characterize the operation of this scrubber as satisfactory. Some initial problems such as erosion/corrosion of the distribution header, erosion of the fiberglass separator, and vibration of the separator assembly were quickly resolved. The biggest operating problem at this installation occurs when salt content of the fuel exceeds 1 percent, causing reduced efficiency (≈70%) of the scrubber.

Fabric Filters

General System Characteristics--

Fabric filters are used on two hogged fuel boiler installations: Simpson Timber Co. in Shelton, Washington, and Long Lake Lumber Co. in Spokane, Washington. A third baghouse system has been purchased but not yet installed at Georgia-Pacific's Bellingham, Washington, mill. The Simpson and Georgia-Pacific mills use logs that have been stored in seawater.

Plant engineers estimate the overall mass efficiency of the Simpson Timber Co. baghouses at 90 to 95 percent, stating that a number of bags are always broken, due to improper installation, faulty construction, etc.

Outlet mass loadings were less than 0.05 g/m^3 (0.02 gr/scf),[15] and opacity did not exceed 3 percent (mostly only heat waves were visible). The Long Lake facility reports an overall mass efficiency of 99 percent.

Although no fractional efficiency data are available, the dramatic reduction in opacity with installation of the baghouses indicates that they are efficient collectors of submicron salt particles. Fractional efficiency data from tests of baghouses in other industries support this view.

Design Factors--

Fabric filters are basically simple. The removal of particulates from gases is accomplished by forcing the gases to flow through the fabric, which removes the particulates by one or more of the following mechanisms:

(1) Inertial impaction
(2) Diffusion to the surface of an obstacle by Brownian diffusion
(3) Direct interception because of finite particle size
(4) Sedimentation
(5) Electrostatic phenomena.

Parameters important to fabric filtration system design include air-to-cloth ratio, pressure drop, cleaning mode and frequency of cleaning, composition and weave of fabric, degree of sectionalization, and gas cooling. Baghouses are relatively insensitive to process variables such as chemical composition of the gas (providing the correct bag fabric is chosen), particle size, electrical resistivity, etc; thus there tends to be very little substantial design difference among baghouses with the same cleaning mechanism, regardless of the application or manufacturer. Differences that are noted generally relate to maintenance (e.g., number of bag rows accessible from an interior walkway, method of bag cuff attachment to cell plate). Table 3-5 summarizes design parameters for the baghouses on two existing and one proposed salt-laden hogged fuel boiler. These parameters are briefly discussed below.

Air-to-cloth ratio/pressure drop--Air-to-cloth ratio (A/C) is the ratio of volume of gas filtered (m^3/s or acfm) to the available filtering area (m^2 or ft^2). The A/C ratio affects the pressure drop across the filter, i.e., a higher ratio yields a higher pressure drop.

The ratio of air to cloth becomes an economic tradeoff in baghouse design because the higher the A/C ratio, the smaller the

TABLE 3-5. DESIGN PARAMETERS FOR BAGHOUSES ON HOGGED FUEL BOILERS

	Simpson Timber	Long Lake Lumber	Georgia-Pacific
Volume flowrate, acfm	130,000	25,000	180,000
Inlet gas temperature, °F	500	400	440
A/C ratio, $acfm/ft^2$	4.5	4.0	4.0
Bag cleaning method	Pulse jet	Pulse jet	Pulse jet
Pressure drop, in. H_2O	9-9.5	5.8-6.8	a
Bag fabric	Teflon-coated fiberglass	Nomex	Teflon-coated fiberglass
Precollector	Mechanical cinder collector	None	None
Material handling system	Screw conveyor	Screw conveyor	Screw conveyor

Metric conversions: acfm x 0.028 = m^3/min

$acfm/ft^2$ x 5.09 = m^3/s per m^2

(°F - 32)/1.8 = °C

in. H_2O x 2.54 = cm H_2O

[a] Collector not yet installed.

amount of filter fabric required. Offsetting this advantage, however, are the requirements for a larger fan and a cleaning mechanism of higher energy, leading to a reduction in bag life. Equipment suppliers determine A/C ratio by considering the characteristics of the dust to be collected, the type of fabric, the cleaning mechanism, and the specified operating pressure drop.

The size range of a significant portion of the particulate emitted from boilers burning salt-soaked hogged fuel is from less than 1 to 10 μm. Thus enough of the larger particles are present to allow use of a fairly high A/C ratio, limited by the amount of fines also in the mix. Operation at higher ratios may lead to excessive pressure drops, as at Simpson Timber Company's baghouse installation. The pressure drop is 8 cm (3 in.) over design, probably because the particle size distribution is skewed toward the submicron range. Operating pressure drops for hogged fuel boiler baghouses range from 15 to 30 cm (6 to 12 in.) water, and it is preferable to operate at the lower end of this range.

Fabric selection--Selection of a suitable fabric is a function of temperature, abrasion resistance, acid resistance, and cost. The main function of the fabric is to provide a rigid filtering medium for formation of the initial dust cake, which then acts as a fine filter that can achieve high efficiencies (>99%) in collection of submicron particulates.

Bag fabrics are woven or felted. Felt is a genuine filter medium and is more efficient than woven fabrics in collection of the dust; it is also more expensive. Bags made of fiberglass coated with Teflon or silicon graphite, woven Teflon, or filtered Teflon may be used in the high temperature range (150° to 260°C, (300° to 500°F). Fabrics for high temperature operation are costly. Table 3-6 lists some of the fabrics available for low and high temperature operation and the characteristics of each. Normal life expectancy of bag fabric is 1 to 3 years in conventional operations.

The two Simpson Timber units contain Teflon B-coated fiberglass bags for operation at 260°C (500°F). The Long Lake baghouse

TABLE 3-6. CHARACTERISTICS OF VARIOUS BAGHOUSE FABRICS[22]

Fiber	Operating exposure, °F		Supports combustion	Air permeability[a]	Composition	Abrasion[b]	Resistance to		Alkali[b]	Cost rank[c]
	Long	Short					Mineral acids[b]	Organic acids[b]		
Cotton	180	225	Yes	10-20	Cellulose	G	P	G	G	1
Wool	200	250	No	20-60	Protein	G	F	F	F	7
Nylon[d]	200	250	Yes	15-30	Polyamide	E	P	F	G	2
Orlon[d]	240	275	Yes	20-45	Polyacrylonitrile	G	G	G	F	3
Dacron[d]	275	325	Yes	10-60	Polyester	E	G	G	G	4
Polypropylene	200	250	Yes	7-30	Olefin	E	E	E	E	6
Nomex[d]	425	500	No	25-54	Polyamide	E	F	E	G	8
Fiberglass	550	600	Yes	10-70	Glass	P-F	E	E	P	5
Teflon[d]	450	500	No	15-65	Polyfluoroethylene	F	E	E	E	9

Metric conversions: (°F −32)/1.8 = °C

ft^3/min per $ft^2 \times 5.09 = m^3/s$ per m^2

[a] ft^3/min per ft^2 at 0.5 in. W.G.

[b] P = poor, F = fair, G = good, E = excellent.

[c] Cost rank on a scale of 1 (low) to 9 (high).

[d] DuPont registered trademark.

is equipped with Nomex bags and operates at about 210°C (410°F). The new unit at Georgia-Pacific will use Teflon-coated fiberglass for operation at 227°C (440°F).

Cleaning mechanisms--The most common methods of dislodging the built-up dust layer are mechanical shaking, reverse air, and pulse jet.

During shake cleaning, the pressure to the bags is reduced by turning off the fan and a gentle motion is applied to the top bag attachment (see Figure 3-9). When bags are made of fiberglass, the cleaning mechanism must be very gentle to prevent damage. Shaking with a period of 50 cycles per minute and about 5 percent of the bag length is recommended.[23]

Reverse air and shaking are equally effective, but pressure drop across the clean filter may increase to the point that both methods are required to bring the pressure drop down to an acceptable level.

The pulse jet cleaning mechanism is relatively new. A sudden blast of compressed air is injected through a nozzle installed at the top of each bag (see Figure 3-10). The bag expands to its maximum diameter at the top, and the expansion travels down the bag, throwing the dust from the outside of the bag. This type of cleaning mechanism is more energy-intensive than the shaker or reverse air mechanisms and usually entails higher A/C ratios and pressure drops.

Pulse jet is the preferred cleaning mechanism for all three hogged fuel boiler baghouses listed in Table 3-5. It allows for maximum filtering time with minimum interruption of the filtering flow and allows for a slightly smaller baghouse.

Operation and Maintenance Problems - Fabric Filters--

Since only two U.S. hogged fuel boiler installations use fabric filters to control particulate emissions, information on maintenance problems and practices is very limited. Simpson Timber Co., which operates a fabric filter on a boiler fired with salt-laden hogged fuel, provided some maintenance data.

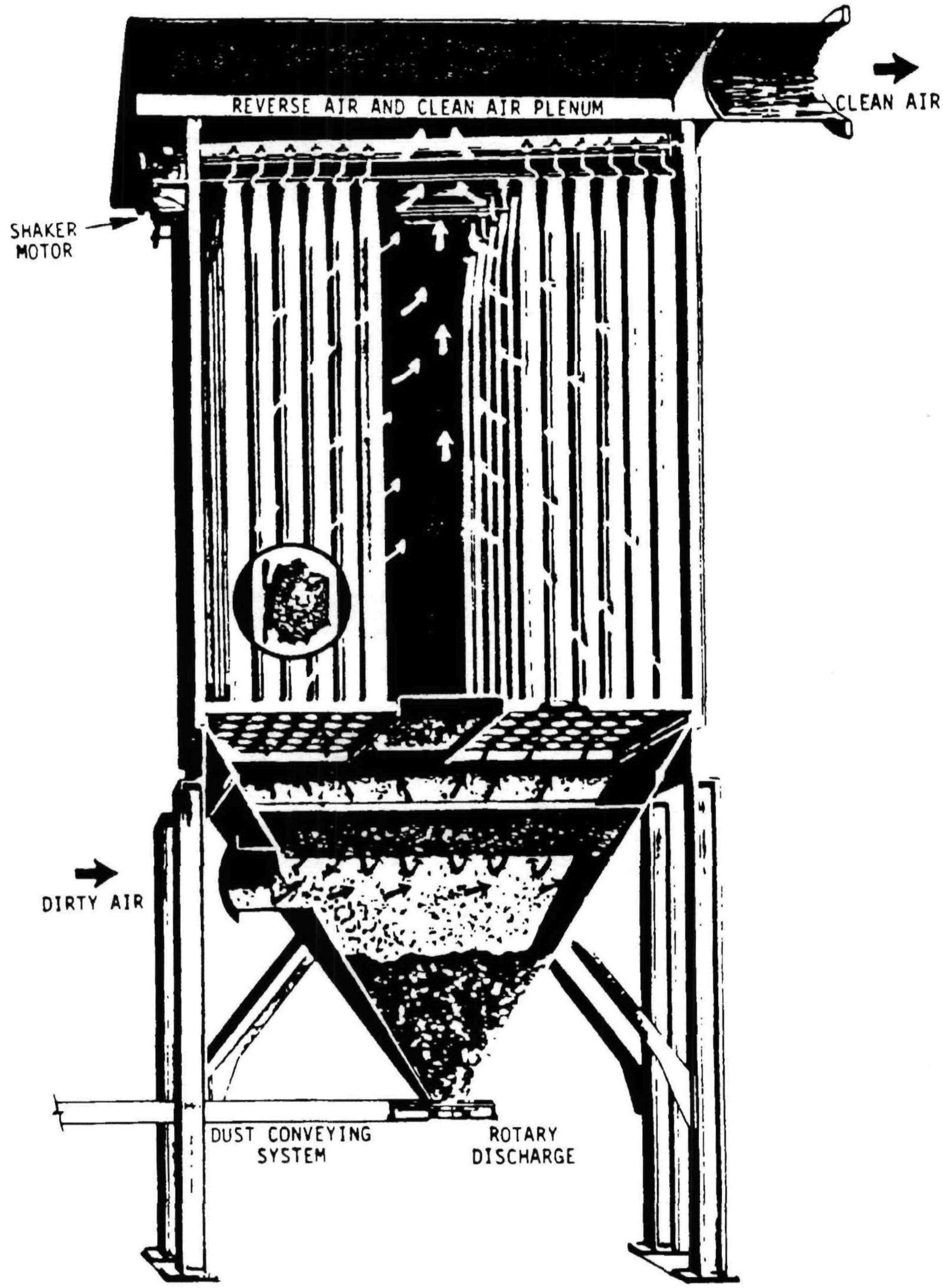

Figure 3-9. Reverse air or shaker type.

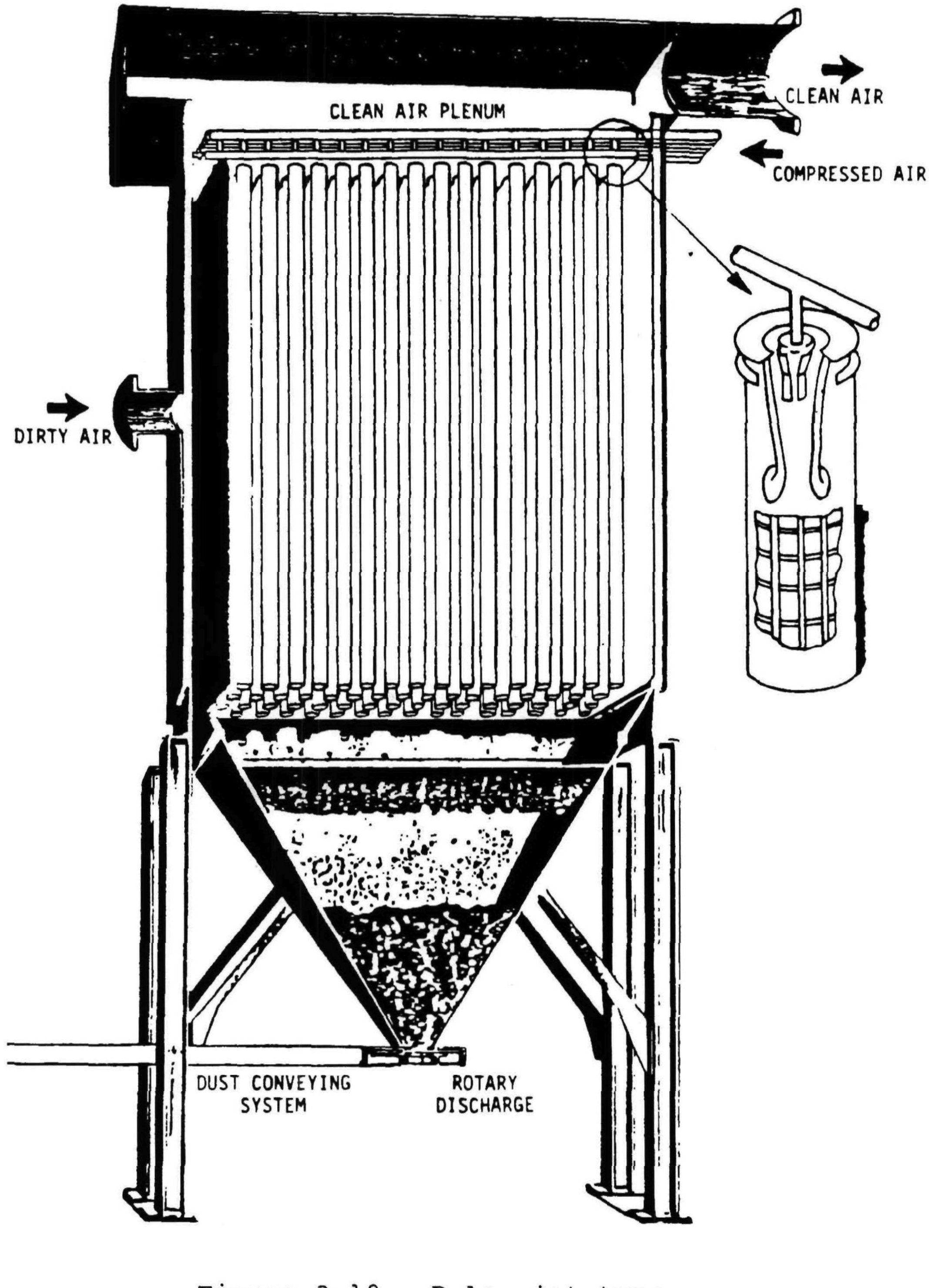

Figure 3-10. Pulse jet type.

The primary problem with operation and maintenance of the two collectors at Simpson Timber centers on the collection hoppers. The very light collected dust has caused plugging. Even though the screw conveyor can adequately handle the volume of material emptying from the hoppers, the material tends to bridge. Much of the dust is submicron NaCl particles. To prevent plugging, Simpson Timber is trying out a hopper vibrator system that is actuated at the end of each cleaning cycle. Although this system appears to be relieving the plugging, personnel also feel the need for a good method of sensing when the hoppers begin to plug. They have not yet devised a reliable mechanism.

Simpson also has installed a bypass chute on the baghouse hopper for use during cleanout. The screw conveyors could not handle the large volume of material released when a plugged hopper was dislodged, so the chute was provided to relieve the extra load.

Except for some operational problems during the first few months of operation, the two baghouses have run satisfactorily for over 2 years. Routine maintenance is, of course, performed. Every 3 to 6 months, when the system is off line, the fan housings and impellers are cleaned by blowing them out with compressed air. Vibration detectors have been installed on the fan to warn of potential imbalances. This system allows maintenance personnel to clean the fans before a scheduled inspection if needed.

Bag life is reported to average around 15 months. The usual cause of bag failure is abrasion against the support cage.

Ultimate Disposal of Salt-laden Ash Collected by Conventional Control Equipment

Although particulate control devices remove particulate from stack gases, the material that is removed must be disposed of by one of several methods referred to as ultimate disposal. The waste products are basically of two types, a dry ash and a wet slurry. The dry ash comes from cyclones, baghouses, and ESP's, and the wet slurry from wet scrubbers and ESP's. Many techniques are available for ultimate disposal of such wastes, but the presence of salt in the waste material (as much as 90%) complicates disposal and limits the choice of ultimate disposal methods.

Where the ash contains little or no salt, it can be disposed of by several methods. The volume of the ash can be reduced by reinjecting it from a cyclone collector into the boiler for a more complete burning.[24] The most common method is to place the ash in a sanitary landfill. Under a properly controlled landfill scheme this can be an effective method of disposal. When a high proportion of the ash is salt, however, the landfill operators must maintain strict control to prevent leaching of the salt into local ground and surface waters.

Several important factors should be considered in selection and design of a landfill. First, upon preliminary selection of the landfill site, the local geology and groundwater conditions must be studied thoroughly as a basis for selection of techniques and materials that will ensure isolation of the landfill and its leachate from the local environment. Where the groundwater table is high, for example, it may be necessary to lower it locally by dewatering techniques. Where the soil is highly permeable (e.g., sand or loam), an impermeable barrier must be constructed to ensure against groundwater contamination. This is usually done by compacting a clay layer (about 5 feet thick) that allows movement of water through it, but at a controlled rate. The clay also filters out the leachate as it passes through. Other types of barriers used with varying degrees of success are asphalt and concrete, which are subject to differential settling and cracking, and plastic, which is subject to puncture and is not entirely resistant. Ideal sites are those where the soil is mainly clay or where the underlying strata are impervious.

The market for the resale of dry ash is increasing, particularly for use in road construction and in the asphalt and concrete industry. Fly ash is being used to stabilize roadbeds (as a sub-base material), as an additive in asphalt, and as an aggregate for concrete when converted to pellets. Again, however, the salt fraction would severely limit any usefulness of the bark ash for such purposes.

Similarly, although some ash is now being applied to the soil as fertilizer, ash that contains salt cannot be used for this purpose.

Methods for disposal of wet slurries containing fly ash and dissolved gases vary widely depending upon the contents of the slurry. When slurry is stored in lagoons the solids fraction often will settle out, given enough time. The supernatant is then drawn for reuse in the slurry system, for further treatment, or for disposal to the environment. When the slurry contains salt or other potential pollutants, the lagoon can be properly designed and constructed to ensure isolation of slurry from the environment. Sludge from the lagoons can be pumped out and sent for further treatment, landfilled, or incinerated. Because solids content of the sludge from lagoons and clarifiers is usually under 10 percent, additional treatment is usually needed to make it disposable. The physical and chemical sludge treatment methods are similar to those used in treating municipal sludges, that is, placement in drying beds, centrifugation, pressing, vacuum filtration, and processing for fertilizer.

Ultimate disposal of the dry cake is similar to that for dry ash. Again it is emphasized that where the ash or sludge cake contains salt or other potential pollutants, the disposal method must ensure protection of the environment.

In installations currently firing salt-laden hogged fuel the primary methods of ash disposal are discharging to municipal treatment facilities, landfilling, or reinjection of the ash into the boiler. Ash from the fabric filters at the Simpson Timber plant in Shelton is mixed with the continuous boiler blowdown and sent to the municipal sewage treatment plant at a rate of about 20 gal/min. Because the suspended solids in this slurry account for approximately two-thirds of the total suspended solids entering the treatment plant, Simpson Timber must pay a surcharge. Requests by Simpson Timber for approval to dump the ash into the bay were rejected because even though the salt would have no detrimental effects, the ash is considered a pollutant. Landfilling of the material was also disapproved because of potential leaching of the salt into ground water.

Crown Zellerbach's Port Townsend Plant treats the slurry from the scrubbing system along with the process wastewater stream. This treatment system consists of a primary clarifier and aerated lagoons. Sludge from the clarifier is sent to a lagoon for aeration and settling. The clarifier supernatant and the lagoon effluent are then discharged to the environment. Ash from the mechanical collectors and the sludge from the aeration lagoon are then disposed of in a landfill.

Weyerhauser's North Bend plant reinjects fly ash in essentially a closed system. Diverting the ash from reinjection was tried,[25] but yielded no significant reduction in emissions and was discontinued.

In summary, there is no standard method for ultimate disposal of fly ash with high salt content. The salt content precludes reuse of the fly ash in many applications, and the salt is too impure to be sold or returned to the sea. Although landfilling is the method most often used for disposal, not all landfills can accept the ash because of severe handling and/or leaching problems. Ash in slurry form, however, can be mixed and treated with other process wastestreams or with municipal wastewater. The ash and salt are thus diluted to levels at which the material can be handled or treated efficiently and economically. Wet treatment therefore seems to be the more effective means for ultimate disposal of ash.

Best Available Conventional System for Controlling Salt Emissions from Hogged Fuel Boilers

Operating data on boilers fired with salt-laden hogged fuel indicate that the best available conventional control system is a mechanical collector followed by a fabric filter. A mechanical collector is needed to remove cinders that would increase the chance of fire in the fabric filter. Table 3-7 gives available performance data for conventional secondary collectors on salt particulate emissions.

Simpson Timber Company's fabric filter installation at Shelton has operated successfully for over 2 years in compliance with both grain loading and opacity regulations. The dramatic decrease in opacity is evidence of the ability of the fabric filter to capture submicron particles of salt. This ability to maintain high levels of collection efficiency in the particle size range from 0.1 to 10 micrometers has been demonstrated in fabric filter applications in other industries. Some maintenance problems were encountered but plant officials do not regard them as excessive.

Use of a venturi scrubber on the salt-laden hogged fuel boiler at Crown-Zellerbach's Port Townsend mill has been partially successful in that operations comply with the applicable emission regulation when the salt content of the fuel is below 1 percent. At higher salt levels the scrubber cannot remove enough of the additional fine salt particles to achieve compliance. More efficient removal of submicron salt particles would require additional pressure drop over the present maximum of 51 cm (20 in.) water. Opacity has not been measured but is estimated by plant officials at 35 percent. Plant engineers report that the Port Townsend scrubber has not required excessive maintenance although trouble areas may become apparent with more operating time.

Electrostatic precipitators have not been applied to boilers burning salt-laden hogged fuel, probably chiefly because ESP manufacturers will guarantee outlet grain loading but not visible opacity. For compliance with visible opacity regulations when the boiler fuel is salt-laden, an ESP may be too large to be economically competitive with a fabric filter or wet scrubber. Sizing of the ESP would have to accommodate the "worst case" in terms of salt content in the fuel.

TABLE 3-7. PERFORMANCE OF CONVENTIONAL SECONDARY COLLECTORS ON SALT-LADEN PARTICULATE FROM HOGGED FUEL BOILERS

Source	Control device	Date of test(s)	Inlet loading, g/sm^3 (gr/scf)	Outlet loading, g/sm^3 (gr/scf)	Efficiency, %	Visible opacity, %	Salt content in fuel, %	Salt content in flue gas, %	Reference(s)
Simpson Timber Co. Shelton, Wash.	Fabric filter	4/76	NA	0.02 and 0.09 (0.01 and 0.04)	90-95	<5	NA	~70	26, a
Crown Zellerbach Port Townsend, Wash.	Venturi scrubber	2/78	NA	0.16 (0.07)	NA	NA	0.4	≈50	20
		5/78 and 7/78	1.28 (0.56)	0.40 (0.17)	~69b	≈35	>1	≈70	c
B.C. Forest Products Victoria, British Columbia	Pilot ESP	9/75 to 1/76	0.53-2.04 (0.23-0.89)	0.11-0.46 (0.05-0.20)	43-95	NA	NA	≈35-81	11

[a] Personal communication with Mr. Robert Hoit, Simpson Timber Co., September 1978.

[b] Approximate efficiency; inlet sample taken on 7/78; outlet sample taken on 5/78.

[c] Personal communication with Mr. Alan Rosenfeld, Crown Zellerbach Environmental Services, August 1978.

NA - Not available.

Appendix C presents two case histories of conventional secondary collectors applied to salt-laden hogged fuel boilers. (Simpson Timber Co. in Shelton and Crown Zellerbach in Port Townsend).

NOVEL FINE PARTICULATE CONTROL DEVICES

Experience at plants with salt particulate emissions shows that, except for fabric filters, the conventional control devices cannot consistently reduce emissions enough for compliance with particulate and stack opacity regulations. Thus, there is a need for more effective control, especially in the submicron particle size range. This section evaluates some novel or promising particulate control devices now being tested for control of salt emissions from hogged fuel boilers. Detailed descriptions of the operation, performance, and costs of each applicable novel device are presented in Appendix D.

Classification of Novel Control Devices

Three categories of wet scrubbing[27] are considered promising for control of the submicron salt particles from hogged fuel boiler emissions: foam scrubbing, flux force condensation, and electrostatic scrubbing. Of these, electrostatic scrubbing appears to offer the greatest potential for full-scale application to salt-laden hogged fuel boilers.

Dry scrubbers also are considered here as a novel device, since there have been two pilot tests and one full-scale test on three salt-laden hogged fuel boilers.

Foam Scrubbing--[28]

In foam scrubbers the foam is generated by forcing aerosol gas through a screen sprayed with a surfactant liquid. Particle collection is believed to take place mainly by diffusion and sedimentation, mechanisms that are predictable and rather well understood. Application of this method has shown that the initial cost is higher than that of the most expensive conventional method, reliability is undetermined, and particulate collection efficiency is not high.

Flux-force/Condensation--

Flux-force/condensation effects accompany the condensation of water vapor from the gas and are generally caused by contacting hot, humid gas with colder liquid or by injecting steam into saturated gas. The transfer of water vapor toward the cold liquid surface sweeps particles with it and is referred to as diffusiophoresis. Heat transfer from the gas to the liquid also causes particle movement toward the cold liquid, called thermophoresis. Condensation of water on the suspended particles causes an increase in mass (particle plus condensate), referred to as particle growth. Collecting the particles by inertial impaction is easier after they have grown by condensation.[29]

A pilot study of this method showed that initial costs and operating costs are very high.[29] The water vapor plume contributes to higher opacity, which is undesirable.

Electrostatic Scrubbing--

This device embodies the principles of an electrostatic precipitator and a scrubber. The basic idea is to augment the collection processes associated with spray scrubbing and electrical collection forces. It involves the use of electrostatically charged water droplets or charged pollutant particles or both.[30,31] The scrubber may be of the spray or venturi type. Particulate collection efficiencies higher than 99 percent have been achieved with some devices.[31,32] The initial costs are somewhat higher than those associated with conventional methods, but lower than those of the foam and force-flux/condensation scrubbers. Operating costs are reported to be much lower than those of conventional methods.[33,34,35] It appears that devices based on electrostatic scrubbing would provide good control over opacity of stack emissions and would be more effective than the other novel devices in controlling particulate emissions. Further testing is required to evaluate electrostatic scrubbing for control of salt-laden particulate emissions from hogged fuel boilers.

Table 3-8 summarizes characteristics of five novel control devices that operate on a principle of electrostatic augmentation. Appendix D presents more detailed descriptions of these devices.

Dry Scrubbers--

The dry scrubber is a recently developed system that uses a moving bed of granular material (media) instead of water droplets to capture particulates. The dirty media is shaken at the bottom of the unit, and particulates fall into a storage bin. The cleaned media is then conveyed back to the top of the unit. The following advantages are claimed for the unit.[5]

1 It requires no water supply.
2. The particulate is removed dry.
3. Because there is no corrosion potential, mild steel can be used.
4. The unit can be small and lightweight because of high-velocity throughput.

This device can be effective when temperature and natural collection are well controlled. Officials of the Simpson Timber plant at Shelton rejected the dry scrubber in favor of a baghouse because the scrubber would not eliminate the stack plume. A full-scale installation on a salt-laden hogged fuel boiler at Port Gamble, Washington, was shut down because of scrubber operating problems. These problems reportedly concern cake buildup at the discharge of the moving bed and blinding of the screen that contains the moving bed.

On a more recent full-scale test on a salt installation in Canada, Conbustion Power Company (CPC) has solved this problem by providing a steeper angle for the discharge cone. However, opacity is still being exceeded.

CPC has decided that in the future an electrostatic cage will be included in each dry scrubber in an attempt to improve fine particulate collection efficiency. The dry scrubber will be marketed as the "electroscrubber". Some existing plants, such as the salt installation in Canada will be retrofitted with the electrostatic cage.

TABLE 3-8. NOVEL FINE PARTICLATE CONTROL DEVICES APPLIED TO BOILERS BURNING SALT-LADEN HOGGED FUEL[a]

Manufacturer/ unit	Commercially available	Base equipment	Particles charged	Water droplets charged	References
Ceilcote Co./ ionizing wet scrubber	Yes	Wet scrubber	Yes	No	36, 39, 40
TRW Inc./ charged droplet scrubber	Yes	Wet scrubber	No	Yes	27, 32, 38
Pollution Control Systems, Inc.,/ UW electrostatic scrubber	Yes	Wet scrubber	Yes	Yes	30, 31
Union Carbide Bendix Division/ APS electrotube	Yes	Wetted-wall pipe precipitator	Yes	No	32, 37
Air Pollution Systems/electro-static scrubber	a	Venturi scrubber	Yes	No	32

[a] All devices have undergone pilot-scale field tests on boilers burning salt-laden hogged fuel; information from some of the tests is sparse.

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SECTION 4

COST ASSESSMENT OF CONTROL TECHNOLOGY FOR SALT-LADEN PARTICULATE EMISSIONS FROM HOGGED FUEL BOILERS

A review of the literature and contact with wood products companies indicate that little information is available regarding costs of conventional control equipment applied to salt particulate emissions from hogged fuel boilers. Only one recent comparative cost study of different control devices has been reported. Other available data consist of scattered cost estimates of only one type of control device rather than comparative costs.

COMPARISON OF ESTIMATED AND ACTUAL COSTS

Weyerhauser Corp. has estimated capital and annual operating costs for ESP's, baghouses, and venturi scrubbers, as applied to their salt-laden hogged fuel boilers in North Bend, Oregon.[1] Table 4-1 summarizes these costs, both with and without combustion modifications to the boiler. Capital costs are in 1978 dollars. Operating costs do not include ash disposal.

With boiler modifications, which result in a smaller gas volume (3136 m^3/min, 112,000 acfm), the ESP is the most expensive, followed closely by the fabric filter and then the venturi scrubber. Without boiler modifications and with a gas flow of 5040 m^3/min (180,000 acfm), the fabric filter is the most expensive, followed by the ESP and venturi scrubber, neither of which involves as drastic an increase in cost as does the fabric filter.

Cost data are available from Simpson Timber Company's hogged fuel boilers in Shelton, Washington, where fabric filters were installed to process a total of 6440 m^3/min (230,000 acfm) of salt-laden particulate emissions. The capital cost in 1976 was

TABLE 4-1. CAPITAL AND ANNUAL OPERATING COST ESTIMATES FOR SECONDARY COLLECTORS AT WEYERHAUSER CO. NORTH BEND PLANT[1]
(in 1978 dollars)

With boiler modifications:	Baghouse	Electrostatic precipitator	High-energy wet scrubber
Total direct cost	$1,142,000	$1,163,000	$ 863,000
Contingency and engineering	171,000	239,000	207,000
Total construction cost	$1,313,000	$1,402,000	$1,070,000
Total operating and maintenance cost/year	$ 116,400	$ 108,700	$ 207,600
Without boiler modifications:			
Total direct cost	$1,629,000	$1,322,000	$ 979,000
Contingency and engineering	244,000	271,000	235,000
Total construction cost	$1,873,000	$1,593,000	$1,214,000
Total operating and maintenance cost/year	$ 190,400	$ 141,100	$ 279,000

$1.9 million, or $295 per m^3/min ($8.26 per acfm). Escalated to 1978 dollars at 7.5 percent per year, this cost is $2.2 million or $341 per m^3/min ($9.56 per acfm). This compares favorably with Weyerhauser's baghouse cost estimate of $372 per m^3/min ($10.41 per acfm) for gas flow of 5040 m^3/min (180,000 acfm).

The venturi scrubber installed in 1977 on the hogged fuel boiler with gas flow of 4872 m^3/min (174,000 acfm) at Crown Zellerbach's Port Townsend mill cost approximately $900,000 installed, or $185 per m^3/min ($5.17 per acfm) in 1977.[3] Escalated to 1978 at 7.5 percent per year, this cost is $968,000 or $199 per m^3/min ($5.56 per acfm). This is approximately 20 percent lower than Weyerhauser's estimate of $241 per m^3/min ($6.74 per acfm) for a high-energy venturi scrubber. Weyerhauser, however, has specified a pressure drop of around 76 cm (30 in.) water, whereas the Crown-Zellerbach unit operates at a maximum of 51 cm (20 in.) water.

The Council of the Forest Industry of British Columbia presented a cost comparison of various control devices in 1974.[4] These costs, which are low because they are in 1974 dollars, show that the ESP and baghouse are most expensive and are approximately equal in capital cost at $179 to 214 per m^3/min ($5 to $6 per acfm), followed by the high-energy venturi scrubber, at $107 to $143 per m^3/min ($3 to $4 per acfm).

Table 4-2 summarizes cost information on conventional secondary control devices.

FINANCIAL HARDSHIP

It is not easy to determine whether financial hardship is created by forcing a company to install secondary collectors to control salt emissions from hogged fuel boilers. Obviously, companies that are operating profitably can more readily afford to install expensive secondary collectors. Marginally profitable installations, in addition to lacking funds, may be located in small communities where a major portion of the population depends on the mill for employment. If a company decides to close such

TABLE 4-2. SUMMARY OF COST INFORMATION ON SECONDARY COLLECTORS APPLIED TO SALT-LADEN HOGGED FUEL BOILERS

Source	Control device			Capital		Annual[a]		Comments
	Type	Efficiency, %	Gas flow, acfm	$ 10^6	$/acfm	$ 10^6	$/acfm	
Weyerhauser Co. Northbend, Oreg.	Fabric filter	NA[b]	180,000 (112,000)	1.873 (1.313)	10.41 (11.72)	0.190 (0.116)	1.06 (1.04)	Numbers in parentheses assume boiler modifications are made; costs are estimates; 1978 dollars
	ESP	NA[b]	180,000 (112,000)	1.593 (1.402)	8.85 (12.52)	0.141 (0.109)	0.78 (0.97)	
	Venturi scrubber	NA[b]	180,000 (112,000	1.214 (1.070)	6.74 (9.55)	0.279 (0.208)	1.55 (1.85)	
Crown Zellerbach Port Townsend, Wash.	Venturi scrubber	60-80	174,000	0.900	5.1	NA	NA	Costs are actual; 1977 dollars
Council of Forest Industries of British Columbia	Wet scrubber	NA[c]	NA	NA	3-4	NA	0.33-0.43	Costs are estimates; 1974 dollars
	ESP	NA[c]	NA	NA	5-6	NA	0.23-0.34	
	Fabric filter	NA[c]	NA	NA	5	NA	NA	
Simpson Timber Co. Shelton, Wash.	Fabric filter	99+(design), 90-95(test)	230,000	1.9	8.26	0.075	0.33	Capital costs are actual; 1976 dollars

Metric conversions: acfm x 0.28 = m^3/min

$/acfm x 35.7 = $/$m^3$ per min

[a] Operating and maintenance costs only.

[b] Particulate emission regulation is 0.46 g/sm^3 (0.20 gr/scf); efficiency is not specified.

[c] Particulate emission regulation is 0.23 g/sm^3 (0.10 gr/scf); efficiency is not specified.

NA - Not available.

a mill, the effect on the community could be detrimental.

When an agency is considering enforcement action against a mill that violates regulations of opacity or particulate emissions because of salt in the hogged fuel, there should be a detailed analysis of the retrofit difficulty and cost of installing secondary collectors. The financial status of the company should be evaluated in terms of the economic feasibility of installing control equipment. If emissions from such a plant are excessive and cause a violation of ambient air standards in the community, the company may have to consider closing the plant if they cannot afford to purchase the control equipment. If, however, emissions are close to complying with the particulate emission regulation and do not cause a violation of ambient air standards, the enforcing agency may consider some compromise, such as improvement of the existing system or treatment of only a portion of the flue gas.

In summary, it is reasonable to expect industry to control emissions that have a detrimental environmental impact. Some consideration, however, should be given to the severity of these impacts and the economic capability of each company. This should be done on a case by case basis.

REFERENCES FOR SECTION 4

1. See, R.C. North Bend Hog Fuel Boiler Emission Collection Options. Weyerhauser Corp., Tacoma, Washington. April 28, 1978.

2. Hoit, R.S. Baghouse Filters on Hog Fuel Power Boilers. Presented to Air Pollution Control Association, Pacific Northwest International Section, Seattle, Washington. April 12, 1978.

3. Personal communication: Mr. J. Walther, Crown Zellerbach Environmental Services. August 24, 1978.

4. Council of the Forest Industry of British Columbia. The Basis for Requesting a Variance on Marine Salts as Polluting Particulates in Stack Gases from Hog Fuel Boilers, Presented to the Pollution Control Branch, Department of Lands, Forests and Water Resources, Government of British Columbia, Victoria, B.C. September 16, 1974.

APPENDIX A

SALT-LADEN HOGGED FUEL BOILERS IN WASHINGTON, OREGON, AND ALASKA

TABLE A-1. INSTALLATION LIST OF SALT-LADEN HOGGED FUEL BOILERS IN WASHINGTON STATE[a]

Description of plant		Fuel characteristics					Emissions characteristics					Control method/equipment characteristics		
Industry name Address NEDS number	Boiler capacity, 10^6 Btu/h, or lb steam/h	Fuel type(s)/firing rate(s): Bark,[c] lb/h	Oil,[c] gal/h	Coal, lb/h	Gas, ft^3/h	Salt fraction of fuel, %	Flowrate, scfm	Particulate loadings, gr/acf: Inlet	Outlet	Salt fraction of particulates, %: Inlet	Outlet	Control method	Control device removal efficiency, %	Remarks
Puget Sound Plywood Tacoma 230 East F Street 1560-0007-01 (206) 627-4111	90 x 10^6 Btu/h or 90,000 lb/h steam[b]	22,550	NA	NA	NA	No data	98,000	No data	No data	No data	70	No data	No data	274 tons/yr of particulate emitted; (NEDS)
North Pacific Plywood Tacoma 1549 Dock 1560-0003-01 (206) 572-4304	40 x 10^6 Btu/h or 40,000 lb/h steam[b]	No data	NA	NA	NA	Varies due to source	56,600	No data	No data	No data	~50	Gravity collector Multiclone Cinder collector	<80	13 tons/yr of particulate emitted (NEDS); by '79 fuel will be out of water
Publishers Forest Products Anacortes 1940-0007-01 (206) 293-2191	Boiler 1: 63 x 10^6 Btu/h or 63,000 lb/h steam[b]	2,000	No data	NA	NA	0.34-1.3	69,100	No data	No data	No data	~50	Multiclone/ reinjection	No data	297 tons/yr of particulate emitted. (NEDS)
	Boiler 2: 32 x 10^6 Btu/h or 32,000 lb/h steam[b]	1,750	No data	NA	NA	No data	50,000	No data	No data	No data	50	No control device		Variance for 2 yrs - 40% opacity; possible baghouse.
Georgia-Pacific Box 1236 Bellingham 2400-0004-01 (206) 733-4410	60 x 10^6 Btu/h or 60,000 lb/h steam[b]	13,333	400	NA	NA	No data	106,000	No data	No data	No data	No data	Centrifugal collector baghouse being installed	No data 95-99+ design	682 tons/yr of particulate emitted; (NEDS).
Mt. Baker Plywood Box 997 Bellingham 2400-0002-01 (206) 733-3960	50 x 10^6 Btu/h or 50,000 lb/h steam[b]	825	NA	NA	18,750[c] natural gas	Variable, no data	50,000	No data	No data	No data	No data	No data available	No data	111 tons/yr of particulate emitted; (NEDS) boiler design to burn hog fuel, residual oil, natural gas, and liquid petroleum gas.
Simpson Timber Co. Waterfront Shelton 1220-0002-03 (206) 426-3381 steam plant 1	1 at 90,000 180 x 10^6 Btu/h	40,000	NA	NA	NA	No data	55,200	No data	0.01	No data	70	Cinder collector Baghouse (1976)	99+ design	Plume opacity less than 5%; 2 additional boilers bypass baghouse and are reserved for oil firing.
1200-0002-04 steam plant 52	4 at 27,500 160 x 10^6 Btu/h 5 boilers	45,000	NA	NA	NA	No data	88,300	No data	0.04	No data	70	Cinder collector	99+ design	

(continued)

TABLE A-1 (continued)

Description of plant		Fuel characteristics					Emissions characteristics					Control method/equipment characteristics		
Industry name Address NEDS number	Boiler capacity, 10^6 Btu/h or lb steam/h	Fuel type(s)/firing rate(s): Bark,[c] lb/h	Oil,[c] gal/h	Coal, lb/h	Gas, ft^3/h	Salt fraction of fuel, %	Flow rate, scfm	Particulate loadings, gr/scf: Inlet	Outlet	Salt fraction of particulates, %: Inlet	Outlet	Control method	Control device removal efficiency, %	Remarks
Crown-Zellerbach Port Townsend 0900-0001-05 (206) 385-1616	Boiler 10 Stoker Wood-200,000 Wood/oil-250,000 Oil-250,000 lb steam/h	51,250	1,424	NA	NA	0.76-1.6	74,000	1.52 0.56	0.56 0.17	No data	50-70	1) Multiclone 2) Venturi scrubber	actual 1) 58.5 2) 69.5 88.8 overall	Efficiency estimates from 6/78 tests; high salt in fuel. 1131 tons/yr of particulate emitted (NEDS)
Weyerhauser Raymond 1480-0004-04 (206) 942-2442	No data	No data	NA	NA	NA	No data	No data	No data	No data	No data	No data	No data	No data	171 tons/yr of particulate emitted (NEDS)
Scott Paper Co. 2600 Federal Avenue Everett 2000-0002-01 (206) 259-7333	60 x 10^6 Btu/h or 60,000 lb/h steam	15,000	No data	NA	NA	No data	74,800	No data	No data	No data	No data	Gravity collector	80-95	286 tons/yr of particulate emitted; baghouse to be installed (NEDS)
Pope & Talbot Port Gamble 1020-0002-02														Boiler shutdown; scrubber did not control salt.
St. Regis Paper 1220 St. Paul Tacoma 1560-0006-01 (206) 572-8300	70 x 10^6 Btu/h or 70,000 lb/h steam[b]	20,000	2-3 bbl to 20 bbl	NA	NA	Highly variable depending on source	75,000	No data	.10-.15	No data	70	1) Ducon multiclone 2) Low ΔP scrubber	No data	400 tons/yr of particulate emitted. (NEDS)

[a] Majority of data from National Emission Data System (NEDS) information supplied by Washington Department of Ecology.

[b] Based on 1000/lb steam.

[c] Based on hourly maximum design rate.

NA - Not applicable.

TABLE A-2. INSTALLATION LIST OF SALT-LADEN HOGGED FUEL BOILER IN OREGON[a]

Description of plant		Fuel characteristics					Emissions characteristics					Control method/equipment characteristics		
Industry name Address	Boiler capacity, 10^6 Btu/h or lb steam/h	Fuel type(s)/firing rate(s): Bark, lb/h	Oil, gal/h	Coal, lb/h	Gas, ft^3/h	Salt fraction of fuel, %	Flow rate to collection device, scfm	Particulate loadings, gr/scf: Inlet	Particulate loadings, gr/scf: Outlet	Salt fraction of particulates, %: Inlet	Salt fraction of particulates, %: Outlet	Control method	Control device removal efficiency, %	Remarks
Georgia Pacific Coos Bay	Boiler 1: lb/hr Design: 100,000 Actual: 75,000 Boiler 2: lb/hr Design: 100,000 Actual: 70,000	Variable[b]	NA	NA	NA	No data	Boiler 1: 85,603 Boiler 2: 31,100	Boiler 1: 1.17 Boiler 2: 0.32	Both boilers <0.2	No data	21	Multiclones	No data	This installation is meeting particulate loading limitations.
Weyerhauser U.S. Highway 101 North Bend	Boiler 1: lb/hr Design: 70,000 Actual: 40,000 Boiler 2: lb/hr Design: 70,000 Actual: 40,000 Boiler 3: lb/hr Design: 100,000 Actual: 70,000	85,000 tons/yr dry, all boilers	Variable	NA	NA	0.09-1.31 range all boilers	195,000 total all boilers	No data	0.13 - 1.32 range all boilers	No data	9-81 range all boilers	Multiclones on all boilers	No data	50-60% opacity. This installation is not meeting opacity or particulate limitations.

[a] Data supplied by Oregon Department of Environmental Quality and Weyerhauser Co.

[b] Fuel consists of bark, plytrim, material waste, and sanderdust.

NA - Not applicable.

TABLE A-3. INSTALLATION LIST FOR SALT-LADEN HOGGED FUEL BOILERS IN ALASKA[a]

Description of plant		Fuel characteristics					Emissions characteristics					Control method/equipment characteristics		
Industry name Address NEDS number	Boiler capacity, 10^6 Btu/h or lb steam/h	Fuel type(s)/firing rate(s) Bark, lb/h	Oil, gal/h	Coal, lb/h	Gas, ft^3/h	Salt fraction of fuel, %	Flow rate scfm	Particulate loadings, gr/scf Inlet	Outlet	Salt fraction of particulates, % Inlet	Outlet	Control method	Control device removal efficiency, %	Remarks
Ketchikan Co. Power boilers 1 and 2	336 x 10^6 Btu/h (240,000 lb steam/h)	80%	20%				277,000	No data	0.5-0.7		86%	Multiclone New mechanical collector to be installed	No data	After installation of a new mechanical collector, the estimated opacity will be 30%.
Alaska Lumber & Pulp Co.		40%	60%								66%			
No. 1 power boiler	165 x 10^6 Btu/h						95,000		0.15			Multiclone and venturi scrubber	85%	Plume appears black with 30% opacity.
No. 2 power boiler	165 x 10^6 Btu/h						76,300						85%	
Alaska Wood Product, Alaska Pulp Co.	36 x 10^6 Btu/h	99%	1%				42,000		0.17		80	Cyclone system	85% 90% design	Plume shows 40% opacity.
Wangell Lumber Plant, Alaska Pulp Co.	42 x 10^6 Btu/h	99%	1%				49,000		0.13		70	Cyclone system	75% 90% design	Plume shows 30% opacity.

[a] Data provided by Alaska Department of Environmental Conservation.

APPENDIX B

TYPES OF HOGGED FUEL BURNING FURNACES[1*]

A furnace or furnace-boiler system fired with hogged fuel incorporates several subsystems: the primary fuel, combustion air, ash handling, instrumentation, and auxiliary fuel systems. A brief discussion of these subsystems is followed by descriptions of the principal types of furnaces that are fired with hogged fuel and the major drying systems used in hogged fuel operations.

The system by which the hogged fuel is introduced to the furnace must be capable of delivering it at variable rates. It must be reliable and easily maintained. Both cost and energy requirements must be considered in fuel system design.

The air system supplies air for combustion and possibly for cooling of grates or refractories. The air system must accommodate variations in fuel flow and maintain efficient combustion. If the system operates by natural draft, the stack must be properly designed. Most modern plants do not use natural draft systems but instead rely on fans to maintain air flow. The fans may be driven by electric motors or steam turbines. The total air system includes grates, ductwork, dampers, and controls and may also incorporate an air heater.

The ash handling system must be sized for the dirtiest possible fuel, that is, for fuel with the maximum expected ash content. Not all of the ash contained in the fuel drops through the grate to the ash pit. Some is carried through the boiler with the combustion gases, where it may accumulate in "dead" spaces. If it does not remain in the boiler, it enters the stack as fly ash, which either is removed from the flue gases by pollution control devices or is emitted from the stack with the gas. If it is removed, final disposal of the fly ash must be provided for.

*Most of this appendix abstracted from reference 1.

Instrumentation and control systems enable the operator to fire the furnace for maximum efficiency with minimum pollution. Particulate matter is generated in the furnace and carried through the boiler. Although the monitoring and control systems are expensive, they are needed to indicate current operating conditions.

An auxiliary fuel system, which carries the load when wood fuel is not available, must come on line rapidly and efficiently. It also must function well with the air supply system and the instruments and controls.

DUTCH OVEN

The Dutch oven was the standard design used for wood firing before World War II. Because they are relatively small, steam plants often operate several Dutch ovens in parallel to provide the desired capacity. Figure B-1 is a cross-section of a Dutch oven, which is primarily a large, rectangular box, lined on the sides and top with firebrick (refractory). Heat is stored in the refractory and radiates to a conical fuel pit in the center of the furnace. The heat aids in driving moisture from the fuel and evaporating the organic materials. The refractory may be water-cooled to minimize damage to the furnace by high temperatures.

The fuel pile rests on a grate, through which underfire air is fed. Overfire air is introduced around the sides of the fuel pile. By design, combustion in a Dutch oven or primary furnace is incomplete. Combustion products pass between a bridge wall and a drop-nose arch into a secondary furnace chamber, where combustion is completed before gases enter the heat exchange section.

This furnace design incorporates a large mass of refractory, which helps to maintain uniform temperatures in the furnace region. This tends to stabilize combustion rates, but also causes a slow response to fluctuating demands for steam. The Dutch oven system works well if it is not fired at high combustion

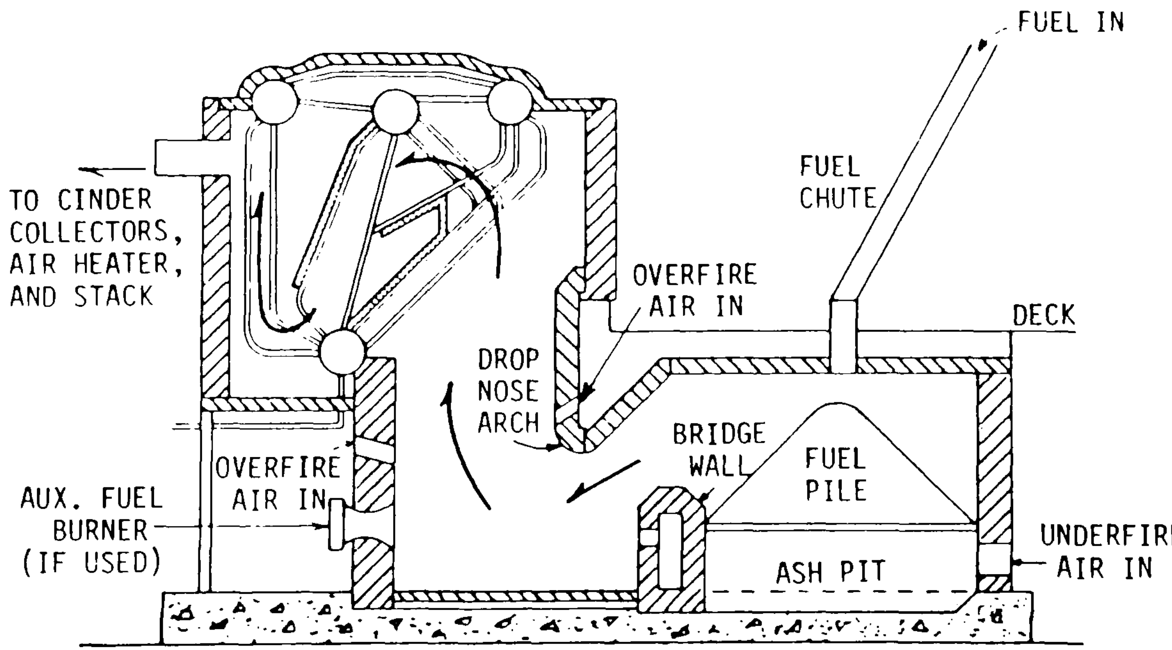

Figure B-1. Dutch oven furnace and boiler.

rates and if the steam load is fairly constant. With this design, however, the underfire airflow rate is dependent upon height and density of the fuel pile on the grates. When the fuel pile is wet and deep, the underfire airflow is low and the fire may be deficient in oxygen. As the pile burns down, the pressure drop through the pile decreases and the flow rate increases, causing an excess of air in the furnace. With fluctuating steam loads, the result is a continuous change from insufficient air to excess air. Because of this feature, together with slow response, high cost of construction, and high cost of refractory maintenance, Dutch ovens are being phased out.

In a well-designed Dutch oven a grate approximately 9 feet on each side is close to the economical limit of area that can be supplied with fuel from one opening. The feed opening is located so that the conical pile thins to a feathered edge at the furnace front and reaches a depth of 12 inches at the bridgewall. With empirical factors, the known slope of the pile, and the clearance between apex and arch, it is possible to determine required height of arch above the grate. The maximum size of the furnace unit or cell is thus well-defined and standardized. The dimensions most frequently used for Dutch oven grates are 8 feet wide by 9-1/2 feet long and 9 feet wide by 11 feet long.

Dutch ovens are usually designed with gravity systems that feed fuel from an overhead conveyor. Airflow may rely on natural draft or fans. Heated forced-draft air is sometimes used, but most designs rely entirely on the mass of the refractory to dry the fuel.

Ash removal is a major problem because not all the ash drops through the grates to the ash pit. Provision must be made for shutting down the furnace periodically to rake the ash from the grates. When several Dutch ovens are operating in parallel, one may be inoperative for cleaning.

Auxiliary fuel usually is not fired into the Dutch oven but rather into the secondary chamber below the boiler. Combustion Engineering[2] reports high maintenance costs because of the tendency of the refractory surfaces to flux when oil is burned in combination with wood; continuous use of auxiliary fuel for Dutch ovens is not recommended.

Most Dutch ovens at lumber mills are of the flat-grate type shown in Figure B-1. A sloping-grate furnace is used at some paper mills that burn wet bark. The fuel enters the front end of the furnace across its full width and travels down the sloping grate as it moves through the furnace. The upper front section of the grate, which forms the primary drying zone, consists of a refractory hearth set at an angle of approximately 50 degrees. A regulating gate controls fuel-bed thickness at the point of entrance.

The middle section is composed of stationary grate bars set at an angle of 45 degrees and provided with horizontal spaces to admit air. The lower section of the grate is set at slightly less than 45 degrees and may be provided with fuel-pushers that can be operated as required. Horizontal dump plates extend from the end of the grate to the bridge wall. Progressive feeding of the fuel from point of entrance to the dump is achieved by grate slope. As the fuel dries, it slips more readily and the lesser slope in the second section serves as a retardant. The slope of the third section prevents the formation of an excessively thick fuel bed at the bridge wall end of the furnace. A portion of the combustion air is supplied through the two lower grate sections, and the remainder through tuyere openings in the front of the bridge wall. The face of the bridge wall is sloped to cause gas from the lower end of the fuel bed to sweep over and mix with gases coming from the drying section of the furnace.

The fuel bed of the sloping-grate furnace is comparatively thin so that, with relatively low undergrate pressures, air can be distributed through the bed to provide uniform combustion throughout. For good operation, however, the fuel should be quite uniform in size; otherwise streaks or pockets of greater density than adjacent areas may lead to formation of blowholes in the thin portions of the bed. The rate of combustion can be increased more rapidly, in relation to the draft, than in flat-grate furnaces, although the latter can carry much higher overloads. By carefully controlling the rate of feed and using zoned air supply, the operator can obtain complete combustion with lower draft velocities and less excess air than in operation of flat-grate furnaces. Because of this responsiveness, the inclined grate lends itself to the use of automatic combustion controls.

Another type of furnace that operates on the same principle as the Dutch oven is the Dietrich cell. Figure B-2 shows a single Dietrich cell under a small, horizontal-return-tube (HRT) boiler. The cell acts to gasify the fuel, and the burning gases then enter the boiler. The operational constraints on the Dietrich cell are the same as those on a Dutch oven. For both, the maximum turndown is 3/1. Control is difficult with rapidly varying steam loads. Refractory maintenance is expensive and time consuming. The ashes must be raked by hand, and disposal is usually by means of a wheelbarrow to an open outside pile.

SPREADER STOKER

Since World War II nearly all of the wood-fired boilers constructed in the United States have been spreader stokers. The design earlier proved satisfactory for coal firing, and many of the early units were only slightly modified to fire wood residue or bark. Some of the more recent units have been specifically designed for wood firing. The spreader stoker is an example of an integral furnace-boiler system. The fuel is burned in the base of a water-wall boiler unit rather than in a refractory chamber. Figure B-3 illustrates a spreader stoker at the Eugene Water and Electric Board, Eugene, Oregon, (EWEB) power plant. Figure B-4 shows a typical small package spreader stoker, which can be sent to a plant in modules and erected rapidly. Several features distinguish the spreader stoker from the Dutch oven.

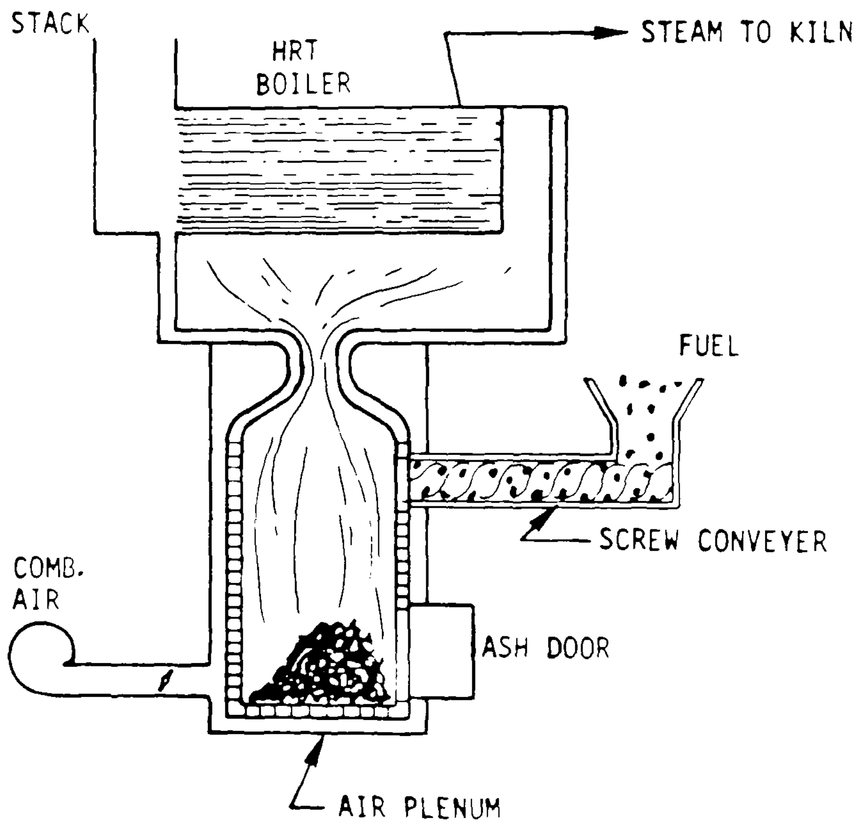

Figure B-2. Pile burning: Dietrich cell,

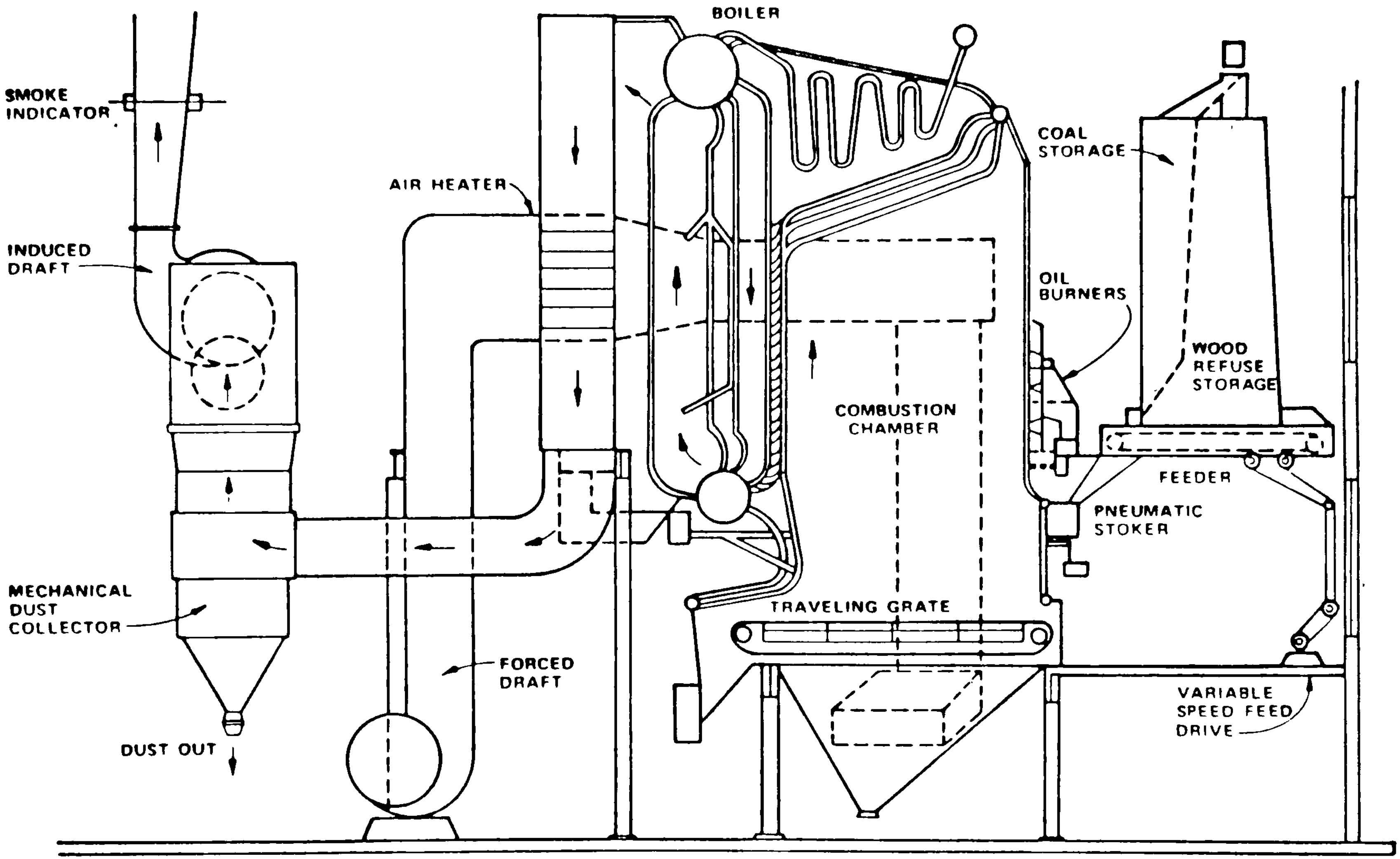

Figure B-3. Spreader-stoker-fired steam generator EWEB - Number 3.[3]

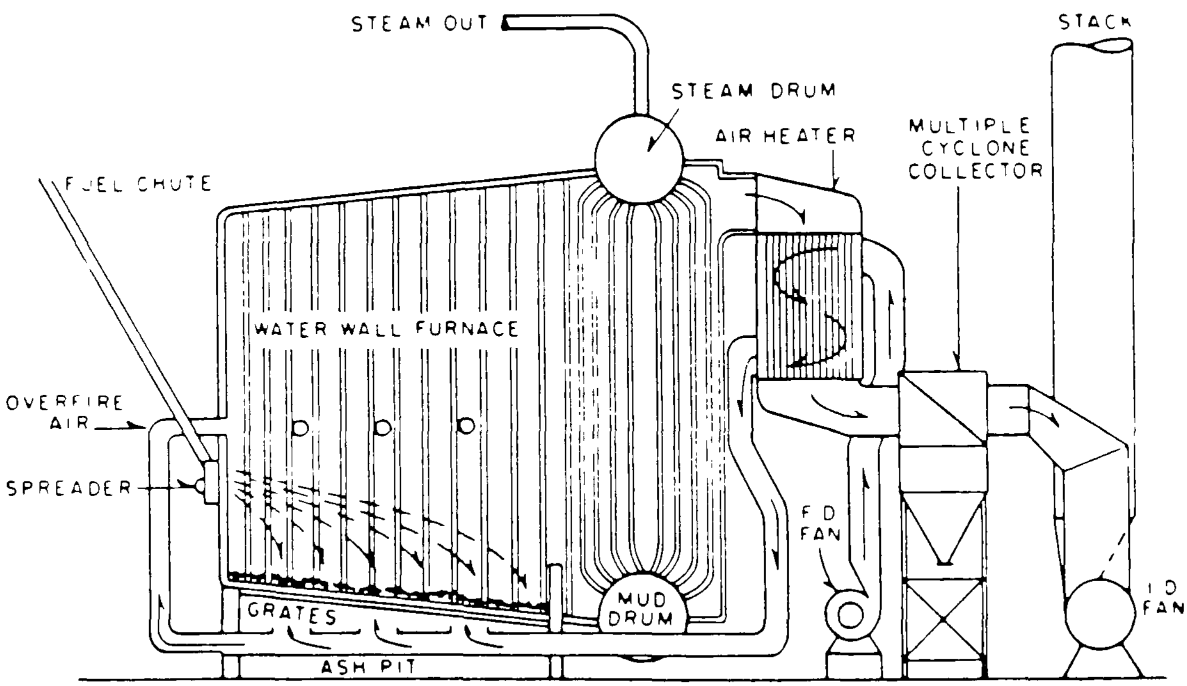

Figure B-4. Small spreader-stoker furnace.

1. The fuel is dried by hot forced-draft air rather than by radiant energy from a large mass of refractory. This is accomplished by passing the flue gases through a gas-to-gas heat exchanger before exhausting them to the stack. The forced-draft fan takes in ambient air and blows it through the heat exchanger, where it is heated to approximately 204°C (400°F) before going to the furnace. This hot air is forced through the thin bed of fuel on the grates to dry the fuel.

2. Fuel is fed to a spreader stoker from an overhead conveyor, usually through a variable-speed auger metering system, to the spreader located at the front of the boiler. The spreader may be a mechanical "paddle wheel" type, which knocks the hogged fuel into the furnace, or a pneumatic type, which uses air pressure to blow the fuel across the grates.

Figure B-5 shows the pneumatic stoker installed at the EWEB plant.

The spreader-stoker system may use a traveling grate, a dump grate, or a fixed grate. The traveling grate moves from the rear of the furnace toward the front. The larger pieces of fuel are thrown to the rear of the furnace and therefore remain on the grate longer to burn. The ashes on a traveling grate system are dumped at the front of the furnace.

3. Because the spreader stoker is an integral furnace-boiler system, it is substantially smaller than a Dutch oven of the same output. Because of the smaller size and lighter weight (no refractory), small units can be transported by truck or rail.

4. Spreader stokers respond rapidly to load changes. The thin fuel bed and lack of refractory contribute to a low "thermal inertia." This rapid response can be detrimental, however, because only a brief failure of the fuel system causes the fire to be extinguished. Turndown ratios of 4:1 are quoted for spreader stokers.

FUEL CELL

A fuel cell is a suspension burning system that burns small-size, dry fuel supported by air rather than by grates. The fuel particles, mixed with combustion air, completely fill the combustion chamber. This feature differs from fluidized-bed

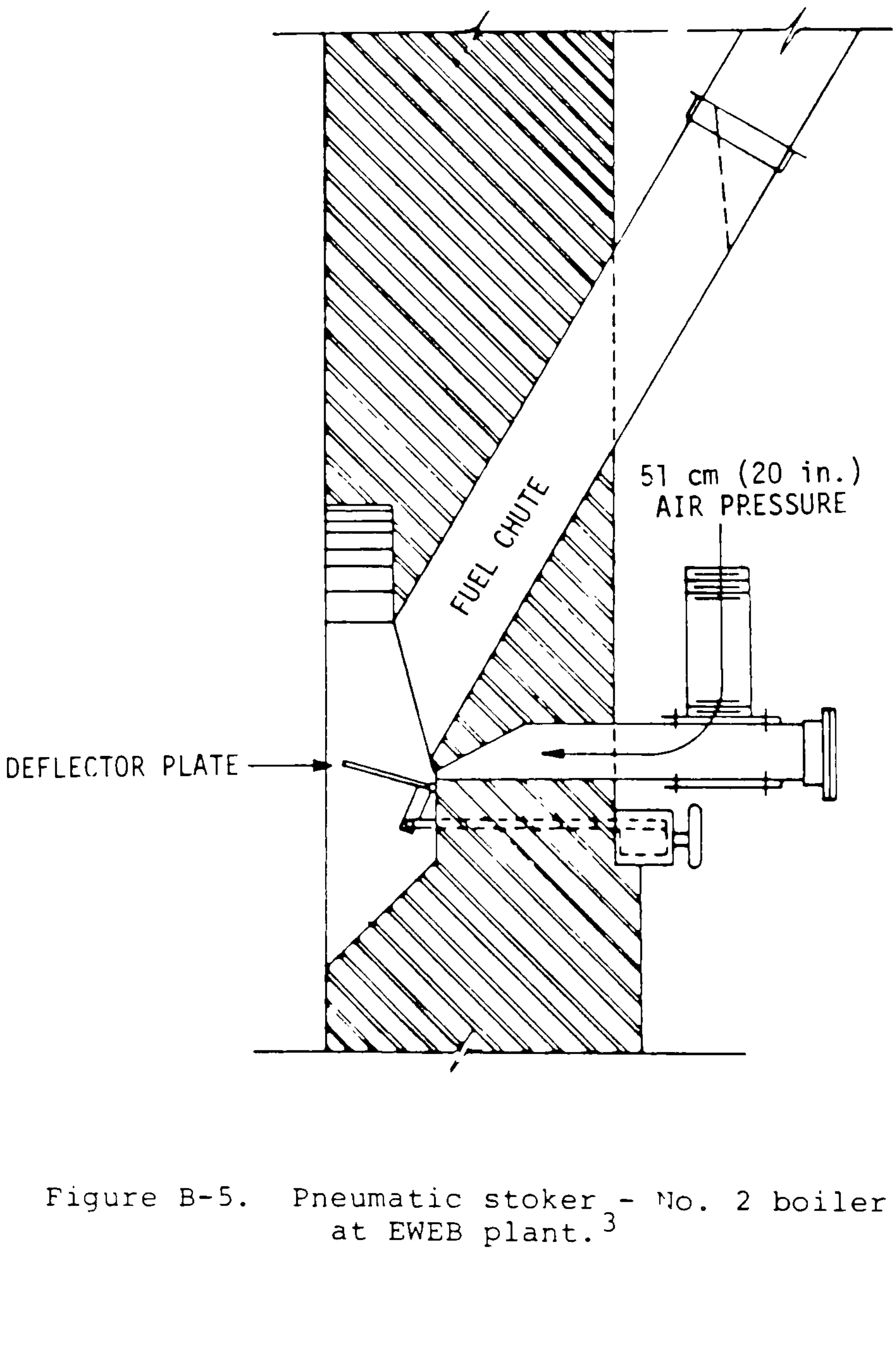

Figure B-5. Pneumatic stoker - No. 2 boiler at EWEB plant.[3]

combustion, wherein fuel particles remain in the "bed" even though supported by air. Sanderdust usually is burned in a fuel cell. With adequate size reduction, wood and bark residues also can be burned in suspension. The advantages of suspension burning include low capital costs for combustion equipment because no grates are required and ease of operation because grate cleaning is eliminated. The ash goes into suspension as particulate matter in the exhaust stream or falls to the furnace bottom for removal. Rapid changes in rate of combustion are possible.

Figure B-6 is a fuel cell of this type. Figure B-7 shows the same fuel cell installed to supply heat to a boiler.

Suspension burning has disadvantages, however. Because most of the ash escapes with the exhaust gases, control of fly ash may be difficult. For this reason some suspension units are designed to "slag" or melt the ash in the combustion chamber and thus reduce the amount of ash entrained in the exhaust-gas stream. Temperature control in the combustion chamber is critical. If the ash-fusion temperature is exceeded, the ash may form large pieces, which can plug or damage the system. Fuel preparation must be thorough to provide sizes small enough for suspension burning. Moisture content also must be controlled within reasonable limits, a requirement that can be costly with systems burning wood and bark. With sanderdust fuel, no further processing is needed. Residence time is critical (as in any combustion system). Suspension burning inherently provides short residence. At high combustion rates, the residence time may be insufficient for the process to go to completion.

The capacity of fuel cells is limited; therefore, as more energy is needed, more fuel cells are added. As fuel-drying systems are perfected, it is probable that more fuel cells will be used, even on larger boilers. Figure B-8 shows the complete system requirement for use of wet wood residue and bark as a fuel for a large suspension burning system. Fuel cells are particularly hard on refractory because of the high temperatures.

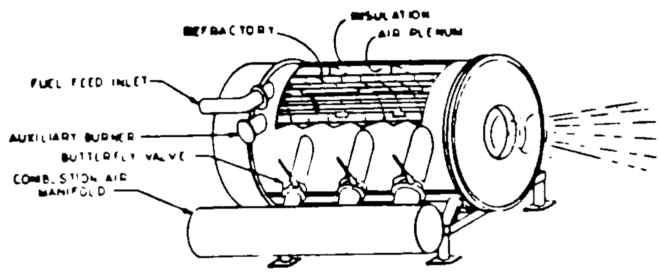

Figure B-6. The Energex cyclonic burner (fuel cell).

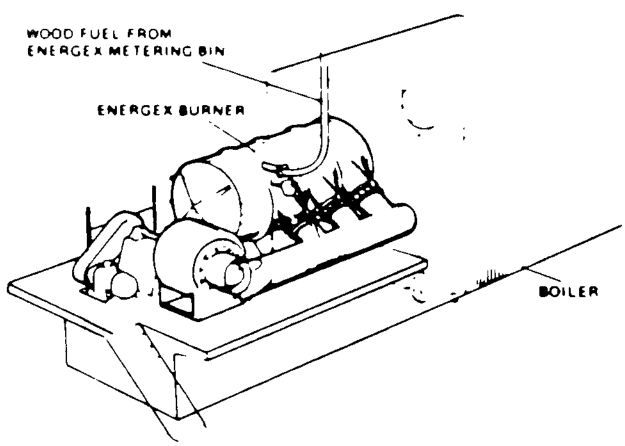

Figure B-7. An Energex-fired package boiler.

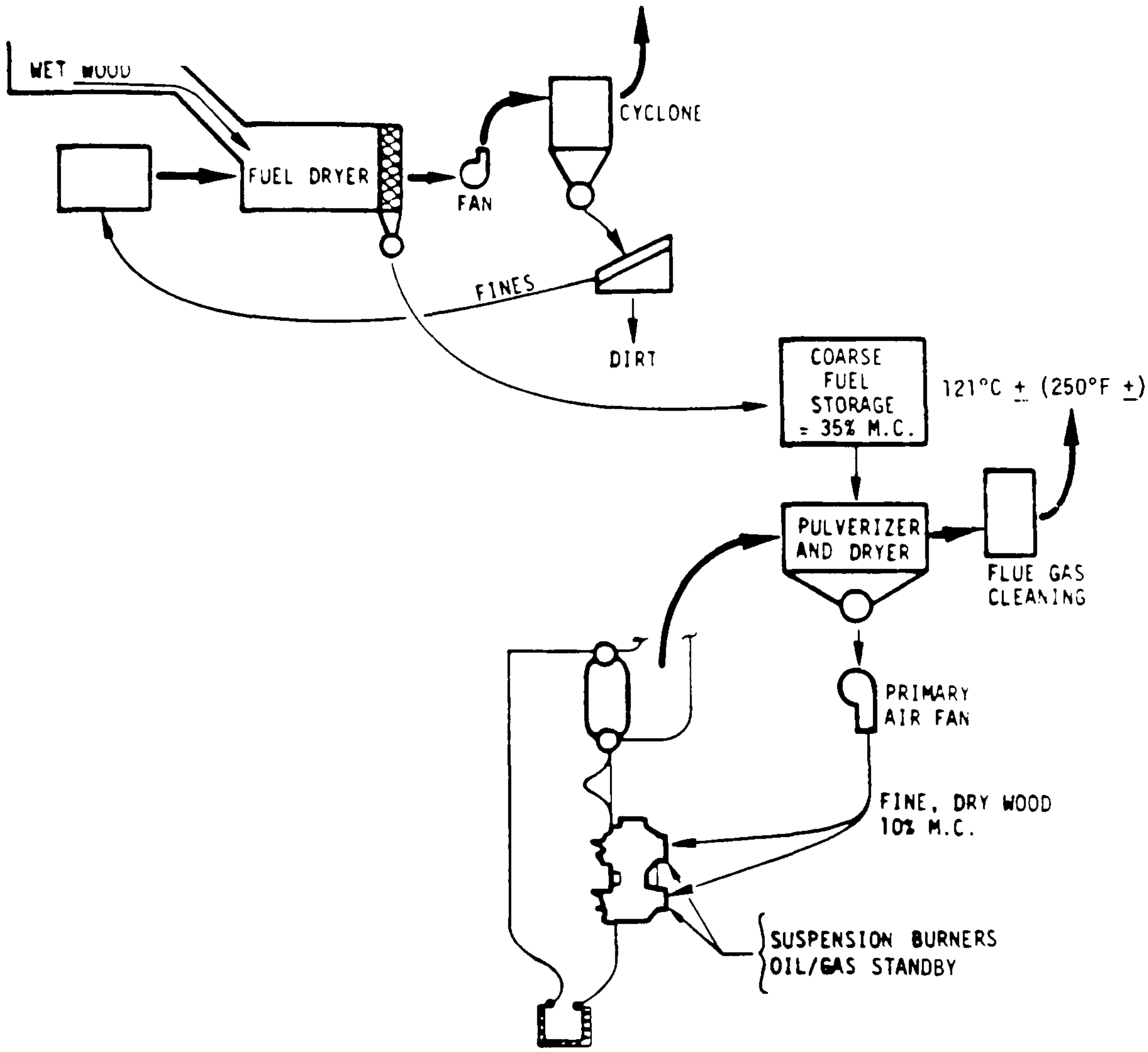

Figure B-8. Large suspension burning system.

FLUIDIZED-BED COMBUSTION

One of the newer systems developed to burn solid fuels is the fluidized-bed combustion furnace. The system can burn high-moisture fuels and can react to changes in steam demand more rapidly than some of the other systems. Fluidized-bed combustion of cellulose materials was originally developed to incinerate wastes from pulp and paper mills having moisture contents up to 67 percent.

The fluidized-bed system incorporates a large mass of finely ground inert material (like sand), which provides a very large exposed surface area. The inert material is contained in a vessel, through which air is passed upward so that the bed becomes "fluidized"; it resembles a boiling liquid that keeps the particles in a state of constant agitation. The bed is preheated to about 760°C (1400°F). When a finely divided solid fuel is introduced, the hot inert mass provides sufficient energy and radiating surface to "flash"-evaporate the fuel moisture and gasify the volatile component of the fuel. The remaining fixed carbon in the fuel is oxidized as it moves through the fluidized bed. The process generates little or no flame but rather a glowing bed. Combustion is rapid, and the fluidized bed proper contains no unburned organic material. Particulate emissions are therefore minimal.

The fluidized bed may be used as a hot gas generator for a separate boiler, or heat may be transferred directly from the bed to the steam by placing bundles of tubes in contact with the inert material of the bed.

In a 1975 presentation, Keller[4] described application of the fluidized-bed system to steam plants using wood residue fuels and indicated plans by Energy Products of Idaho to have 10 fluidized-bed units in operation by September of that year. This development has not proceeded on schedule.

DIRECT FIRING

Within the past 5 years, installations have been made in the United States in which the hot gases from burning bark (and wood) are used directly for heat. Applications involving direct firing of wood and bark include veneer dryers, drying kilns for lumber, and dryers for wood and bark particles.

Deardorff[5] describes a pile-burning, hogged-fuel-fired furnace that supplies heat directly to a veneer dryer. Jasper and Kock[5] report on a suspension burning system in which undried bark is pulverized and burned in a cylindrical, annular combustion chamber. The system has been tested in the laboratory, and the authors propose construction of a production model to be used with a lumber dry kiln.

Although direct-firing systems are not hogged-fuel-fired boilers, they are included in this report for two reasons: (1) the problems involving fuel, control, and pollutant emissions are similar to those with furnaces used in conjunction with steam-producing boilers; and (2) direct-fired units may replace the current wood waste boilers, since developmental work on direct firing is progressing rapidly.

OPERATING VARIABLES

Variables governing furnace operation are classified in Table B-1 as fuel-related, air-related, and operator-related; all of these factors contribute to the overall efficiency of the system.

TABLE B-1. FACTORS AFFECTING THE COMBUSTION REACTION IN BOILER INSTALLATIONS FIRED BY HOGGED FUEL[6]

Fuel-related factors
Species
Size
Moisture content
Ultimate analyses
Proximate analyses
Heating value
Method of feeding fuel
Distribution of fuel in furnace
Variations in fuel feed rates
Depth of fuel pile in furnace
Separate firing practices
Auxiliary fuel usage
Air-related factors
Percent excess air
Air temperature
Ration of overfire air to underfire air
Turbulence of air
Flow relation between forced-draft and induced-draft systems
Other factors
Cleanliness of the combustion system
Basic furnace design
Maintenance of components
Steam generation rate
Steam drum water level

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APPENDIX C

CASE HISTORIES OF SECONDARY COLLECTORS FOR CONTROL OF SALT-LADEN PARTICULATE FROM HOGGED FUEL BOILERS

FABRIC FILTER, SIMPSON TIMBER COMPANY, SHELTON, WASHINGTON

The Emission Problem

The Shelton power plant of Simpson Timber Company consists of seven boilers. Six of the boilers are rated at 12,480 kg/h (27,500 lb/h) of steam production each. Boiler 7 produces about 20,420 kg/h (45,000 lb/h) steam, with a rated capacity of 40,840 kg/h (90,000 lb/h) steam production. Almost all fuel burned in the boilers is derived from salt-water-borne logs.[1,2]

Historically, visible emissions were 4 to 5 Ringelmann No. opacity and over 0.69 g/std m^3 (0.3 gr/sdcf). Attempts to reduce emissions by combustion with large amounts of overfire air were futile because about 70 percent of the flue gas is salt particulate. Large chimney diameter also contributed to a high apparent smoke density. Changes in log handling in 1973 substantially increased visible emissions from stacks. Flat raft storage was replaced by bundled log storage in an effort to reduce the space occupied by floating logs and to reduce the depositing of debris in the bay by dumping of single logs.[3]

Emission source tests clearly indicated that submicron salt particles constituted a major portion of particulate emissions. Efforts were made to limit the log storage time in saltwater and thereby reduce the salt content of logs. Limiting the log storage time reduced the salt content in stack emissions somewhat, but even with as little as 2 weeks storage (logistically the shortest possible time) compliance with the particulate emission regulation was not achieved. The use of mechanical bark presses to reduce the salt and moisture content of fuel was rejected because of the serious problem of disposing of bark pressate water.[2]

Selection of Particulate Control Device

A preliminary study of wet scrubbers indicated that only high-energy units would remove the submicron salt particulates to the degree required for compliance. Because of corrosion and operational problems, the test facilities were not available within the allowable time limit.[3]

Then pilot tests were performed with a static bed dry scrubber. The visible salt plume from stack persisted, and because of the limited operating experience with dry scrubbers on boiler gases, the use of dry scrubbers was rejected.

After pilot tests with fabric filters indicated that this system could achieve compliance with emission regulations, Simpson Timber Co. decided to install baghouses for particulate control.[3]

The Fabric Filter System[3]

Two baghouses manufactured by Standard Havens Company were installed in 1976. One unit handles 47.2 m^3/s (100,000 acfm) of flue gas from Boiler 7 while the other unit handles 61.4 m^3/s (130,000 acfm) of flue gas from four smaller boilers, part of a group of six, of which two were allowed to bypass the baghouse.

The two baghouses are identical except for size, one having six compartments or modules and the other eight. Each module is 3.66 m (12 ft) square and contains 196 bags, 12.7 cm (5 in.) diameter by 4.30 m (14 ft) long. The two systems use a total of 2744 bags. Effective air-to-cloth ratio is 22.9 to 1 m^3/s per m^2 (4.5 to 1 acfm/ft^2). Temperature of gas entering the baghouse ranges from 205° to 260°C (400° to 500°F) and spikes to 290°C (550°F). The bags are Teflon-coated woven fiberglass and are supported on 1.3 cm by 3.8 cm (0.5 in. by 1.5 in.) galvanized wire mesh cages suspended from a top tube sheet.

Baghouse construction is basically mild steel because operating temperatures are above the dew point and the salt remains dry and solidified. Heaters are installed in the reverse air ducts to maintain heat during shutdown periods and before startup. The housings are insulated with 7.5 cm (3 in.) of fiberglass and have a galvanized outer skin to prevent internal condensation. The structural frame is also galvanized for ease of long-term maintenance. Bags can be replaced with the facility in full operation by isolating one module at a time with the reverse air dampers.

Total additional power required for the filter system including compressors, agitators, conveyors drives, and new induced-draft fans is about 900 watts (1200 hp). Both boiler systems are equipped with Buell multiclone-type cinder collectors ahead of the baghouses. For the purpose of cleaning, a dual system of reverse air and pulse jet is used, with pulse jet as the basic mode. In reverse air cleaning low-pressure air is supplied in reverse direction through the bags while the module is isolated from the main stream by dampers. In pulse jet cleaning high-pressure air is injected for brief periods into the outlet of the bags and no isolating dampers are needed. Typically, a given bag is pulsed every 15 to 20 minutes to hold the pressure drop across the baghouse in the range of 2.5 to 2.7 kPa (10 to 11 in. W.G.). Air for bag pulsing is supplied at 690 kPa (100 psi) by two 75-watt (100-hp) screw-type compressors.

The particulates caught by the two baghouses average 1360 kg (3000 lb) per day with 70 percent salt. These are disposed of in the city sanitary sewer along with 38 to 76 liters/s (10 to 20 gal/min) of blowdown water.

Operational Experience[3]

From a gas-cleaning standpoint the performance of these filters to date has been successful. The National Council for Air and Stream Improvement (NCASI) emission tests conducted on the smaller unit indicated outlet particulate concentrations below 0.046 g/std m^3 (0.02 gr/sdcf) corrected to 12 percent CO_2.[4] The larger unit tested by CH_2M-Hill produced an outlet concentration of 0.092 g/std m^3 (0.04 gr/sdcf) corrected to 12 percent CO_2. The opacity of stack emissions was 5 percent.

In the first year of operation, plugging of the tapered hoppers beneath the bags caused a buildup to the point that the lower ends of the bags were surrounded with hot salt and ash. The heat and lack of ventilation apparently caused the bags to break down and disintegrate. In 2 years of operation 70 percent of the bags have been replaced; of these, 300 were destroyed by plugging that occurred on two occasions. The onset of plugging is hard to detect and harder to prevent. Bag replacement has become a continuing process. Cages can be reused but about 20 percent are lost by normal wear and tear or by damage suffered in the bag-changing process. Bag replacement cost was budgeted at $60,000 per year, out of $75,000 total annual operating costs.

Among other problems, a leaky bag can often fill the cage solidly from end to end with salt and ash, making it heavy and awkward to handle. The rotary air lock valves handling the baghouse residue are not large enough to handle the amount of ash broken loose during cleaning of a hopper. A bypass chute was installed to alleviate this situation. Because the original electric resistance heaters in the reverse air ducts failed in the salty atmosphere, they were replaced with steam coils. No fire in the baghouse has occurred so far.

A problem with new ID fans is caused by the tendency of the forward-curved blades to catch a buildup of salt, causing an imbalance when it is released from one or more blades. Vibration detectors were installed on the bearings to give an alarm when this happens. Several brief shutdowns for removal of this deposit have been required.

VENTURI SCRUBBER, CROWN ZELLERBACH CORPORATION, PORT TOWNSEND, WASHINGTON

The Emission Problem[5]

The Crown Zellerbach Corporation's Port Townsend plant replaced nine Dutch oven boilers with one 99,800 kg/h (200,000 lb/h) hogged fuel boiler in September 1977. Under normal operating conditions this new boiler provides all power for the 400-tons/day kraft mill. No. 6 fuel oil is burned as auxiliary fuel. The boiler control system can respond automatically to changes in steam demand by adjusting the fuel rate for either the hogged fuel or the No. 6 fuel oil.

The hogged fuel consists of sawmill wastes purchased from neighboring mills, of which approximately 90 percent is fir and hemlock. The moisture content ranges from 53 to 58 percent by weight and the salt content ranges from 0.7 to 1.6 percent, all dependent on source and season. Sulfur content of the No. 6 fuel oil is high, approximately 1.5 percent. Sludge from the primary clarifier with moisture content of 60 to 65 percent is also burned in the boiler, but this is considered to reduce boiler efficiency.

Pollution Control Equipment

For control of particulate emissions Crown Zellerbach has installed a 660-tube multiclone system manufactured by U.O.P. Air Correction Division. The pressure drop for the multiclone system is 6.4 cm (2.5 in.) water gauge. Additional information with respect to the multiclone system is not available. Downstream of the multiclone system, Crown Zellerbach has installed a variable-throat venturi scrubber manufactured by Western Precipitation. Pressure drop ranges from 38 to 51 cm (15 to 20 in.) of water. The scrubber is designed to handle a total gas flow of 4925 m^3/min (174,000 acfm) with an inlet temperature of 202°C (395°F) and an exit temperature of 66°C (150°F).

Operational Experience

Total particulate emissions from the boiler in February 1978[6] were reported as being 0.23 g/m^3 (0.07 gr/dscf). This complies with the current emission standard of 0.239 g/m^3 (0.10 gr/dscf) set for this installation. Salt content of the fuel was 0.4 percent, and salt accounted for approximately 26 percent of total emissions. More recent tests (June 1978) with the salt content of the fuel greater than 1 percent have shown outlet loadings of 0.32 to 0.41 g/m^3 (0.14 to 0.18 gr/dscf).[7] In some of these tests an attempt was made to induce nucleation of the particulate in the stack by adding water to the venturi scrubber sump to cool the gases. Only -15 to -12°C (5 to 10°F) reductions in temperature were achieved. In these tests salt constituted 70 percent or more of the outlet emissions. Opacity of the plume was estimated at 35 percent.

Thus operation of the scrubber does not comply with the particulate emission regulation when salt content of the fuel is greater than 1 percent; pressure drops above 51 cm (20 in.) water would be required to achieve compliance.

Detailed operation and maintenance procedures are not yet well defined. A few operating problems have been reported to date. Vibration that occurred during startup was eliminated by additional reinforcement of the scrubber's structural steel. Erosion and corrosion that occurred in the distribution header are now prevented by enclosing the header and scrubber nipples. Upon erosion of the fiberglass separator, it was replaced with a stainless steel separator.

No major operation and maintenance problems with respect to the U.O.P. multiclone system have been reported.

Cost of Pollution Control Equipment

The capital cost of the scrubber system, flange-to-flange, is $500,000. The ductwork, stack, and miscellaneous items totaled $400,000, giving a total of $900,000 for the complete scrubbing system.

Operation and maintenance costs for the multiclone and the scrubber systems are not yet available.

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APPENDIX D

PERFORMANCE OF NOVEL CONTROL DEVICES APPLICABLE TO SALT PARTICULATE EMISSIONS

IONIZING WET SCRUBBER[1]

The ionizing wet scrubber (IWS) combines the principles of electrostatic particle charging, image force attraction, inertial impaction, and gas absorption to collect submicron solid particles. It was developed by Ceilcote Company to remove fine solid particulate down to 0.05 μm diameter. The unit requires little energy and its collection efficiency is high for both submicron and larger particles. With fiberglass-reinforced polyester and thermoplastic materials throughout most of the IWS, it is impervious to corrosive atmosphere according to Ceilcote Co.[1] Figure D-1 depicts the ionizing wet scrubber.

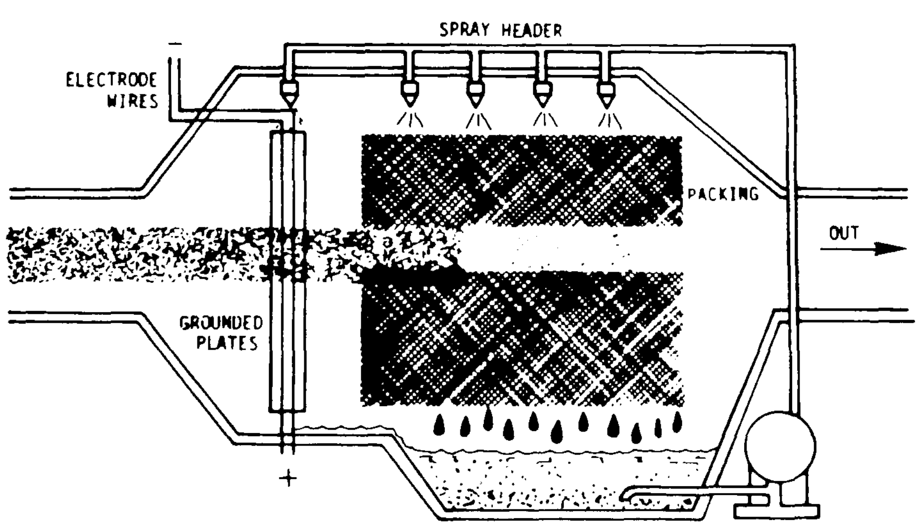


Figure D-1. Ionizing wet scrubber (IWS).[1]

Operation

Pollutant particles in entering gas steam are first electrostatically charged within an ionizer section that utilizes a high-voltage d.c. power source. Discharge electrodes have negative polarity, and wetted "mini-plates" serve as grounded electrodes. The plates are continuously flushed with water to prevent an accumulation of solid particles or residues. Then the gas stream enters a packed scrubber section where particles are removed either by inertial impaction or by attraction of the charged particles to a neutral surface. Particles of 3 to 5 μm and larger are collected through inertial impaction within the packed bed. Smaller charged particles are removed by image force attraction, as shown in Figure D-2; they are attracted to neutral packing surfaces or scrubbing liquid droplets. The collected particles are removed continually from the stream by a liquid scrubbing medium, which flows vertically down through the packing. Operating temperature range is 93° to 121°C (200° to 250°F).

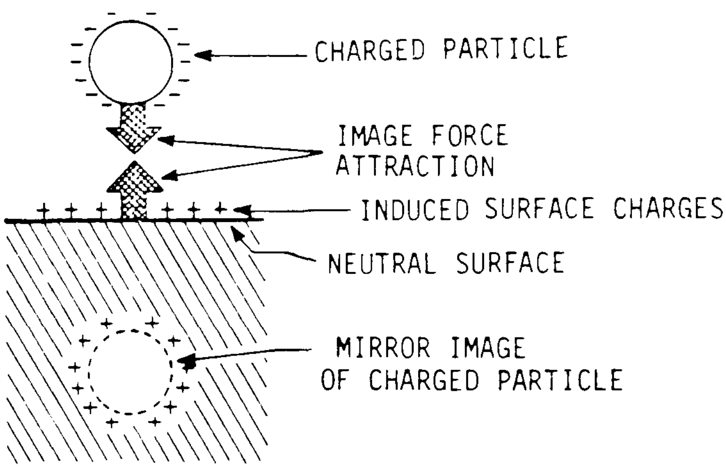


Figure D-2. Image force attraction.[1]

Collection Efficiency

Ceilcote reports that collection efficiency in the fine particle range decreases only slightly as the particles become smaller. The collection efficiency characteristics of ESP's, fabric filters, and the IWS from Ceilcote are shown in Figure D-3.

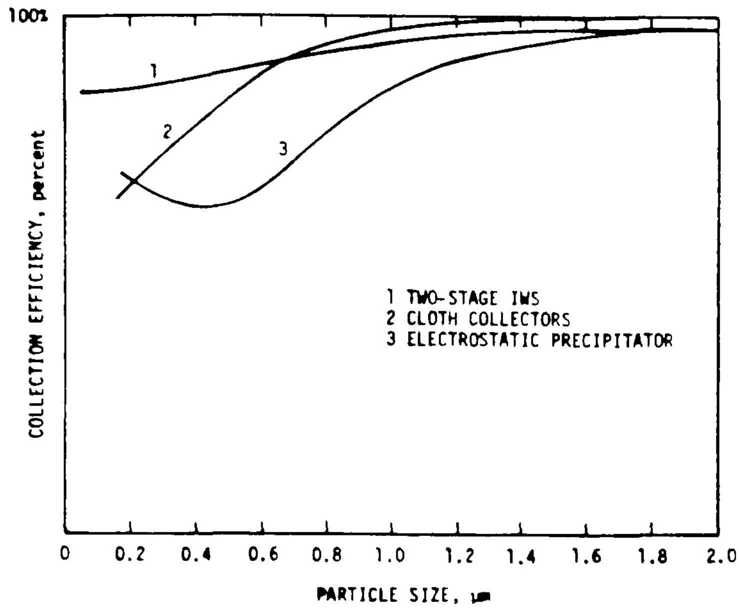


Figure D-3. Collector efficiency versus fine particle size.[1]

The IWS is a fractional collector. A single-stage IWS unit removes a fairly constant percentage of incoming particles regardless of particle size distribution of the total loading. To increase the collection efficieny, the IWS can be used as a multistage unit.[1] Figure D-4 presents typical collection efficiency curves for single and two-stage systems.

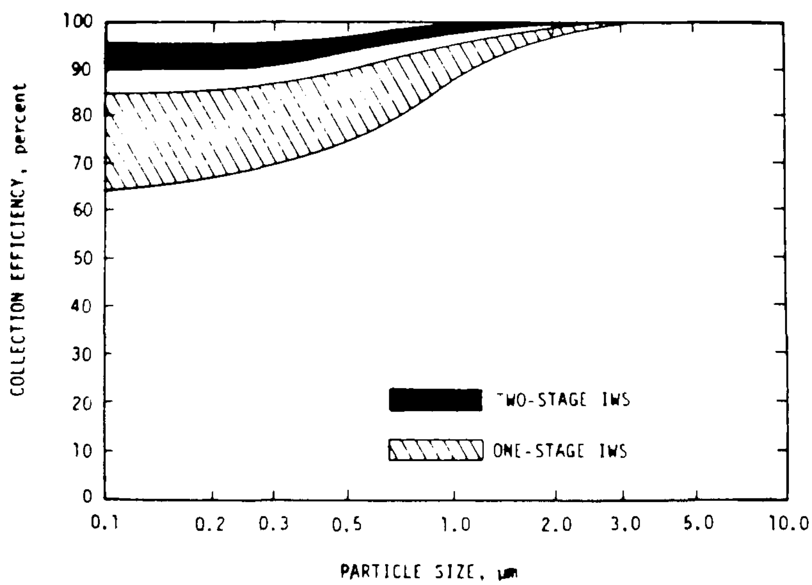


Figure D-4. Collector efficiency of typical one-stage and two-stage IWS units.[1]

Energy Consumption

Operating costs of the IWS are reportedly very low. Pressure drop through a single-stage unit is approximately 3.8 to 5.0 cm (1.5 to 2 in.) water. Total system energy usage by a single-stage unit is approximately 52.7 to 65.9 watts per cm^3/min (2.0 to 2.5 bhp/1000 acfm). Energy usage by a two-stage unit is 105 to 131 watts per m^3/min (4.0 to 5.0 bhp/1000 acfm).

Pilot Studies on Salt-laden Hogged Fuel Boilers[2]

In mid-1976 a test program was established to evaluate the Ceilcote IWS in removing fine salt particles from flue gas of a typical hogged fuel boiler firing fuel with high salt content. The pilot tests were conducted jointly by eight companies at Simpson Timber Company. It was concluded that the Ceilcote IWS can achieve a typical compliance level of stack emissions at 0.229 g/sdm^3 (0.10 gr/sdcf) adjusted to 12 percent CO_2 and also can achieve less than 20 percent opacity.[2] The operating pressure drop per stage of IWS was about 1.3 cm (0.5 in.) water.

Emission source--

The source of the salt fume was the No. 7 hogged fuel boiler of Simpson Timber Company. The boiler burned only hogged bark, sawdust, and shavings from logs transported and stored in salt water for 3 weeks to 6 months. A slip stream of 28.3 to 85.0 m^3/min (1000 to 3000 acfm) was used with the pilot plant. Particulate in the flue gas at this point measured 0.46 to 0.69 g/sdm^3 (0.2 to 0.3 gr/sdcf), of which 79 percent was NaCl particulate, 4 to 6 percent was CO_2, and 14 to 16 percent was O_2 and negligible organic compounds. Flue gas temperature ranged from 260° to 315°C (500° to 600°F).

Ceilcote IWS pilot plant--

The Ceilcote IWS pilot plant consisted of a quench section, a prescrubber, and two IWS stages. Each stage included an ionizing section followed by a cross-flow packed scrubber similar to the prescrubber. The quench section was used to cool the inlet gas from 204 to 206°C (400 to 475°F) to about 65°C (150°F) to protect the polypropylene tellerette packing in the scrubbing sections. The prescrubber was installed to remove large particles. The electrical potential in the ionizing section was maintained at 16 to 26 kV, and current ranged from 2 to 4 mA at high particulate loadings to about 20 mA at low loadings.

Results--

Table D-1 summarizes the pilot test results. Overall efficiency of the pilot control system typically ranged from 99.5 percent at low gas flow rate to 94.6 percent at very high gas flow rate. The overall efficiency without electrostatic augmentation was 63.8 percent, which showed that the IWS had a significant effect on fine particulate collection. Measurement of aerodynamic particle size distribution at inlet and outlet indicated that IWS efficiency is nearly independent of particle size.

No information is available on disposal of the wastewater collected from the IWS.[2]

CHARGED DROPLET SCRUBBER (CDS)[3,4,5]

The charged droplet scrubber (CDS) was developed by TRW Systems, Redondo Beach, California. The operating principle is similar to that of the IWS, but instead of charging the particles, the TRW scrubber charges the water droplets. The CDS is designed as standard modules that can be combined in parallel to handle higher inlet gas flow rates.

Operation

Figure D-5 illustrates the operation of the TRW module. The CDS produces a spray of electrically charged liquid droplets, which are accelerated through the electrostatic field between the spray tube and collector plate. The pollutant particles in the entering gas are attracted to liquid droplets by means of direct collisions or indirect charging encounters. The particles are

TABLE D-1. PILOT TEST RESULTS OF CEILCOTE IWS ON SALT-LADEN HOGGED FUEL BOILER, 1976

Typical test runs[a]	Gas flow rate, m^3/min (acfm)	Gas velocity across ionizing plates,	Pressure drop per stage, cm (in.) H_2O	Inlet particulate concentration,[b] g/sdm^3 (gr/sdcf)	Particulate concentration[b] between stages g/sdm^3 (gr/sdcf)	Outlet particulate concentration,[b] g/sdm^3 (gr/sdcf)	Opacity against blue sky, %
1	34.6 (1230)	~1.31 (4.3)	0.76 (0.3)	0.837 (0.3660)	0.0254 (0.0111)	0.0048 (0.0021)	<10
2	49.3 (1740)	~1.89 (6.2)	1.0 (0.4)	0.556 (0.2430)	0.0799 (0.0349)	0.0153 (0.0069)	<10
3	58.5 (2066)	~2.29 (7.5)	1.3 (0.5)	0.490 (0.2140)	0.0772 (0.0337)	0.0162 (0.0071)	20
4[c]	87.8 (3100)	~3.1 (10.2)	1.8 (0.7)	0.781 (0.3414)	0.1117 (0.0488)	0.0419 (0.0183)	NA[e]
5[d]	59.3 (2095)	NA[e]	NA[e]	0.423 (0.1850)	0.2400 (0.1050)[f]	0.1500 (0.0670)	NA[e]

[a] No data available on water requirements.

[b] No information available for correction to 12% CO_2.

[c] Flow rate higher than test range.

[d] High voltage turned off across ionizing section.

[e] Not available.

[f] Particulate concentration after prescrubber.

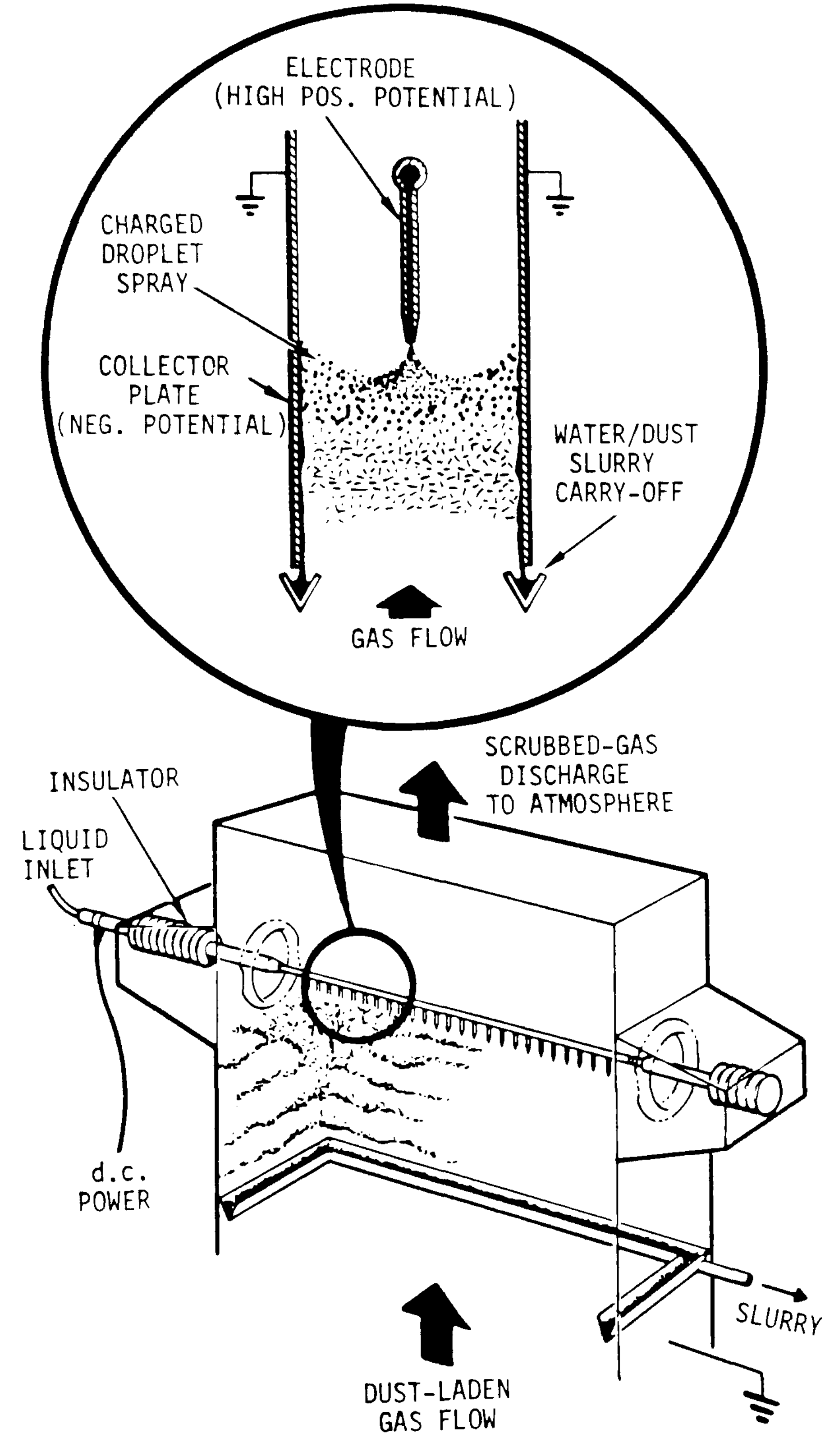


Figure D-5. Charged droplet scrubber operation.[4]

carried to the collector plate, from which they are continuously drained off with the liquid.

The feed tube is held at a high positive potential with respect to collector plate. The droplets theoretically have high local charge densities without wasteful corona currents so that the CDS can use smaller collector surfaces and operate at lower power levels. The slurry is drained into a settling tank or other processor, and liquid is then clarified and recirculated through the CDS. The residual sludge can be recovered or discarded.

Field Pilot Tests

Field pilot tests have been conducted for various installations. Typical industries in which the CDS has been pilot-tested are pulp and paper, utility (coal-fired), rock products, and metal foundry. Overall collection efficiencies of over 99 percent have been achieved for fine particulates.[4] The overall efficiency can be increased by adding collection stages or increasing the specific collecting area.

Recovery Boiler Sulfite Process--

A pilot test was conducted to control submicron particulate emissions containing 70 percent NaCl and 25 percent SO_3 from a recovery boiler in the sulfite process of a pulp and paper industry. The mass mean particle size was 0.5 μm, and inlet loading to the CDS ranged from 0.229 to 0.687 g/sdm^3 (0.1 and 0.3 gr/sdcf). In all tests the discharge far exceeded the allowable maximum of 0.0916 g/sdm^3 (0.04 gr/sdcf). Efficiency was most sensitive to specific collecting area (SCA, plate collecting area per unit value of gas). With a SCA of 0.52 m^2/am^3 per min (0.16 ft^2/acfm), collection efficiency was 95 percent. The overall energy consumption was about 18 watts per am^3/min gas flow (0.5 watts/acfm).

Bark Boiler--

Though no field tests have been performed on a boiler burning salt-laden hogged fuel, pilot tests have been successful on a bark boiler fired with combinations of heavy oil and hogged fuel.[6] The flue gas contained ash, carbon, and 5 percent NaCl.

A field pilot test is required to show the effectiveness of the CDS in collecting fine particulates emitted from burning of salt-water-soaked hogged fuel. Table D-2 presents a comparison by TRW of CDS performance with that of conventional control devices. TRW says that low energy consumption by the CDS would lead to low operating costs.

UNIVERSITY OF WASHINGTON ELECTROSTATIC SCRUBBER[3,7]

The UW electrostatic scrubber was developed at the university under the direction of Dr. Michael Pilat. This device is also based the principle of electrostatic augmentation, but configuration is different. The scrubber is electrostatically augmented by charging of the liquid droplets and the particulates to opposite polarities by inductive charging and corona charging, respectively.

Operation

Figure D-6 shows schematically the UW electrostatic scrubber operation.[7]

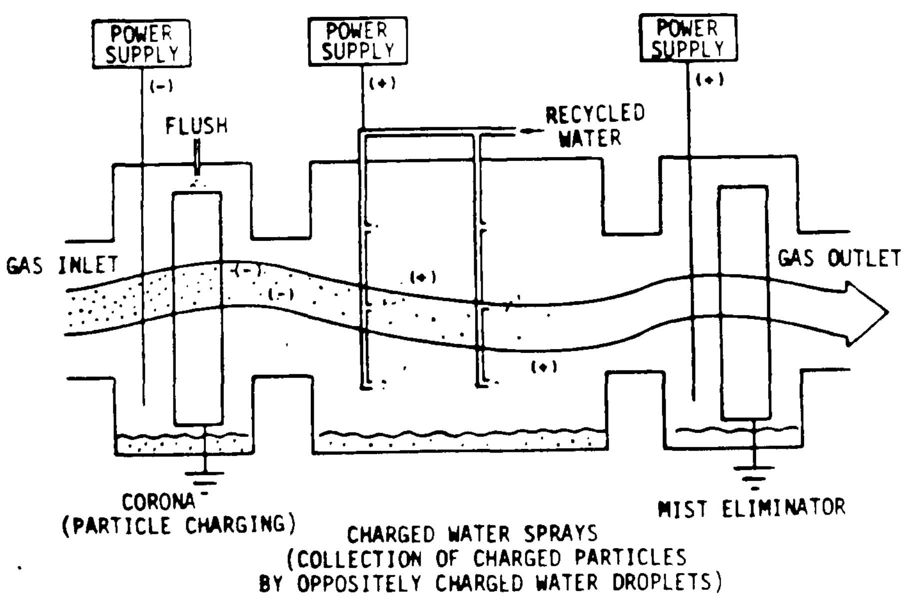
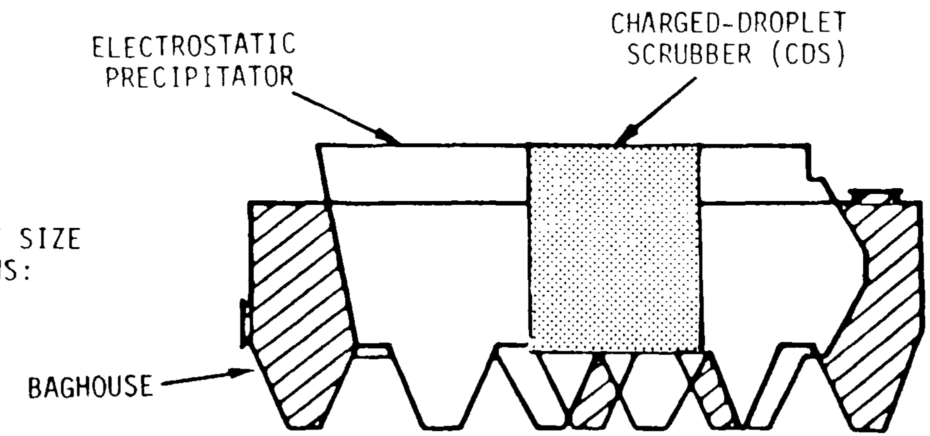


Figure D-6. UW electrostatic scrubber operation.[7]

TABLE D-2. CHARGE DROPLET SCRUBBER PERFORMANCE COMPARISONS AT EQUIVALENT COLLECTING EFFICIENCIES[4]

APPROXIMATE SIZE COMPARISONS:



Performance comparisons:

	CDS[a]	Baghouse[b]	Electrostatic precipitator[c]	Venturi scrubber[d]
Power[e] watts/m^3/min (watts/cfm)	10.6-28.2 (0.3-0.8)	35.3-46.0 (1.0-1.3)	10.6-28.2 (0.3-0.8)	141.0-424.0 (4.0-12.0)
Residence time[f] m^3/m^3/min (ft^3/cfm)	0.03-0.04 (0.03-0.04)	0.09-0.14 (0.09-0.14)	0.12-0.20 (0.12-0.20)	0.01 (0.01)
Collecting area m^2/m^3/min (ft^2/cfm)	0.20-0.65 (0.06-0.20)	0.56-1.64 (0.17-0.50)	0.65-2.00 (0.2-0.6)	Not applicable
Pressure drop cm (in.) H_2O	1.3-1.8 (0.5-0.7)	10.2-15.2 (4.0-6.0)	0.5-1.3 (0.2-0.5)	51.0-152.0 (20.0-60.0)
Mechanical	No moving parts	Frequent pulsing or shaking	Frequent rapping	High fan noise steam plume

[a] Estimated for 10 - 20 cm collector spacing.

[b] Estimated at air-to-cloth ratios of 2 and 6, pulse air cleaned.

[c] Estimated for 2-3 and 3-5 field sectionalization.

[d] Estimated for 51 - 152 cm H_2O pressure drop.

[e] Includes process gas fan pressure, power supplies, and auxiliaries.

[f] Includes demisters, hoppers, gas distribution, and collecting sections.

The pollutant particles in the entering gas are electrostatically charged (negative polarity) in the corona section. From the corona section the gases and charged particles flow into a scrubber chamber, into which are sprayed electrostatically charged water droplets (positive polarity). The gases and some entrained water droplets flow out of the spray chamber into the mist eliminator, consisting of a positively charged corona section in which the positively charged water droplets are removed from the gas stream.

Collection Efficiency

The fractional mass efficiency of the UW scrubber versus aerodynamic diameter was determined using simultaneously operated impactors. Results are given in Figure D-7,[3] which shows that collection efficiency increases with increase in particle size from 0.3 to 1.0 μm and then remains approximately constant. Data on the collection efficiency of the scrubber operated with and without particle/droplet charging show the effects of the charging on collection efficiency. In a pilot test on emissions

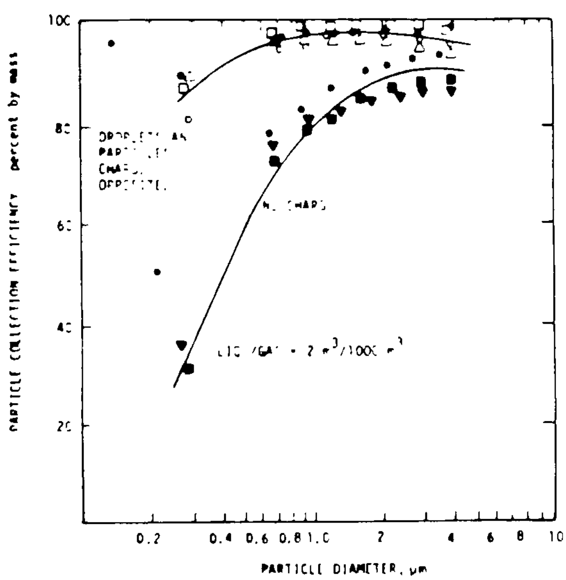


Figure D-7. Particle collection efficiency of electrostatic spray droplet scrubber as function of particle size.[3]

from a pulverized-coal-fired boiler, fractional collection efficiency for a 0.5 μm particle was 99.1 percent.[8] The inlet gas flow rate was 1.694 m^3/h (997 acfm). Particle and droplet charging voltages were -65 kV and +20 kV, respectively, and a water to gas ratio was 0.78 $m^3/1000\ am^3$ (5.82 gal/1000 acf). The outlet concentration was 0.0046 g/sdm^3 (0.002 gr/sdcf).

The pilot tests indicate that the UW electrostatic scrubber can effectively collect fine particulates in the 0.3 to 1.0 μm size range when operated with water usage rates of approximately 0.8 $m^3/1000\ am^3$ (6.0 gal/1000 acf).[8] Similar pilot tests of the UW scrubber on an electric arc steel furnace, a magnesium sulfite recovery boiler (pulp and paper mill), and a hogged fuel (wood waste) boiler[7] have also shown its effectiveness.

Energy Consumption

The UW scrubber consumes power in four portions of the equipment: energizing of the pump to provide pressure drop across the scrubber, energizing of the pump to supply water pressure for the spray nozzles, corona charging of the particulate, and inductive charging of the water droplets. The pressure drop across the scrubber is very low, about 1.3 cm (0.5 in.) water.[7] Calculated total power consumption for the UW scrubber is 600 watts per 28.3 m^3/min (0.8 hp/1000 acfm).[3]

Wastewater Disposal

Requirements for treatment of the wastewater from a UW electrostatic scrubber would be the same as that for wastewater from any scrubber used to clean the same off-gas. This electrostatic scrubber consumes more water than most scrubbers, and therefore the cost of wastewater treatment would be somewhat higher.[3]

Field Pilot Test on Salt-laden Hogged Fuel Boiler

A field pilot test was conducted recently with a UW electrostatic scrubber to control salt particulate emissions from a hogged fuel boiler. The test was conducted at a pulp and paper company in the northwestern United States by Pollution Control Systems, Inc., a licensee of the UW electrostatic scrubber.[9] Operation within the compliance levels of 0.114 g/sdm^3 (0.05 gr/sdcf) particulate and 20 percent opacity was achieved. Two-stage operation of the UW electrostatic scrubber appeared to be more stable than one-stage operation. The inlet gas was cooled before entering the scrubber, and large particulates were collected in the cooling section. The remaining particulates were negatively charged, and sprayed droplets were positively charged. The water for generation of droplets was recycled with some make-up supply. The ratio of water to gas was approximately 2 m^3/1000 am^3 (15 gal/1000 acf). The surface area of the charging section was about half of that of an ESP of same capacity. Additional information concerning the pilot tests was not available.

A.P.S. ELECTRO-TUBE

The electro-tube was developed by Air Pollution Systems, Inc., and is licensed to Union Carbide Corporation.[10] The APS electro-tube is a pipe-type electrostatic precipitator with a central rod electrode and wetted wall collector. Figure D-8 depicts the APS electro-tube.[11]

Operation

Pollutant particles in the entering gas are charged in a high-energy field by a high-intensity ionizer at the base of the electrode. The charged particles then migrate to the wetted wall in the body of the device. The initial saturation charge on the particles, higher than that in a conventional ESP, facilitates migration in the collecting electric field. A laboratory pilot test has been performed with a range of gas flow rates, 17.0 to 22.7 am^3/min (600 to 800 acfm) with a test aerosol, titanium dioxide (TiO_2).[11] The mass median aerodynamic diameter of the dispersed aerosol was about 1.2 μmA. Overall efficiency of 99.3 percent was obtained at a gas flow rate of 17 am^3/min.

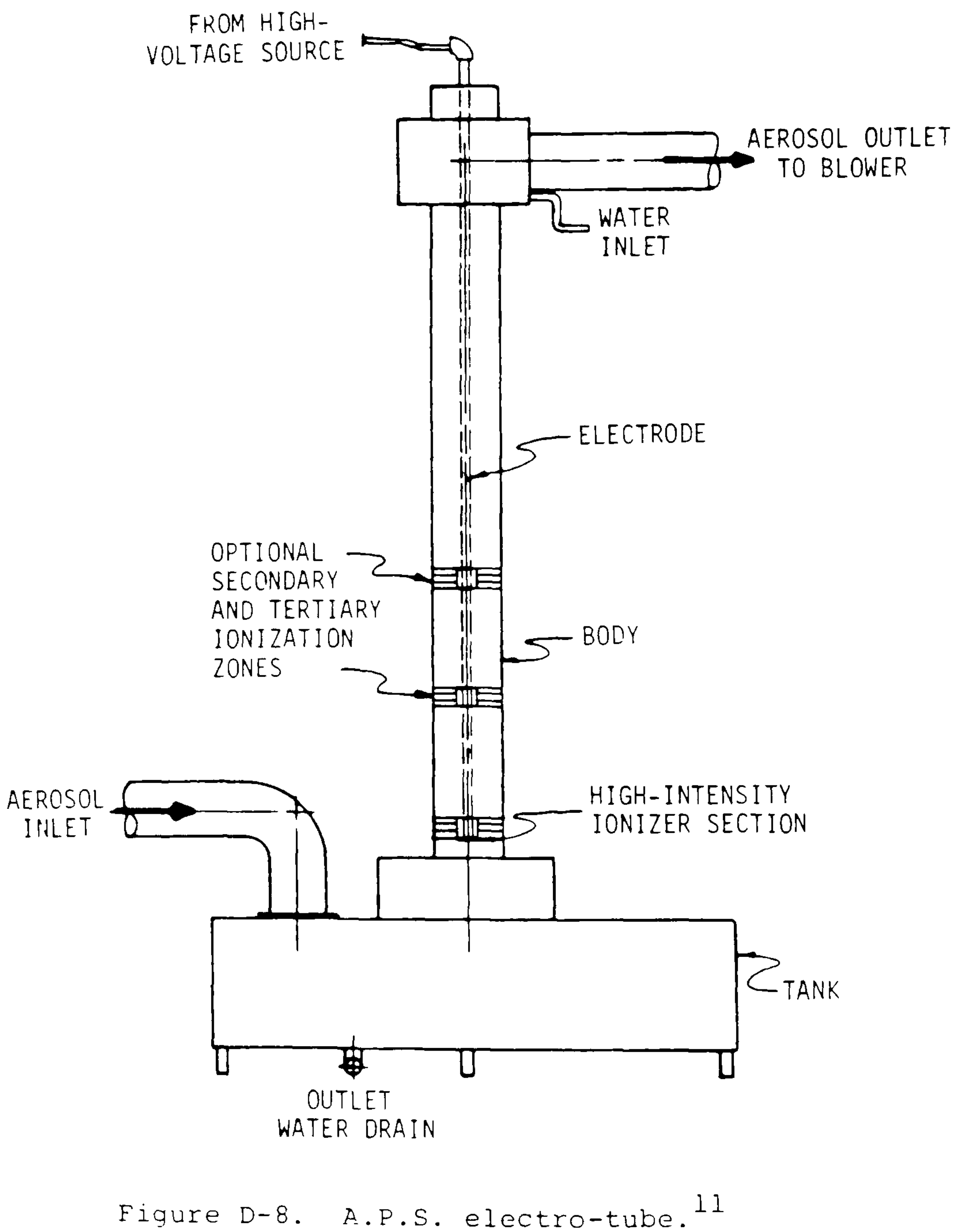


Figure D-8. A.P.S. electro-tube.[11]

Field Pilot Test on Salt-laden Hogged Fuel Boiler[12]

Figure D-9 shows the pilot scale setup for the APS electro-tube. The electro-tube was tested at a gas flow rate of 23 m^3/min (800 acfm), maximum per tube. The wetted-wall anode is 3.05 m long by 0.30 m diameter (10 ft by 1 ft). Since these tube dimensions are the same for both the pilot and full-size installations, scaleup to a full-size unit should require simply adding the number of tubes needed for a specific application. A 5.1-cm-diameter (2-in.) driving field electrode was used for testing.

The inlet gas flow rates ranged from 14 to 23 m^3/min (500 to 800 acfm). Analysis of total particulate showed 35 to 80 percent NaCl; 30 to 35 percent of the total was less than 1.0 μm in size. Inlet gas temperatures ranged from 101° to 192°C (214° to 378°F). The inlet particulate concentrations ranged from 0.39 to 2.13 g/sdm^3 (0.17 to 0.93 gr/sdcf) at 12 percent CO_2. Corrected outlet concentrations ranged from 0.0043 to 0.10 g/sdm^3 (0.0019 to 0.044 gr/sdcf) at 12 percent CO_2; opacity was near zero. Actual outlet particulate concentrations ranged from 0.002 to 0.049 g/sdm^3 (0.00087 to 0.0214 gr/sdcf). The overall collection efficiency ranged from 95.6 to 99.0 percent. The measured pressure drop across the electro-tube ranged from 0.75 to 2.5 cm (0.3 to 1.0 in.) water. The water-to-gas ratio ranged from 0.18 to 0.80 m^3/1000 am^3 (1.33 to 6 gal/acf). The only operating problem was plugging of inadequate drain fittings.

Energy Consumption

The electrical operating costs of this device are only a fraction of what is required for conventional particulate collection devices. One of the reasons is the very low pressure drop.

Wastewater Disposal

Wastewater treatment requirements are the same as those for a conventional scrubber.[13]

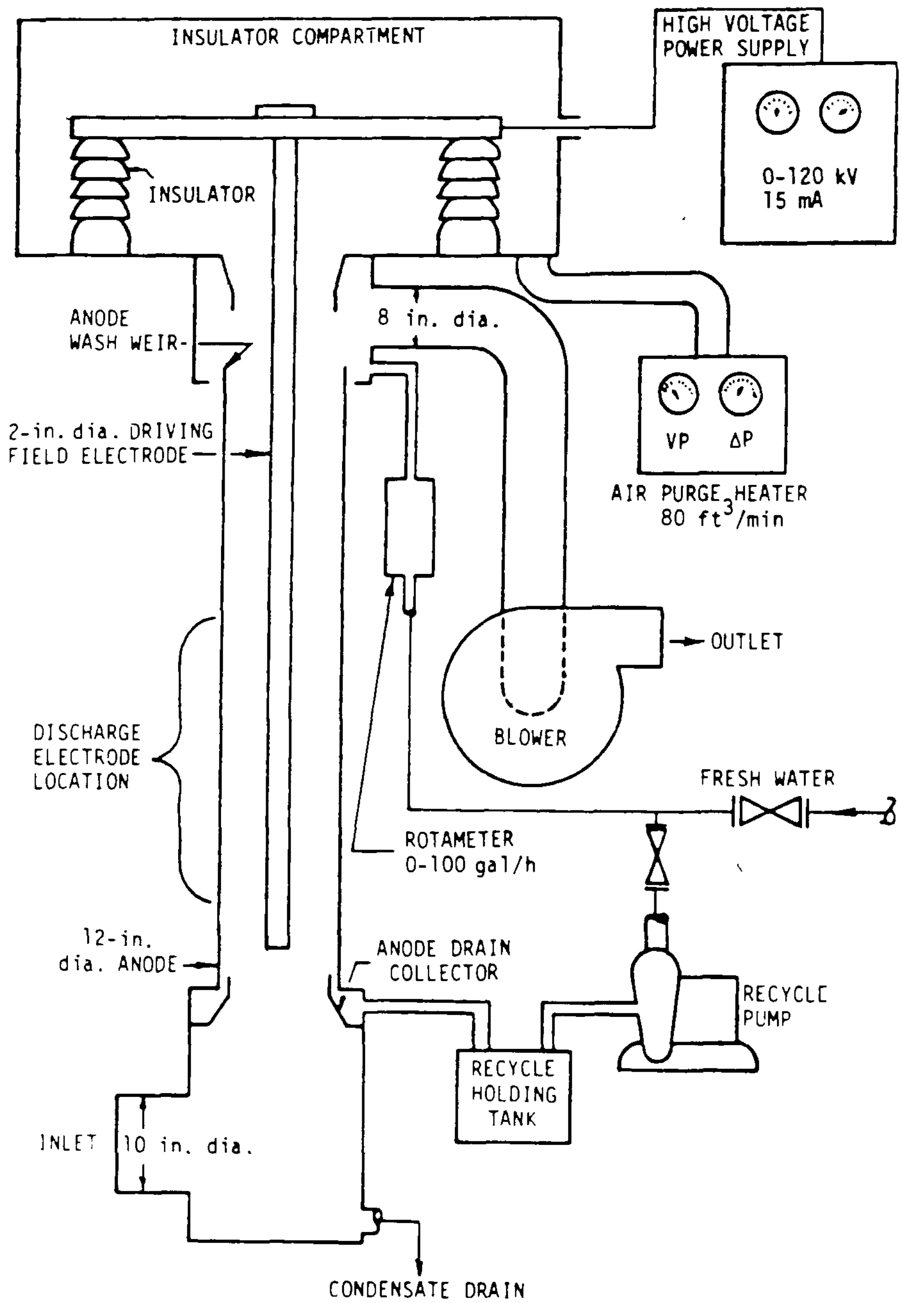


Figure D-9. A.P.S. electro-tube pilot.[12]

A.P.S. ELECTROSTATIC SCRUBBER

The electrostatic scrubber developed by Air Pollution Systems is basically an electrostatic ionizer followed by a venturi scrubber.[11] Figure D-10 shows a schematic diagram of this device. An electrode is placed upstream of the venturi to charge the inlet particles, which then enter the venturi throat. The charged particles are attracted and collected by the highly polarized water molecules.

The charged particles are also collected on the walls of the ionizer section prior to the throat of the venturi. A thin film of water runs down the inclined surfaces to keep the walls clear and prevent high-voltage arcing. The particle-laden water droplets are then collected by a cyclonic separator and sent into a settling tank (clarifier), from which water can be recycled to the scrubber system.

Laboratory pilot tests have been conducted at inlet gas flow rates of 21.0 am^3/min (740 acfm) and 22.7 am^3/min (800 acfm).[11] The test aerosol was TiO_2 with mass median aerodynamic diameter of 1.0 μmA.

Field Pilot Tests on Salt-laden Hogged Fuel Boiler

A pilot test was conducted in 1977 at a Canadian company in the Pacific Northwest on a hogged fuel boiler firing saltwater-soaked logs.[10] No further details are available.

MATERIALS OF CONSTRUCTION

Moist flue gas containing large amounts of salt particulate is highly corrosive. Materials of construction constitute a significant part of the total capital cost of a novel device to control salt emissions. A good corrosion-resistant material of construction such as Inconel 625 is very expensive. The ionizing wet scrubber and the charged droplet scrubber are made of fiber-reinforced plastics. A proper balance of costs, corrosion-resistance, and strength is required in selecting materials for devices handling corrosive gases.

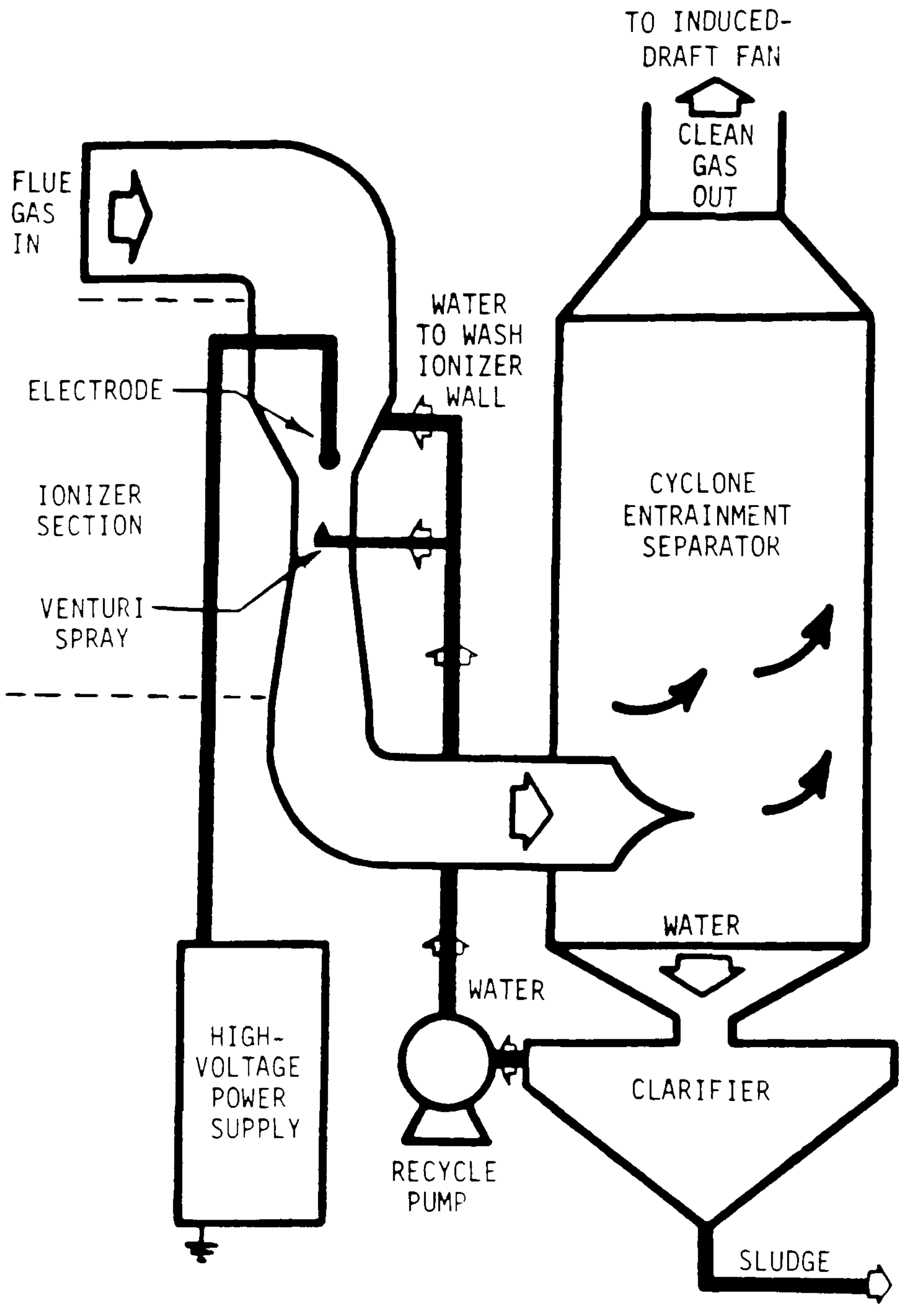


Figure D-10. APS electrostatic scrubber.[11]

COMMERCIAL AVAILABILITY AND COSTS

Table D-3 lists the manufacturers of the novel control devices just described.

TABLE D-3. COMMERCIAL AVAILABILITY OF NOVEL CONTROL DEVICES.

Control device	Manufacturer/address
Ionizing wet scrubber	Ceilcote Co. 144 Sheldon Road Berea, OH 44017
Charged droplet scrubber	TRW Systems, Inc. One Space Park Redondo Beach, CA 90278
UW electrostatic scrubber	Pollution Control Systems Corp. 300 Evergreen Bldg. Renton, WA 98055
APS electro-tube	Union Carbide, Bendix Div. 61 E Park Dr., Wood Road Ave. Tonewanda, NY 14150
APS electrostatic scrubber	Air Pollution System, Inc. 18642 68th Avenue, South Kent, WA 98031

Capital Costs

No detailed cost data are available with which to determine capital costs of these control devices. Order-of-magnitude comparisons can be made with conventional control devices. Initial costs depend mainly on configuration of the charging section, materials of construction, and collecting area. The latter depends upon volume of gas handled, size distribution of particulates, salt content of the flue gas, and inlet gas temperature. The initial costs of an electrostatically augmented scrubber are generally reported to be somewhat higher than cost of a baghouse (higher reliability and no hazards are claimed, however). As an example, in 1978 the installed cost of a two-stage ionizing wet scrubber with maximum capacity of 85,000 am^3/h (50,000 acfm) gas is $350,000.[14]

Operating Costs

The operating costs of these devices are reported to be very low relative to those of conventional control devices. Overall energy consumption by a single-stage unit ranges from 27.0 to 52.7 watts per am^3/min (0.8 to 2.0 hp/1000 acfm). The cost of wastewater treatment would be same as with a conventional scrubber. Hence overall cost of operation is reported to be less than that of operating a conventional wet scrubber or venturi scrubber.

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13. Personal Communication: Mr. Mike Guidon, Georgia-Pacific Corp., Bellingham, Washington. July 17, 1978.

14. Personal Communication: Mr. Roger Ruehl, Air Pro, Inc., Rep., Ceilcote Co., Cincinnati, Ohio. July 20, 1978.