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APPLYING FABRIC FILTRATION TO COAL FIRED INDUSTRIAL BOILERS

A PILOT SCALE INVESTIGATION

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APPLYING FABRIC FILTRATION TO COAL FIRED INDUSTRIAL BOILERS

A PILOT SCALE INVESTIGATION

by

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ABSTRACT

A pilot scale investigation was conducted to determine the techno-economic feasibility of applying a fabric filter dust collector to coal fired industrial boilers. This report extends and confirms earlier work reported in July of 1974, EPA Publication 650/2-74-058. The pilot facility, installed on a slip stream of a 60,000 lb./hr. boiler, was sized to handle 11,000 acfm when operating at an air-to-cloth ratio of 6/1. Filter media evaluated were Nomex® felt, Teflon® felt (2 styles), Gore-Tex®, and Dralon®-T.

Fractional efficiency was determined using an Andersen inertial impactor for the four filter media at three A/C levels. The effect of reverse air volume on outlet loading and pressure drop across the bags was evaluated for Nomex felt.

Nomex felt achieved the lowest outlet dust concentrations while Teflon felt operated at the lowest pressure drop. All media tested achieved outlet loadings well within allowable limits. When Nomex felt was employed, higher collection efficiencies were achieved by discontinuing the reverse air cleaning. Varying the volume of reverse air from 1400 to 4000 ACFM had little effect on removal efficiency. Increasing the amount of air used for cleaning does reduce the pressure drop across the bags.

Installed costs, annual operating costs and total annualized costs for a fabric filter and an electrostatic precipitator, capable of handling 70,000 ACFM of flue gas from a coal fired boiler, are presented.

A full scale demonstration program is anticipated. The purpose of this program is the acquisition of bag life data and evaluation of the relationship between overall performance and on-stream time.

This report was submitted by Enviro-Systems & Research, Inc., Roanoke, Virginia, in fulfillment of Contract No. 68-02-1093 under the joint sponsorship of Enviro-Systems & Research, Inc., Kerr Industries and the Environmental Protection Agency.

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INTRODUCTION

This report extends and confirms the work initiated under Contract No. 68-02-1093 and reported in July of 1974 publication EPA 650/2-74-058. The purpose of this study was to evaluate the application of fabric filter dust collection to industrial size coal fired boilers. The techno-economic evaluation conducted was based primarily upon data obtained from a pilot plant installed on a slip stream of a stoker boiler stack.

The earlier studies indicated the critical parameters influencing pressure drop and outlet loadings. The prior studies were mainly conducted on Nomex® felt. The work cited in this report expands and confirms the earlier studies on Nomex and extends them to include Teflon® felt, Gore-Tex® and Dralon® T felt.

The performance data, obtained in the screening of the various filter media, was employed in the development of capital and operating costs. Various bag life assumptions were employed in developing these costs, since no bag life data was obtained in this program.

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CONCLUSIONS

The four (4) filter media studied had different performance characteristics.

Nomex felt achieved the lowest outlet dust concentrations.

Studies employing Nomex felt indicated that higher collection efficiencies are possible when no cleaning is employed.

Increasing the duration of cleaning time from 7 seconds to 25 seconds does not improve the cleaning of Nomex felt.

Teflon felt operated at the lowest pressure drop.

The dust release properties of Teflon felt and Gore-Tex appeared better than those of Nomex felt and Dralon felt.

An increase in filtering velocity (air-to-cloth ratio) results in an increase in outlet loading.

Varying the volume of cleaning air from 1400 to 4000 ACFM has little effect on overall dust removal efficiency.

An increase in the amount of air used for cleaning reduces the pressure drop across the bags.

For the industrial boiler size studied, if two (2) year bag life can be achieved, fabric filter dust collectors appear economically attractive when compared to electrostatic precipitators operating at 95% efficiency or better.

A PTFE laminate on a woven backing can yield dust removal efficiencies similar to that of felt media.

In view of the different performance characteristics obtained on the four (4) filter media types tested, careful filter media selection appears important for both particulate removal efficiency and pressure drop requirements.

RECOMMENDATIONS

The pilot scale study has indicated that it is possible to operate the fabric filter dust collector at high filtering velocities (6 fpm or greater) and to achieve both high dust removal efficiencies and economically tolerable pressure drops. The limitation of this program has been the fact that it does not provide life data on the filter media.

It is recommended that a full scale unit be built and tested over a year or more duration. Such a program would provide bag life data necessary for the evaluation of annualized costs. It is also recommended that such a demonstration program include periodic performance evaluation in order to determine whether or not performance changes occur with increasing on-stream time.

The data obtained in this program is only valid for stoker boiler applications. If the same high velocity filter approach to pulverized coal boilers is desirable, it is recommended that a similar pilot plant program first be conducted.

In order to provide better correllation of dust removal efficiency and filtering velocity it is recommended that a bench scale program be undertaken. The laboratory program is recommended over the pilot plant for this purpose because of the better control of inlet conditions achievable on the bench.

RESEARCH NEEDS

In studying outlet particulate loadings at the various filtering velocities or air-to-cloth ratios, it was determined that as the velocity increased the overall outlet loading also increased. In studying the different size fractions, however, there were indications that while the largest particle penetration increased, the finer size fractions did not correlate in the same manner (e.g. See Figure 32).

It is generally recognized that the finest size fractions are controlled by a different mechanism (diffusion) than control the larger fractions (controlled by inertial impaction and interception). The results obtained appear, on the surface at least, to be contrary to the collection - velocity relationships dictated by these simple single mechanism formulae. There does not exist at present a correlation which accommodates the results obtained.

In order to refine the type of data obtained and perhaps gain some insight into the combination of mechanisms at work it will be necessary to conduct experiments under much more controlled and well defined conditions than are possible via a pilot plant. It is therefore recommended that a bench scale experimental effort be undertaken for the purpose of developing correlations between penetration and filtration velocity, as a function of particle size. Such basic information would be of significance in developing the technical underpinnings of any future fine particulate codes.

Two other research areas of interest, but lesser immediate significance, are further studies of laminate (e.g. Gore-Tex) filtration mechanisms and also bench exploration of the impact reverse air volumes and durations on pressure drop and penetration.

GLOSSARY OF TERMS

ACID DEW-POINT - The temperature at which the condensation of the acid vapors initiates for a given state of humidity and pressure.

AIR-TO-CLOTH RATIO - The volumetric rate of capacity of a fabric filter; the volume of air (gas), cubic feet per minute, per square foot of filter media (fabric).*

BAG - The customary form of filter element. Also known as tube, stocking, etc. Can be unsupported (dust on inside) or used on the outside of a grid support (dust on the outside).

BLINDING (BLINDED) - The loading, or accumulation, of filter cake to the point where capacity rate is diminished. Also termed "plugged".

CLOTH - In general, a pliant fabric; - woven, knitted, felted, or otherwise formed of any textile fiber, wire, or other suitable material.

CLOTH WEIGHT - Is usually expressed in ounces per square yard or ounces per square foot. However, cotton sateen is often specified at a certain number of linear yards per pound of designated width. For example, a 54" - 1.05 sateen weighs 1.05 linear yards per pound in a 54" width.

DAMPER - An adjustable plate installed in a duct for the purpose of regulating air flow.

DIMENSIONAL STABILITY - Ability of the fabric to retain finished length and width, under stress, in hot or moist atmosphere.

DUST LOADING - The weight of solid particulate suspended in an air (gas) stream, usually expressed in terms of grains per cubic foot, grams per cubic meter or pounds per thousand pounds of gas.

*Although it is EPA's policy to use the metric system for quantative descriptions, the British system is used in this report because not to do so would tend to confuse some readers from industry. Readers who are more accustomed to metric units may use the table of conversions in the appendix to facilitate the translation.

GLOSSARY OF TERMS

FABRIC - A planar structure produced by interlacing yarns, fibers or filaments.

KNITTED fabrics are produced by interlooping strands of yarn, etc.

WOVEN fabrics are produced by interlacing strands at more or less right angles.

BONDED fabrics are a web of fibers held together with a cementing medium which does not form a continuous sheet of adhesive material.

FELTED fabrics are structures built up by the interlocking action of the fibers themselves, without spinning, weaving or knitting.

FILTER MEDIA - The substrate support for the filter cake; the fabric upon which the filter cake is built.

FILTER VELOCITY - The velocity, feet per minute, at which the air (gas) passes through the filter media, or rather the velocity of approach to the media. The filter capacity rate.

FILTRATION RATE - The volume of air (gas), cubic feet per minute, passing through one square foot of filter media.

FRACTIONAL EFFICIENCY - The determination of collection efficiency for any specific size or size range of particles.

GRAIN - 1/7000 pound or approximately 65 milligrams.

INCH OF WATER - A unit of pressure equal to the pressure exerted by a column of liquid water one inch high at a standard temperature. The standard temperature is ordinarily taken as 70°F. One inch of water at 70°F. = 5.196 lb per sq. ft.

MASS MEAN PARTICLE DIAMETER - Refers to the point of a curve plotting particle diameter versus cumulative mass percent that shows 50% of the material is less than and 50% of the material is greater than the indicated particle diameter.

MICRON (um) - A unit of length, the thousandth part of 1 mm or the millionth of a meter, (approximately 1/25,000 of an inch).

MULLEN BURST - The pressure necessary to rupture a secured fabric specimen, usually expressed in pounds per square inch.

NEEDLED FELT - A felt made by the placement of loose fiber in a systematic alignment, with barbed needles moving up and down, pushing and pulling the fibers to form an interlocking of adjacent fibers.

GLOSSARY OF TERMS

NON-WOVEN FELT - A felt made either by needling, matting of fibers or compressing with a bonding agent for permanency.

NYLON - A manufactured fiber in which the fiber forming substance is any long-chain synthetic polyamide having recurring amide groups.

PEARLING - Refers to a condition of the dust cake on the fabric which appears as nodular structures of agglomerated dust.

PERMEABILITY, FABRIC - Measured on Frazier porosity meter, or Gurley permeometer, etc. Not to be confused with dust permeability. The ability of air (gas) to pass through the fabric, expressed in cubic feet of air per minute per square foot of fabric with a 0.5" H_2O pressure differential.

PITOT TUBE - A means of measuring velocity pressure. A device consisting of two tubes - one serving to measure the total or impact pressure existing in an air stream, the other to measure the static pressure only. When both tubes are connected across a differential pressure measuring device, the static pressure is compensated automatically and the velocity pressure only is registered.

POROSITY, FABRIC - Term often used interchangeably with permeability. Actually percentage of voids per unit volume - therefore, the term is improperly used where permeability is intended.

PRESSURE, STATIC - The potential pressure exerted in all directions by a fluid at rest. For a fluid in motion, it is measured in a direction normal to the direction of flow. Usually expressed in inches water gage, when dealing with air.

PRESSURE, TOTAL - The algebraic sum of the velocity pressure and the static pressure (with due regard to sign). In gas-handling systems these pressures are usually expressed in inches water gage. The sum of the static pressure and the velocity pressure.

TEMPERATURE, DEW-POINT - The temperature at which the condensation of water vapor in a space begins for a given state of humidity and pressure as the temperature of the vapor is reduced. The temperature corresponding to saturation (100 per cent relative humidity) for a given absolute humidity at constant pressure.

TWILL WEAVE - Warp yarns floating over or under at least two consecutive picks from lower left to upper right, with the point of intersection moving one yarn outward and upward or downward on succeeding picks, causing diagonal lines in the cloth.

GLOSSARY OF TERMS

VELOCITY HEAD - Same as velocity pressure. (See Pressure, Velocity).

VELOCITY OF APPROACH - The velocity of air (gas), feet per minute, normal to the face of the filter media.

VELOCITY TRAVERSE - A method of determining the average air velocity in a duct. A duct, round or rectangular, is divided into numerous sections of equal area. The velocity is determined in each area and the mean is taken of the sum.

BACKGROUND

Fabric filters (baghouses) have historically been one of the major types of control for particulate emissions employed by industry. Baghouses have been used to control industrial dusts since the early nineteenth century. They have been used with good success in industries such as carbon black, aluminum, asbestos, steel, ferroalloy, cement, rock products and others. Baghouses are typically noted for high efficiencies and have proven to be one of the better control methods for fine particulates. It has been, however, only in the last decade that baghouses have been used for large combustion sources. The combustion of coal[1], 400 million tons per year, by utility and industrial boilers is a major source of particulate emissions, some 5.7 million tons of fly ash annually. Industrial boilers account for 100 million tons per year and generate 2.6 million tons of particulate emissions per year.

The capacity range typically designated for industrial boilers is from 10 million to 500 million BTU/Hour output (10 thousand to 500 thousand pounds of steam per hour). Commercial boilers are smaller and utility boilers are larger, even though some industrial boilers are used for electrical generation by utilities. The Battelle study[2] characterizes the current field population of industrial boilers.

Table 1 shows the capacity range for industrial boilers in approximately equivalent units of output and fuel input.

The significance of industrial steam generation can be seen in Table 2, which shows the usage of fossil fuels for major industrial applications in comparison to the total usage and to the utility sector.

Steam generation is the predominant industrial use and is almost as large in fuel consumption as the utility sector. In the base year,

Table 1

Capacity Range for Industrial Boilers in Approximately Equivalent Units

Capacity Rating	Minimum Capacity	Maximum Capacity
Boiler Output Units		
BTU/Hr. Output	10,000,000	500,000,000
Pounds Steam/Hr. Output, PPH[a]	10,000	500,000
Boiler Horsepower[b]	300	---
Fuel Input Units[c]		
Oil Input Gallons/Hr.	83	4,200
Barrels/Day	48	2,400
Gas Input, Cubic Feet/Hr.	12,000	620,000
Coal Input, Lb./Hr.	1,000	50,000
Tons/Day	12	600

[a] Based on equivalent output of saturated steam.

[b] One boiler horsepower is equivalent to approximately 33,500 BTU/Hr. output. Boiler horsepower ratings are commonly used for firetube boilers, which are generally available only in sizes up to about 900 boiler horsepower.

[c] Assuming full-load operation at 80 percent boiler efficiency and fuel heating value 150,000 BTU/Gal. for residual oil, 1,000 BTU/cubic foot for natural gas, and 12,500 BTU/Lb. for coal.

Source for Above Table: D. W. Locklin, et al, "Design Trends and Operating Problems in Combustion Modification of Industrial Boilers", April - 1974, NTIS PB-235-712.

Table 2

Industrial and Utility Use of Fossil Fuels

	Trillions of BTU's for Base Year 1968			
	All Fossil Fuels	Coal	Oil	Gas
TOTAL - ALL SECTORS	59,639	13,326	26,749	19,564
UTILITY SECTOR TOTAL	11,556	7,130	1,181	3,245
INDUSTRIAL SECTOR TOTAL	19,348	5,616	4,474	9,258
Fuel-Fired in Boilers for Steam Generation				
Process & Space Heating	10,132	2,349	1,986	5,797
Electricity Generated On-Site	410	95	80	235
Fuel Used for Direct Heat Applications (Not including purchased electrical energy.)	6,604	3,025	808	2,771
Fuel Used as Feedstocks	2,202	147	1,600	455

Source for Above Table: D. W. Locklin, et al, "Design Trends and Operating Problems in Combustion Modification of Industrial Boilers", April - 1974, NTIS PB-235-712.

gas accounted for 57 percent of the fuel input to boilers for industrial steam generation, with coal and oil accounting for 23 and 20 percent, respectively. The coal share has declined steadily in the past few decades, due primarily to the low cost of gas and low capital and operating costs of gas-fired package boilers. Coal-fired steam plants must include coal storage and handling, air pollution control and ash disposal. Emission requirements have also increased the number of conversions of coal fired plants to gas or to low sulfur oil, adding to the demand for these clean fuels. However, as these clean fuels become less available, it appears probable that the industrial sector will be forced to rely increasingly upon coal.

Tables 3 and 4 give the population breakdown by fuel capability for all industrial boilers now in service in the U.S. and by burner type for coal fired facilities. The estimated trends for these two categories thru 1990 are given in Tables 5 and 6. The national population of industrial boilers is approximately 36,000 of which only 23% are greater than 100,000 pounds of steam per hour. This places the bulk of industrial units (approximately 28,000) in the less than 100,000 pounds of steam per hour size range.

Traditionally, the method of emission control for coal fired boilers has been electrostatic precipitation (ESP), often in conjunction with mechanical collection, generally of the cyclone type dust collector. This is particularly true of utility boilers. There are an estimated 1200-1500 ESP's on coal fired boilers. The need to minimize SO_2 emissions by using low sulfur coal, however, has caused problems of reduced ESP efficiency. Also the control of fine particulates requires a more costly design .

In contrast, the number of baghouses installed on coal fired boilers is very limited, most of these installations are summarized in Table 7. Although fabric filters are highly efficient there are problems associated with their use on large combustion sources. Some of these are large size

Table 3

Population Breakdown by Fuel Capability (Percentage Basis) for All Industrial Boilers Now in Service

Rated Capacity Size Range	10^6 BTU/Hr. or 10^3 Lb. Steam. Hr. 10-16	17-100	101-250	251-500
FUELS				
Oil Only	35	35	30	22
Gas Only	45	35	22	22
Coal Only	3	10	18	22
Oil & Gas and Gas & Oil	16	18	26	23
Oil & Coal and Coal & Oil			0.5	3
Gas & Coal and Coal & Gas			0.5	3
Misc. Fuels (Alone or With Alternate Fuels)	1	2	3	5
TOTAL	100%	100%	100%	100%

Table 4

Population Breakdown by Burner Type (Percentage Basis) for All Coal Fired Industrial Boilers Now in Service in U.S.

	Approximate 10^3 Lb. Steam/Hr. 10-16	17-100	101-250	251-500
COAL BURNERS				
Spreader	15	20	50	30
Underfeed	70	60	20	15
Overfeed	10	15	10	10
Pulverized			15	40
Other (Hand-firing, Miscellaneous and Unreported)	5	5	5	5
TOTAL COAL	100%	100%	100%	100%

Source for Above Table: D. W. Locklin, et al, "Design Trends and Operating Problems in Combustion Modification of Industrial Boilers", April - 1974, NTIS PB-235-712.

Table 5

Estimated Trends by Fuel Capability (Percentage Basis) for All Industrial Boilers Installed in Years Noted, Including Conversions

Rated Capacity	10-16				17-100				101-250				251-500			
Year 19--	30	50	70	90	30	50	70	90	30	50	70	90	30	50	70	90
FUEL CAPABILITY																
Oil	17	43	30	13	13	30	30	10	5	20	24	*	5	15	20	*
Gas	5	20	30	6	10	30	30	4	5	20	24	*	5	15	20	*
Coal	75	10	5	30	75	30	5	40	90	38	15	50	90	60	20	60
Oil & Gas and Gas & Oil	*	25	30	45	*	5	30	40	*	10	25	30	*	5	20	20
Oil & Coal and Coal & Oil									*	5	5	10	*	3	10	10
Gas & Coal and Coal & Gas									*	5	5	5	*	2	10	5
Misc. Fuels	3	2	5	6	2	5	5	6	*	2	2	5	*	*	*	5
TOTAL	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

*nil

Source for Above Table: D. W. Locklin, et al, "Design Trends and Operating Problems in Combustion Modification of Industrial Boilers", April - 1974, NTIS PB-235-712.

Table 6

Estimated Trends by Burner Type (Percentage Basis) for All Industrial Boilers Installed In Years Noted (Including Conversions)

Rated Capacity	10-16				17-100				101-250				251-500			
Year 19--	30	50	70	90	30	50	70	90	30	50	70	90	30	50	70	90
COAL BURNER																
Spreader	*	10	25	35	*	40	50	65	*	50	60	35	*	25	10	5
Underfeed	60	60	70	50	60	25	15	10	50	20	*	*	25	10	*	*
Overfeed	35	25	*	10	35	30	25	15	45	15	10	10	60	10	*	*
Pulverized									*	10	20	40	10	50	80	85
Others	5	5	5	5	5	5	5	10	5	5	10	15	5	5	10	10
TOTAL COST	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

*nil

Source for Above Table: D. W. Locklin, et al, "Design Trends and Operating Problems in Combustion Modification of Industrial Boilers", April - 1974, NTIS PB-235-712.

Table 7

Baghouse Installations on Coal Fired Boilers

Facility	Location	Boiler Data Type	Boiler Data Size	Date Inst.	Present Status	Coal %Ash/%S	Flue Gas T° F/Vol.	Bag Design Dia"/L'/#Bags	ΔP "H_2O	A/C	Fabric	Cleaning	Des. Eff.	Manufacturer & Remarks
Carborundum Ind. Boiler	Niagara Falls N. Y.	Spreader Stoker		1968	Operating		375/10^4		3	3/1	Glass/ Nomex			Pangborn Pilot unit
PSE & GNJ Mercer	Trenton N.J.	Pulverized	20,000 acfm	1965	Dismantled		270/7500 680/15,000	11.5"/39.5'/		1.8 3.5	Glass	Rev. Air		Air Preheater Co. pilot pt.
SCE Almitos	Long Beach Calif.			1965	On Stand-by	Oil/1.6 + gas	285/8.2x10^5	11.5"/38.8'	6	6-7	Glass			B & W-Menardi
Pennsylvania Power & Light	Sunberry Pa.	Pulverized	2 Boilers 400 x 10^3 pph	1973	Operating	2/1.3	4x 325/220x10^3	11.5"/30'/4x 1260	2.5	2/1	Glass	Rev. Air	99+	Western Precipitator
du Pont	Waynesboro Va.			1973	Operating	7/1.2	375/125x10^3		3-4	8/1	Nomex	Pulse Jet		Std. Havens pilot unit
du Pont	Parkersburg W. Va.	Stoker	4 Boilers Total Capacity 500 x 10^3 pph	1974	Operating	7/2.5	350/various	6"/9'/	2-3	4/1	Teflon& Glass	Pulse Jet		Std. Havens
Pennsylvania Glass & Sand	Huntington Pa.			1972			700/300/25,000				Nomex			Fuller-Draco Pilot unit
Hanes Dye & Finishing Co.	Winston-Salem N.C.	Stoker	40 x 10^3 pph 75 x 10^3 pph	1974	Operating	/1.5	310/19 x 10^3 310/34 x 10^3	6"/12'/	6-8	6-7	Glass	Rev. Air		Dustex

Table 7 (cont'd.)

Baghouse Installations on Coal Fired Boilers

Facility	Location	Boiler Data Type	Boiler Data Size	Date Inst.	Present Status	Coal %Ash/%S	Flue Gas T° F/Vol.	Bag Design Dia"/L'/#Bags	ΔP "H_2O	A/C	Fabric	Cleaning	Des. Eff.	Manufacturer & Remarks
B & W	Bakerton Ohio			1973	Operating	/High								B & W pilot unit
U. Notre Dame	South Bend Ind.			1973	Dismantled	10/2-4	125-/300/4.8x10^3	6"/9'/	6½	7/1	Glass & Felts		99+	Wheelabrator-Frye/pilot unit
Colorado Ute. Elec. Assoc.	Nulca Station Nulca, Colo.	Stoker	3 Boilers 120 x 10^3 pph	1-1973 1-1974	Operating	12/0.7	310/86x10^3	8"/22'/3x672	6½	3.35	Glass	Rev. Air + Shake	99+	Wheelabrator-Frye
Sorg Paper	Middletown Ohio	Pulverized	55x 10^3 pph	1973	Operating	10/1.0	350/10^5	11.5"/30'/	2.5-3.5		Glassw/ Teflon	Slow Col Rev. Air.	~ 99%	Zurn
Crisp County Power Comm.	Cordele Ga.	Pulverized	120x10^3 pph	1975	Start-up Jn or Ju.	10/1.0	280-325°F 60,000 acfm	11.5"/30'/	4-5.5	2.8	Glass w/ Teflon	Slow Col. Rev. Air	~ 99%	Zurn
du Pont	New Johnsonville Tennessee	Stoker	135 x 10^3 pph	1975	In Construction	7/3.2	400/57 x 10^3	6¼"/9'/1200	5.0	3.2	Teflon	Pulse Air	99+	Standard Havens
Kerr Industries	Concord N.C.	Stoker	60x10^3 pph	1972-74	Not Operating	7/0.7	300/35,000	5"/8'8"/216	2-7	3-14	Various	Rev. Air		Enviro-Sys. & Res. Inc. Pilot unit
Carborundum Ref. Div.	Buffalo N.Y.	Stoker	75x10^3 pph	1967		/2.7								

Table 7 (cont'd.)

Baghouse Installations on Coal Fired Boilers

Facility	Location	Boiler Data Type	Boiler Data Size	Date Inst.	Present Status	Coal % Ash/%S	Flue Gas T° F/Vol.	Bag Design Dia"/L'/#Bags	ΔP "H_2O	A/C	Fabric	Cleaning	Des. Eff.	Manufacturer & Remarks
Pennsylvania Power & Light.	Holtwood Pa.	Pulverized	$700x10^3$ pph	1975	Operating	25/1.8	$360/200x10^3$	8"/22'/	4.5	2.42	Glass		99+	Wheelabrator Frye
Amalgamated Sugar Co.	Nyssa Oregon	Stoker	$200x10^3$ pph	1973	Operating	13/0.6	$300/92x10^3$	8"/22'/	6.5	3.56	Glass		99+	Wheelabrator Frye
Harrison Rad. Div. of G.M.	Lockport N.Y.	Stoker	$125x10^3$ pph $150x10^3$ pph	1974	Operating	10/.75	$400/61.9x10^3$ $400/76 \times 10^3$	6"/12'/	4 4	4.5- 5.5	Nomex w/lime	pulse-jet	99+	West. Ppt.
Neb. Publ. Power Dis.	Kramer Sta. Belleue, Ne	Pulverized		1976		11/								
Coors Brewery	Denver Colorado	Stoker	$350/10^3$ pph	1976	In Construction	12/1.2	$400/150x10^3$	8"/22'/	6.5	3.02	Glass		99+	Wheelabrator Frye

requirements, high gas temperatures and fabric or bag durability. Existing baghouses on coal fired boilers typically operate at an air-to-cloth ratio of 2/1 (ACFM/$Ft.^2$ Cloth) and use glass fiber bags. The low filtering velocity dictated by allowable outlet loadings and lack of durability of the bags leads to high capital and maintenance costs. In order to improve and expand the availability of fabric filters as viable controls for coal fired boilers it is necessary to provide systems capable of operating at air-to-cloth (A/C) ratios greater than presently used, and to employ fabrics which will be durable at the higher filtering velocities.

While it has been demonstrated that baghouse dust collectors can be applied to fly ash removal, there was a need for a techno-economic evaluation of fabric filters as specifically applied to industrial size coal fired boilers. There have been some recent developments in bag technology which may affect application problems previously encountered by others and the economics of fabric filters applied to fly ash removal.

PROGRAM DESCRIPTION

The fabric filter pilot unit installed at Kerr Industries in Concord, North Carolina was operated during the summer of 1974 from May until September. The operating mode and testing schedule were designed to accomplish the purpose and scope of work outlined below.

Purpose

The purpose of the subject program was to conduct, via a pilot plant, a techno-economic evaluation of the application of fabric filter dust collection to coal fired industrial boilers.

Scope of Work

Task 1 - Using the existing pilot baghouse located at Kerr Industries, Concord, North Carolina, the contractor shall operate the unit so as to provide data for:

A. A family of curves of pressure drop and size efficiency vs. air-to-cloth ratio for three levels of reverse air for Nomex felt.

B. A family of curves of pressure drop and size efficiency vs. air-to-cloth ratio for Teflon felt.

C. A family of curves of pressure drop and size efficiency vs. air-to-cloth ratio for expanded Teflon coated woven Nomex (Gore-Tex/Nomex).

D. A family of curves of pressure drop and size efficiency vs. air-to-cloth ratio for acrylonitrile homopolymer.

E. Relationships among reverse air volume, air-to-cloth ratio and outlet grain loadings by size.

F. Baghouse operating and capital costs for the fabrics studied which meet existing Federal or State emission codes.

G. Relationships between reverse air durations for less than 30 seconds and pressure drop across the bags.

Task 2 - Using the data obtained in 1 above, the Contractor shall write a report containing suitable graphs and tables to show:

A. Pressure drop vs. air-to-cloth ratios for the various levels of reverse air volumes and bag material types.

B. Outlet loadings by size versus air-to-cloth ratios for the various levels of reverse air volume and bag material types.

C. SO_2, SO_3, inlet loadings and particle size distributions.

D. Capital and operating cost comparisons for the different bag materials.

E. Boiler load for the various tests performed.

Kerr Industries

Kerr Industries is a textile dye and finishing plant located in the textile belt of central North Carolina. There are some 22 textile facilities in a two county area around Concord-Kannapolis, North Carolina. Therefore, the local economy is relatively dependent on this industry.

Kerr's normal production schedule is three shifts per day, five days per week with 450-500 employees. Plant capabilities include processes to bleach, mercerize, dye, nap, finish and sanforize both cotton and synthetic fabrics, as well as cutting and preparing corduroy. Production capacity is 4 million yards finished cloth per month.

PILOT PLANT DESCRIPTION

The fabric filter pilot plant employed for the program is shown in Figure 1. The house consists of two modules with two cells per module. Each cell has two doors on top of the house for access to the bags; all visible in the schematic drawing, Figure 2. A general arrangement drawing of the baghouse is presented in Figure 3.

Each of the four separate cells contains fifty-four bags. The bags are 5 inches in diameter and 8 feet - 8 inches long. Each bag has 11.48 $ft.^2$ of cloth giving 620 $ft.^2$ of cloth per cell and 2,480 $ft.^2$ of cloth for the house. The bags are set into the tube sheet, see Figures 2 and 4 located approximately 13 inches from the top of the house, by the use of two snap rings incorporated into the bag itself. The snap rings lock in place, one above and one below the tube sheet. A spiral cage (not shown in figures) is set inside the bag and keeps the bag from collapsing. As shown in Figure 4, the dirty gasses enter one end of the unit, pass through the tapered duct, into the classifier, and then through the bags. The classifier forces the dirty gases to change direction 90°, then 180°. This quick directional change forces the larger and heavier particles out of the flow so that they fall directly into the hopper. Dirty gases enter the classifier thru a central duct which is tapered to feed the same volume of gas into each of the four cells. The gases are forced thru the fabric filter into the center of the bags, leaving the particulate on the outer surface of the bags where it is removed periodically during the cleaning cycle. The cleaned gases are drawn up and out thru the center of the filtering bag into a center exit plenum via an open damper in the cell above the tube sheet. The bags are cleaned one cell at a time by activating the pneumatic cell damper. When the damper is in the up position, the flow is thru the bags from the dirty side to the center plenum or clean side. When the damper is dropped to the down position, the flow is from the reverse air plenum thru the bags to the dirty side or hopper. As the solid matter collects on the outside of

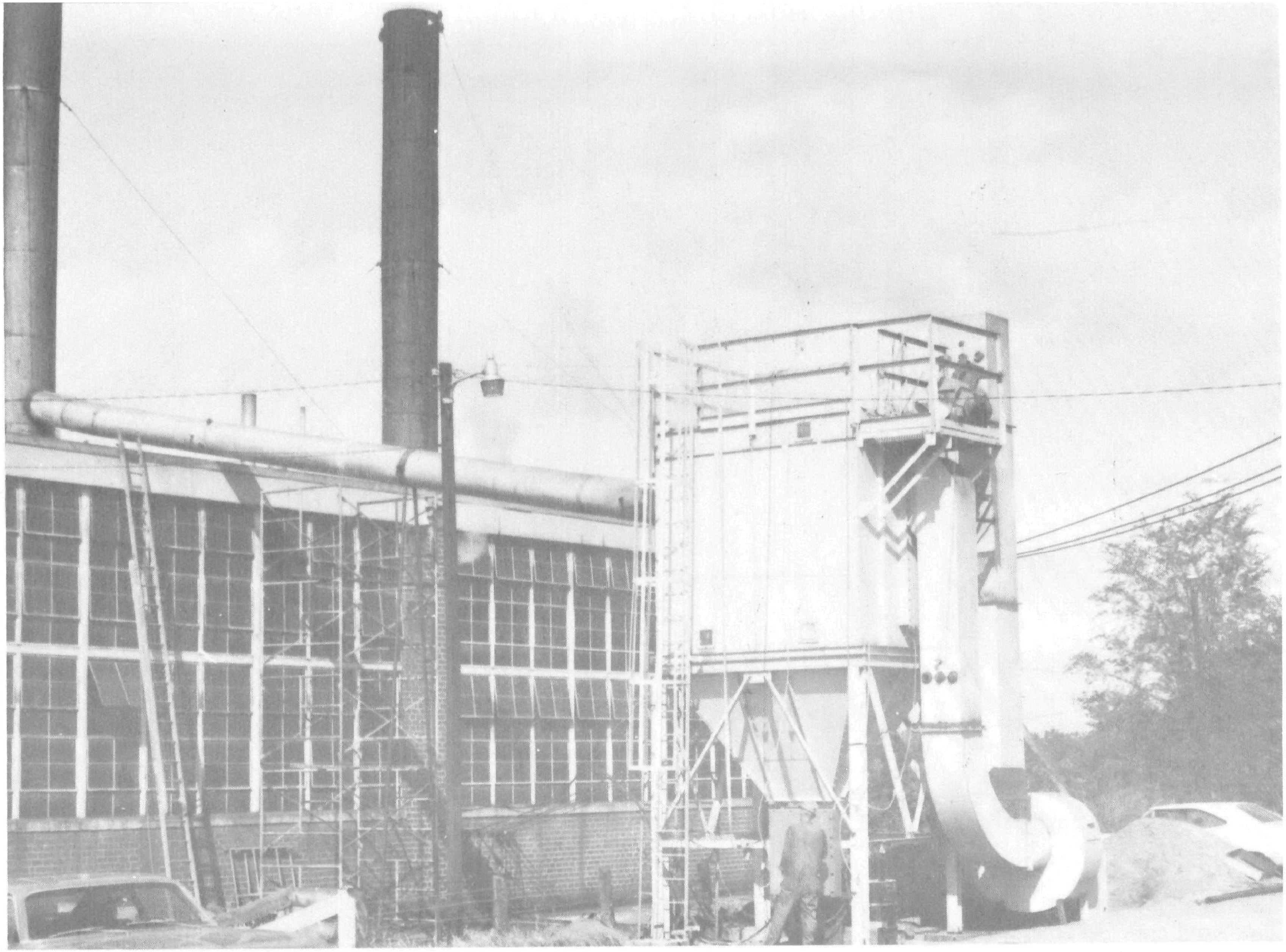
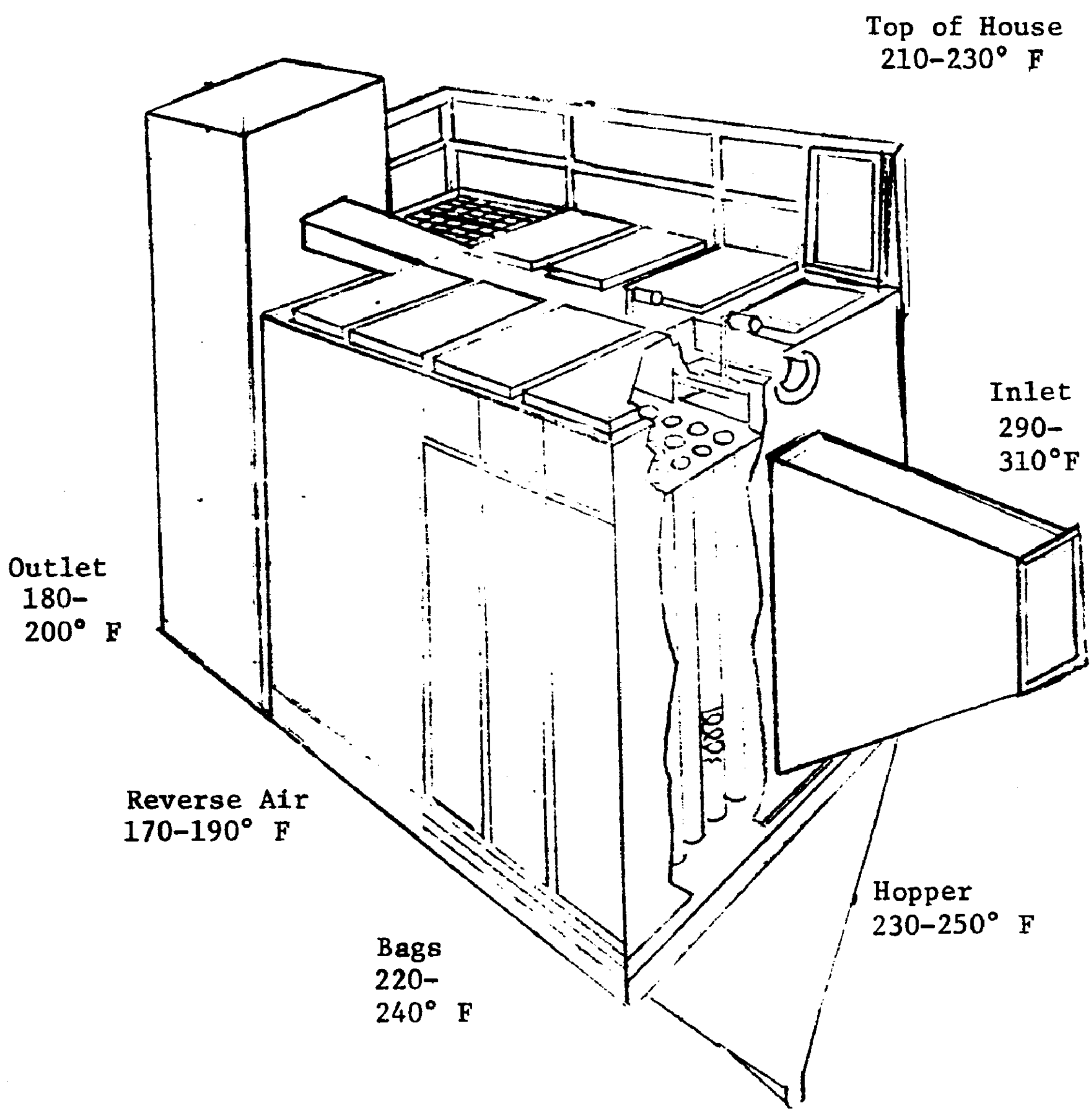


Figure 1

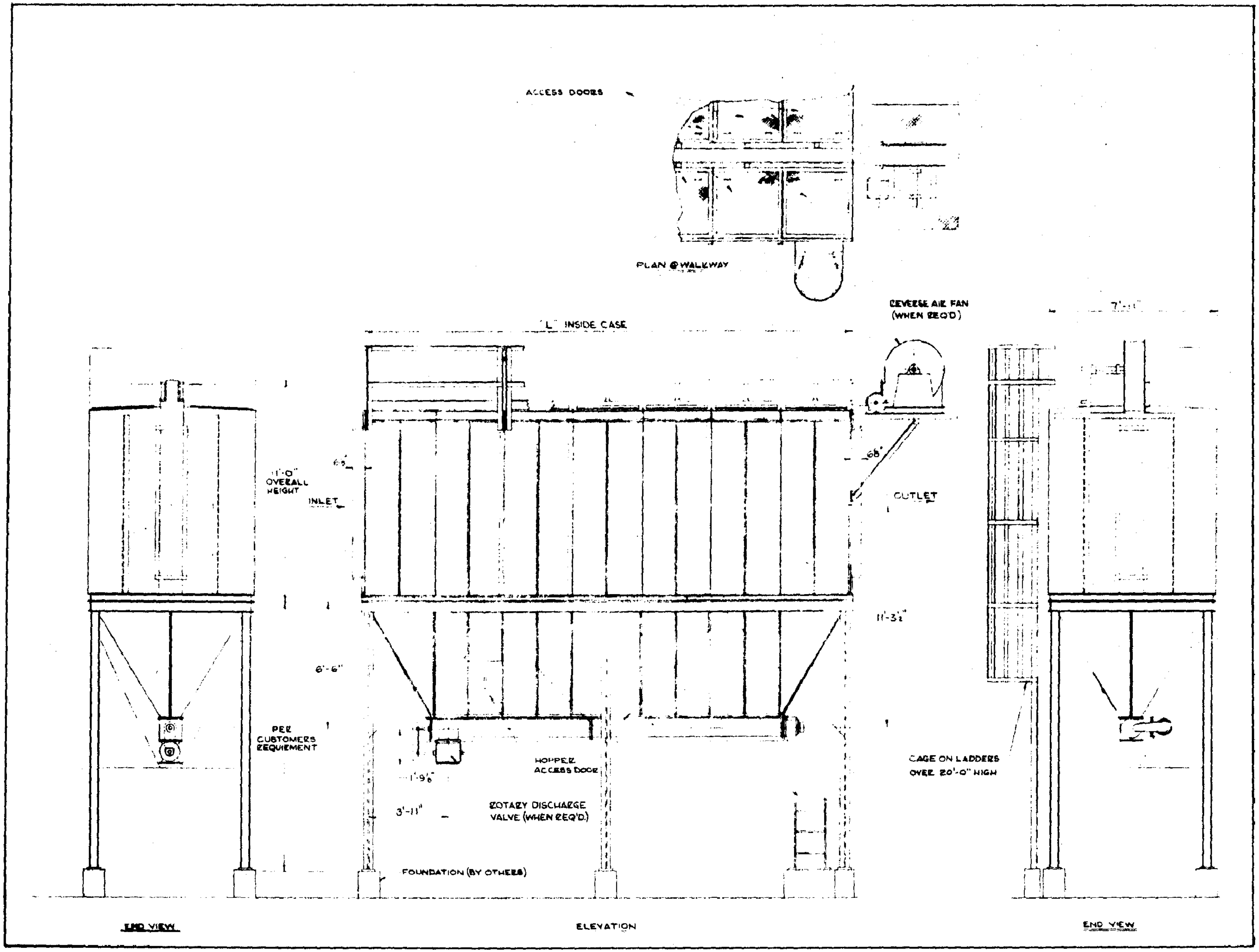
Fabric Filter Pilot Plant
Installed at Kerr

Figure 2



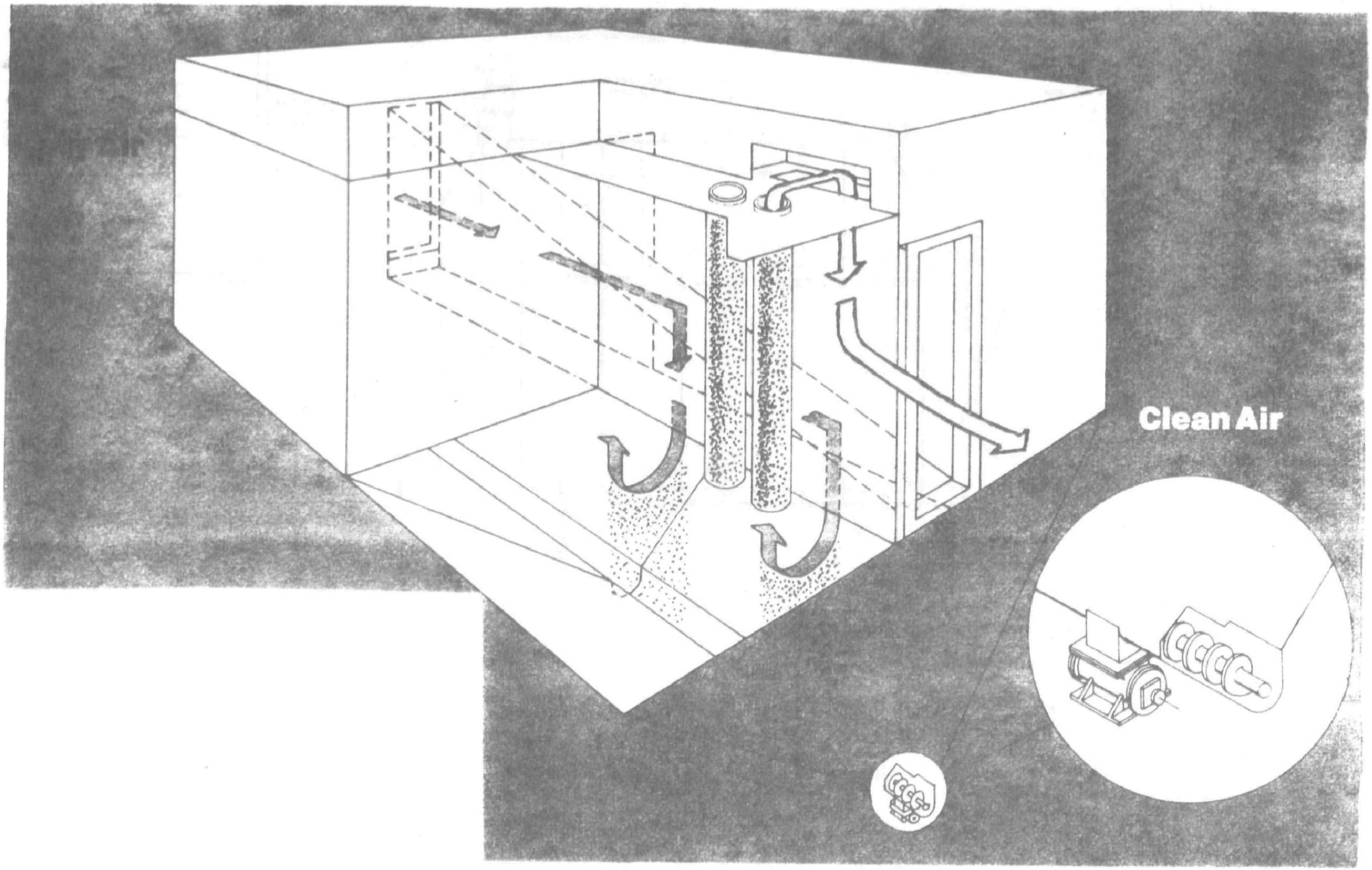
Pilot Plant Temperature Profile

Figure 5



General Arrangement Drawing

Figure 4



Baghouse Pictorial Showing Gas Flow

the filter bag, it builds a cake or crust which begins to restrict the flow of the gases. During the cleaning cycle, clean air enters the cell thru the pneumatic damper. The clean air is forced down the filter bag, opposite to the normal flow direction. The bag expands with a shock so that the cake is cracked and the particulate falls off the bag into the hopper. After the shock has expanded the filter bag and broken off the cake, the clean air continues to flow providing a drag which pushes and pulls the dust particles away from the fabric. The smaller particles are thus forced out of the fabric and fall into the hopper for removal from the unit. Damper system and control panel arrangements allow for variations in main gas volume, reverse air volume, duration of cleaning and frequency of cleaning. The existance of four cells allows for the repetitive sequential testing of different bag types without the need to change bags.

Filter Media Employed

Four types of filter media were evaluated. These were Nomex felt - a polyamide, Teflon felt, Dralon-T felt - a homopolymer acrylic, and Gore-Tex laminate - an expanded Teflon on Nomex backing. Specifications for these filter media are given in Table 8. Bench results of the Gore-Tex had shown promise of higher A/C capabilities as well as quick release properties. The bench results on Gore-Tex were presented earlier.[3]

Description of Kerr Industries' Boilers

Two Babcock & Wilcox boilers are in operation at the Kerr facilities. Each has a design capacity of sixty thousand pounds of steam per hour and both are equipped with spreader stokers. Both boilers are equipped with fans for supplying draft; and unit number two, the unit tapped for the pilot plant slip stream, has overfire steam injection for better combustion control. In January, 1973, emission tests were conducted on these boilers by the North Carolina Office of Water and Air Resources, Air

Table 8

Filter Media Characteristics

Filter Media	Weight Ozs. Yd.^{2}	Permeability CFM/Sq. Ft.	Mullen Burst psi
Nomex® Felt[1]	14	25-35	450
Teflon® Felt[2] Style 2663	22-24	15-35	250
Teflon® Felt Style 2063	18-20	25-65	250
Gore-Tex®[3]	4-5 + Laminate	8-15	329-400
Dralon®-T Felt[4]	13-15	20-30	250

[1]High Temperature Resistant Nylon Fiber (Polyamide)

[2]Tetrafluoroethylene (TFC) Fluro-Carbon

[3]Expanded Teflon (Polytetrafluroethylene) with Interfacing Air Filled Pores

[4]Homopolymer of 100% Acrylonitrile

Quality Division, and L. E. Wooten and Company. The complete stack emission test report was presented earlier.[3] The particulate emission rates were found to be approximately 130 pounds/hour versus an allowable of about 25 pounds/hour. Gas volumes were determined to be about 35,000 acfm at a temperature of about 355° F. Thus the grain loading measured was about 0.4 grains per acfm. Orsat analysis indicated 9.5% CO_2, 10% O_2, 0% CO and 80.5% N_2. Coal analysis indicated the percent sulfur at that time to be about 0.6%. An analysis of the coal burned during the subject test program is presented in Table 9.

Installation at Kerr

The pilot plant was installed on a slip stream from boiler number two at Kerr Industries. The slip stream was 18" duct - 40 feet long with a 90° elbow directed down into the gas flow of the Kerr boiler stack, see Figure 5. A typical temperature profile was shown in Figure 2. The reverse air used for cleaning the bags is taken from the pilot plant exhaust stack. Both the slip stream duct and the pilot plant were uninsulated.

Table 9

Coal Analysis

	As Received	Dry
% Mositure	2.7	-
% Volatile Matter	35.0	36.0
% Fixed Carbon	55.7	57.2
% Ash	6.6	6.8
TOTAL	100.0	100.0
% Sulfur	0.71	0.73
BTU/Pound	13,650	14,000

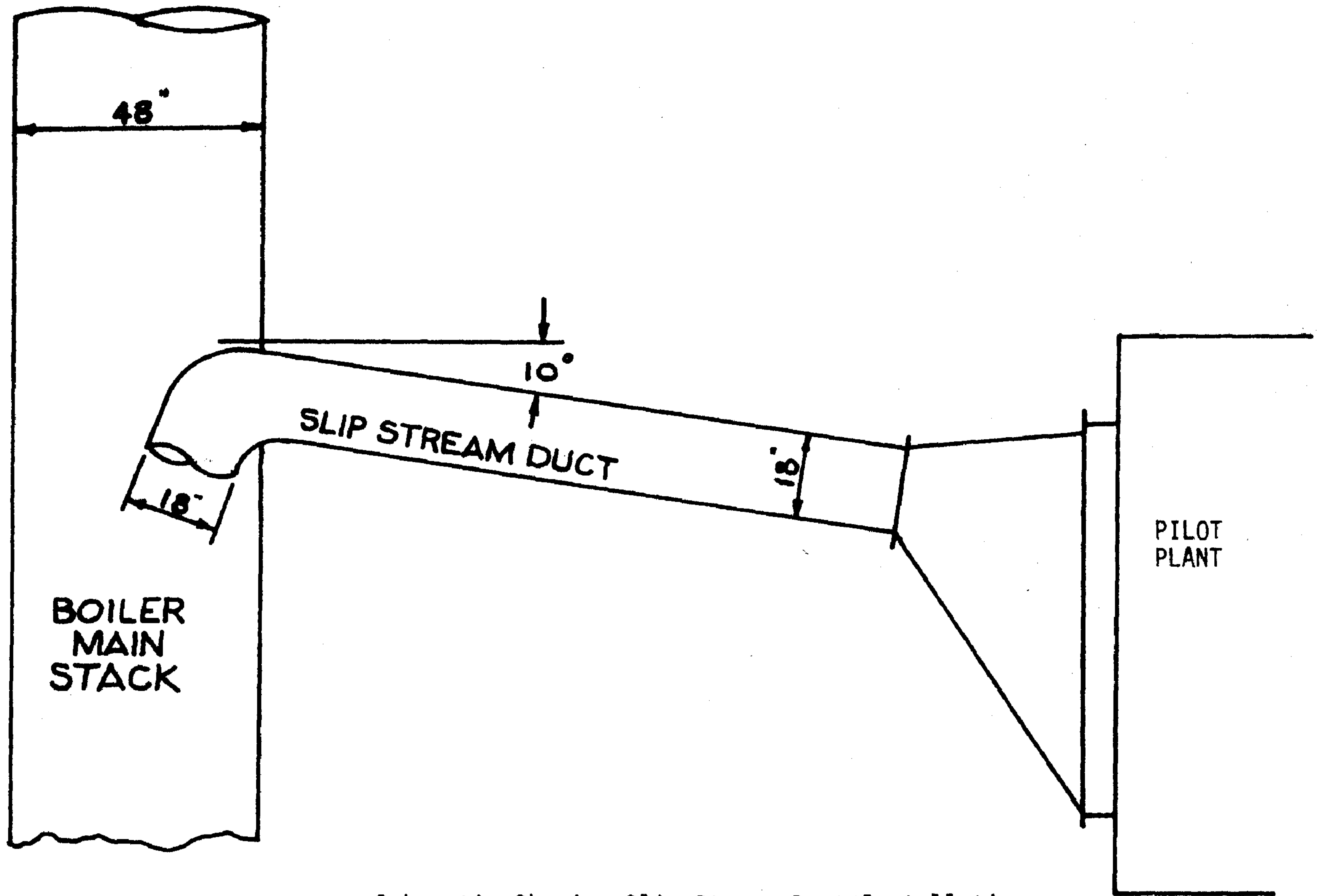
Fusion Temperature of Ash: 2800 Plus °F

Size of Coal: 1¼" X ¼"

Coal from Island Creek Coal Sales, Bluefield, West Virginia, Mine Guyan Eagle #5 located at Kelly, West Virginia.

Analysis conducted by General Testing & Engineering Company, Whitewood, Virginia

Figure 5



Schematic Showing Slip Stream Duct Installation

PILOT PLANT OPERATING PROCEDURES

Standard operating procedures were established for the pilot plant at the beginning of the program. These were followed precisely throughout the program in order to establish and maintain a normal operating mode. The basic operating procedures are outlined briefly below. All data reported was obtained with the system operating in the normal mode unless specified otherwise.

A. Start-Up Procedure

1. Open clean air port at baghouse inlet.
2. Start compressor - allow pressure to reach 80 psig.
3. Start reverse-air fan.
4. Start main system fan.
5. Turn damper control switch to automatic.
6. Open inlet blast gate.
7. Close clean air port.

B. Air-to-Cloth Ratio

The filtering velocity or A/C ratio was the primary variable throughout the program. The filtering velocity was established in the following manner.

1. Start-up system and run until outlet temperature reaches equilibrium.
2. Turn off reverse-air fan.
3. Run velocity traverse on outlet; calculate volume at outlet temperature and A/C ratio.

To Change air-to-cloth ratio:

4. Open or close outlet duct blast gate (located between fan and house) as required.
5. Run velocity traverse on outlet; calculate volume at outlet temperature and A/C ratio.
6. Repeat steps 4 and 5 until desired A/C ratio (± 10 percent) is obtained.

C. Normal Cleandown Mode

Each cell is cleaned for 7 seconds once every 140 seconds. Reverse air volume is to be such that cleaning A/C ratio is greater than 10/1. Except for the evaluation of cleaning durations less than 30 seconds vs. pressure drop across the bags and except for the evaluation of the effect of volume of reverse air on outlet loading at three A/C ratios for Nomex felt, the system was in the normal cleandown mode for all testing.

D. System Monitoring

The following parameters were monitored and manually recorded hourly: pressure drop across the house, pressure drop across active cells, inlet and outlet gas temperature, reverse air temperature, reverse air static pressure, main fan static pressure, boiler load and boiler excess air.

The above parameters were also recorded whenever the A/C ratio of reverse air level were changed.

E. System Inspection

Daily checks, generally in the morning before start-up, were made of the system for condition of the bags and cake characteristics.

F. System Shutdown

1. Open clean air port at baghouse inlet.
2. Close inlet blast gate.
3. Run for fifteen minutes to flush house with clean air.
4. Shut off main fan.
5. Shut off reverse air fan.
6. Turn damper control switch to OFF.

F. System Shutdown (continued)

7. Shut off compressor, bleed tank to drain moisture.
8. Close clean air port.

TEST METHODS

The intent of this section is to describe briefly and to document the test methods employed and the operating procedures followed in obtaining the data. It is assumed that the reader is familiar with the accepted ASME and EPA test methods, therefore the procedures for these are not elaborated.

Velocity

Velocity traverses, performed with a Stauscheibe pitot tube and inclined draft gauge, were conducted in general accordance with EPA Method 2 for determining inlet, outlet and reverse air volumetric flow rates. All velocity data was obtained in this manner. An orifice plate was installed in the outlet stack to provide a continuous flow monitor but this proved unreliable during calibration and was not used.

Static Pressure

Magnehelic pressure gauges (0-15 inches w.g.) and twelve inch U-Tube manometers were utilized for monitoring static pressure differentials (Δp) throughout the system. Locations of pressure taps for the various Δp measurements are given below.

Pressure Drop Across the House: One tap located in the inlet transition to the house and one in the transition from the house to the outlet duct ahead of the system fan.

Pressure Drop Across the Cells: One common tap located in the inlet transition to the house and individual taps located above the tube sheet on the clean air side of each cell.

System Fan Static Pressure: Pressure taps located in duct ahead of system fan and in stack downstream from the fan.

Reverse Air Static Pressure: One tap located at end of reverse air plenum and one to atmosphere.

The system fan and reverse air static pressures were used solely as operational checks on the system and are not reported in the data.

Temperature

All-metal dial thermometers (50-500° F) with eight inch stainless steel stems were employed for temperature measurements. Accuracy of these thermometers was ½ of 1% of total scale reading. These were permanently mounted and well sealed in the following locations: inlet and outlet transitions of the house, reverse air duct between outlet stack and reverse air fan and in the hopper.

SO_2-SO_3

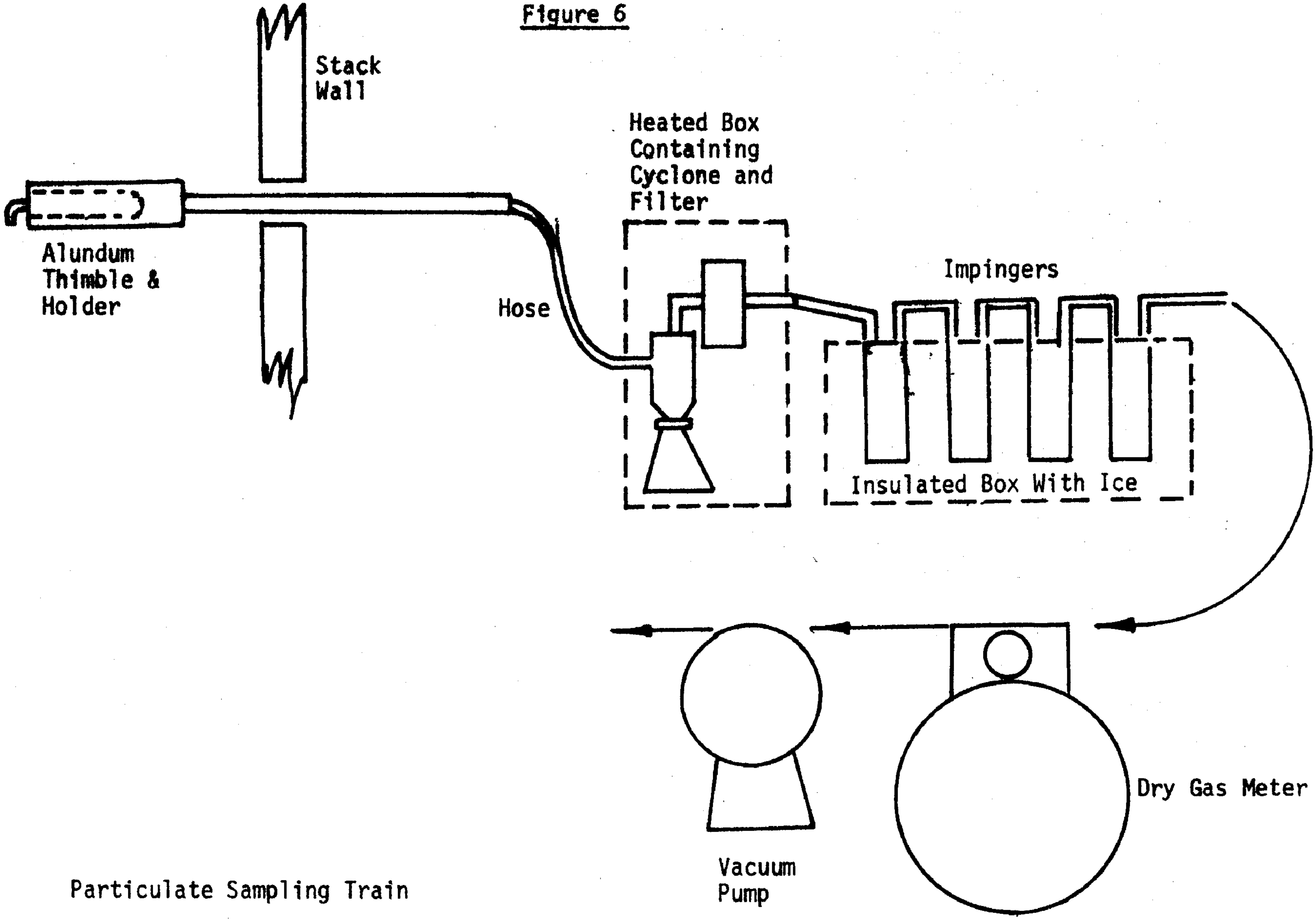
EPA Method 8 was employed for determination of SO_2 and sulfuric acid mist concentrations in the inlet to the baghouse. Sulfuric acid mist including SO_3 was reported as SO_3.

Particulates

Particulate concentration measurements were conducted in general accordance with the methods specified in ASME Power Test Code 27. The sampling train consisted of a stainless steel nozzle, alundum thimble holder, heated cyclone and fiberglass filter, impingers for moisture determinations, dry gas meter, and vacuum source (see Figure 6).

Particle size analysis was performed with an Andersen in-situ particle size analyzer. Use of the Andersen inertial impactor followed the procedures recommended in "Guidelines to Conduct Fractional Efficiency Evaluations of Particulate Control Systems" prepared April, 1974, by Process Measurements Section of the Control Systems Laboratory of EPA at Research Triangle Park, North Carolina. Since this guideline necessarily allows for certain options in Andersen methodology, the procedures

Figure 6



Particulate Sampling Train

utilized are given below:

1. One sample was conducted for each test. All sampling was in-situ.
2. Special glass fiber impaction stage substrates and a 2½ inch diameter glass fiber substrate as a back-up filter were employed.
3. The impactor was oriented horizontally inside both the inlet duct and the outlet stack during sampling.
4. The impactor was heated by means of electrical heat tape and a thermocouple feedback temperature controller. Gas exiting the impactor was maintained at a temperature of 250° F or 20° F above the stack temperature, whichever was greater.
5. No precutter was used.
6. Flow rate thru the impactor was adjusted so as not to exceed the critical velocity for the last stage.
7. Inlet sample time was two minutes.
8. Outlet sample time varied from 1-2 hours, depending on the rate of loading - a function of the media and A/C ratio being tested.
9. Sampling time was designed to avoid overloading any single stage.
10. Sampling rates were maintained as close to isokinetic conditions as possible without exceeding recommended stage velocities.
11. All substrate weighings were accomplished on a Type 28N Ainsworth analytical balance which has a sensitivity of 0.1 milligrams. Substrates were oven dried and dessicated prior to weighing.

Except when investigating the relationship of reverse air level to outlet loading at different filtering velocities, particle size analyses were run at zero reverse air in all cases. Zero reverse air signifies the reverse air fan was off and no cleaning was achieved over the duration of the test. The zero reverse air was necessary since only one cell contained the filter media being tested, and operation of the reverse air would have created velocity fluctuation at the test point.

The Andersen impactor has been calibrated by several independent laboratories to arrive at the current respective size cuts for each stage. The calibrations were referenced to unit density (1g/cc), spherical particles so that the aerodynamically equivalent sized particles collected on each stage are always identical for any given flow rate. Therefore, a stack sample containing a mixture of shapes and densities is fractionated and collected according to its aerodynamic characteristics and is aerodynamically equivalent in size to the unit density spheres collected on each specific stage during calibration. The effective aerodynamic diameter at 70° F is determined for each Andersen sample based on the flow rate thru the impactor. A correction factor for determining the physical diameter of spherical particles having other than unit density must be used. This correction factor yields the effective aerodynamic diameter for a specific density. Also a correction factor is used for determining the effective aerodynamic diameter for elevated temperatures.

All particle size presented was corrected for particle density and gas temperature using correction factor curves supplied by the impactor manufacturer.

Permeability

Permeability tests on the fabrics employed were performed on a Frazier air permeability instrument. All testing was conducted in accordance with the manufacturers specifications. Obtaining initial data before exposure presented a problem due to the fact that the bag could not be cut up for testing and testing an intact bag necessitated air flow from the inside of the bag out - the latter being opposite to the flow of dirty gas thru the bag in the baghouse. After testing several fabrics it was determined that direction of flow did not alter the permeability data significantly either for dirty or exposed bags or for clean ones. Therefore testing data represents air flowing from inside the bag to the outside.

DATA OBTAINED

Introduction

Operation of the pilot plant was tied directly to the dye and finishing plant operations via the boiler slip stream. The boiler load and on stream time was dictated solely by plant production requirements. All day-time boiler flue gas conditions were incurred by the pilot facility; however, when inlet and outlet loadings were measured care was taken to avoid boiler grate cleaning times.

Inlet Conditions

Measurements of inlet mass concentrations with the particulate sampling train described previously indicated the loading to be from 0.41 to 0.48 grains/SCFD* (See Table 10).

Particle size analyses using the Andersen inertial impactor indicated the inlet loading to be less than the above.

Analyses of the inlet flue gas indicated SO_3 concentrations were between 3.6 and 6.1 parts per million (ppm) by volume, and SO_2 concentrations ranged from 250 to 500 ppm.

Since it was not feasible within the scope of the program to run inlet loadings simultaneously with each outlet loading determination for fractional efficiency, an average inlet concentration by particle size was established. The average was derived from numerous inlet particle size determinations over the duration of the program. The average inlet conditions was used to develop all fractional efficiencies reported.

Table 11 gives the average inlet concentrations by particle size. The inlet particle size distribution is shown in Figure 7.

*SCFD, Dry Standard Cubic Feet

Table 10

Particulate Concentration Data

Flue Gas Data

Test No.	Date	Temp. °F	Volume ACFM	Moisture %	Concentration Grains/SCFD*
1	5/22/74	275	1724	6.9	0.48
2	5/29/74	280	2380	5.6	0.41

*SCFD - Dry Standard Cubic Foot (29.92 in H and 70° F)

Table 11

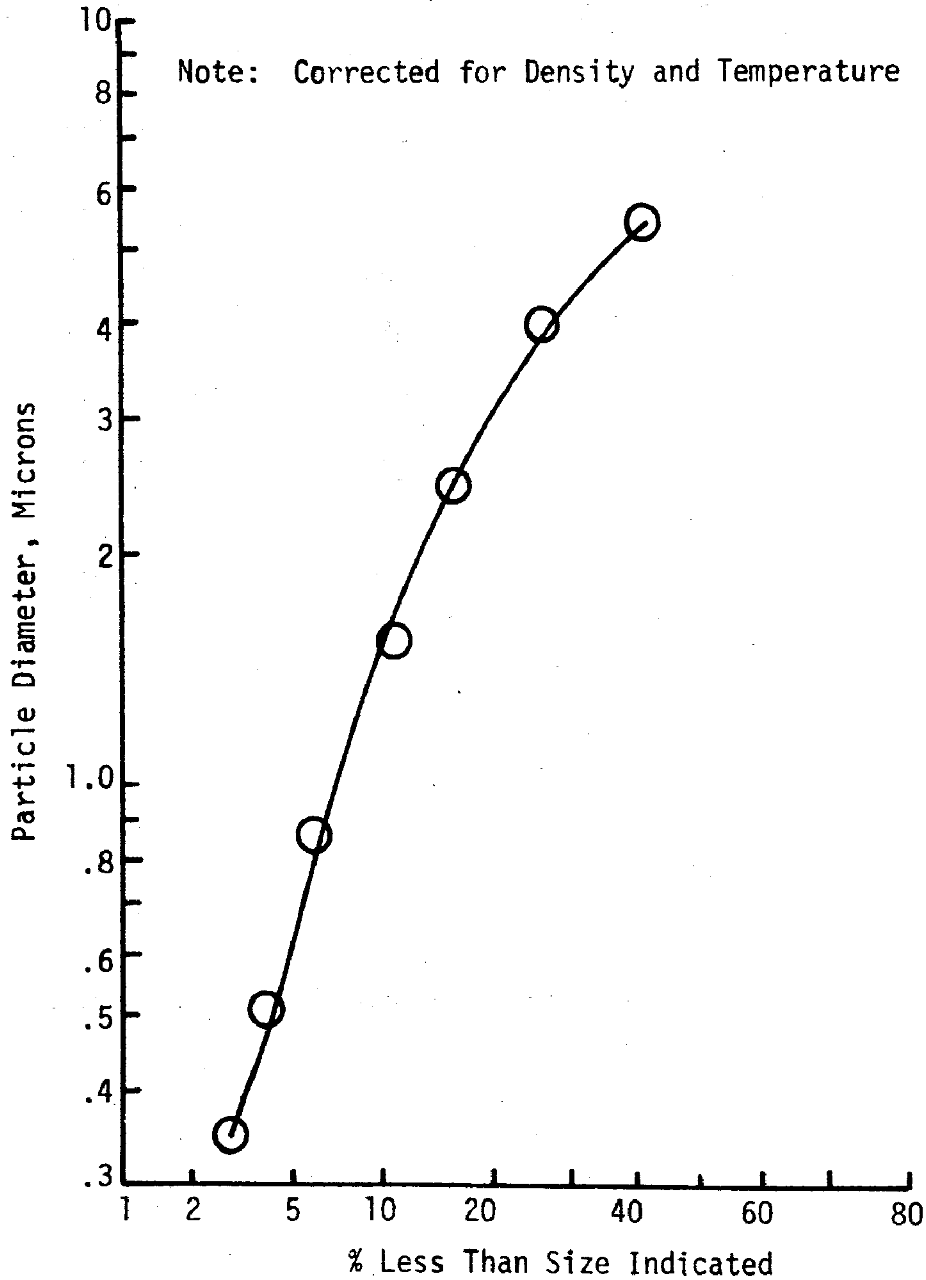
Inlet Concentration by Particle Size

Average Particle Diameter (Dp)* Microns	Average Concentration mg/SCFD	Average Concentration Grains/SCFD
> 8.72	9.4273	.14546
5.45	2.4951	.03850
4.02	1.7127	.02643
2.47	.8341	.01287
1.55	.8270	.01276
.86	.3191	.00492
.51	.1750	.00270
.35	.1923	.00297
< .35	.2781	.00429
	16.2607	.2509

*Corrected for particle density (2.6 grams/c.c.) and stack temperature.

Figure 7

Inlet Particle Size Distribution



Simultaneous sampling at each end of the slip stream duct indicated that some of the particulate was dropping out and therefore not present in the baghouse inlet. Table 12 gives the results of these analyses.

Baghouse operating temperature was also a variable which could not be maintained as a constant. Since the slip stream duct and the house were uninsulated the system temperature was a function of velocity or acfm thru the unit and to a lesser extent the boiler stack temperature. Table 13 shows the effect of gas volume on the baghouse operating temperatures.

At approximately the mid point of the test program, a transmissometer (Lear Siegler, RM 4 Cross Stack Portable Unit) was installed on the baghouse inlet. No attempt was made to calibrate the transmissometer in order to obtain quantitative data. It was intended only as a qualitative check to monitor relative levels of particulate in the inlet. Table 14 shows outlet emissions at different A/C ratios with the corresponding boiler load and transmissometer readings.

The general indication was that while the inlet conditions did vary they did not have a significant effect on the outlet loading from the baghouse.

Permeability

Permeability data for clean bags is given in Table 15 and Figure 8. Fabric specifications give a permeability range at 0.5 inches of water; the permeabilities at higher pressure drops were obtained to determine if the different fabrics would have similar pressure drop vs. permeability curves.

The effect of exposure time on permeability and the results of vacuum cleaning the exposed bags are shown in Table 16. Nomex felt and Dralon T exhibited higher permeabilities after cleaning than initially.

Table 12

Inlet Concentrations by Particle Size

Sampling Time Period 1116-1120, August 14

Average Particle Diam. Microns	Inlet to Baghouse Average Conc. Gr./SCFD	Beginning of Slip Stream Duct Average Conc. Gr./SCFD
>10.0	.02642	.09686
6.2	.04333	.05181
4.18	.03276	.03829
2.84	.01902	.02365
1.79	.01797	.01689
.96	.01163	.02140
.58	.00739	.01126
.39	.00211	.00788
< .39	.00106	.01577
	.16169	.28381

Sampling Time Period 1400-1404, August 14

Average Particle Diam. Microns	Inlet to Baghouse Average Conc. Gr./SCFD	Beginning of Slip Stream Duct Average Conc. Gr./SCFD
>10.0	.14007	.1543
6.2	.04669	.03630
4.18	.02668	.03744
2.84	.01334	.01815
1.79	.02001	.01702
.96	.00778	.01815
.58	.00333	.00908
.39	.00111	.00567
< .39	.00445	.00567
	.26346	.30178

Above sampling conducted while baghouse was operating at an A/C ratio of 6.7 to 1.

Table 13

Effects of Gas Volume on the Baghouse Operating Temperatures

Date	Gas Volume ACFM	Temperatures Inlet °F	Outlet °F	Reverse Air °F	Ambient °F
6/14/74	5721	305	250	195	-
8/6/74	5909	312	230	198	76
6/17/74	1080	250	140	100	80
6/18/74	1068	265	140	110	76
6/18/74	975	255	115	105	76
7/30/74	2828	282	200	162	83
7/31/74	2812	285	191	164	89

Table 14

Effects of Inlet Conditions on Outlet Emissions

Fiter Media - Nomex Felt

① Andersen Test No.	② Air-to-Cloth Ratio ACFM/Ft.^{2}	③ Boiler Load Pounds Steam Per Hour	Ratio ③/④ X 10^3	④ Transmissometer* Readings Percent Absorbance	Ratio ③/⑤ X 10^7	⑤ Outlet Emissions Grains/SCFD	Ratio ④/⑤ X 10^4
39	8.7/1	29,500	1.23	24	0.41	.00719	0.33
40	8.2/1	38,400	1.32	29	0.82	.00469	0.62
53	6.4/1	46,500	1.47	31.7	0.85	.00549	0.58
54	6.4/1	46,600	2.01	23.2	0.62	.00747	0.31
55	6.4/1	47,600	1.78	26.8	0.92	.00516	0.52

Filter Media - Dralon T

① Andersen Test No.	② Air-to-Cloth Ratio ACFM/Ft.^{2}	③ Boiler Load Pounds Steam Per Hour	Ratio ③/④ X 10^3	④ Transmissometer* Readings Percent Absorbance	Ratio ③/⑤ X 10^7	⑤ Outlet Emissions Grains/SCFD	Ratio ④/⑤ X 10^4
64	8.5/1	36,200	1.30	27.8	0.69	.00525	0.53
65	8.9/1	40,600	1.35	30	0.68	.00595	0.50
66	6.1/1	40,600	1.12	36.3	0.63	.00647	0.56
67	6.1/1	39,700	1.26	31.5	0.73	.00545	0.58
68	6.1/1	45,400	1.42	32	0.53	.00853	0.38
69	3.3/1	50,500	1.84	27.4	0.54	.00934	0.29
70	3.3/1	--	--	24.5	--	.00801	0.31

*Transmissometer located on inlet duct just prior to inlet sampling port about two feet from the pilot plant.

Table 15

Permeabilities of Clean Bags

Permeabilities ACFM/Ft.^{2}

Pressure Drop H_2O"	Nomex Felt	Dralon T	Teflon Felt 2663	Gore-Tex/Nomex
0.5	35.6	29.06	24.92	12.77
1.0	78.11	56.78	49.84	24.68
3.0	201.8	148.74	123.10	70.20
5.0	306.6	227.52	184.88	109.5
7.0	409.46	301.12	-	141.8

Data obtained on clean cloth while varying the pressure drop on the Frazier perm gear.

Figure 8

Permeabilities of Clean Bags

(Pressure Drop vs. Permeability)

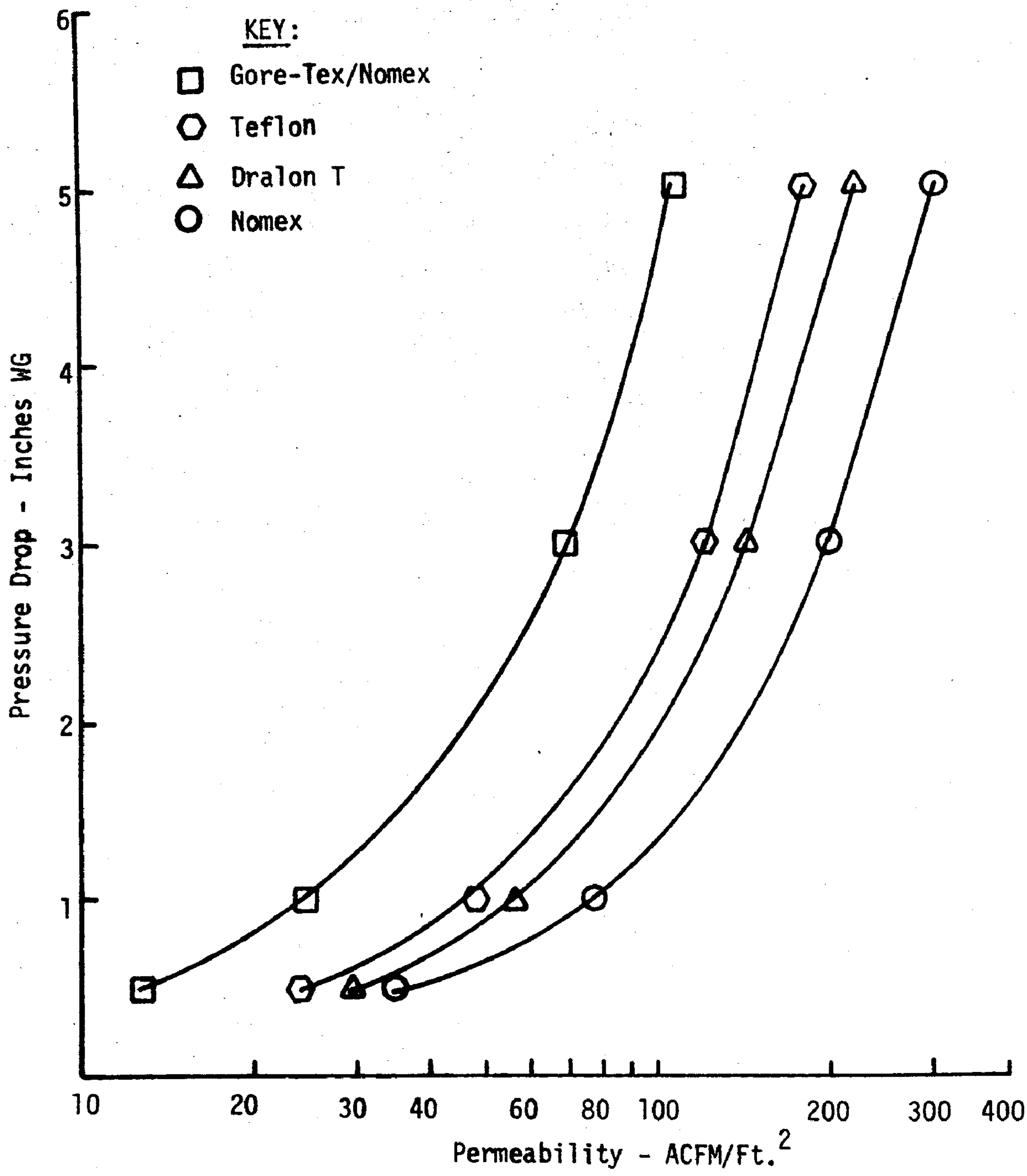


TABLE 16

FILTER MEDIA PERMEABILITY

CFM Air/Ft.^{2} Cloth

Bag Material	Before Exposure	After Exposure	After Cleaning*
Nomex Felt (After 195 Hrs.)	34.4-35.6	8.5-10.7	44.51
Nomex Felt (After 50 Hrs.)	34.4-35.6	21.79	40.26
Gore-Tex/Nomex (After 105 Hrs.)	13-16.4	1.66-2.5	5.79
Gore-Tex/Nomex (After 50 Hrs.)	13-16.4	Not Available	10.63
Teflon Felt (After 50 Hrs.)	37.8-54.8	6.4-10.6	16.24
Dralon T (After 50 Hrs.)	19.4-31.1	18.7-21.9	26.55-30.95

* Bag was vacuumed on dirty side and retested in laboratory with air flow passing thru bag from clean side to dirty side.

Teflon Felt - Style 2663

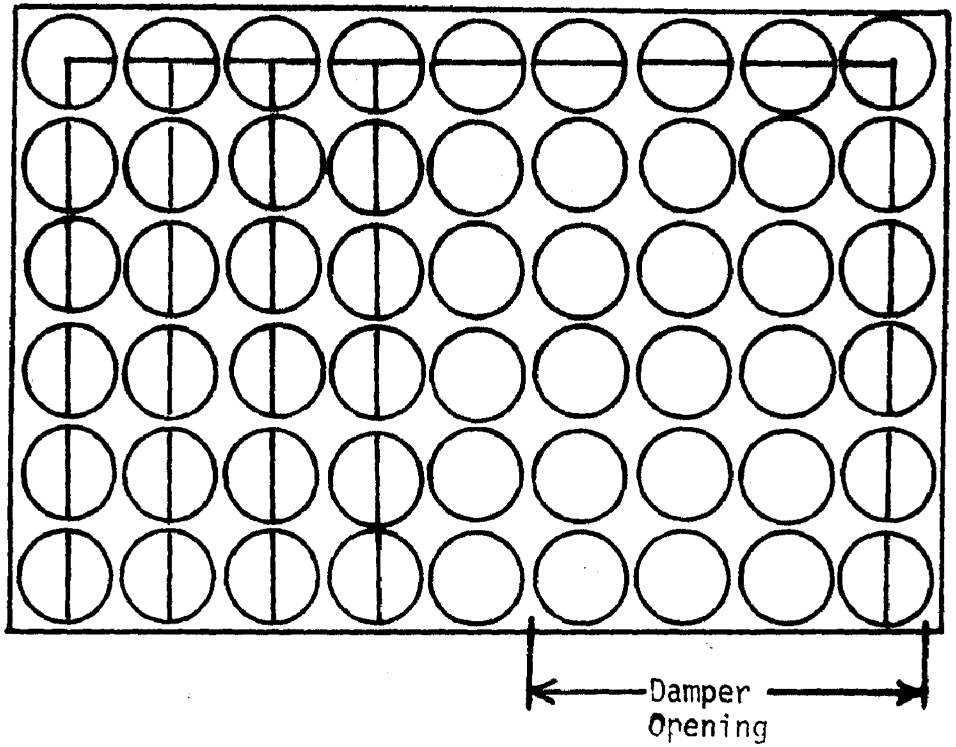
Two styles of Teflon felt were investigated in the program. First Teflon Felt - Style 2063, was evaluated. However, this media proved unsatisfactory with respect to removal efficiencies and has since become unavailable commercially. In its place the manufacturer offered Teflon felt, Style 2663, a heavier weight fabric. This fabric was evaluated at the end of the test program and the data reported in lieu of reporting data on Style 2063, not generally available to industry. The data for Teflon felt - Style 2063 is included in the Appendix for information only.

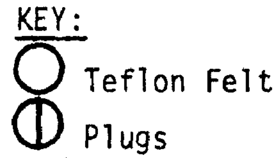
Twenty Teflon felt - Style 2663 bags were placed in Cell #3. Since each cell has a capacity for fifty-four bags, plugs were used to seal the empty tube sheet holes. The positioning of the Teflon felt bags is shown in Figure 9. Although the number of bags employed was not the same for the four fabrics, this general arrangement was used for each fabric to minimize any position effects, if present, on overall performance.

The Andersen sampler was used to obtain in-situ particle size data at air-to-cloth (A/C) levels of 5.4/1, 8.4/1 and 14.1/1. Inlet flue gas volumes ranged from 1180 to 3260 acfm. Because of the limited amount of Teflon cloth on hand, difficulty was experienced in trying to operate at the lower A/C levels. In order to reach an A/C ratio of 5.4/1, the main fan was almost completely throttled. The reverse air volume, although not used during sampling periods, was 3500 acfm.

The particle size distribution for the individual runs was averaged at each of the three levels of A/C. The particle sizes and fractional loadings for all individual Andersen tests may be found in the Appendix. The comparison of the data is graphically displayed in Figure 10. The mass mean particle diameters were 1.36, 1.94 and 1.20 micrometers (micron, um) for A/C ratios of 5.4, 8.4 and 14.1 respectively.

Figure 9



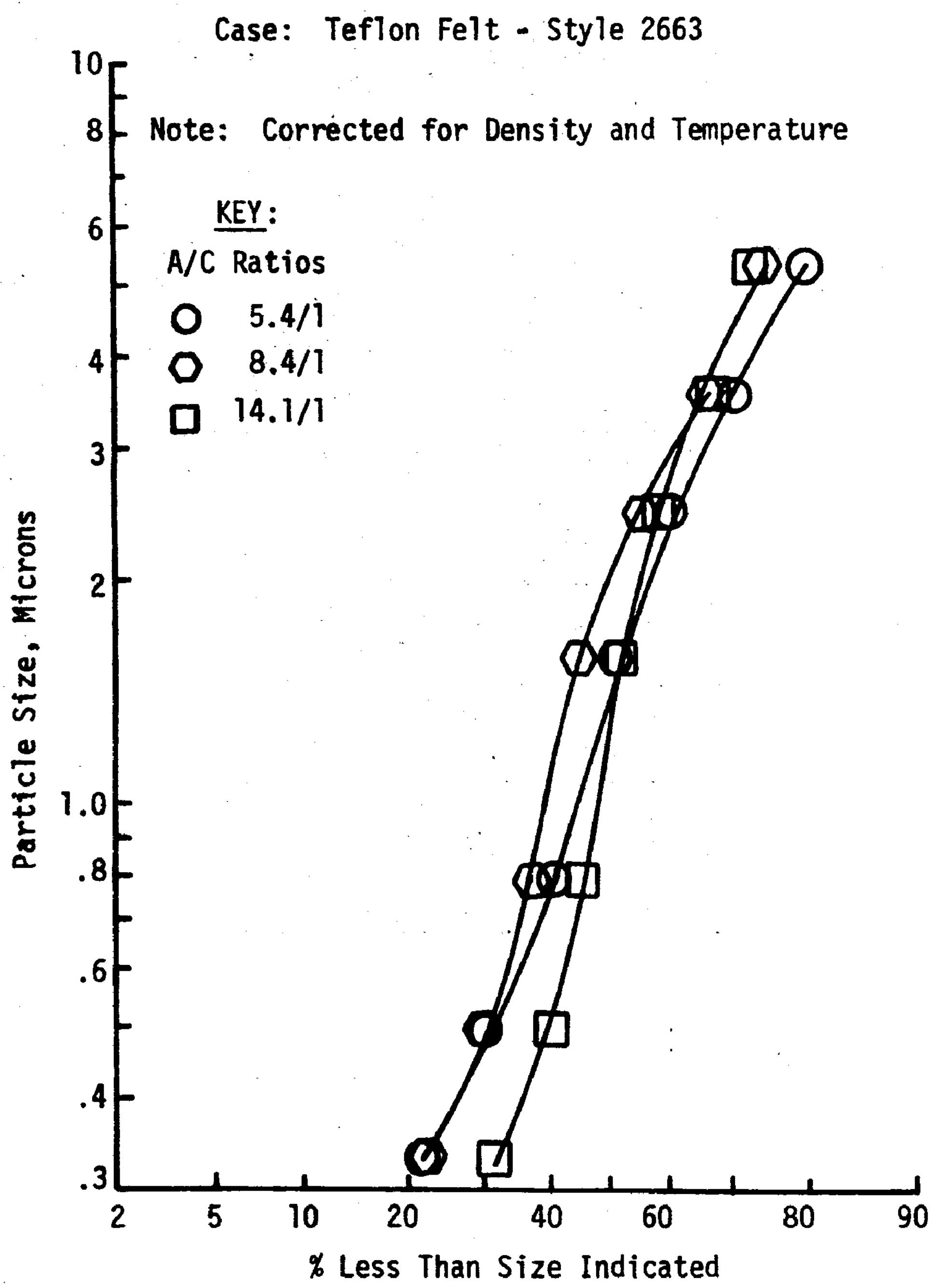


Cell 2

Positioning of Teflon Felt Bags
Style 2663

Figure 10

Outlet Particle Size Distribution



The particle size distribution curves indicate that about 67% was less than 3 microns at the lowest A/C, while 64% of the particulate, by weight, was less than 3 microns at 14.1/1.

Average outlet concentration, cumulative percent and penetration by particle size* are given in Table 17. Figure 11 shows outlet concentration for four particle sizes versus (vs) A/C ratio. It can be seen here that the largest particle size fraction is most sensitive to increases in the velocity or A/C ratio. Generally an increase in A/C ratio resulted in an increase in outlet loadings. For the smaller size fractions the curve does appear to flatten above an A/C of about 8. This curve is in general agreement with the data for the other materials tested. Penetration or 1- collection efficiency vs. particle diameter is presented in Figure 12. Three curves are shown, one for each of the three levels of A/C ratio. All three show the same general trend, with the curve sloping downward to the right indicating less penetration of the larger particles. Two of the curves indicate some leveling or decrease of penetration for the very small fractions. This improved collection of the finest fractions is also present and in some cases even more pronounced in the data for the other media.

Pressure drop versus A/C data is presented in Figure 13, while examples of typical cleandown cycles are shown in Figure 14. Although Teflon felt exhibited the highest dust penetration of the materials tested, it was capable of operating with the lowest pressure drops. As shown in Figures 13 and 14 it would be economically feasible to operate at even the higher A/C ratios.

After fifty-eight hours on stream the bags were inspected. They showed no sign of wear with only slight evidence of pearling in a 3/16" cake of a friable dust.

*Particle size is actually the aerodynamically equivalent particle size corrected for density and temperature.

Table 17

Outlet Concentration, Cumulative % and Penetration

Teflon Felt, Style 2663

	Air-to-Cloth Ratio 5.4/1			Air-to-Cloth Ratio 8.4/1			Air-to-Cloth Ratio 14.1/1		
Avg.(1) Part. Diam. um	Avg. (2) Outlet Conc. Gr./SCFD	Cuml.(3) %	Pene- (4) tration	Avg. Outlet Conc. Gr./SCFD	Cuml. %	Pene- tration	Avg. Outlet Conc. Gr./SCFD	Cuml. %	Pene- tration
>8.38	.00091	100	.0063	.00257	100	.0177	.00321	100	.0221
5.29	.00041	80.13	.0106	.00082	74.89	.0213	.00079	74.06	.0205
3.55	.00043	71.18	.0163	.00108	66.87	.0409	.00107	67.67	.0405
2.47	.00045	61.79	.0350	.00108	56.31	.0839	.00080	59.02	.0622
1.57	.00051	51.96	.0400	.00082	45.75	.0643	.00082	52.55	.0643
.79	.00052	40.82	.1057	.00087	37.73	.1768	.00069	45.92	.1402
.49	.00036	29.47	.1333	.00072	29.23	.2667	.00110	40.34	.4074
.33	.00046	21.61	.1549	.00093	22.19	.3131	.00092	31.45	.3098
<.33	.00053	11.57	.1235	.00134	13.1	.3124	.00297	24.01	.6923
TOTAL	.00458		.0183	.01023		.0408	.01237		.0493

1. Corrected for particle density (2.6 grams/C.C.) and stack temperature.
2. At 5.4/1 two (2) tests averaged, at 8.4/1 one (1) test averaged, at 14.1/1 two (2) tests averaged.
3. Percent of total outlet concentration less than size indicated.
4. Penetration based on average inlet concentration at corresponding impactor stages.

Figure 11

Outlet Concentration by Particle Size
vs.
Air-to-Cloth Ratio

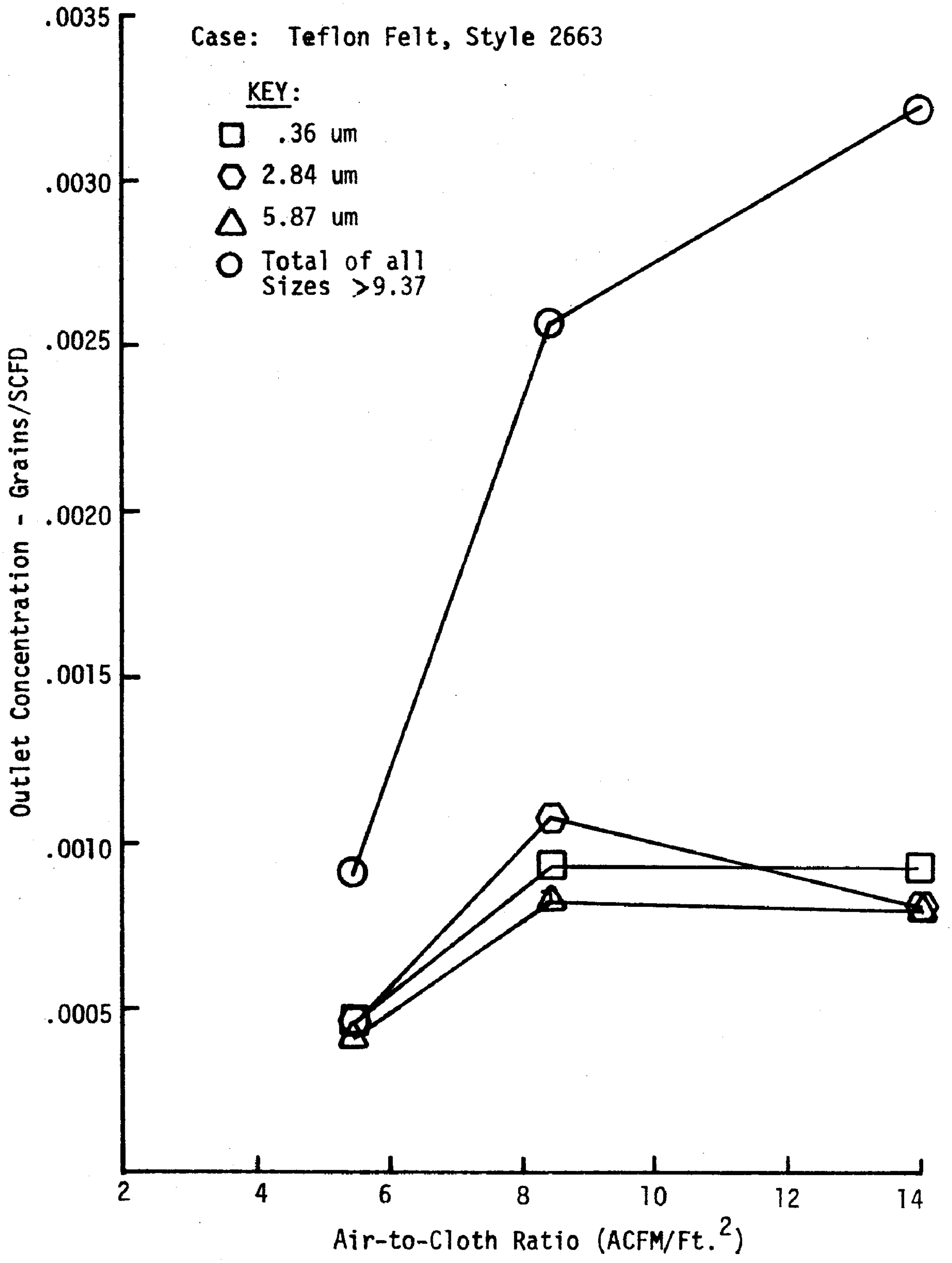


Figure 12

Penetration
vs.
Particle Diameter

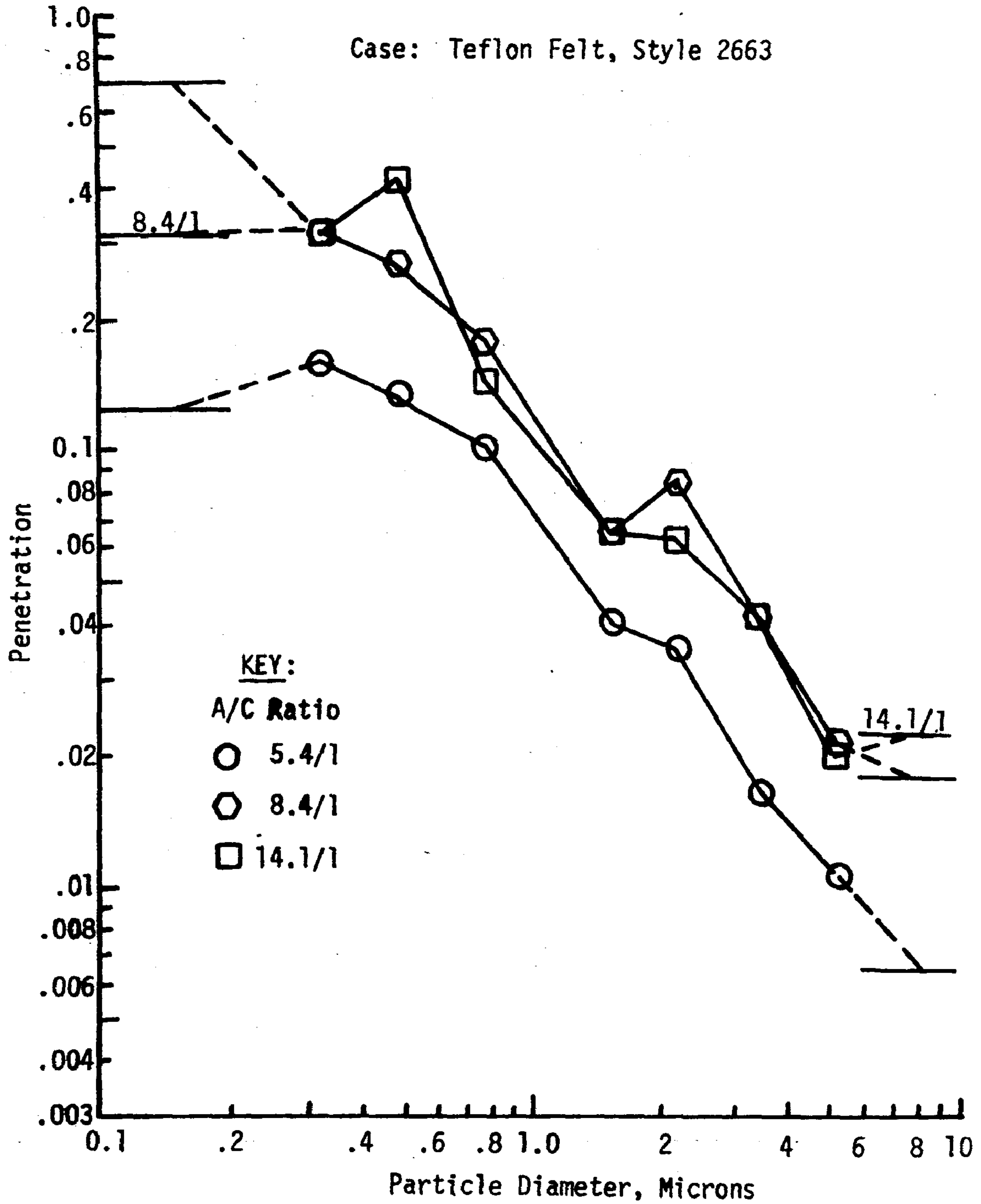


Figure 13

Pressure Drop Across Bags
vs.
Air-to-Cloth Ratio

Case: Teflon Felt - Style 2663

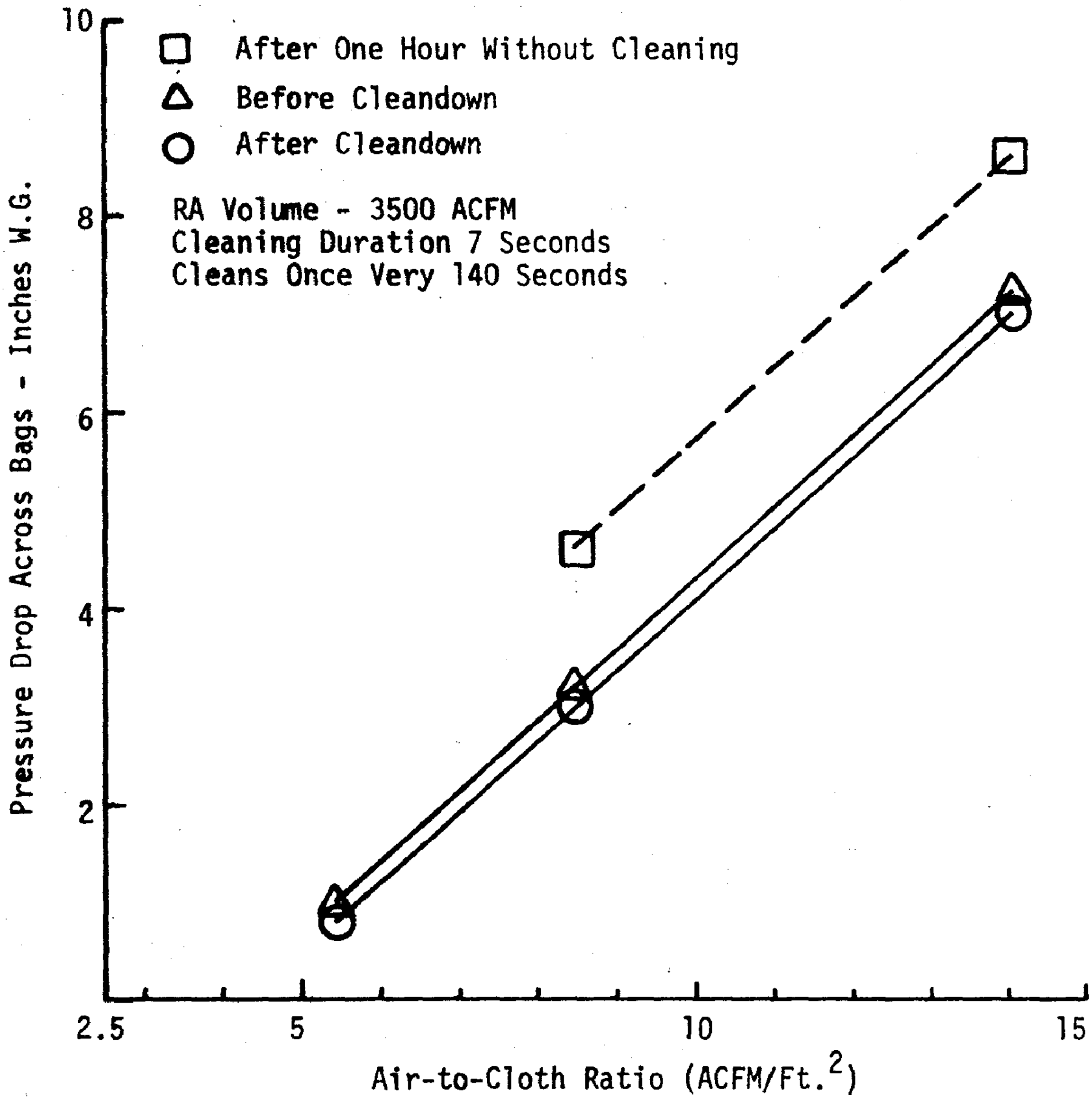
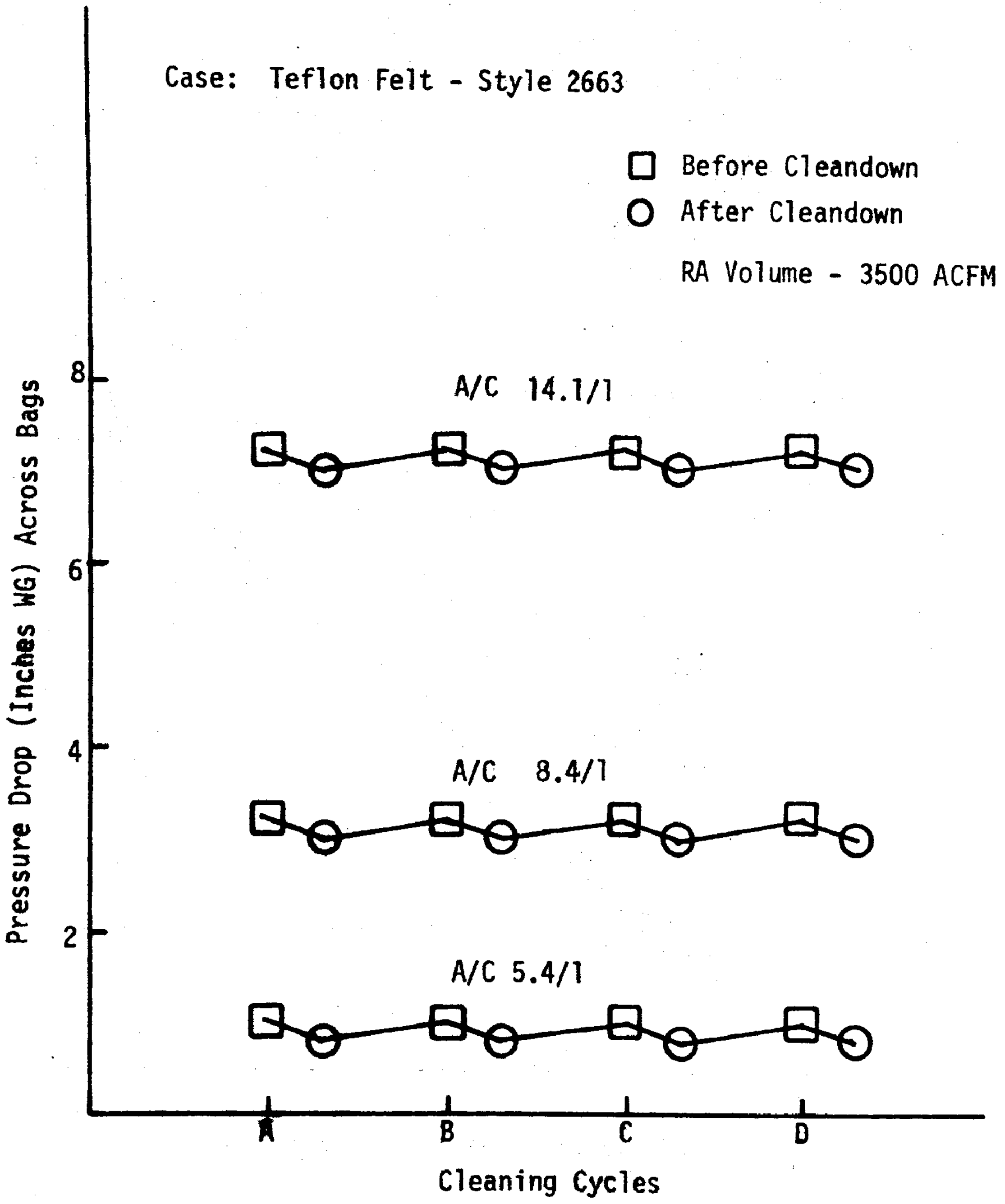


Figure 14

Typical Cleaning Cycles



Gore-Tex/Nomex

Thirty Gore-Tex/Nomex bags were placed in Cell 4. Location of the bags in the cell is shown in Figure 15.

Inlet flue gas volumes ranged between 1000 and 3100 acfm. In-situ particle size data was obtained at A/C ratios of 3.2/1, 6.1/1 and 8.8/1. Test periods lasted up to two hours during which time the reverse air fan remained off. No testing was carried out during boiler grate pulling operations.

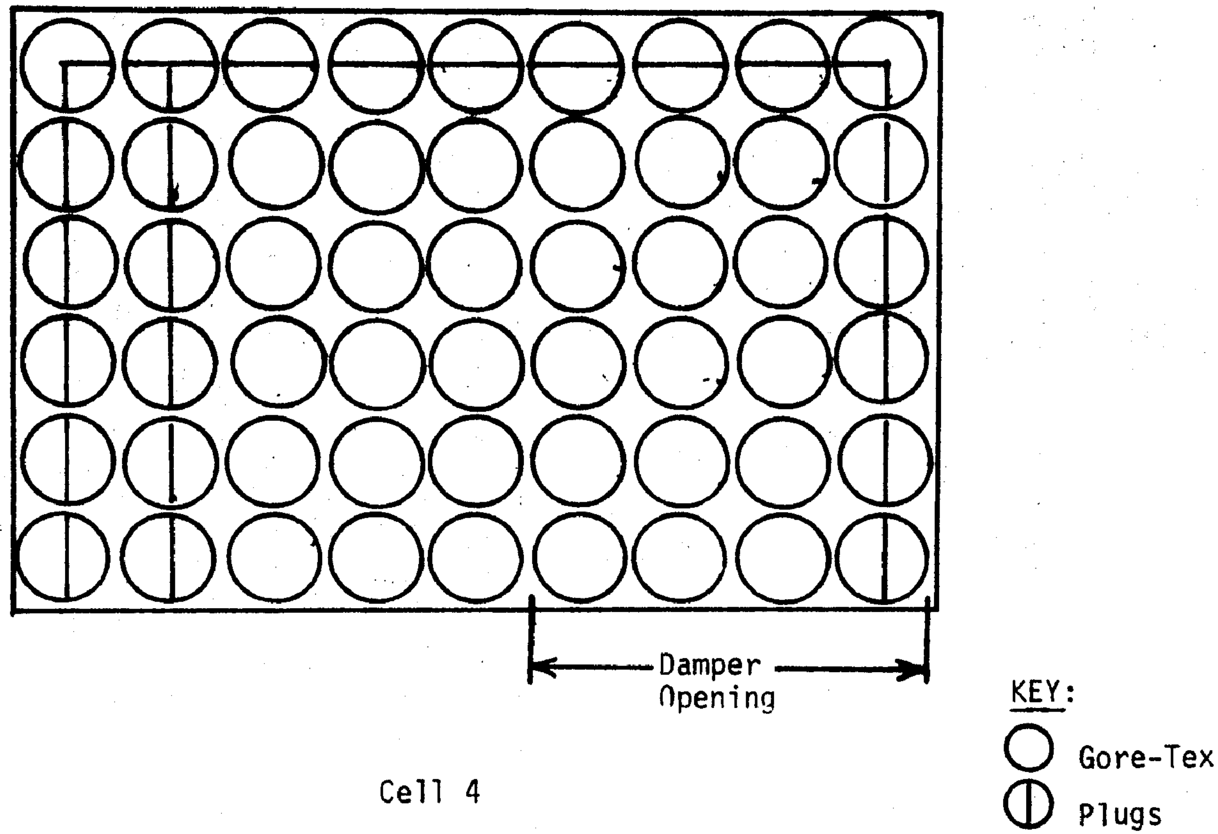
The particle size distribution for the individual runs was averaged at each of the three levels of A/C as shown in Figure 16. The comparison of this data indicates that about 57% of the particulate by weight was less than three microns at the lowest A/C. The two higher A/C levels showed 54 and 49%, respectively, of the particulate, by weight, was less than three microns.

The mass mean particle diameters were 2.55, 2.7 and 3.05 respectively. The performance of the Gore-Tex on sub-micron particles seemed essentially the same at the three levels of A/C.

Average outlet concentration, cumulative percent and penetration by particle size are given in Table 18. Figure 17 shows outlet concentration for four particle sizes versus A/C ratio. Like the Teflon felt case, the largest particle size fraction, i.e. the total of all sizes greater than 9.35 microns, are most sensitive to increases in A/C ratio and an increase in velocity results in an increase in the outlet concentration.

Figure 18 shows penetration versus particle size. Three curves are shown, one for each of the A/C ratios. These curves indicate an increase in penetration as the fractions become smaller from 10 microns down to about ½ micron. Below ½ micron there is a sharp decrease in penetration for all three A/C ratios. The performance of the Gore-Tex on sub-micron particles seems essentially the same at the three levels of A/C.

Figure 15



Cell 4

Positioning of Gore-Tex Bags

Figure 16

Outlet Particle Size Distribution

Gore-Tex/Nomex

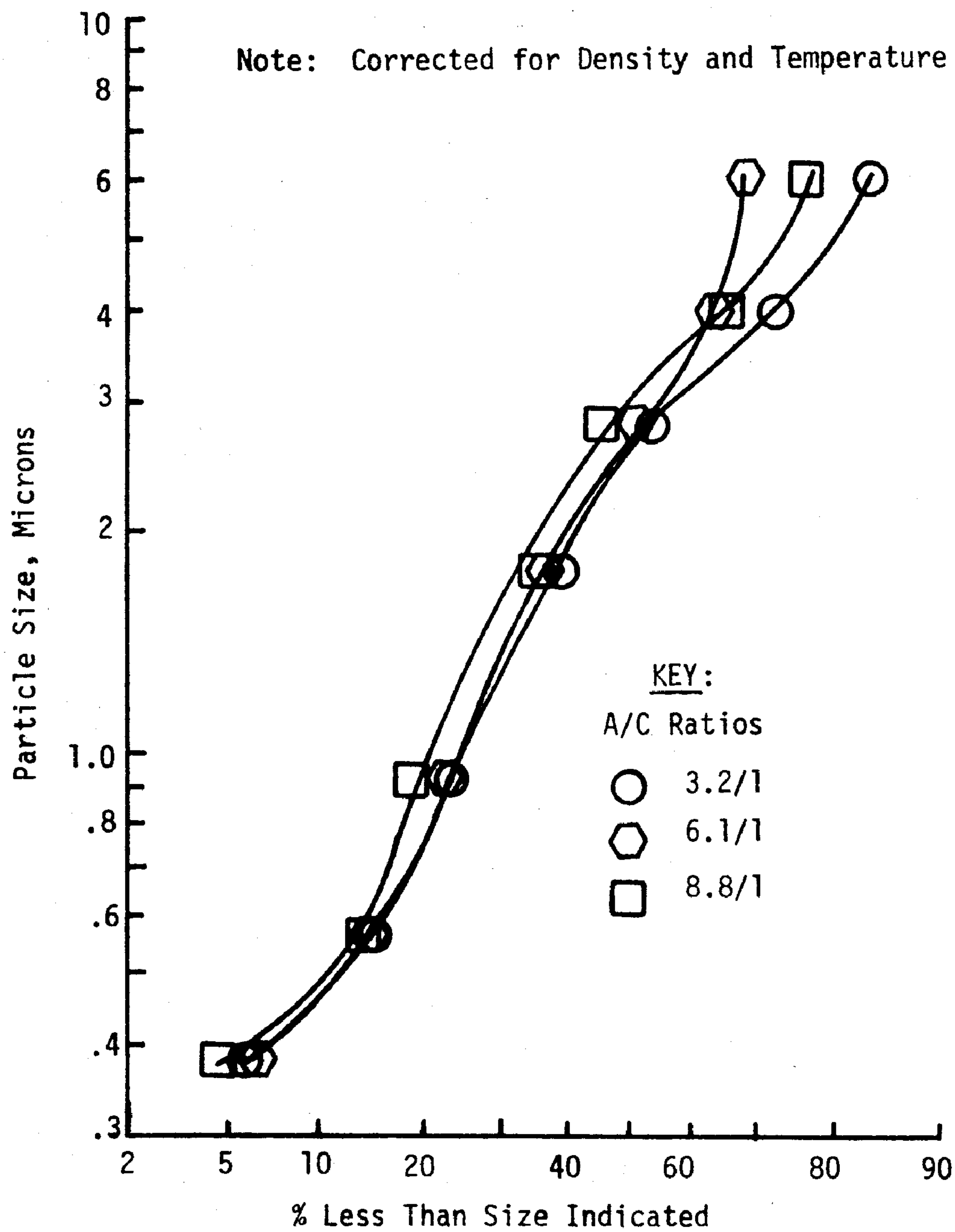


Table 18

Outlet Concentration, Cumulative % and Penetration

Gore-Tex/Nomex

Avg.(1) Part. Diam. um	Air-to-Cloth Ratio 3.2/1 Avg.(2) Outlet Conc. Gr./SCFD	Cuml.(3) %	Pene-(4) tration	Air-to-Cloth Ratio 6.1/1 Avg. Outlet Conc. Gr./SCFD	Cuml. %	Pene-tration	Air-to-Cloth Ratio 8.8/1 Avg. Outlet Conc. Gr./SCFD	Cuml. %	Pene-tration
>9.35	.00071	100	.0049	.00116	100	.0080	.00173	100	.0119
6.05	.00051	84.16	.0132	.00016	68.39	.0042	.00082	76.78	.0213
4.03	.00083	72.78	.0314	.00045	64.03	.0170	.00149	65.77	.0564
2.81	.00067	54.25	.0521	.00057	51.77	.0443	.00078	45.77	.0606
1.78	.00071	39.29	.0556	.00050	36.24	.0392	.00124	35.30	.0972
.92	.00039	23.44	.0909	.00031	22.62	.0723	.00036	18.66	.0839
.56	.00040	14.73	.1481	.00029	14.17	.1074	.00068	13.83	.2519
.38	.00010	5.80	.0337	.00006	6.26	.0202	.00012	4.70	.0404
<.38	.00016	3.57	.0373	.00017	4.63	.0396	.00023	3.09	.0536
TOTAL	.00448		.0179	.00367		.0146	.00745		.0297

1. Corrected for particle density (2.6 grams/C.C.) and stack temperature.
2. At 3.2/1 three (3) tests averaged, at 6.1/1 six (6) tests averaged, at 8.8/1 two (2) tests averaged.
3. Percent of total outlet concentration less than size indicated.
4. Penetration based on average inlet concentration at corresponding impactor stages.

Figure 17

Outlet Concentration by Particle Size
vs.
Air-to-Cloth Ratio

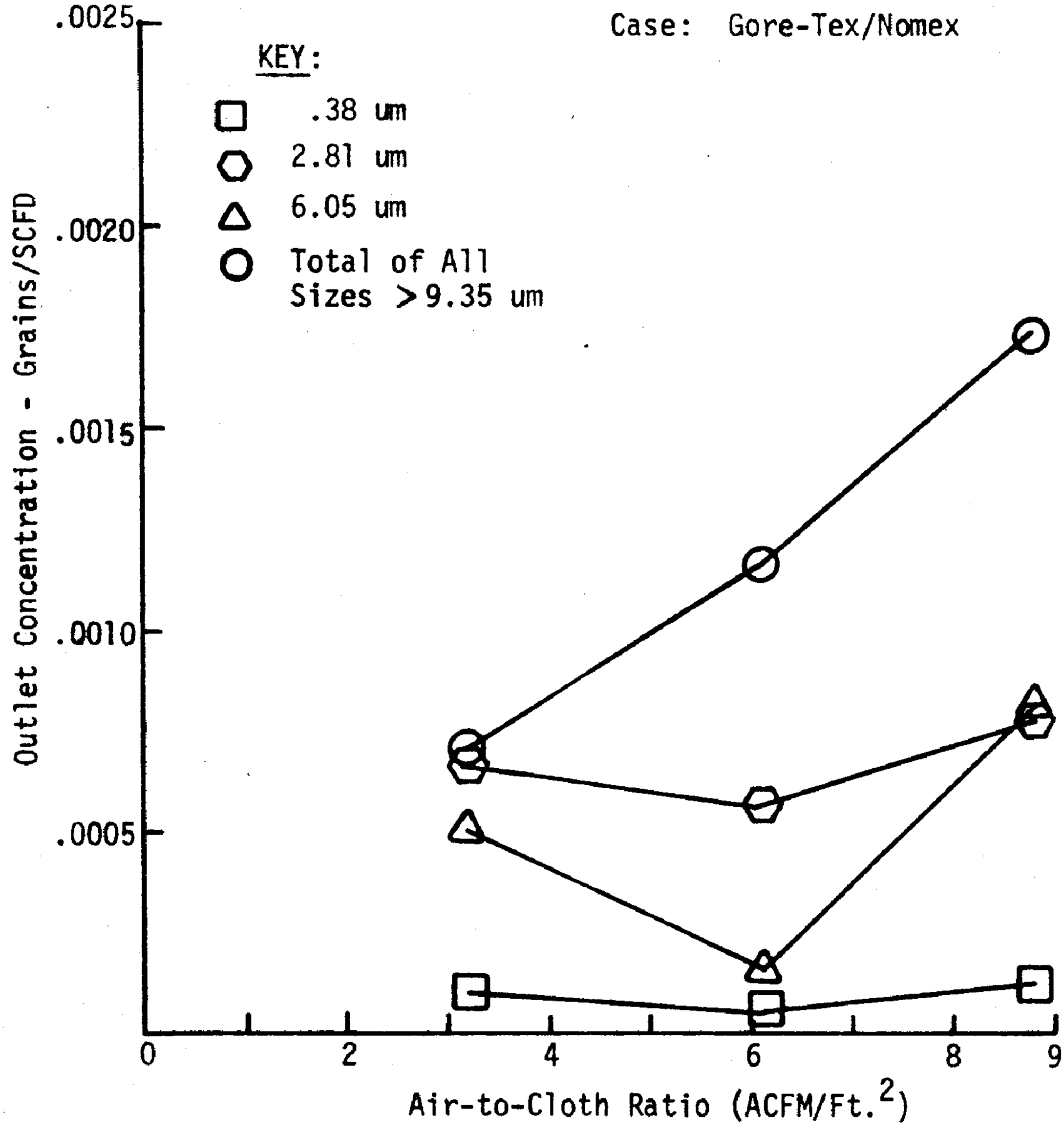
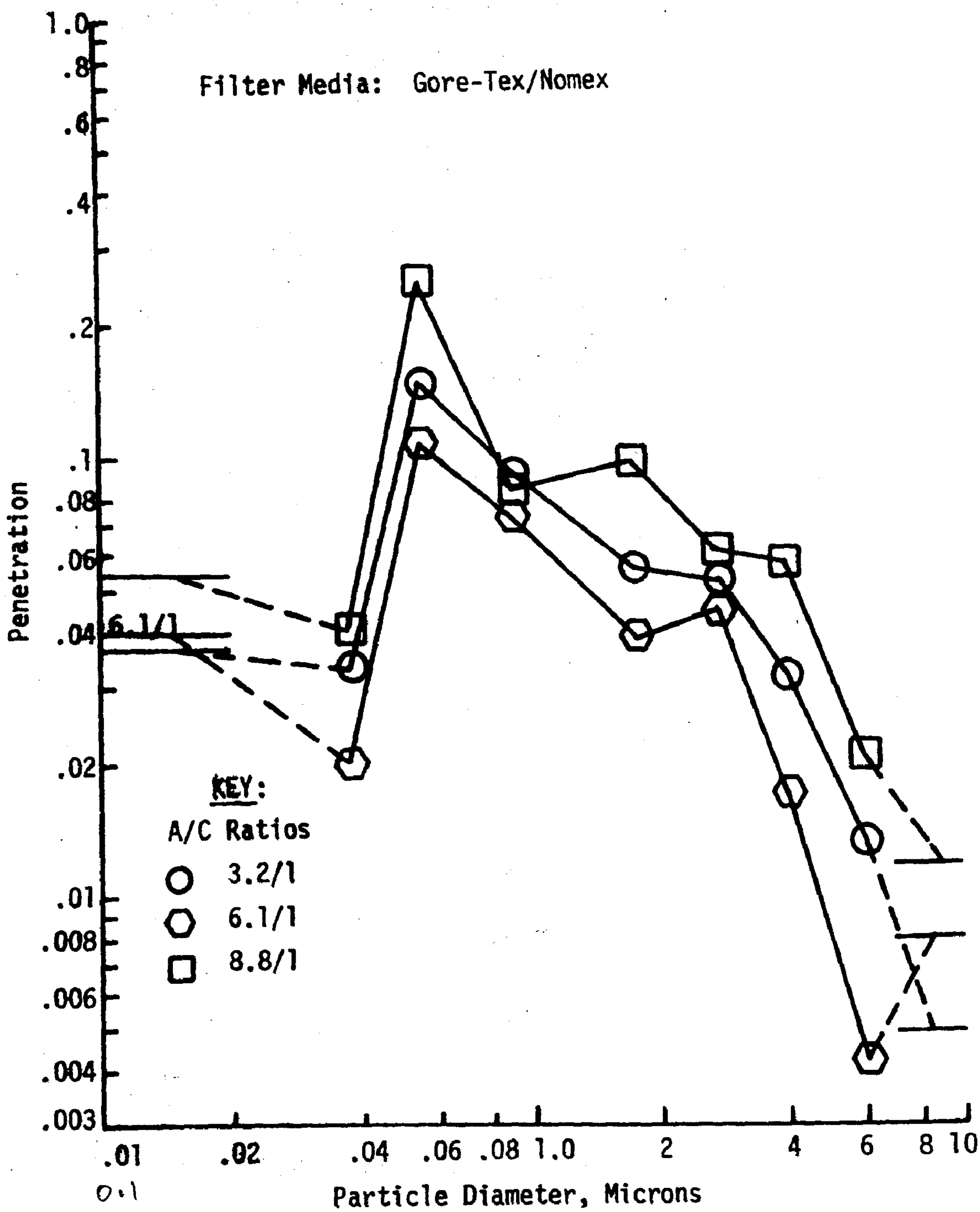


Figure 18

Penetration vs. Particle Diameter



The data would seem to indicate that we experienced the heaviest dust penetration at either end of the A/C spectrum.

Pressure drop comparisons at the three levels of A/C are presented in Figure 19. Examples of typical cleandown cycles are shown in Figure 20.

Because of the failures of the Gore-Tex due to vibrational fatigue experienced in the earlier work,[3] certain precautionary steps were taken to alleviate this problem. The bags were fixed on a rigid cage, i.e. strips were welded lengthwise along each side of the spiral cages to reduce flexing. The cages were also painted to provide a smooth surface. In addition, the bottoms of the bags were strapped to tie rods which had been placed beneath Cells 3 and 4. The strapping of the bottoms of the bags was to reduce the sway which occurs when the lightweight bags are subjected to the gas flow through the baghouse.

After forty-eight hours run time the bags were inspected and appeared in good condition, a 1/32" - 1/16" friable dust had built up on the bags and there was no evidence of pearling.

After sixty-eight (68) hours four damaged bags were removed. The bottoms of the bags had ripped directly above the seam. This tear was also just above the strap which was provided for securing the bag to the tie rod. The bags were inspected daily thereafter and after twenty-six additional hours, two more were found to be damaged. In both cases, the bag failures were discovered after running at the highest air-to-cloth level.

One possible explanation for the failures is that in securing the bottom of the bags in a fixed position they were subjected to unusual stress at the high gas velocities.

Thus, the main problem associated with Gore-Tex bags, that of durability, remains unresolved. Obviously before Gore-Tex bags can be considered seriously as a viable filtering alternative, this problem must be corrected.

Figure 19

Pressure Drop Across Bags
vs.
Air-to-Cloth Ratio

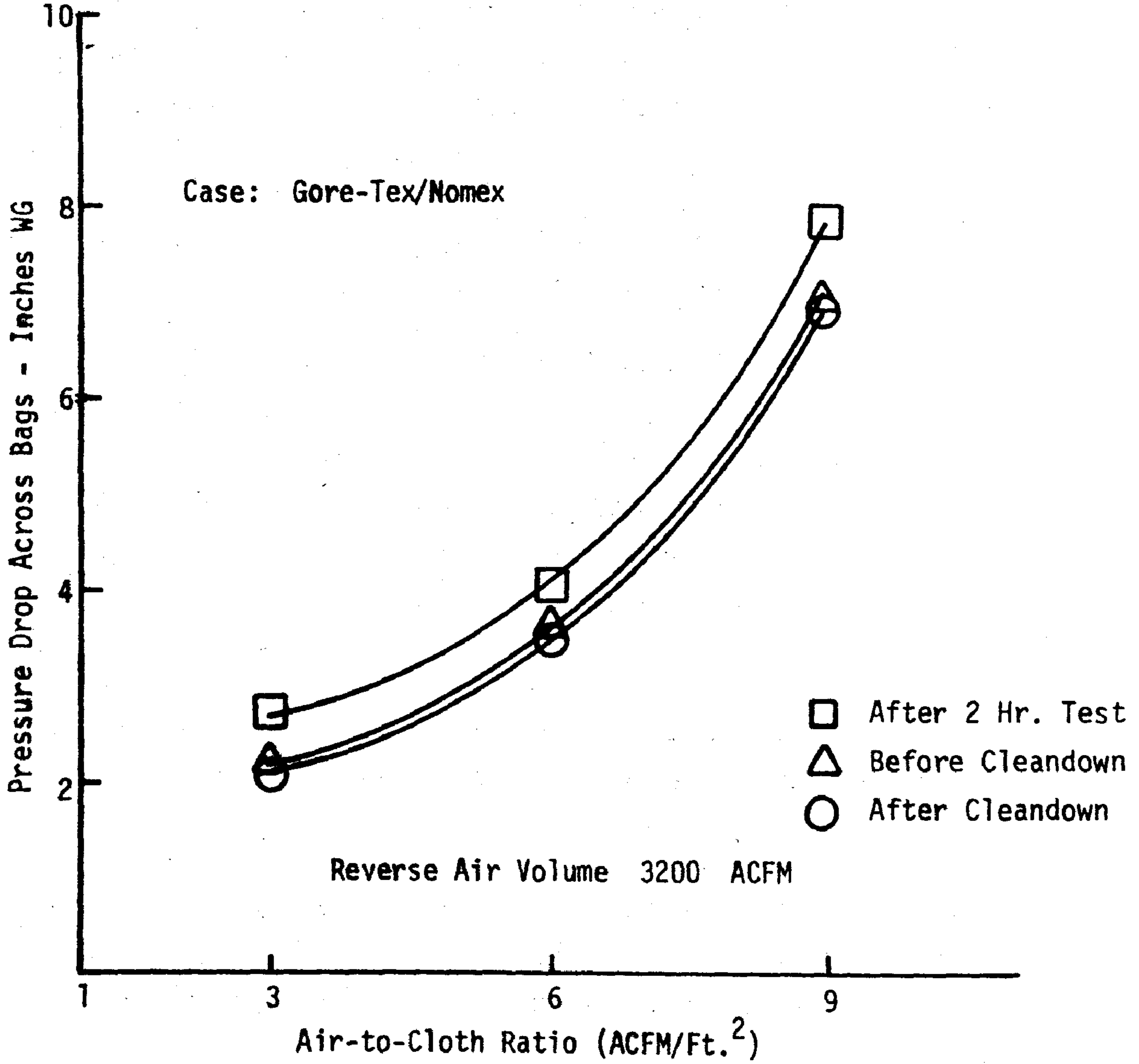
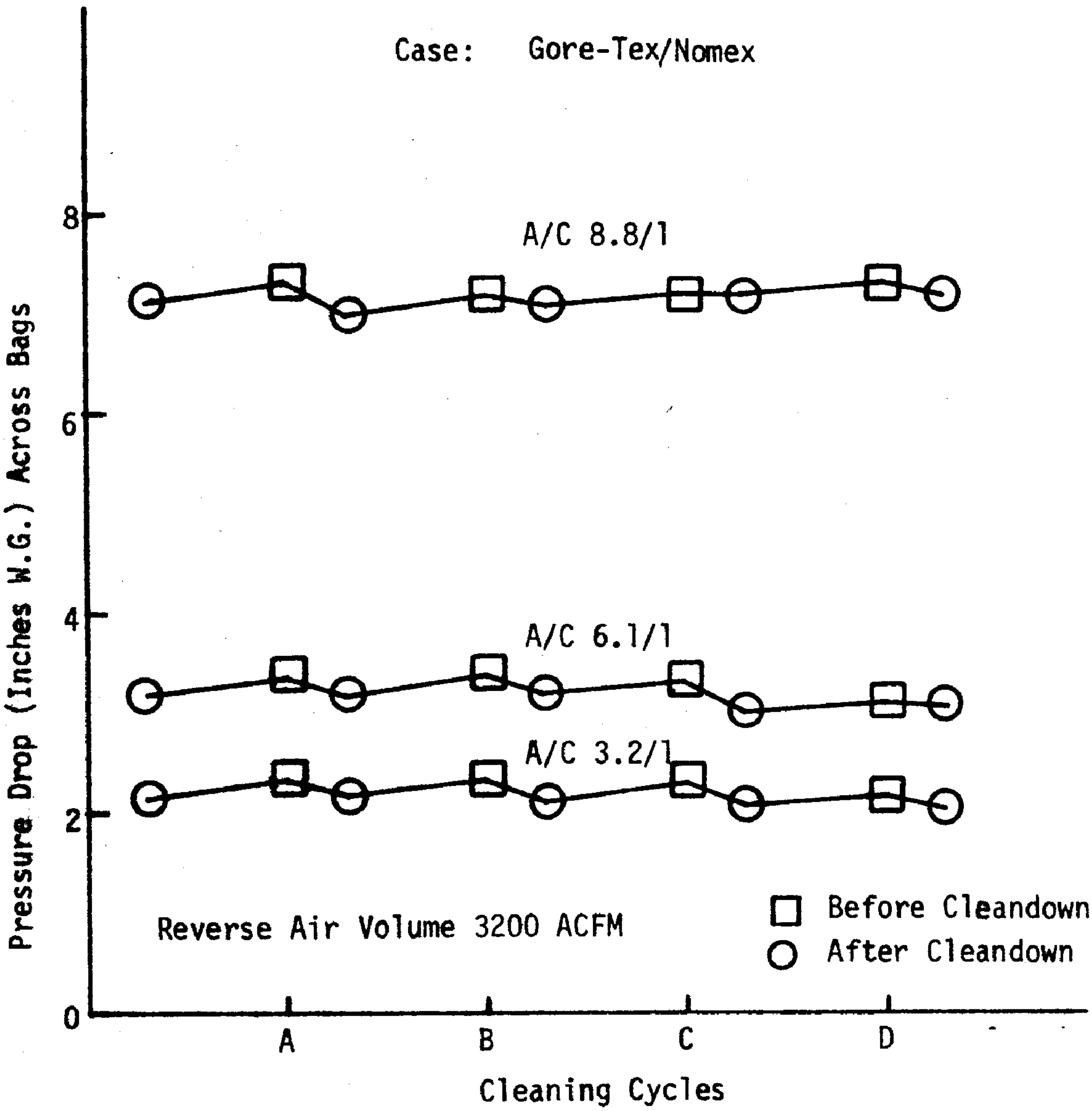


Figure 20

Typical Cleaning Cycles



Dralon-T

Twenty-six Dralon-T bags were placed in Cell 4 (See Figure 21 for bag positioning).

Inlet flue gas volumes ranging from 980 to 2,800 acfm and A/C levels of 3.3/1, 6.1/1 and 8.7/1 were explored.

Average particle size data indicates that 47% of the material penetrating the bags was less than 2 microns at the lowest A/C, 54% was less than 2 microns at 6.1/1, while only 44% was less than 2 microns at an A/C of 8.7/1.

The mass mean particle diameters were 2.8, 1.62 and 2.5 microns for the air-to-cloth ratios in ascending order. The size distribution data is presented in Figure 22.

As is evident in Table 19, Dralon-T exhibited greater filtering capabilities as the A/C ratio increased. This result is further supported by Figures 23 and 24 which show that both overall and particle size efficiency improved as the A/C ratio increased.

Pressure drop comparisons at the three levels of A/C are presented in Figure 25. Examples of typical cleandown cycles are shown in Figure 26.

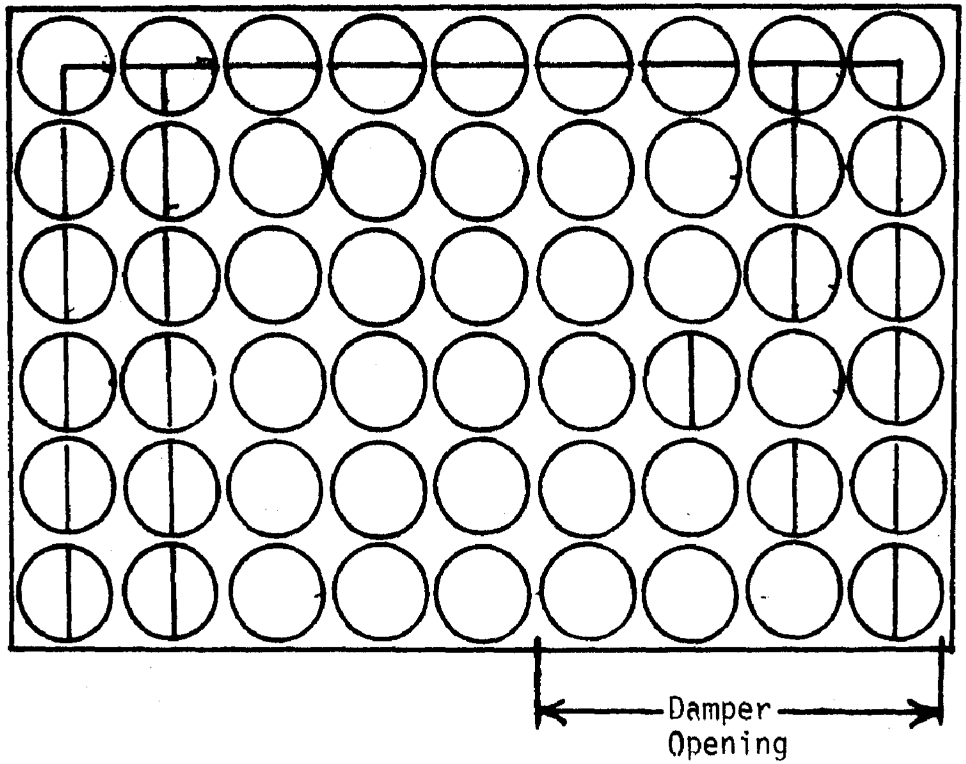
Nomex Felt

Thirty bags were positioned in Cell 4 as per Figure 27. The reverse air fan was off during testing periods. Particle size and concentration data was obtained at air-to-cloth levels of 3, 6 and 8.5 to 1.

A numerical average of the particle size data for the three levels of air-to-cloth is presented in Figure 28.

The curves indicate that the dust penetration by particle size was essentially the same for the three levels of air-to-cloth, with 43% of

Figure 21



KEY:
Dralon T
Plugs

Cell 4

Positioning of Dralon T Bags

Figure 22

Outlet Particle Size Distribution

Dralon T

Note: Corrected for Density and Temperature

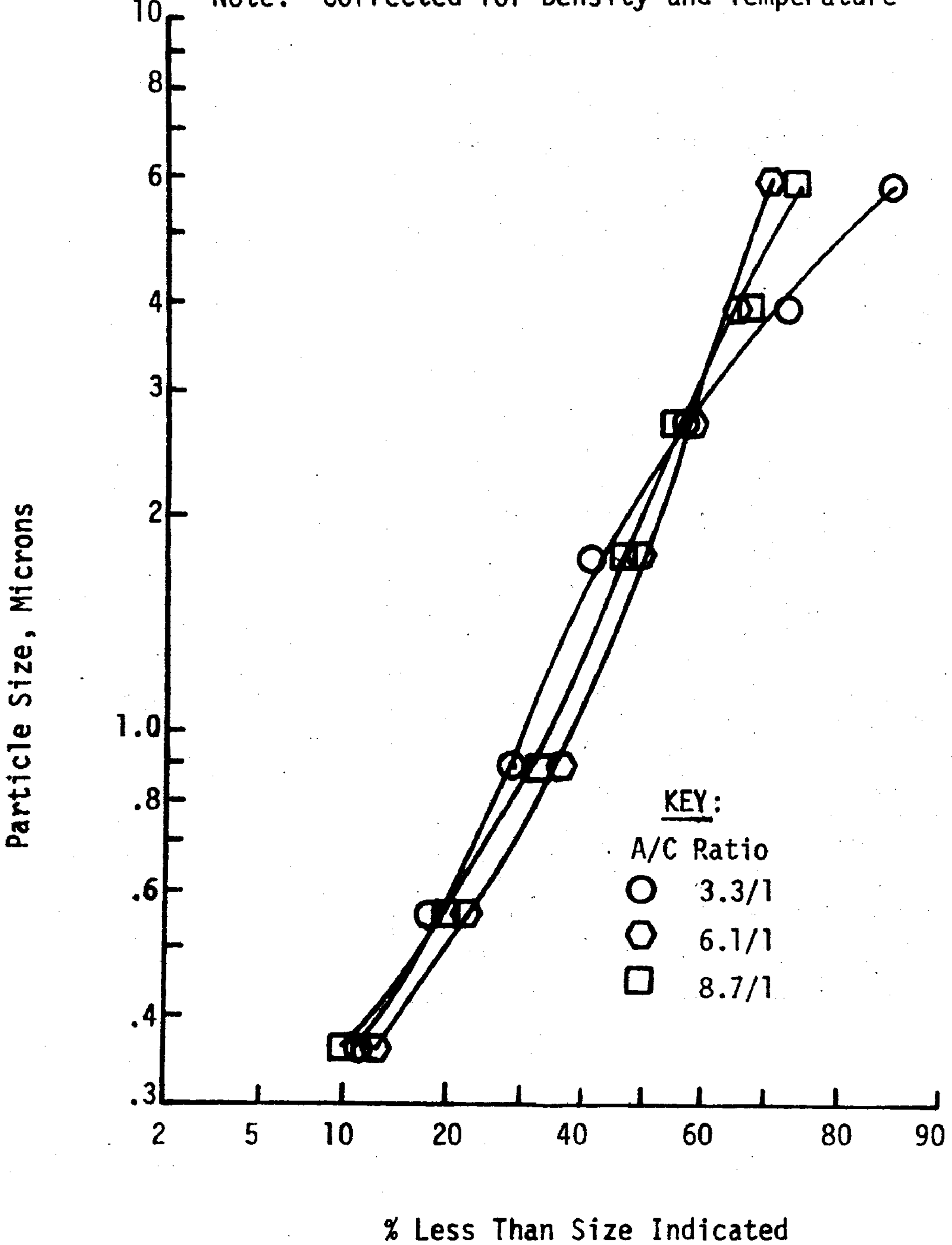


Table 19

Outlet Concentration, Cumulative % and Penetration

Dralon T

	Air-to-Cloth Ratio 3.3/1			Air-to-Cloth Ratio 6.1/1			Air-to-Cloth Ratio 8.7/1		
Avg.(1) Part. Diam. um	Avg. (2) Outlet Conc. Gr./SCFD	Cuml.(3) %	Pene- (4) tration	Avg. Outlet Conc. Gr./SCFD	Cuml. %	Pene- tration	Avg. Outlet Conc. Gr./SCFD	Cuml. %	Pene- tration
>9.37	.00122	100	.0084	.00202	100	.0139	.00144	100	.0099
5.86	.00106	85.94	.0275	.00039	70.39	.0101	.00052	74.29	.0135
3.89	.00144	73.73	.0545	.00048	64.67	.0182	.00055	65.00	.0208
2.7	.00133	57.14	.1033	.00060	57.63	.0466	.00051	55.18	.0396
1.73	.00114	41.82	.0893	.00087	48.83	.0682	.00073	46.07	.0572
.89	.00092	28.69	.1873	.00094	36.07	.1911	.00074	33.03	.1504
.55	.00061	18.09	.2559	.00066	22.29	.2444	.00055	19.82	.2037
.36	.00046	11.06	.1549	.00048	12.61	.1616	.00034	10.00	.1145
< .36	.00050	5.76	.1166	.00038	5.57	.0886	.00022	3.93	.0513
TOTAL	.00868		.0346	.00682		.0272	.00560		.0223

1. Corrected for particle density (2.6 Grams/C.C.) and stack temperature.
2. At 3.3/1 two (2) tests averaged, at 6.1/1 six (6) tests averaged, at 8.7/1 two (2) test averaged.
3. Percent of total outlet concentration less than size indicated.
4. Penetration based on average inlet concentration at corresponding impactor stages.

Figure 23

Outlet Concentration by Particle Size

vs.

Air-to-Cloth Ratio

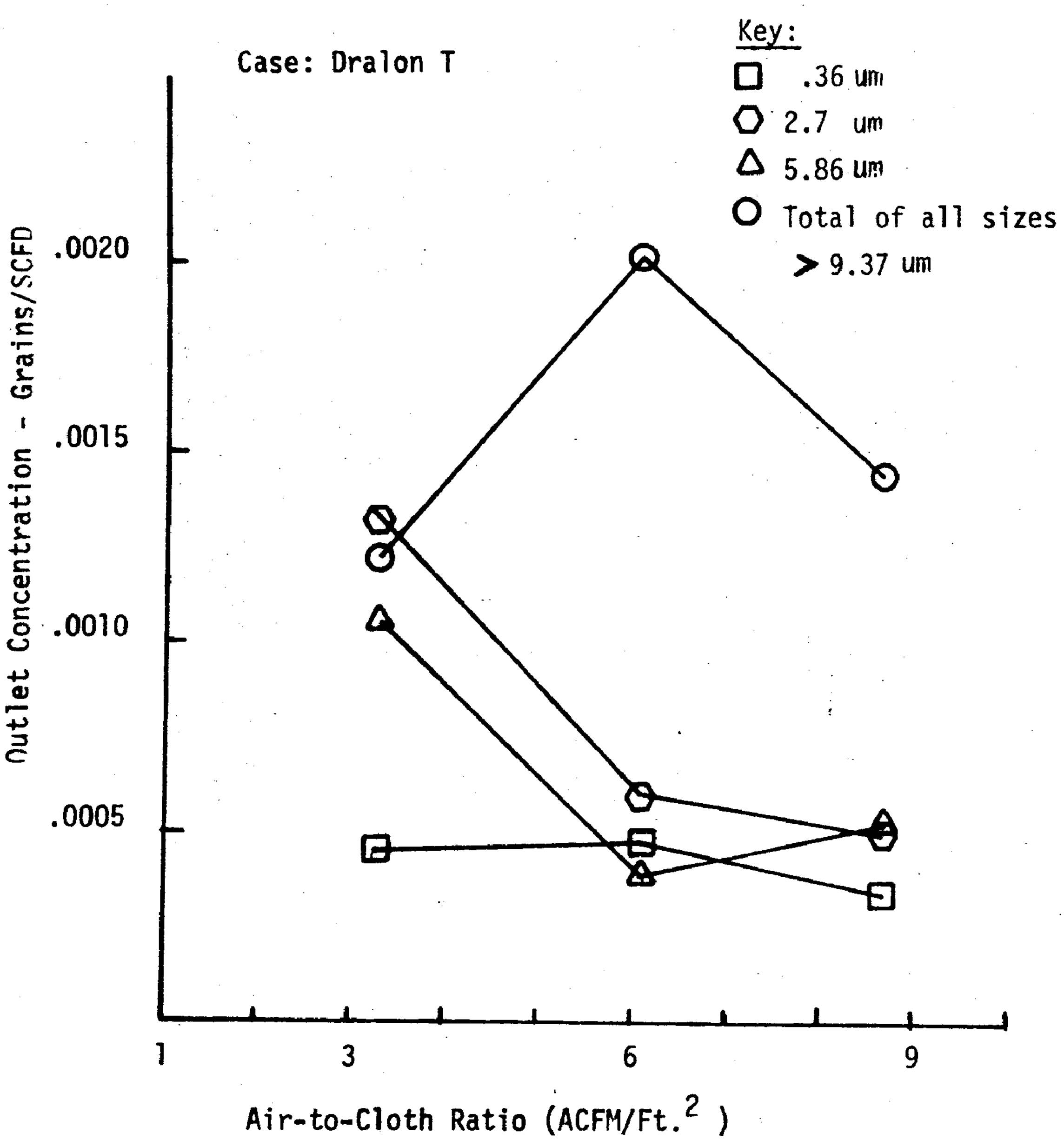


Figure 24

Penetration vs. Particle Diameter

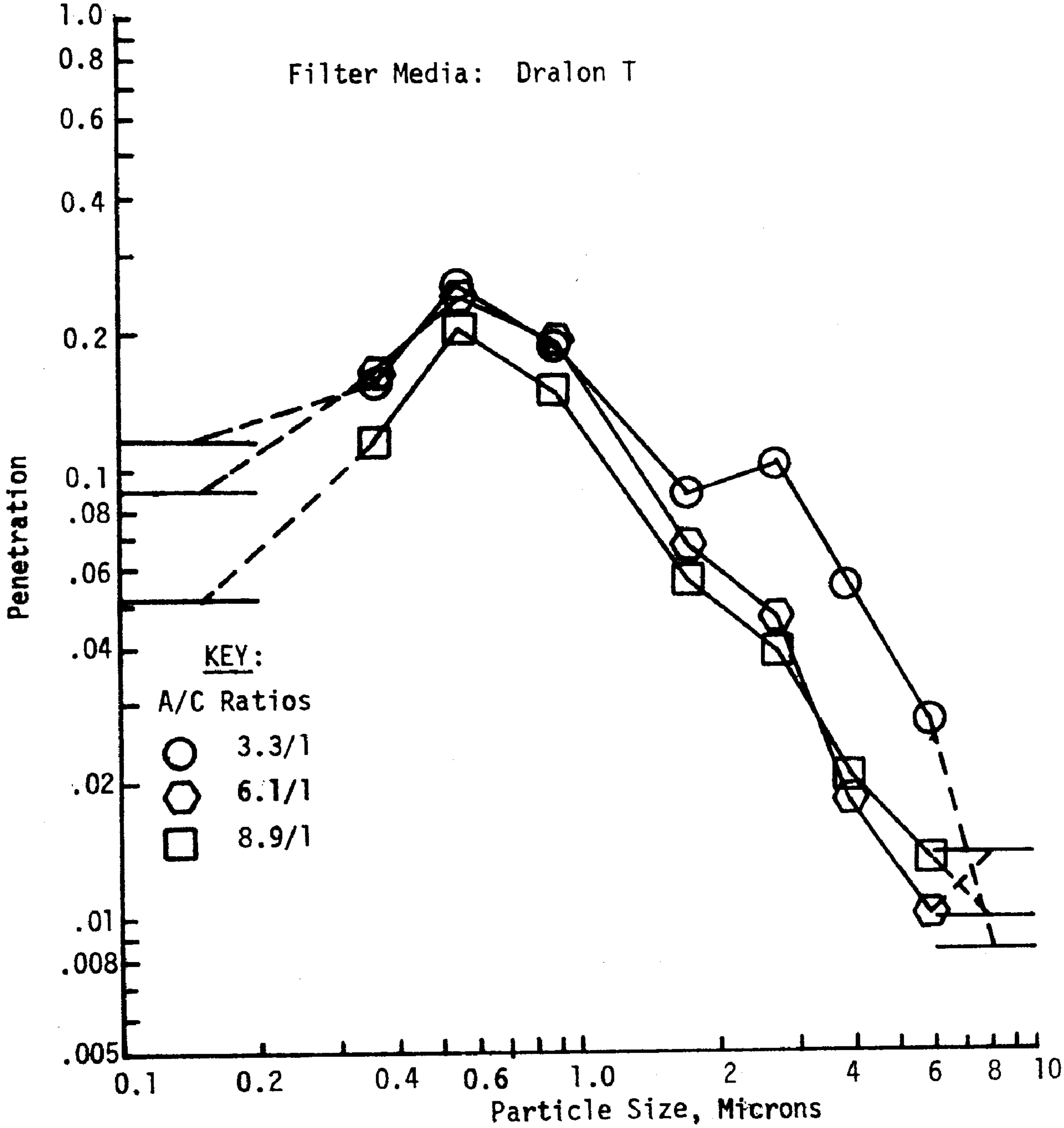


Figure 25

Pressure Drop Across Bags

vs.

Air-to-Cloth Ratio

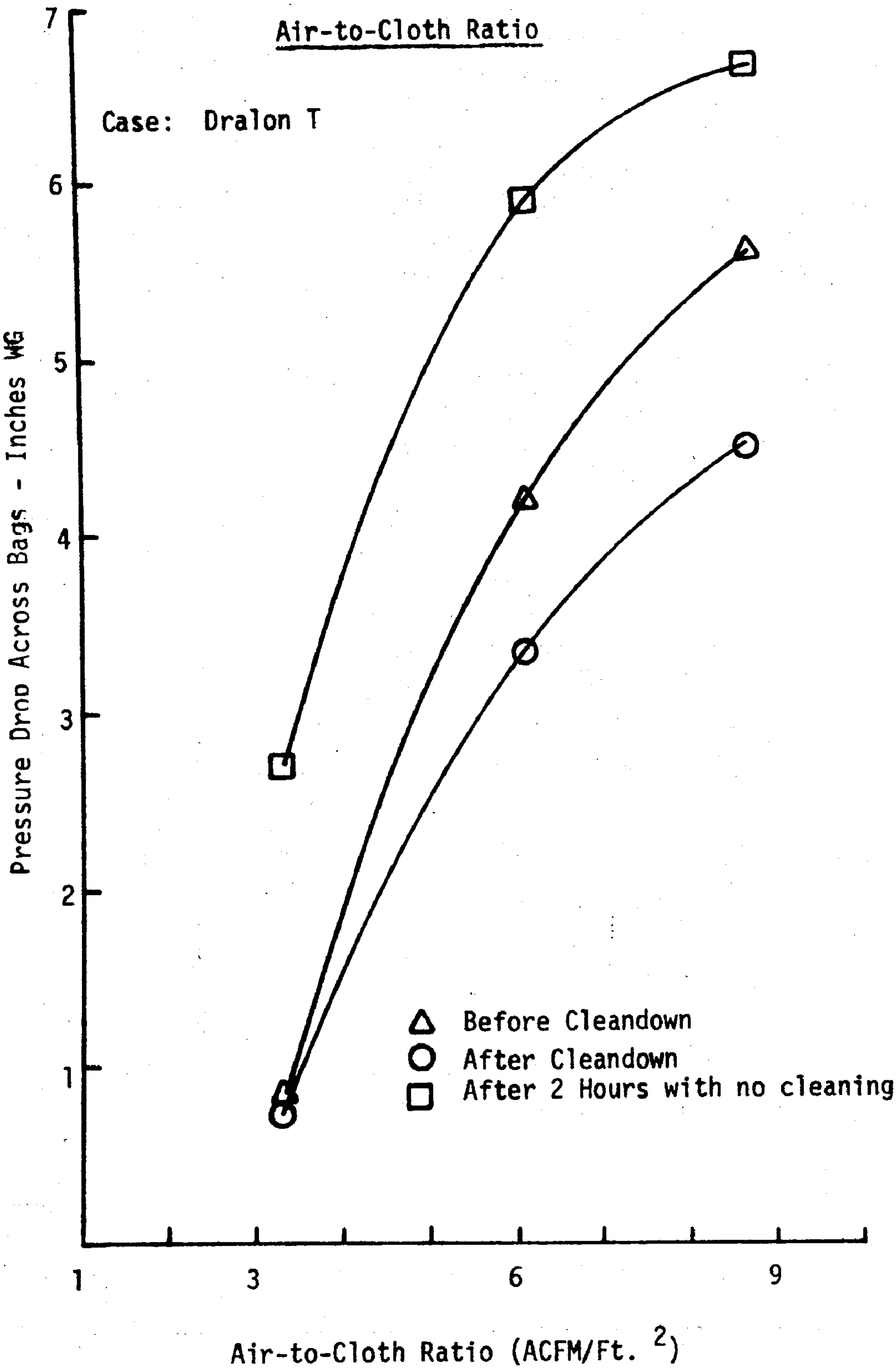


Figure 26

Typical Cleandown Cycles

Dralon T

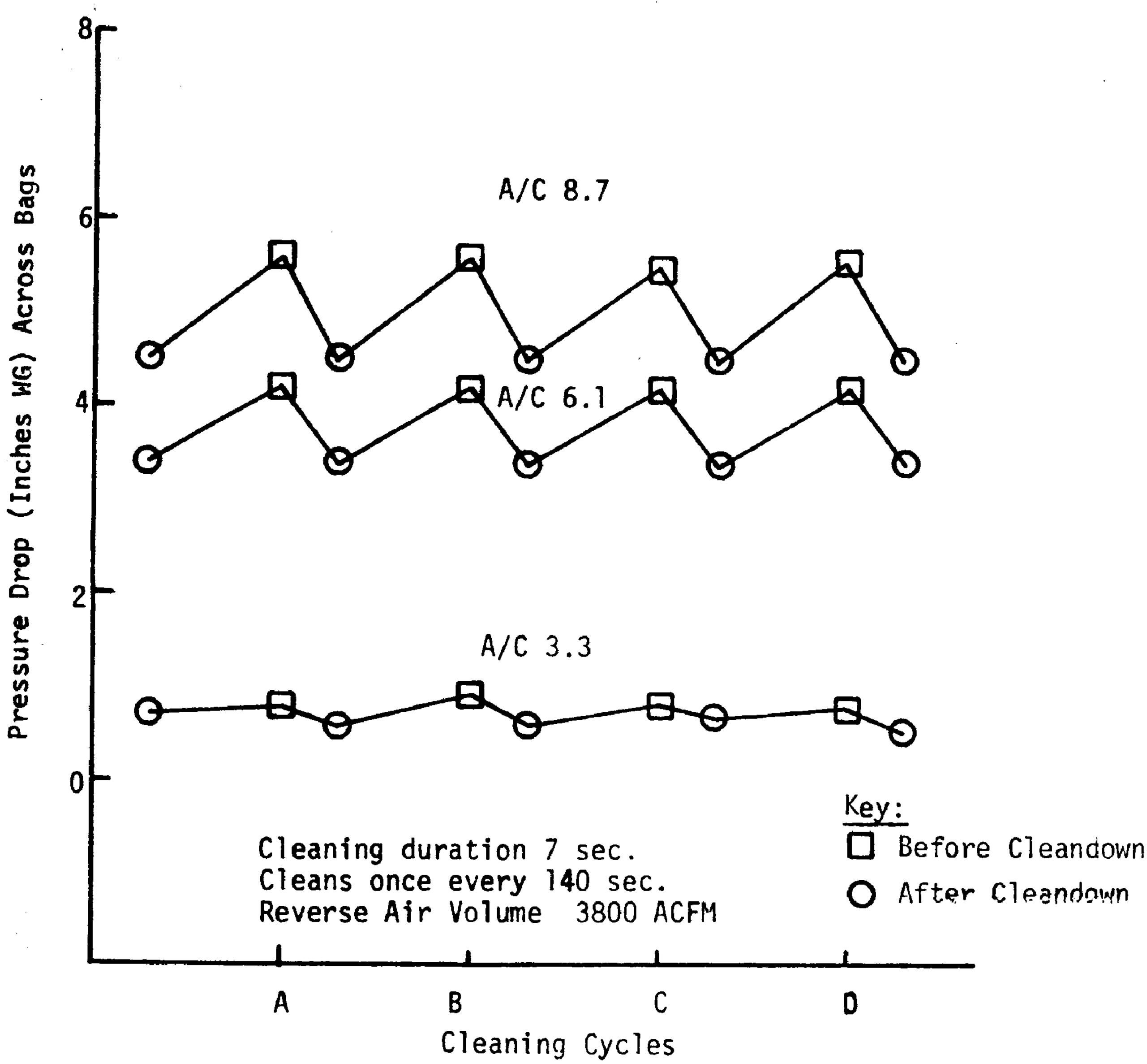
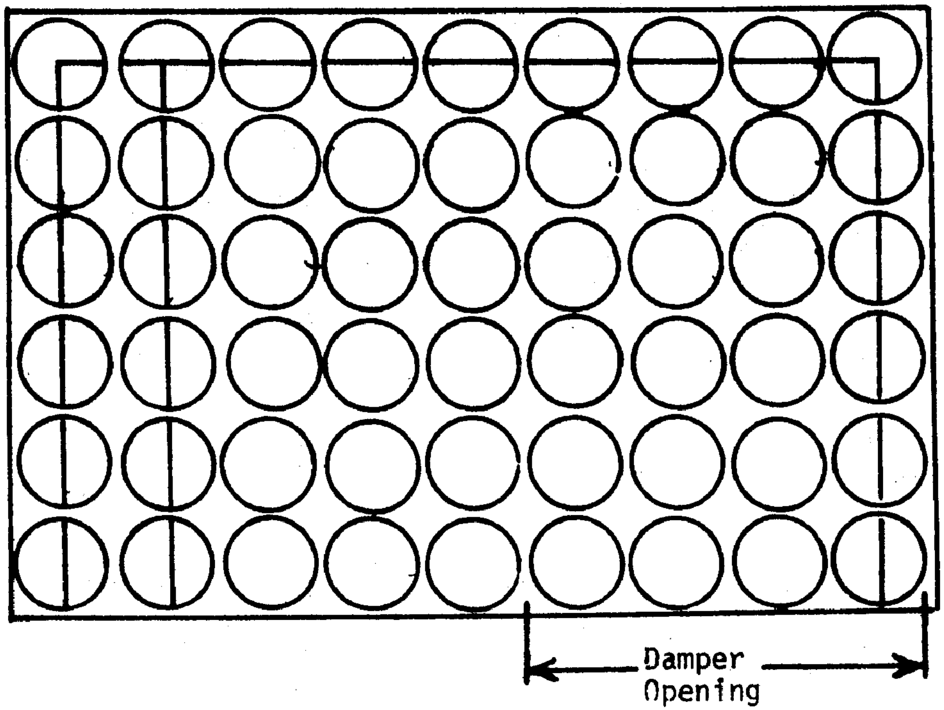


Figure 27



KEY:
Nomex Felt
Plugs

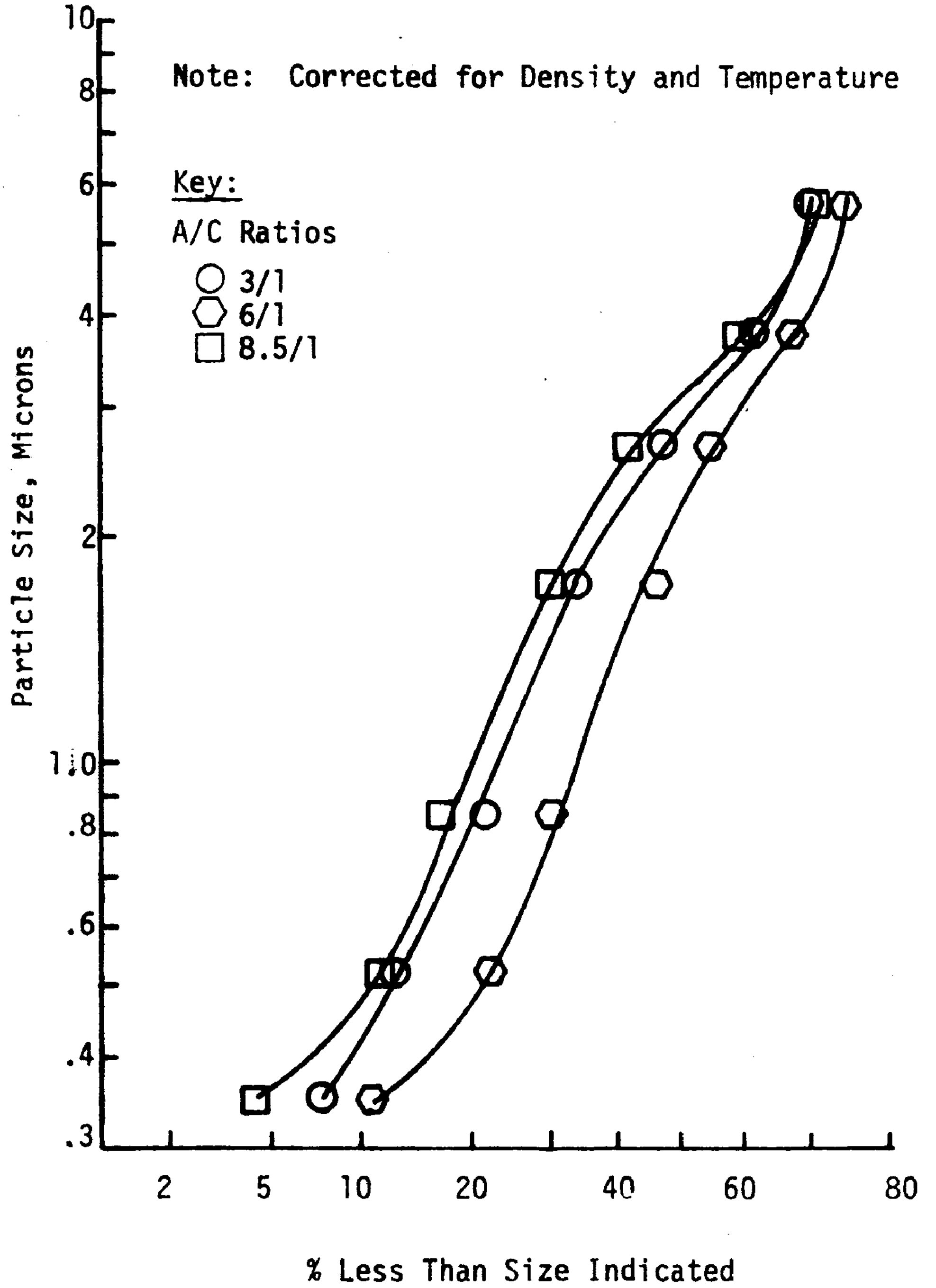
Cell 4

Positioning of Nomex Felt Bags

Figure 28

Outlet Particle Size Distribution

Nomex Felt



the particulate, by weight, less than 2 microns at A/C of 3 to 1 and 5.8/1 and 54% less than 2 microns at 6/1.

When compared with the other bag materials, Nomex showed the greatest propensity for filtering efficiency.

Average outlet concentration, cumulative percent and penetration by particle size, for the three levels of air-to-cloth are listed in Table 20. Figure 29 shows outlet concentration by particle size.

Penetration vs. particle diameter is plotted in Figure 30. Again the higher efficiency for the larger particles is evident. All three curves indicate a significant decrease in penetration of the two smallest fractions.

In addition to the aforementioned tests, a number of other parameters were studied with Nomex felt as the filter media. These included the effect of duration and volume of cleaning air on particle size efficiency, cleandown and operating pressure drop.

To determine the effect reverse air volume has on filtering efficiency, the Andersen sampler was utilized in obtaining in-situ particle size data at air-to-cloth ratios of 3.4, 6.4 and 8.9 to 1 and reverse air volumes of 1,400, 3,160 and 4,000 acfm. The reverse air fan was employed continuously (including during sampling periods). Duplicate tests were performed at each combination of air-to-cloth ratio and reverse air volume. Outlet concentration, cumulative percent and penetration by particle size for three levels of reverse air at A/C ratios of 3.4/1, 6.4/1 and 8.9/1 are given in Tables 21, 22 and 23 respectively.

As shown in Figure 31, the data indicates that higher collection efficiencies are possible when the reverse air fan is not employed and that varying the volume of reverse air (once in operation) has little effect on overall efficiency.

Table 20

Outlet Concentration, Cumulative % and Penetration

Nomex Felt - Zero RA

Avg.[1] Part. Diam. um	Air-to-Cloth Ratio 3/1: Avg.[2] Outlet Conc. Gr./SCFD	Air-to-Cloth Ratio 3/1: Cuml.[3] %	Air-to-Cloth Ratio 3/1: Pene-tration[4]	Air-to-Cloth Ratio 6/1: Avg. Outlet Conc. Gr./SCFD	Air-to-Cloth Ratio 6/1: Cuml. %	Air-to-Cloth Ratio 6/1: Pene-tration	Air-to-Cloth Ratio 8.5/1: Avg. Outlet Conc. Gr./SCFD	Air-to-Cloth Ratio 8.5/1: Cuml. %	Air-to-Cloth Ratio 8.5/1: Pene-tration
>8.98	.00064	100	.0044	.00074	100	.0051	.00171	100	.0118
5.62	.00017	70.37	.0044	.00021	74.9	.0045	.00064	71.21	.0166
3.76	.00032	62.5	.0121	.00037	67.80	.0140	.00109	60.44	.0412
2.68	.00029	47.68	.0225	.00026	55.25	.0202	.00065	42.09	.0505
1.73	.00027	34.26	.0212	.00048	46.44	.0376	.00084	31.14	.0658
.85	.00020	21.76	.0406	.00023	30.17	.0467	.00032	17.0	.0650
.52	.00011	12.5	.0407	.00034	22.37	.1259	.00043	11.62	.1593
.35	.00008	7.4	.0269	.00010	10.85	.0337	.00007	4.4	.0236
<.35	.00008	3.7	.0186	.00022	7.46	.0513	.00019	3.2	.0443
TOTAL	.00216		.0086	.00295		.0118	.00594		.0237

1. Corrected for particle density (2.6 Grams/C.C.) and stack temperature.
2. At 3/1 three (3) tests averaged, at 6/1 three (3) tests averaged, at 8.5/1 two (2) tests averaged.
3. Percent of total outlet concentration less than size indicated.
4. Penetration based on average inlet concentration at corresponding impactor stages.

Figure 29

Outlet Concentration by Particle Size

vs.

Air-to-Cloth Ratio

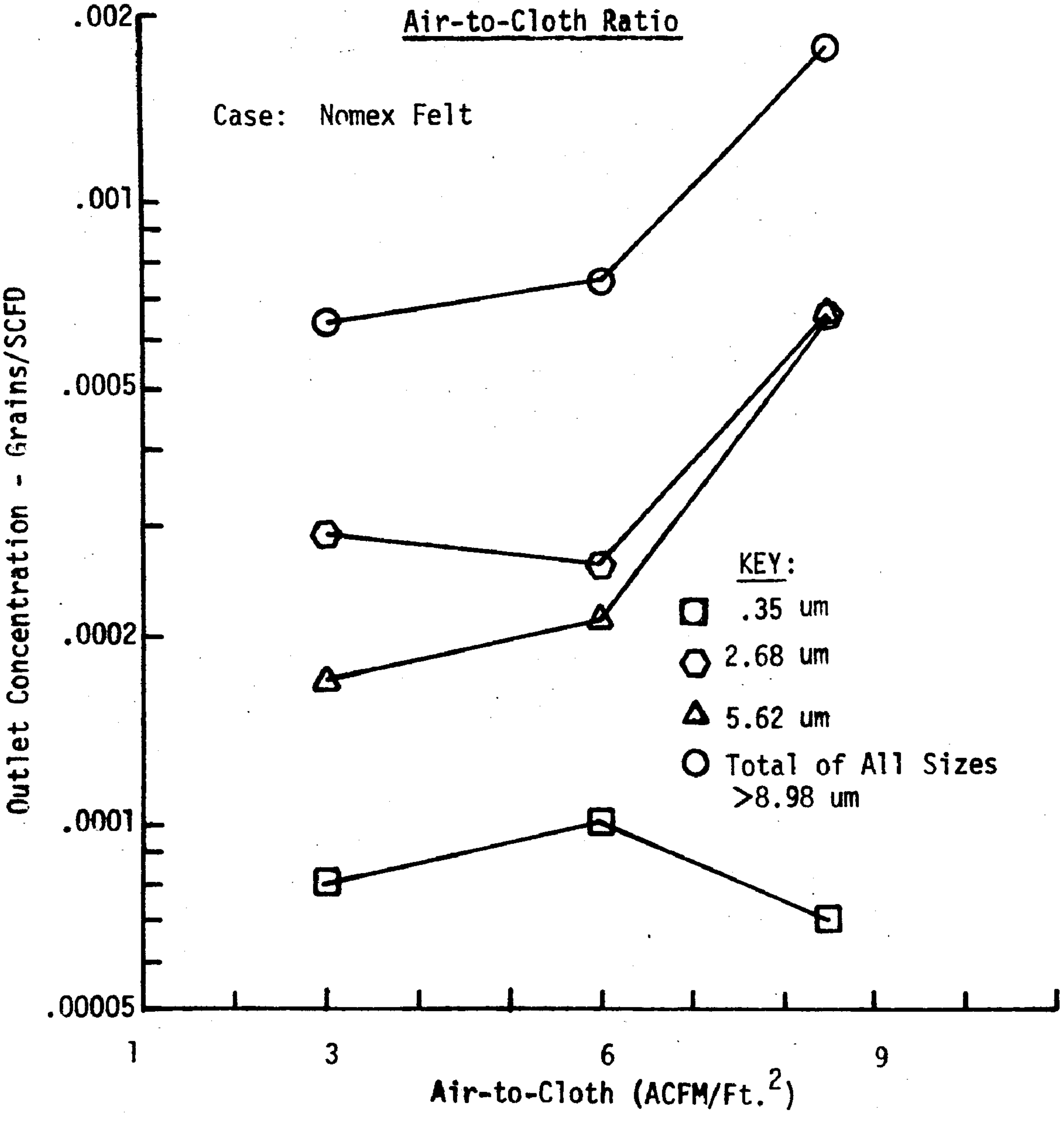


Figure 30

Penetration vs. Particle Diameter

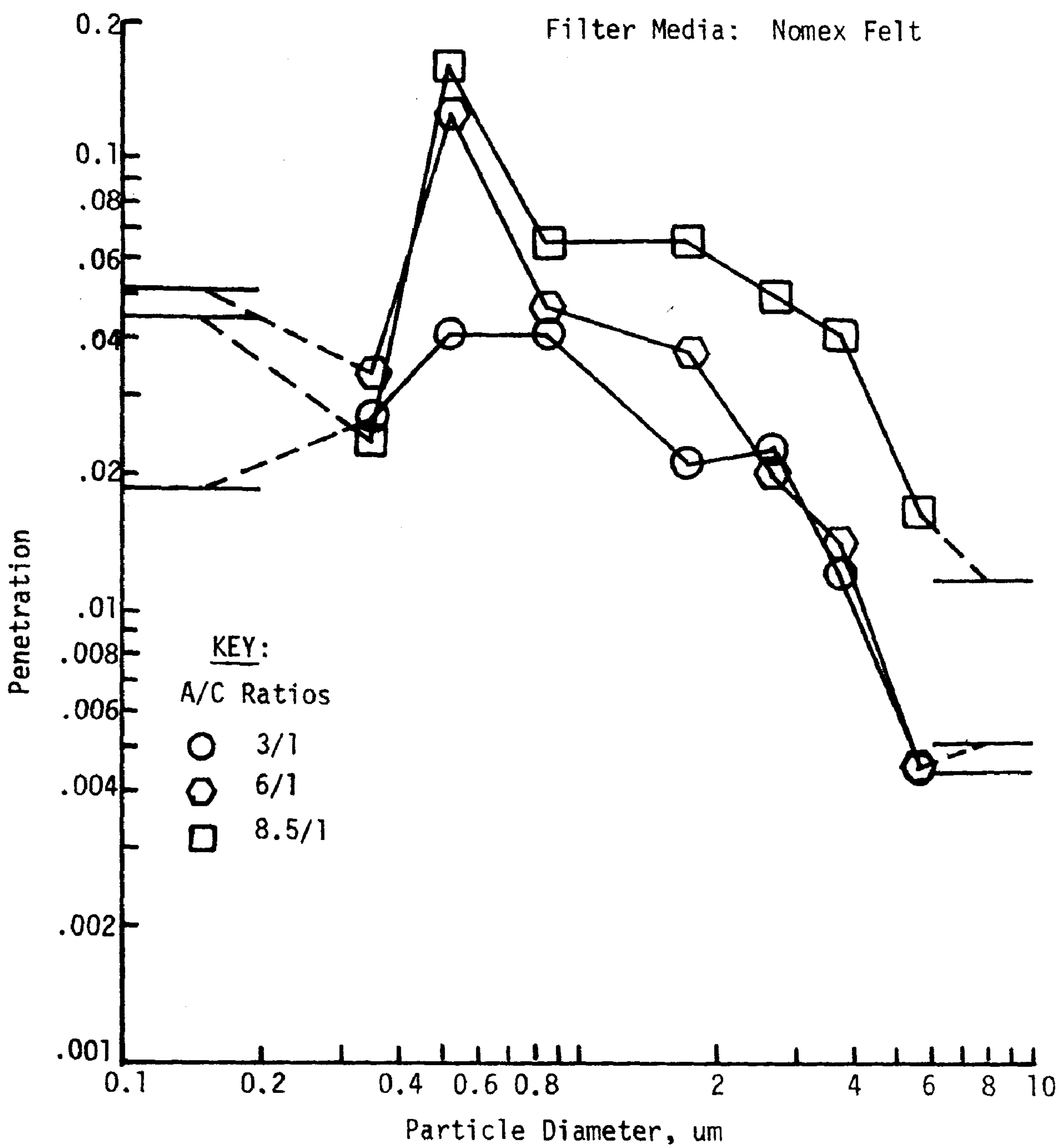


Table 21

Outlet Concentration, Cumulative % and Penetration

Nomex Felt - Three Levels Reverse Air
A/C 3.4/1

	Reverse Air 1400 ACFM			Reverse Air 3100 ACFM			Reverse Air 4000 ACFM		
Avg.[1] Part. Diam. um	Avg. (2) Outlet Conc. Gr./SCFD	Cuml.[3] %	Pene-[4] tration	Avg. Outlet Conc. Gr./SCFD	Cuml. %	Pene- tration	Avg. Outlet Conc. Gr./SCFD	Cuml. %	Pene- tration
> 9.31	.00126	100	.0087	.00110	100	.0076	.00109	100	.0075
5.89	.00041	69.77	.0106	.00033	57.19	.0086	.00034	64.83	.0088
3.88	.00046	59.94	.0174	.00029	44.35	.0110	.00031	53.86	.0117
2.73	.00019	48.91	.0148	.00016	33.07	.0124	.00029	43.86	.0225
1.82	.00048	44.35	.0376	.00021	26.84	.0165	.00033	34.51	.0259
.89	.00041	32.84	.0833	.00022	18.67	.0447	.00028	23.86	.0569
.54	.00030	23.01	.1111	.00006	10.11	.0222	.00020	14.83	.0741
.36	.00039	15.82	.1313	.00013	7.78	.0438	.00017	8.38	.0572
< .36	.00027	6.47	.0629	.00007	2.72	.0163	.00009	2.9	.0210
TOTAL	.00417		.0166	.00257		.0102	.00310		.0124

1. Corrected for particle density (2.6 grams/C.C.) and stack temperature.
2. Two (2) tests averaged for all cases.
3. Percent of total outlet concentration less than size indicated.
4. Penetration based on average inlet concentration at corresponding impactor stages.

Table 22

Outlet Concentration, Cumulative % and Penetration

Nomex Felt - Three Levels Reverse Air
A/C 6.4/1

Avg. (1) Part. Diam. um	Reverse Air 1400 ACFM Avg. (2) Outlet Conc. Gr./SCFD	Cuml. (3) %	Pene- (4) tration	Reverse Air 3100 ACFM Avg. Outlet Conc. Gr./SCFD	Cuml. %	Pene- tration	Reverse Air 4000 ACFM Avg. Outlet Conc. Gr./SCFD	Cuml. %	Pene- tration
> 9.31	.00133	100	.0091	.00182	100	.0125	.00107	100	.0074
5.89	.00096	74.67	.0249	.00078	71.92	.0203	.00074	82.20	.0192
3.88	.00076	56.38	.0288	.00073	59.88	.0276	.00094	69.89	.0356
2.73	.00080	41.90	.0622	.00073	48.61	.0567	.00071	54.25	.0552
1.82	.00037	26.66	.0290	.00061	37.34	.0478	.00065	42.44	.0509
.89	.00049	19.61	.0996	.00058	27.93	.1179	.00052	31.62	.1057
.54	.00003	10.28	.0111	.00040	18.98	.1481	.00051	22.97	.1889
.36	.00041	9.71	.1380	.00054	12.81	.1818	.00044	14.48	.1481
< .36	.00010	1.9	.0233	.00029	4.48	.0676	.00043	7.15	.1002
TOTAL	.00525		.0209	.00648		.0258	.00601		.0240

1. Corrected for particle density (2.6 grams/C.C.) and stack temperature.
2. Two (2) tests averaged for all cases.
3. Percent of total outlet concentration less than size indicated.
4. Penetration based on average inlet concentration at corresponding impactor stages.

Table 23

Outlet Concentration, Cumulative % and Penetration

Nomex Felt - Three Levels Reverse Air
A/C 8.9/1

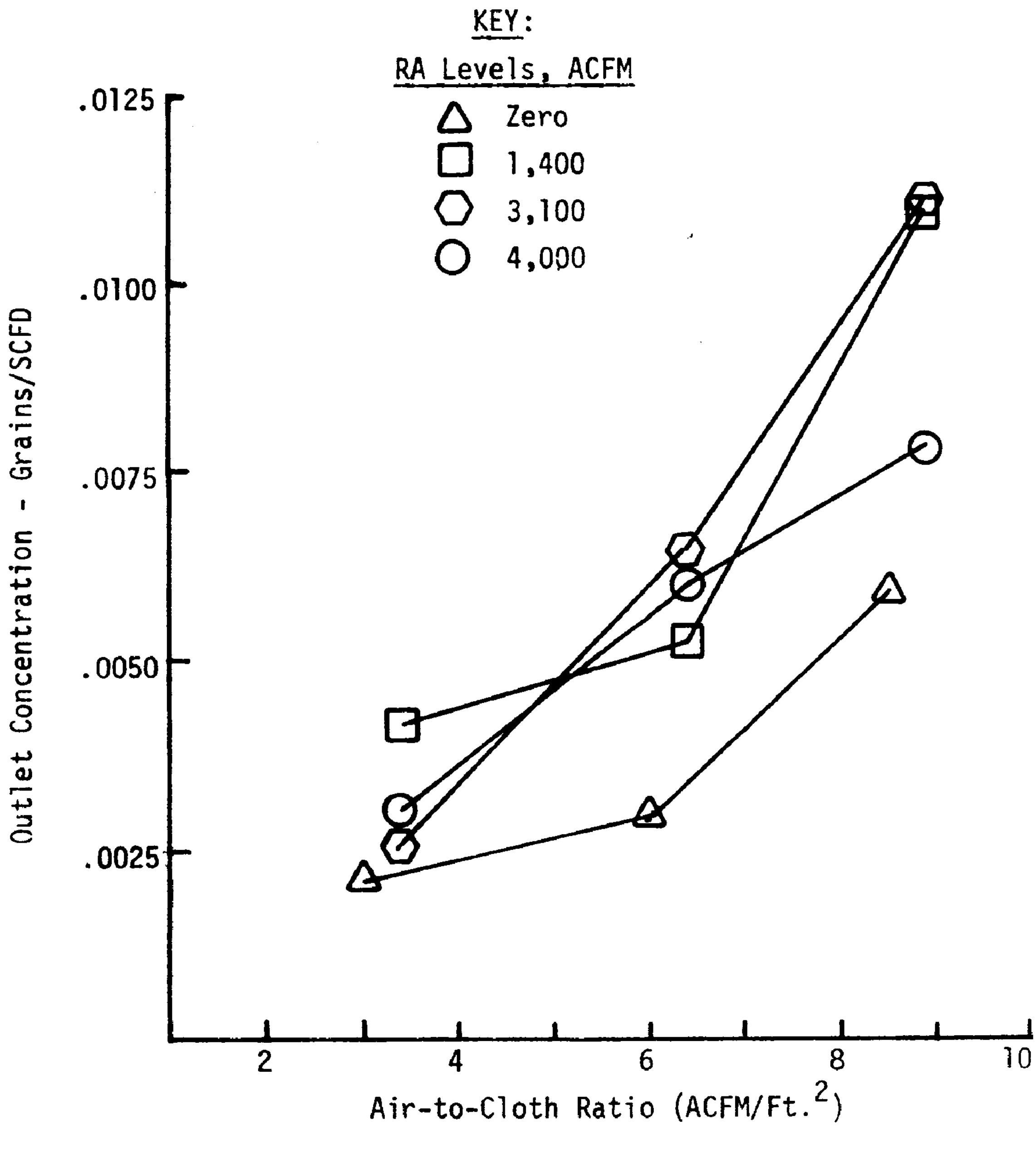
	Reverse Air 1400 ACFM			Reverse Air 3100 ACFM			Reverse Air 4000 ACFM		
Avg. Part. Diam. um [1]	Avg. Outlet Conc. Gr./SCFD [2]	Cuml. % [3]	Pene-tration [4]	Avg. Outlet Conc. Gr./SCFD	Cuml. %	Pene-tration	Avg. Outlet Conc. Gr./SCFD	Cuml. %	Pene-tration
> 9.31	.00322	100	.0221	.00226	100	.0155	.00252	100	.0173
5.89	.00141	70.41	.0366	.00102	79.62	.0265	.00117	67.81	.0304
3.88	.00186	57.45	.0704	.00175	70.42	.0662	.00131	52.87	.0496
2.73	.00145	40.35	.1127	.00187	54.64	.1453	.00114	36.14	.0886
1.82	.00159	27.02	.1246	.00217	37.78	.1701	.00053	21.53	.0415
.89	.00038	12.41	.0772	.00070	18.21	.1423	.00065	14.81	.1321
.54	.00069	8.92	.2556	.00059	11.90	.2185	.00007	6.51	.0259
.36	.00008	2.58	.0269	.00053	6.58	.1785	.00042	5.62	.1414
< .36	.00020	1.84	.0466	.00020	1.8	.0466	.00002	.26	.0047
TOTAL	.01088		.0434	.01109		.0442	.00783		.0312

1. Corrected for particle density (2.6 grams/C.C.) and stack temperature.
2. Two (2) tests averaged for all cases.
3. Percent of total outlet concentration less than size indicated.
4. Penetration based on average inlet concentration at corresponding impactor stages.

Figure 31

Outlet Concentration vs. Air-to-Cloth Ratio for Different Levels of Reverse Air

Case: Nomex Felt



Figures 32, 33, 34 and 35 further illustrate that air-to-cloth ratio, rather than varying the level of reverse air volume, is the key parameter in predicting baghouse efficiency. It is significant that these four figures show an increase in outlet loading with increasing velocity for the three larger fractions while the outlet loading for the smallest fraction do not seem to increase above an A/C ratio of 6/1.

The reverse air volume has a significant influence on the operating pressure of the baghouse. Figure 36 demonstrates quite vividly that increasing the reverse air volume decreases the pressure drop across the bags.

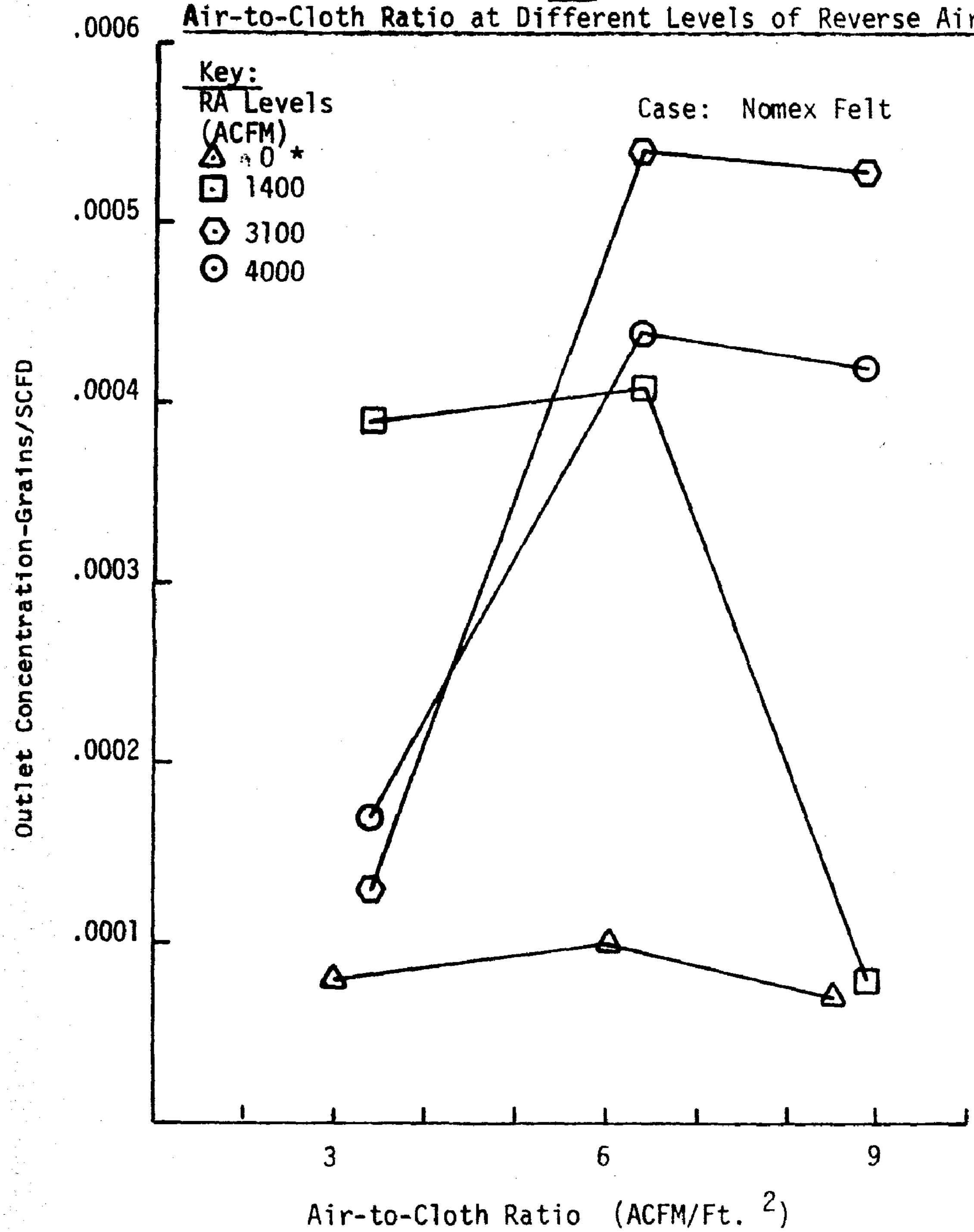
Tests were conducted on duration of cleaning time. These studies were made at 7, 15 and 25 seconds. As shown in Figure 37, no significant improvement in the cleandown pressure drop was observed when the cleaning duration was increased. Obviously, there is a point where duration of cleaning time has a significant influence on bag cleaning efficiency; apparently this takes place at some duration less than 7 seconds.

The Nomex bags were subjected to a total of 195 hours on stream. Table 24 shows a comparison of Nomex bag characteristics for new bags and bags exposed for 195 hours. The physical property measurements show a significant 40-60% reduction in tensile level which undoubtedly results from hydrolytic attack by the SO_2-SO_3-H_2O in the flue gas. Better than 90% property retention would be expected for Nomex in a neutral environment. The drop in inherent viscosity (a measure of chain scission) confirms the hydrolytic attack theory.

The hydrolytic attack was anticipated based on earlier studies.[3] An attempt was made to minimize the degeneration of Nomex felt bags by coating the bags with lime at the time of installation and daily thereafter. The lime coating was accomplished by introducing 100 lbs. of lime into the house thru the clean air port while the system fan was running. The liming procedure was conducted during the daily start-up

Figure 32

Outlet Concentration (Particle Diameter .36 Microns)
vs.
Air-to-Cloth Ratio at Different Levels of Reverse Air



* Particle Diameter .35 Microns for Zero Reverse Air

Figure 33

Outlet Concentration (Particle Diameter 2.73 Microns

vs.

Air-to-Cloth Ratio of Different Levels of Reverse Air

Case: Nomex Felt

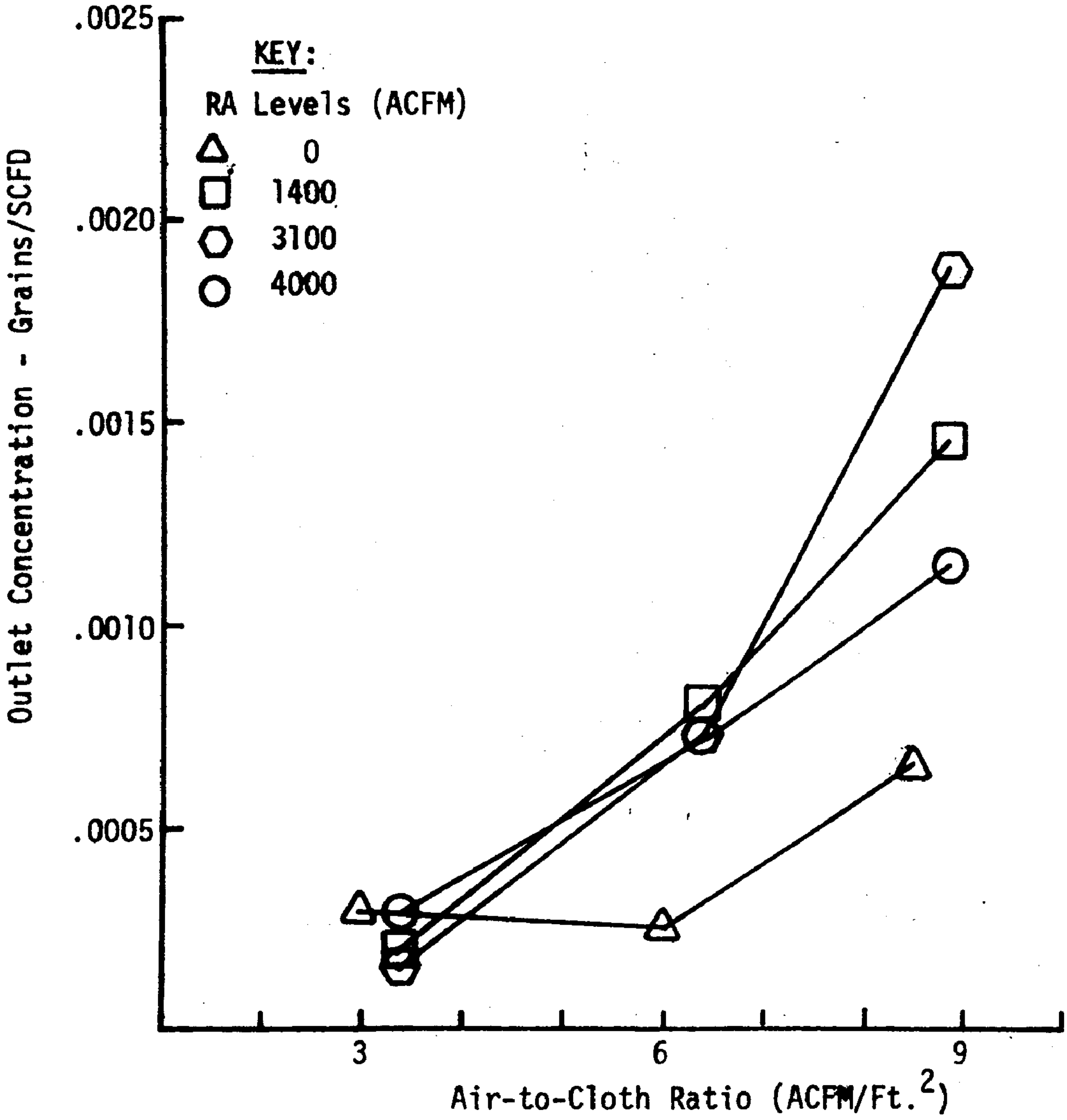
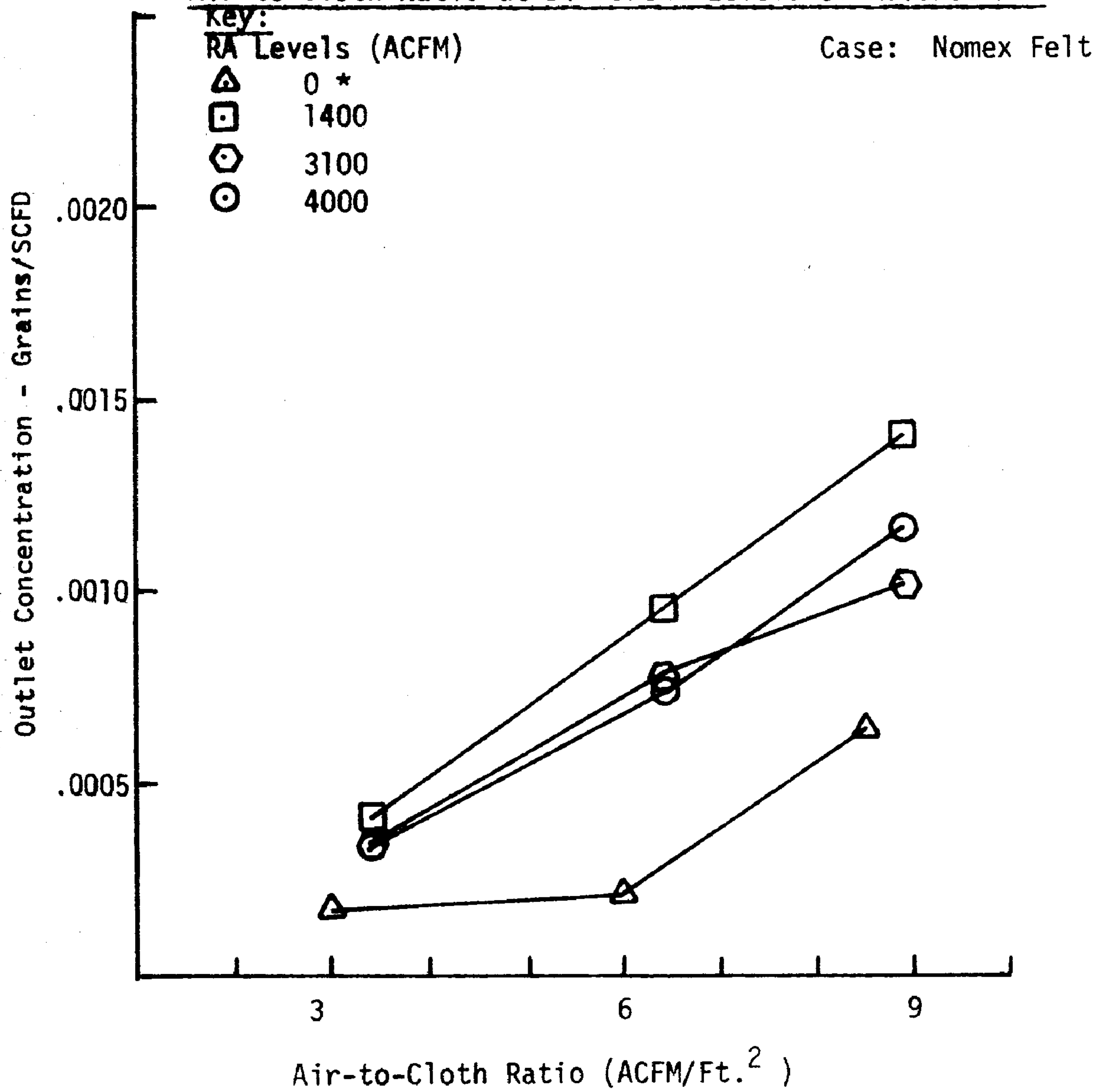


Figure 34

Outlet Concentration (Particle Diameter 5.89 Microns)

vs.

Air-to-Cloth Ratio at Different Levels of Reverse Air



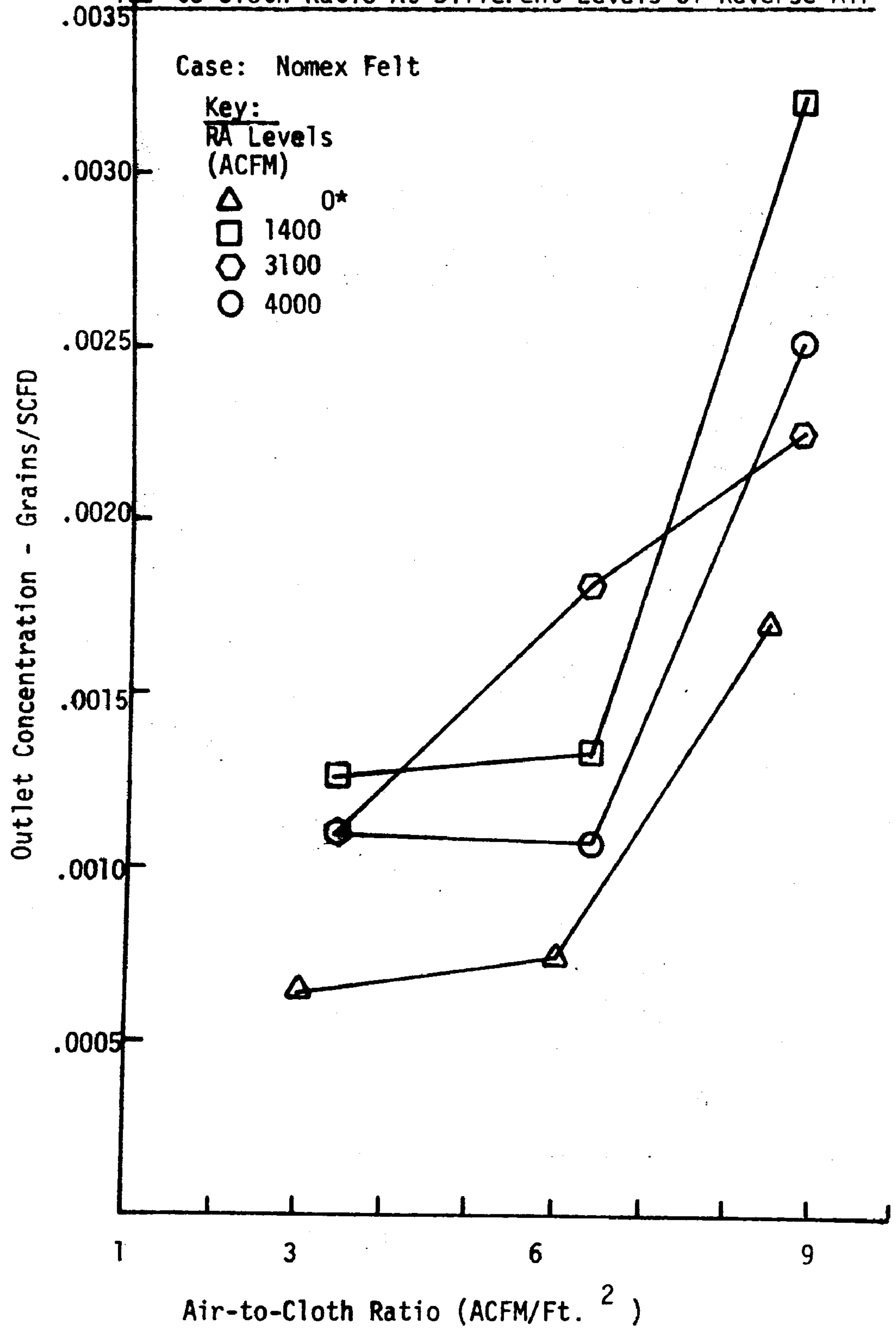
* Particle Diameter 5.62 Microns for Zero Reverse Air

Figure 35

Outlet Concentration (Particle Diameter > 9.31 Microns)

vs.

Air-to-Cloth Ratio At Different Levels of Reverse Air



* Particle Diameter > 8.98 for Zero Reverse Air

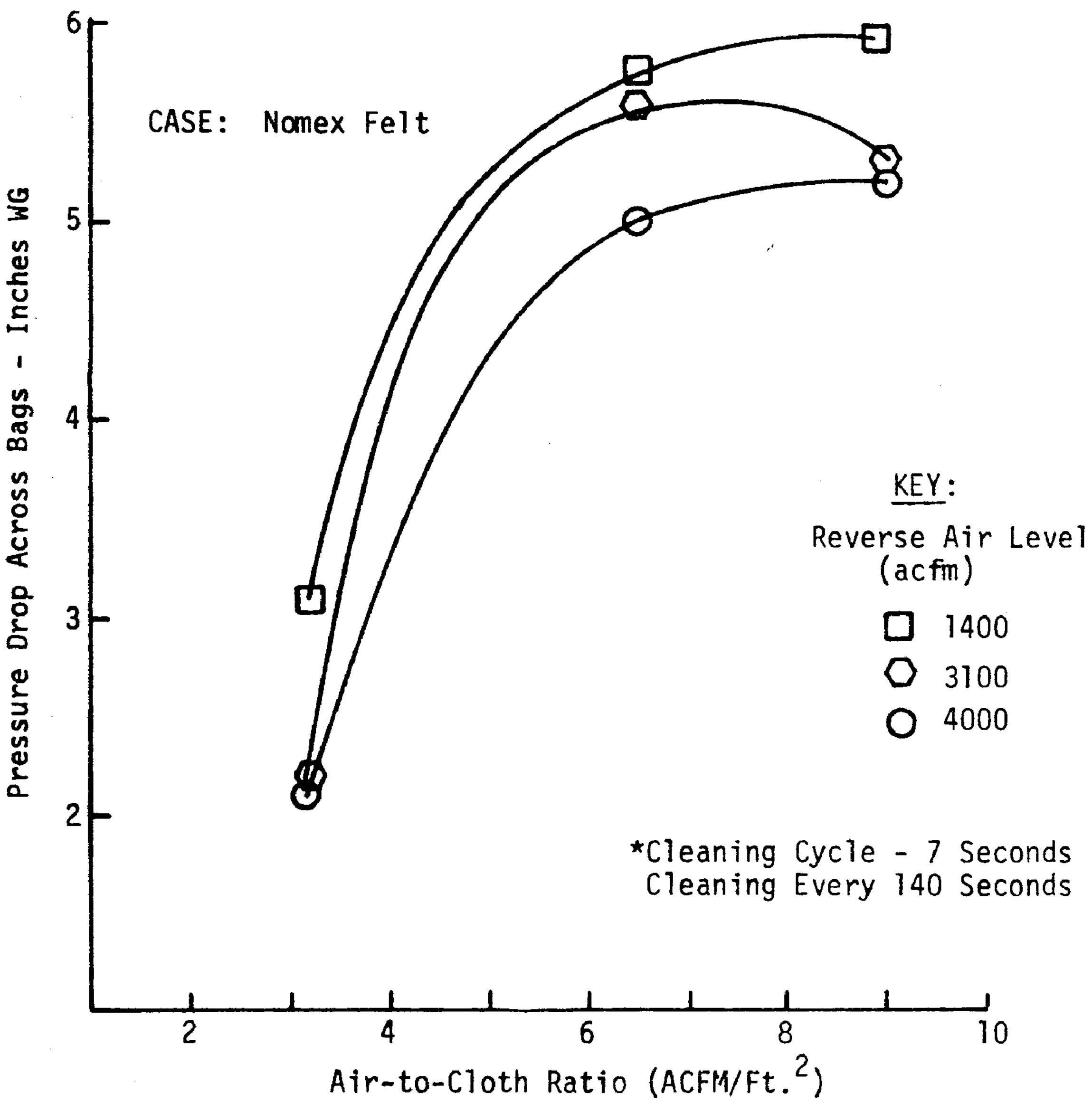
Figure 36

Pressure Drop

vs.

Air-to-Cloth for 3 Levels of Reverse Air

(Values obtained just after cleandown during normal cleaning cycle.*)



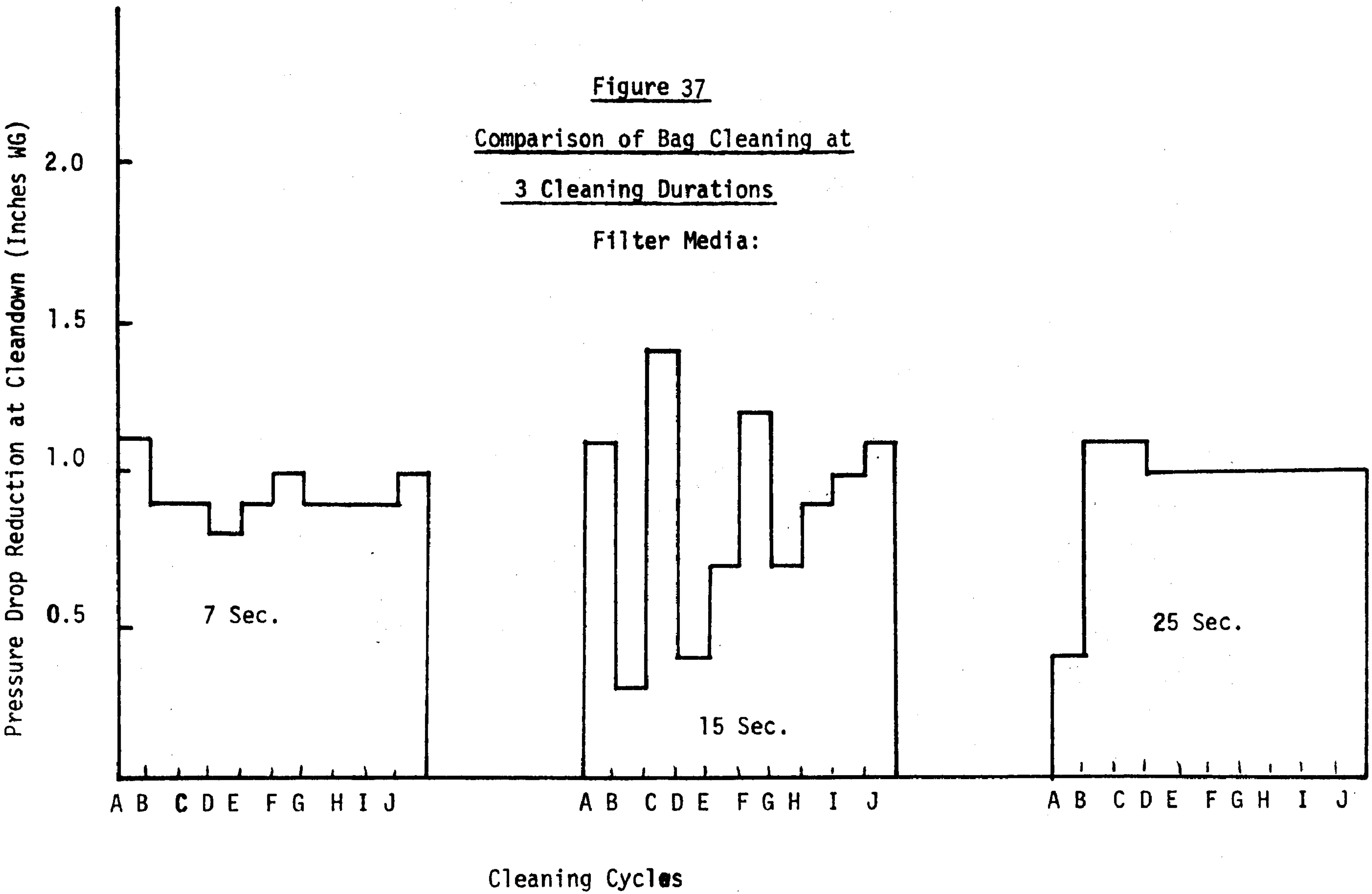


Figure 37

Comparison of Bag Cleaning at

3 Cleaning Durations

Filter Media:

Table 24

Analysis of Nomex Felt Properties*

	Properties	
	New Bag	Exposed 195 Hrs.
Weight, Oz./Yd.^{2}	15.9	14.7
Thickness, Mils	99	112
Strip Tensile (MD/XD)**		
Breaking Strength, Lbs./In.	74/211	57/125
Elongation, %	25/53	14/33
Work-to-Break, Lbs./In.	13/66	5/26
Inherent Viscosity	1.5	0.78

*Analysis conducted October 10, 1974 by H. H. Forsten, E. I. duPont, Wilmington, Delaware

**Machine Direction and Cross Direction

procedure. Due to the program constraints the lime coating was stopped after 57 hours on stream. Analyses of coated vs. uncoated Nomex bags showed very little difference between the two with respect to hydrolytic attack. This observation was due to the short exposure time and therefore no conclusions can be made regarding lime coating to retard chemical degradation.

The bags were routinely checked throughout their usage and never exhibited any signs of wear. A dust layer of ¼" was attained after 20 hours and remained about the same for other observations during the program. Nomex, more than any other material, exhibited evidence of pearling in the dust layer.

ECONOMIC CONSIDERATIONS

An economic analysis was performed similar in scope and methodology to that accomplished under Contract No. 68-02-1093.[3] The cost figures presented herein are generally higher due to design improvements in the baghouse and inflation. One additional variable, introduced for calculating operating and annualized cost, changed slightly the relationship between the cost curves. This variable is pressure drop across the house. Actual observed pressure drops for each bag material were used here whereas in the prior work equal assumed values were employed.

The economics of applying a fabric filter to the coal fired boilers at Kerr Industries were evaluated and comparative costs for an electrostatic precipitator (ESP) were developed. Installed costs, flange-to-flange hardware costs plus installation costs, were determined for a fabric filter dust collector sized for 70,000 ACFM at 350° F. Installation costs were based on in-house engineering cost estimates. This was done for five fabric materials: Nomex Felt, Gore-Tex/Nomex, Gore-Tex/Gore-Tex, Dralon-T and Teflon Felt. Air-to-cloth (A/C) ratios considered for each fabric were 2.9, 5.8, 8.9 and 11.3. Fabric filter (baghouse) sizes versus air-to-cloth ratios are given in Table 25. Annual operating and annualized (total costs of control) costs were also determined for each case. The methods used are those presented by Edmisten and Bunyard[4]. Example calculations for computing annual operating and annualized costs may be found in the Appendix.

The installed costs for a fabric filter employing Nomex felt were based on the following assumptions. First, that it is necessary to insulate the house, hopper and inlet ducts and second that continuous lime coating of the bags is required. Capital costs were found to be $244,870, $133,590, $109,560 and $99,960 respectively at air-to-cloth ratios of 2.9, 5.8, 8.9 and 11.3, or on the basis of dollars per ACFM $3.50, $1.91, $1.57 and $1.43. These cost estimates were based on a bag price of $17.30 each (vendor quote - September, 1974).

Table 25

Fabric Filter Unit Size vs. Air-to-Cloth Ratio

Air-to-Cloth Ratio	Number of Cells	Number of Bags	Net Filter Area Sq. Ft.
2.9*	60	2,160	23,980
5.8	30	1,080	11,990
8.9	20	720	7,850
11.3	16	576	6,200

*Based on two (2) units; each with 30 cells, 1,080 bags and 11,990 square feet net filter area.

Installed costs for the case of Gore-Tex on Nomex backing are $218,120, $120,220, $98,250 and $89,460. On a $/ACFM basis these costs are $3.12, $1.72, $1.40 and $1.28. Costs assume no insulation and no lime coating are required. These costs were based on a bag price of $22.00 each (vendor quote - September, 1974).

The Gore-Tex on Gore-Tex case installed costs are $267,800, $145,060, $114,810 and $102,710. Or on a $/ACFM basis they are $3.83, $2.07, $1.64 and $1.47. Again it was assumed that no insulation and no lime coating would be required. The price used for Gore-Tex/Gore-Tex bags was $45.00 each (vendor quote - September, 1974).

Installed costs for Dralon T were $192,200, $107,260, $89,610 and $82,550 or $2.75, $1.53, $1.28 and $1.18 on a $/ACFM basis. Costs assume no insulation and no lime coating required. The price for Dralon T bags was $10.00 each (vendor quote - September, 1974).

Finally, installed costs for a baghouse employing Teflon felt (Style 2663) were determined. Because of the quick release properties of the Teflon and its resistance to chemical attack, it was assumed that no insulation and no lime coating would be required. The capital costs were found to be $332,600, $177,460, $136,407 and $119,990. On a $/ACFM basis these costs are $4.75, $2.54, $1.95 and $1.71. These costs were based on a bag price of $75.00 each (vendor quote - September, 1974).

A graphical comparison of the installed costs for the five bag materials is made in Figure 38. Teflon felt is seen to be the most expensive cost for all four (4) air-to-cloth ratios investigated and Dralon T is seen to be the least expensive. The curves draw closer together as the air-to-cloth ratio increases. Obviously this is due to a decreasing percentage of the total costs attributed to the bags as the size of the house decreases. Table 26 shows the cost of the bags as a percentage of installed costs.

Figure 38

Installed Costs vs. Air-to-Cloth Ratio

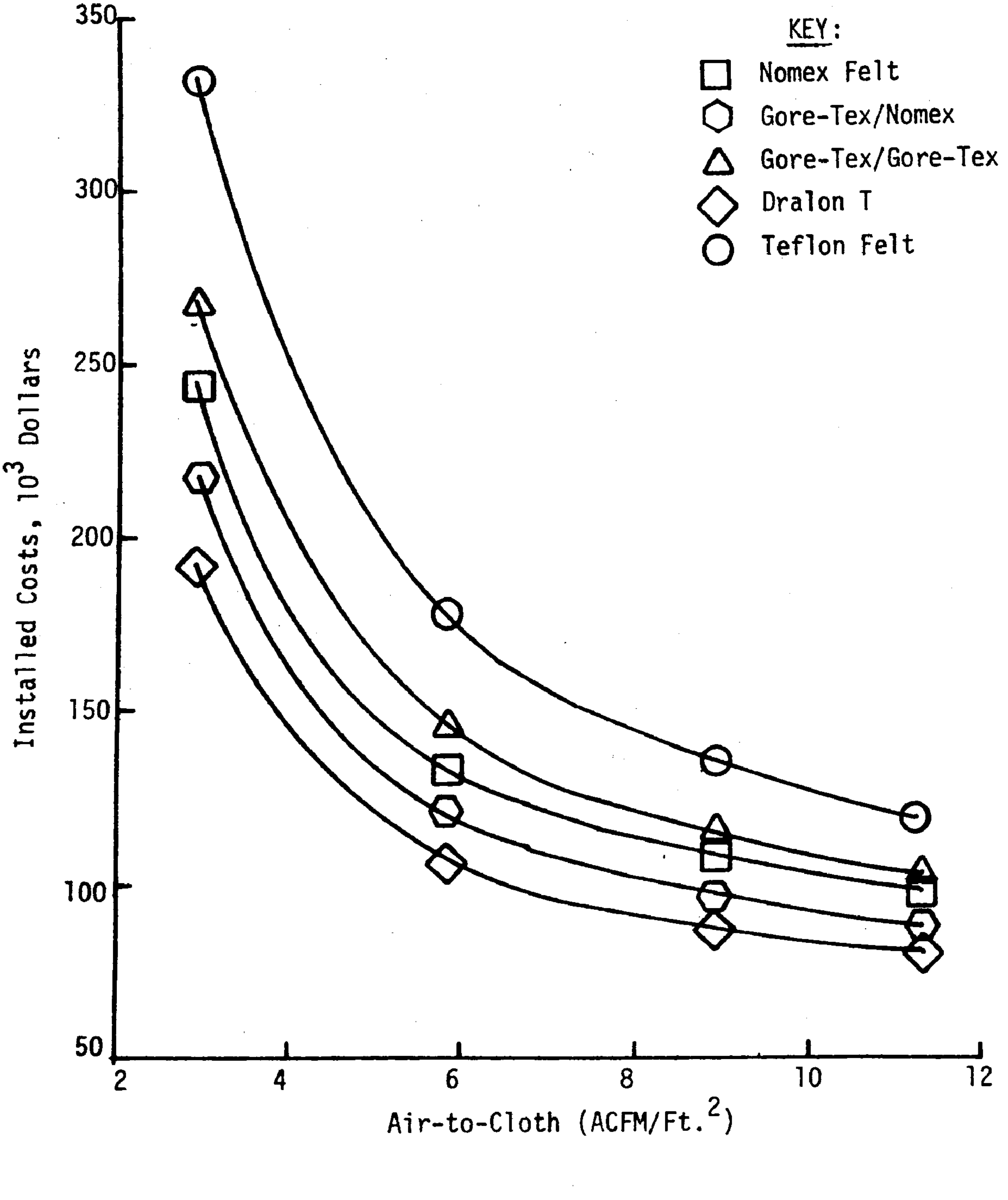


Table 26

Bag Costs as Percent of Installed Cost

	Installed Costs	Bag Costs	% of Installed Cost for Bags
Nomex			
2.9	244,866	37,368	15.3
5.8	133,591	18,684	14.0
8.9	109,563	12,456	11.4
11.3	99,952	9,965	10.0
Gore-Tex/Nomex			
2.9	218,118	47,520	21.8
5.8	120,217	23,760	19.8
8.9	98,247	15,840	16.1
11.3	89,459	12,672	14.2
Gore-Tex/Gore-Tex			
2.9	267,798	97,200	36.3
5.8	145,057	48,600	33.5
8.9	114,807	32,400	28.2
11.3	102,707	25,920	25.2
Dralon T			
2.9	192,198	21,600	11.2
5.8	107,257	10,800	10.1
8.9	89,607	7,200	8.0
11.3	82,547	5,760	7.0
Teflon			
2.9	332,598	162,000	48.7
5.8	177,457	81,000	45.6
8.9	136,407	54,000	39.6
11.3	119,987	43,200	36.0

The installed costs for an electrostatic precipitator capable of handling 70,000 ACFM at 350° F were determined for three (3) levels of efficiency. These were 90, 95 and 99% removal efficiency. The basis for development of these costs is provided in the Appendix. The corresponding installed costs were found to be $412,970, $471,590 and $600,100. These are shown in Figure 39. On a $/ACFM basis, these costs are $5.90, $6.74 and $8.57. Thus the installed costs of the electrostatic precipitator, even at 90% collection efficiency, are higher than all cases for the fabric filter; the greatest cost differential being Teflon with an air-to-cloth ratio of 2.9 at $332,600. The ESP capital costs may have been more favorable if the coal utilized for the case in point had not been low in sulfur. In fact, several of the ESP manufacturers who were asked to furnish quotes for the Kerr boilers refused to quote due to the low sulfur coal.

Operating costs were determined for the five (5) bag materials. Four (4) year bag life was assumed for all fabrics. The cost of replacing the bags was divided equally over the four years and treated as an annual operating cost equivalent to 25% bag replacement per year. The actual pressure drops observed for each fabric at the different air-to-cloth ratios, plus two inches w.g. for the inlet duct and house, were used for determining power costs. These costs are presented in Figure 40.

The curves for operating costs are very different except for the two types of Gore-Tex which exhibit similarly shaped curves. The shape of the curve is determined by the two variables used in the equation for computing operating costs, namely bag price and pressure drop (Δp). Values for these are given in Table 27. While bag price is constant for a given fabric the pressure drop increases as the A/C ratio increases. The rate of Δp increase is different for each bag material except the two Gore-Tex, thus the reason for the similarity of the two Gore-Tex curves. As can be seen in Table 27, the Δp's for Gore-Tex/Nomex and Gore-Tex/Gore-Tex are identical. Gore-Tex/Gore-Tex was not tested in the pilot plant, hence the Δp's were assumed to be the same as Gore-Tex/Nomex.

Figure 39

Installed Cost vs. Efficiency

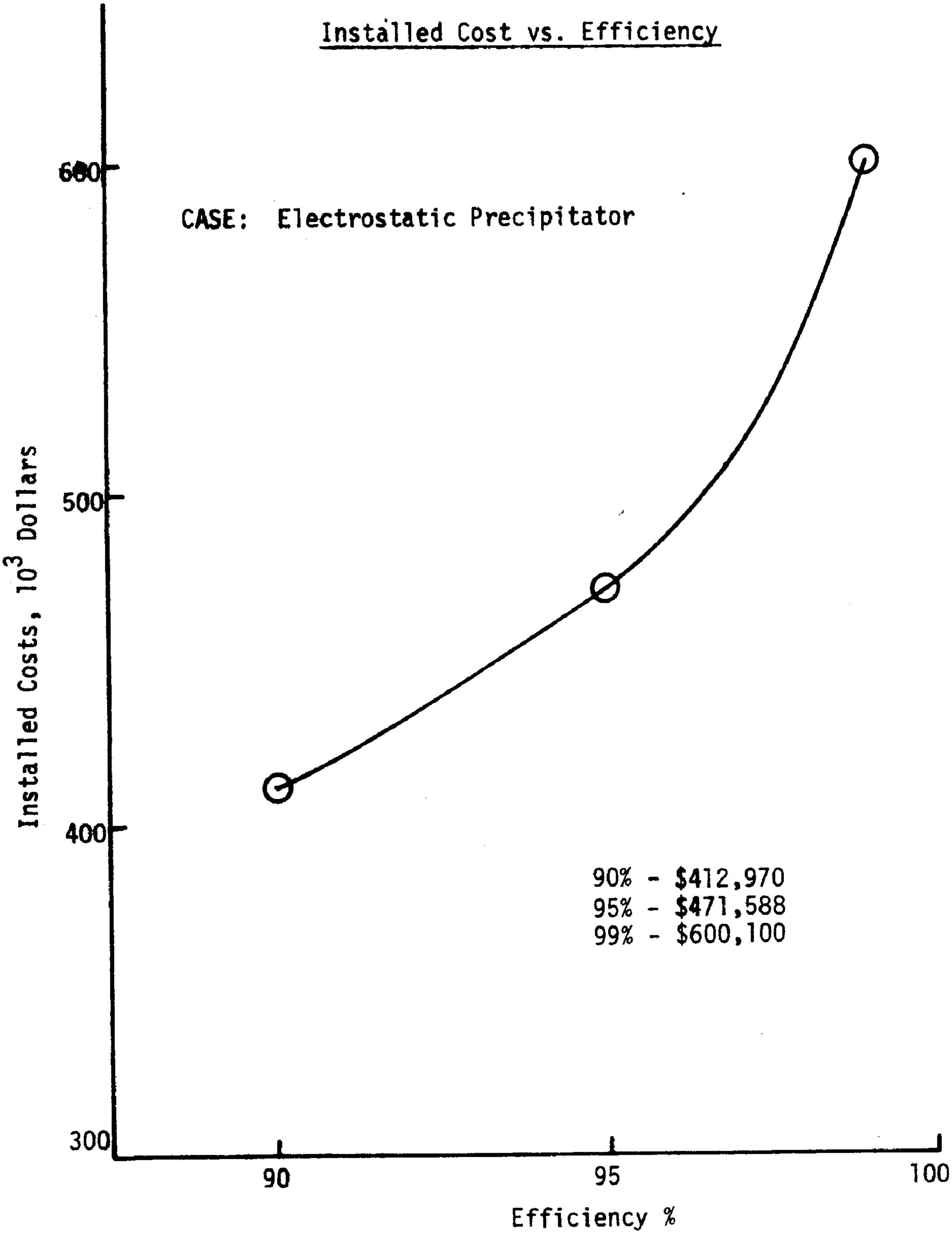


Figure 40

Annual Operating Costs vs. Air-to-Cloth Ratio

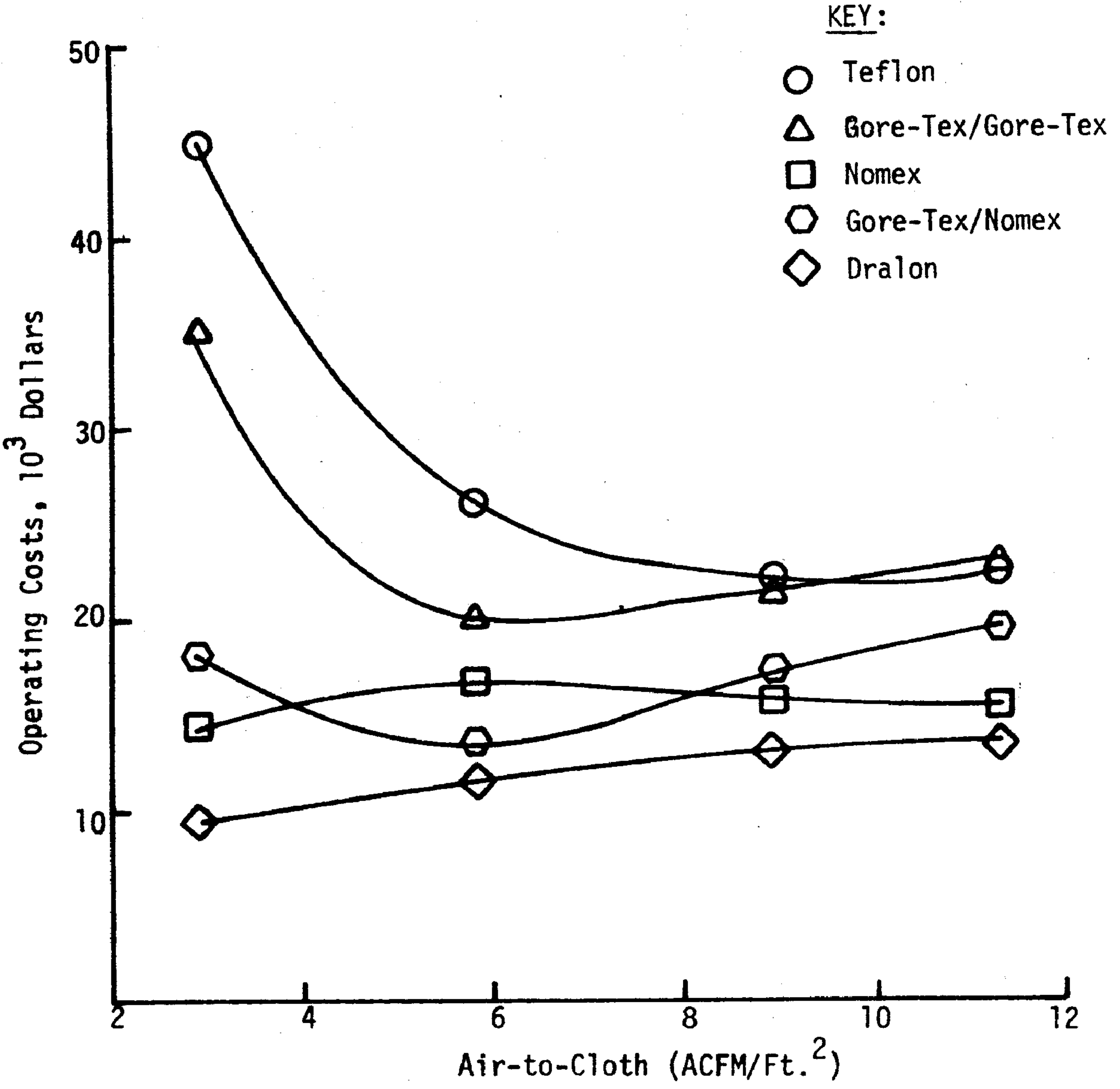


Table 27

Pressure Drop Values for Five Bag Materials at Four A/C Ratios

Bag Material	Bag Price	A/C Ratio	ΔP[1] In. H_2O
Nomex	$17.30	2.9	3.5
		5.8	8.2
		8.9	8.5
		11.3	8.7
Gore-Tex/Nomex	$22.00	2.9	4.2
		5.8	5.3
		8.9	8.9
		11.3	11.0
Gore-Tex/Gore-Tex[2]	$45.00	2.9	4.2
		5.8	5.3
		8.9	8.9
		11.3	11.0
Dralon T	$10.00	2.9	2.8
		5.8	6.0
		8.9	7.5
		11.3	8.1
Teflon Felt	$75.00	2.9	2.5
		5.8	3.4
		8.9	5.9
		11.3	9.2

(1) The ΔP for each case is the operating pressure in Figure 52 plus two (2) inches pressure drop added to allow for pressure drop across the inlet duct and the house.

(2) ΔP for Gore-Tex/Gore-Tex assumed to be the same as those for Gore-Tex/Nomex.

As stated above, bag life for all five materials was assumed to be four (4) years, equivalent to 25% bag replacement per year. Operating costs for Dralon T and Teflon felt were also determined for other periods of bag life. These were 1, 2, 3 and 5 years which correspond to 100%, 50%, 33 1/3% and 20% replacement per year. Figures 41 and 42 show the resultant curves for Dralon T and Teflon felt respectively. Obviously, the shorter the bag life the higher the annual operating costs. It is interesting, however, that the curves for average bag life of three (3) years and greater are relatively close together. Therefore, the impact of bag life on operating cost is extremely significant up to three (3) years but for periods greater than three (3) years the costs do not decrease as significantly with increasing bag life. The same data is presented in Figures 43 and 44, with annual operating costs vs. percent bag replacement per year instead of A/C ratio. Again the sharp drop in costs is evident for the two shorter periods of bag life. Also the slope of the curve can be seen to increase as the size of the house increases.

Operating costs were also determined for an electrostatic precipitator at 90, 95 and 99% collection efficiency (sample calculations in appendix). These costs were found to be $5,840, $6,380 and $8,150 respectively, see Figure 45. Thus the ESP operating costs are lower than all cases of the fabric filter, even for Dralon T with air-to-cloth ratio of 2.9/1 at $9,880. This difference is due primarily to costs related to percent annual bag replacement and higher pressure drops in the fabric filter.

The annualized costs or total costs of control were developed from the proceeding installed and operating costs. These results, shown in Figure 46 were based on the following assumptions: First, hardware and installation costs are depreciated over fifteen (15) years. Second, the straight line method of depreciation (6 2/3 percent per year) is used. This method has the simplicity of a constant annual write-off. Third, other costs called capital charges, which include interest, taxes,

Figure 41

Dralon T

Annual Operating Cost vs. Air-to-Cloth Ratio for Different Bag Life Assumptions

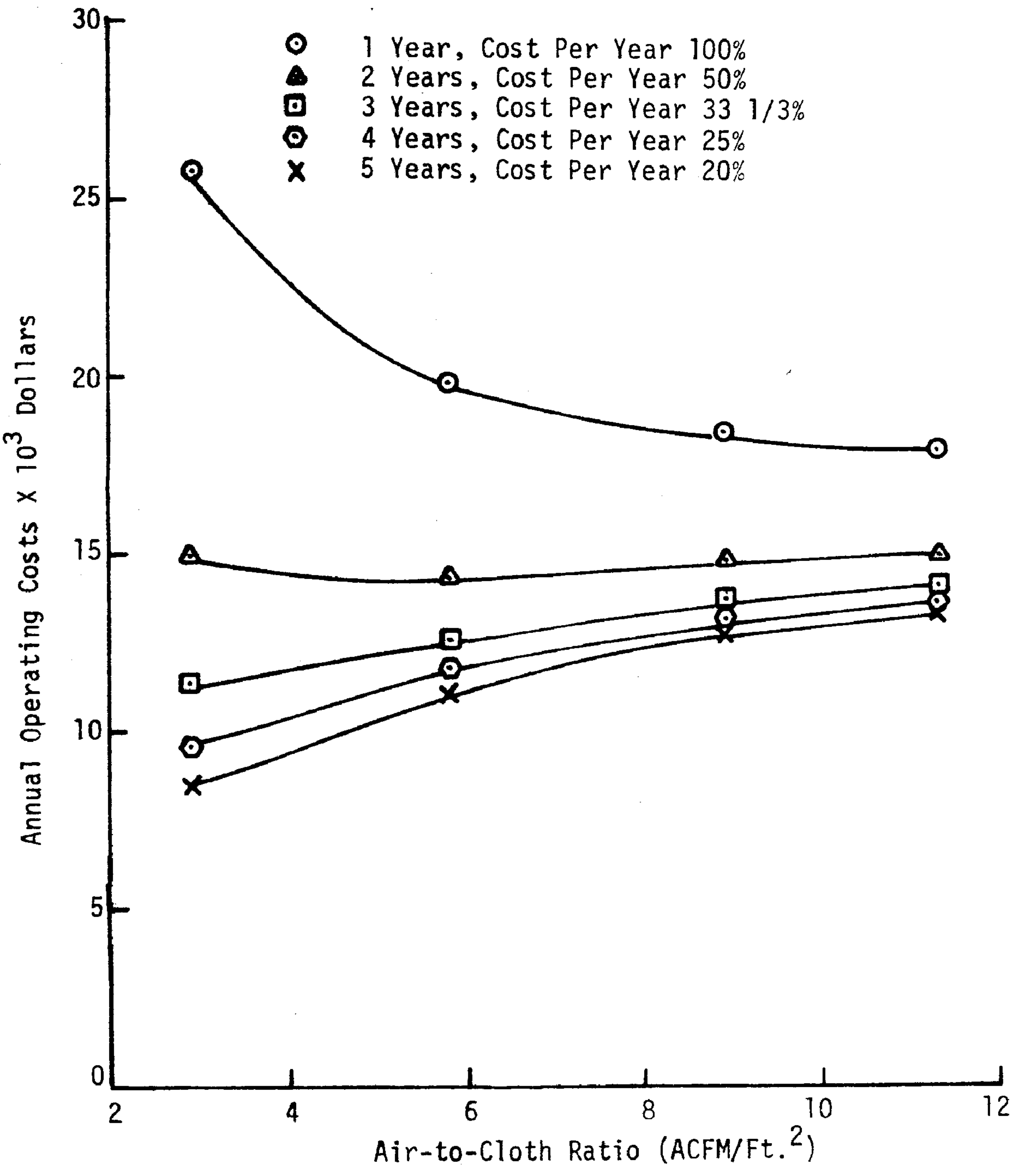


Figure 42

Annual Operating Cost vs. Air-to-Cloth Ratio for Different Bag Life Assumptions

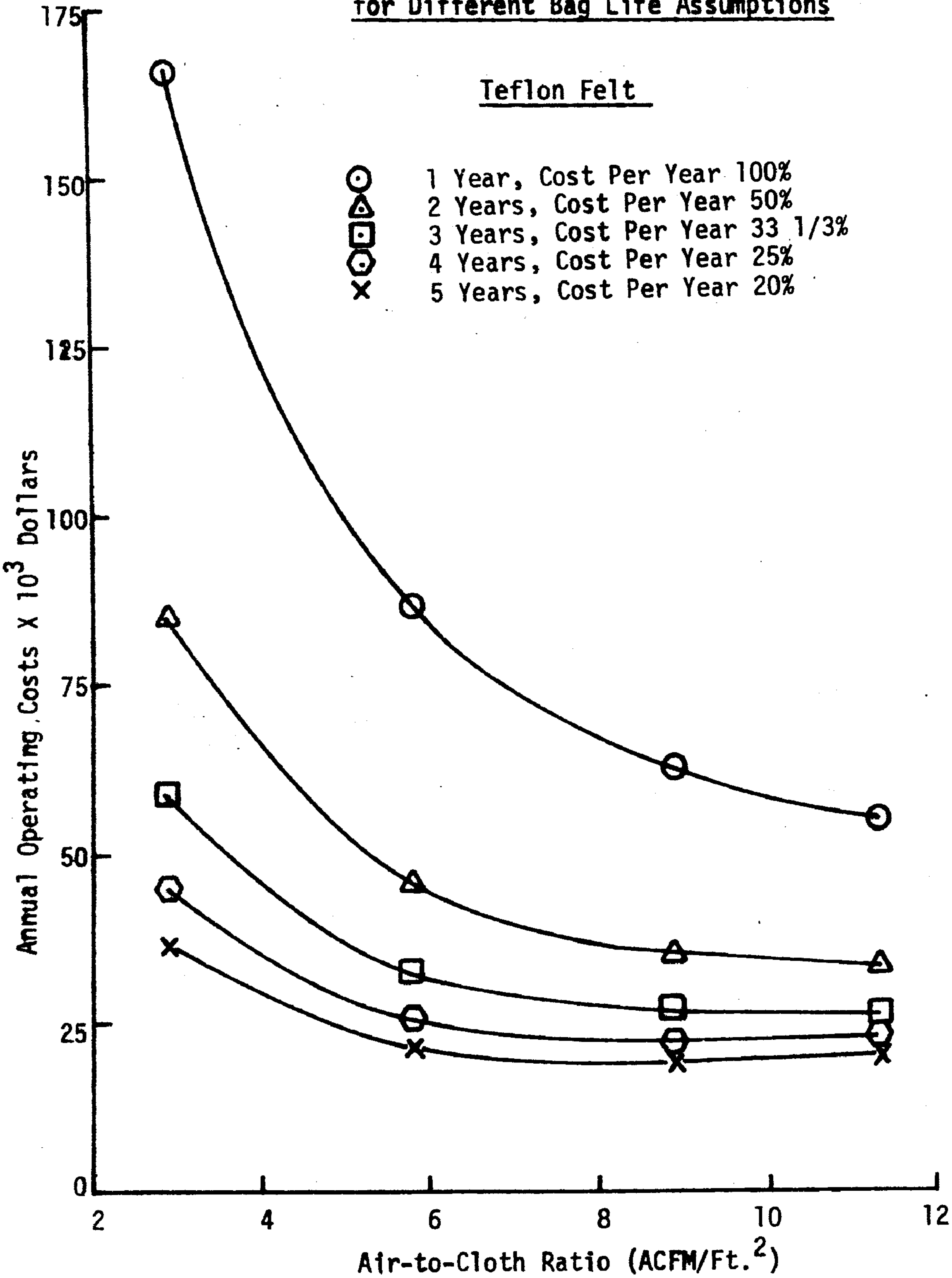


Figure 43

Dralon T

Annual Operating Costs vs. % Bag Replacement Per Year at Different Air-to-Cloth Ratios

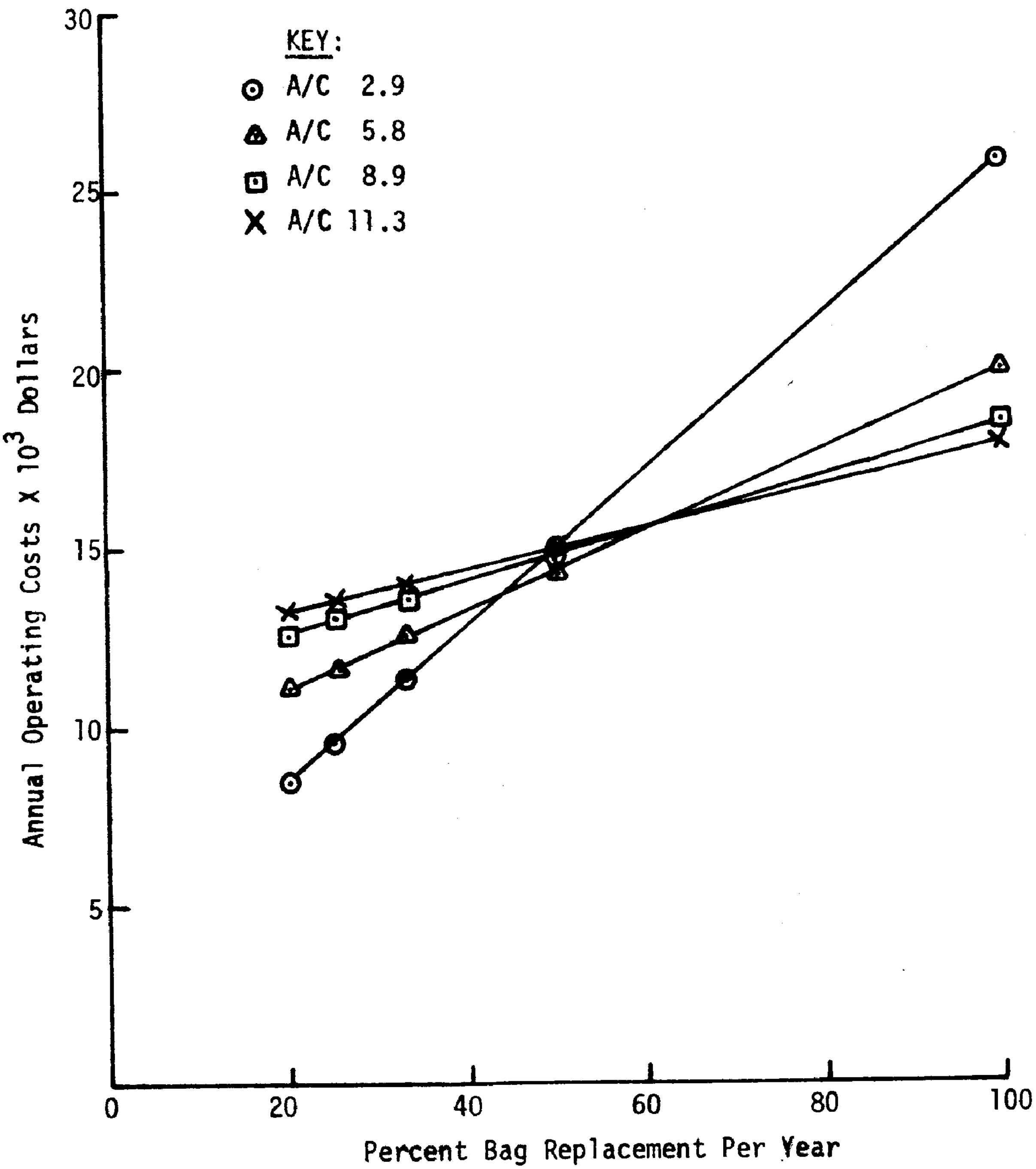


Figure 44

Annual Operating Costs vs. % Bag Replacement Per Year at Different Air-to-Cloth Ratios

Teflon Felt

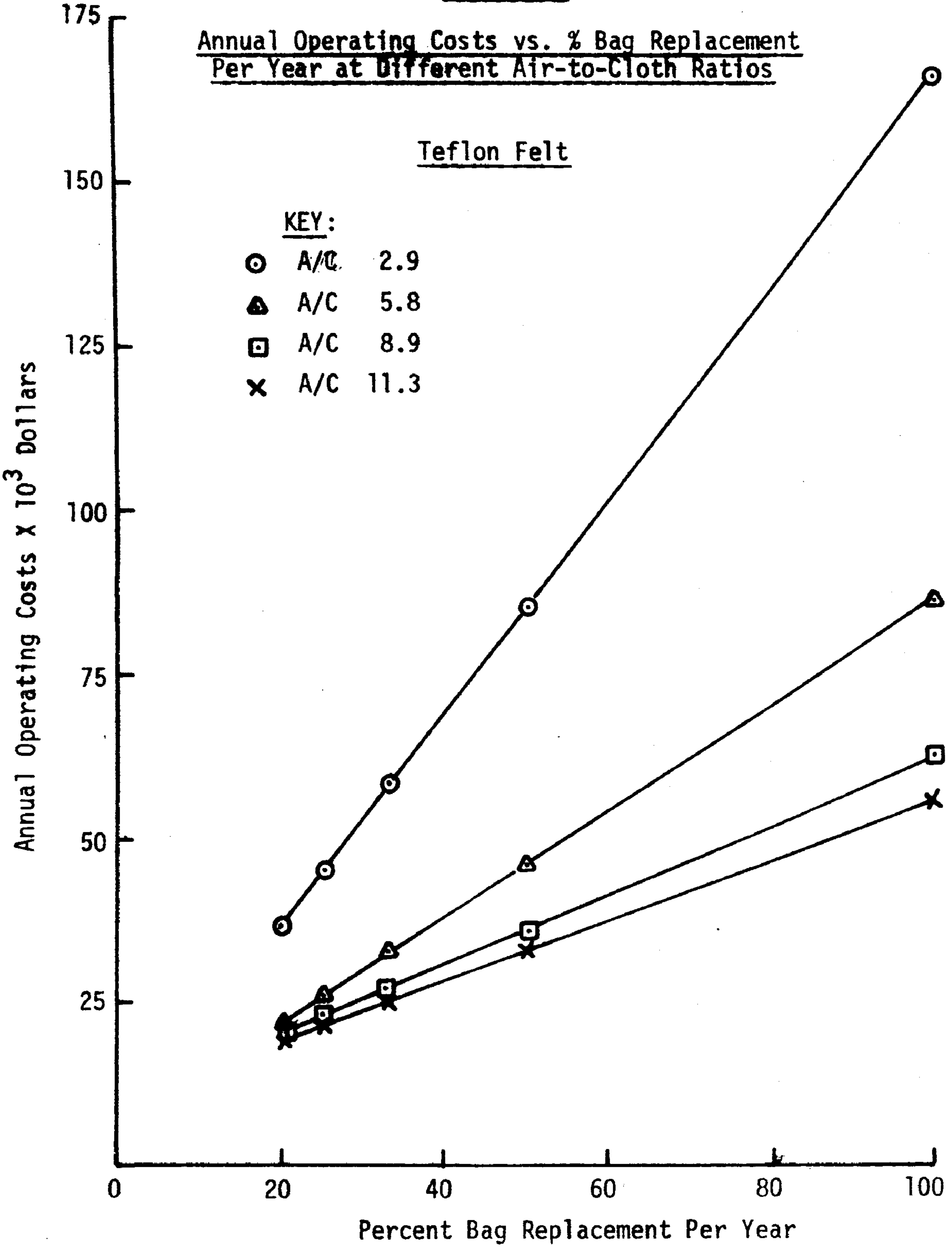


Figure 45

Annual Operating Costs vs. Efficiency

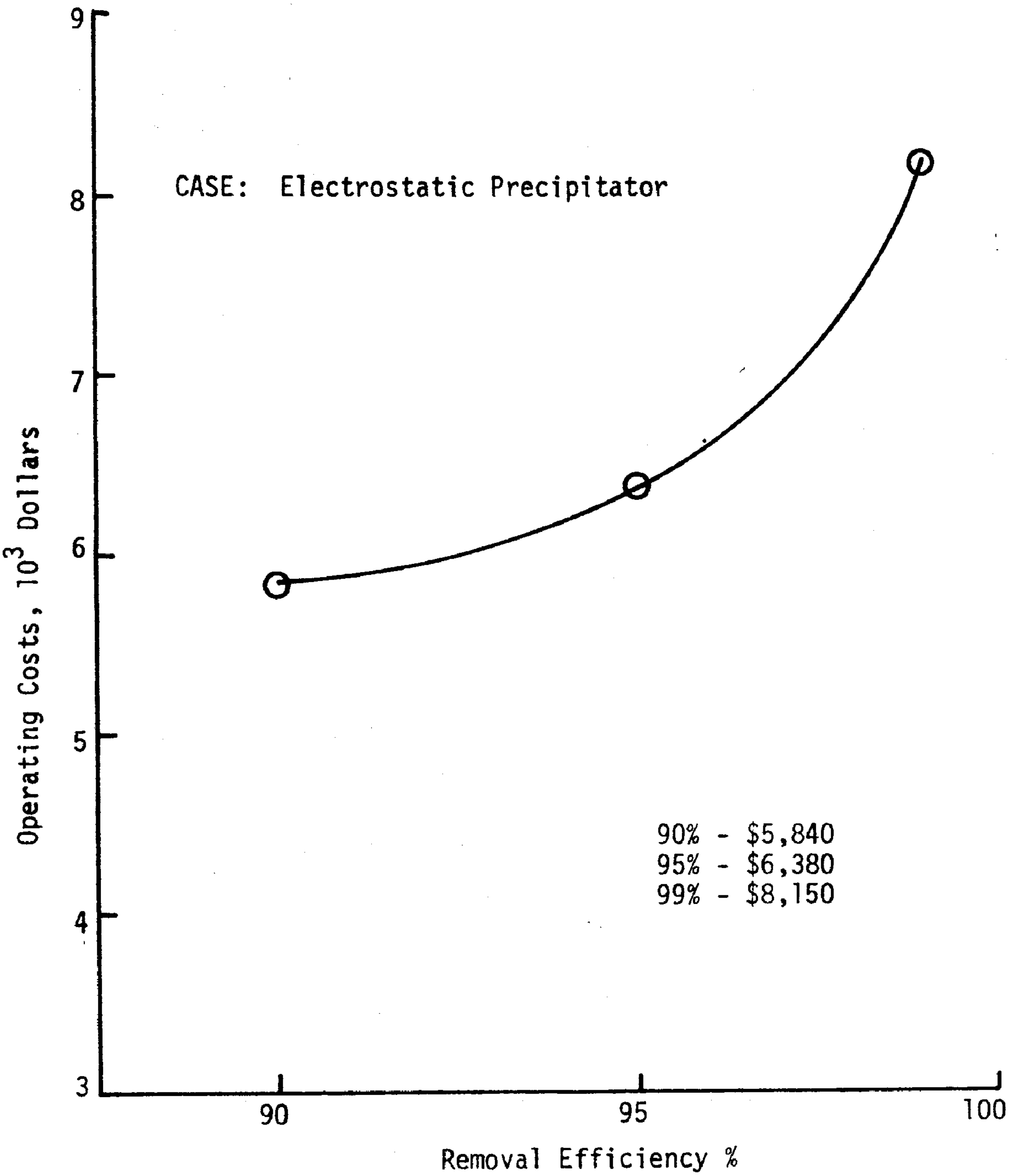
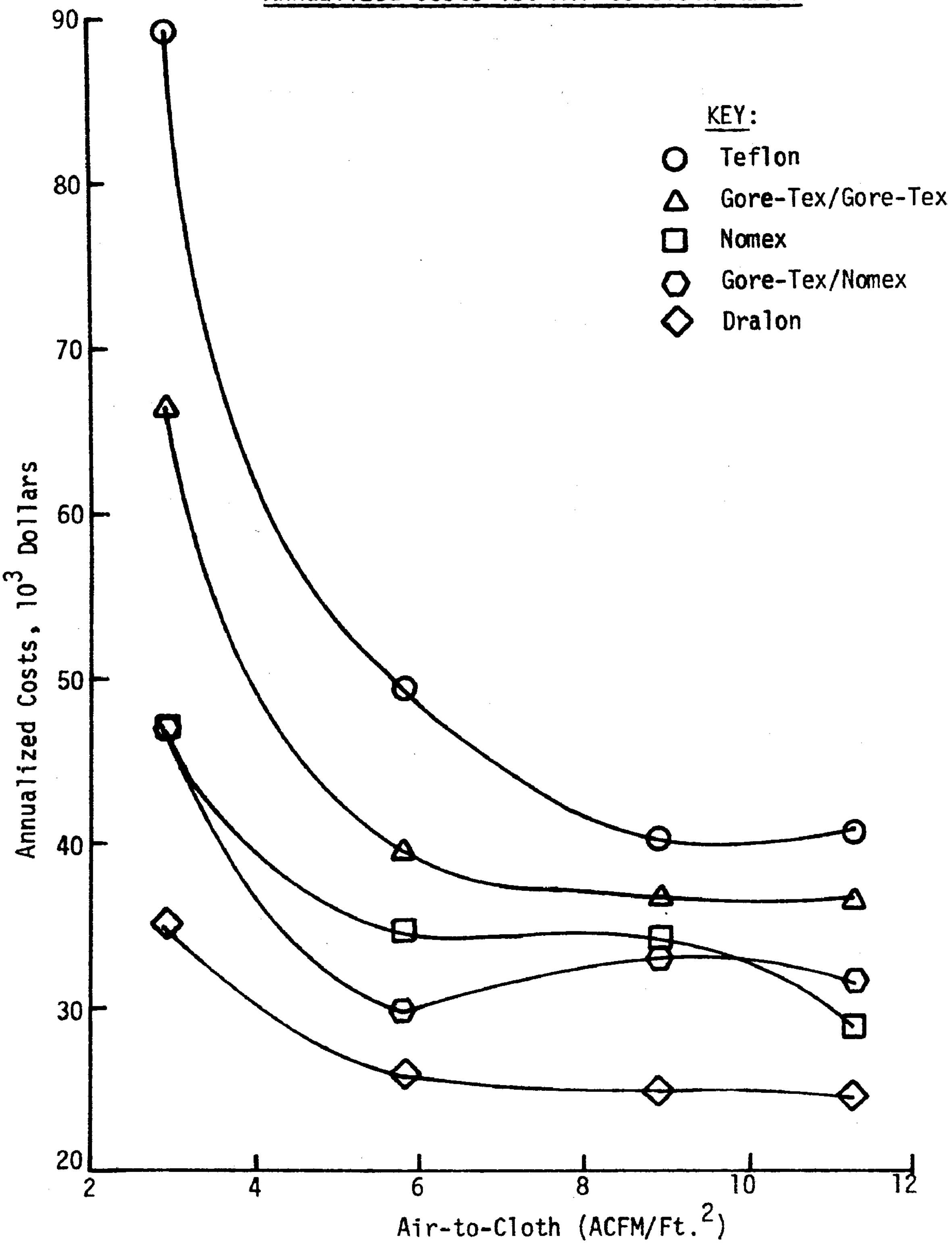


Figure 46

Annualized Costs vs. Air-to-Cloth Ratio



insurance and other miscellaneous costs, are assumed equal to the amount of depreciation, or 6 2/3% of the initial installed cost. Therefore, depreciation plus these other annual charges amount to 13 1/3 percent of the installed costs. See example calculation of annualized cost in the Appendix.

Annualized cost for the ESP case at 90, 95 and 99% collection efficiencies were determined to be $60,766, $69,097 and $87,960 respectively, see Figure 47. The annualized cost for 90% is higher than all cases of the fabric filter at A/C ratio of 5.8 and greater. Even at A/C ratio of 2.9 the fabric filter annualized cost is less than that for the ESP at 90% for three (3) of the five (5) bag materials with only Teflon and Gore-Tex/Gore-Tex being higher. All costs are tabulated in Tables 28 and 29 for easy reference.

A cursory attempt was made at determining the effect of accelerated depreciation on annualized cost. The resultant costs are presented in Table 30 and Figure 48. Accelerated depreciation was based on straight line depreciation over five (5) years (20% per year) plus 6 2/3 percent used again for other capital charges. This basis for capital charges was used only to be consistent and is not meant to be indicative of the real case. To establish a realistic factor for "other capital charges" would involve a detailed cash flow analysis with the result applicable only to a single case. The basis chosen was discussed with by Mr. F. L. Bunyard(4), EPA Cost Analysis Section. It was felt that the comparison of accelerated and standard depreciation was worthwhile as long as the basis was clearly established. The net result as seen in Figure 48 was an accentuation of the difference between annualized costs for fabric filters as opposed to electrostatic precipitators.

Finally, outlet loading versus annualized cost is presented in Figure 49 for the fabric filter employing four (4) types of bags and the electrostatic precipitator. This comparison indicates that the fabric filter may be capable of competing with the electrostatic precipitator

Figure 47

Annualized Costs vs. Efficiency

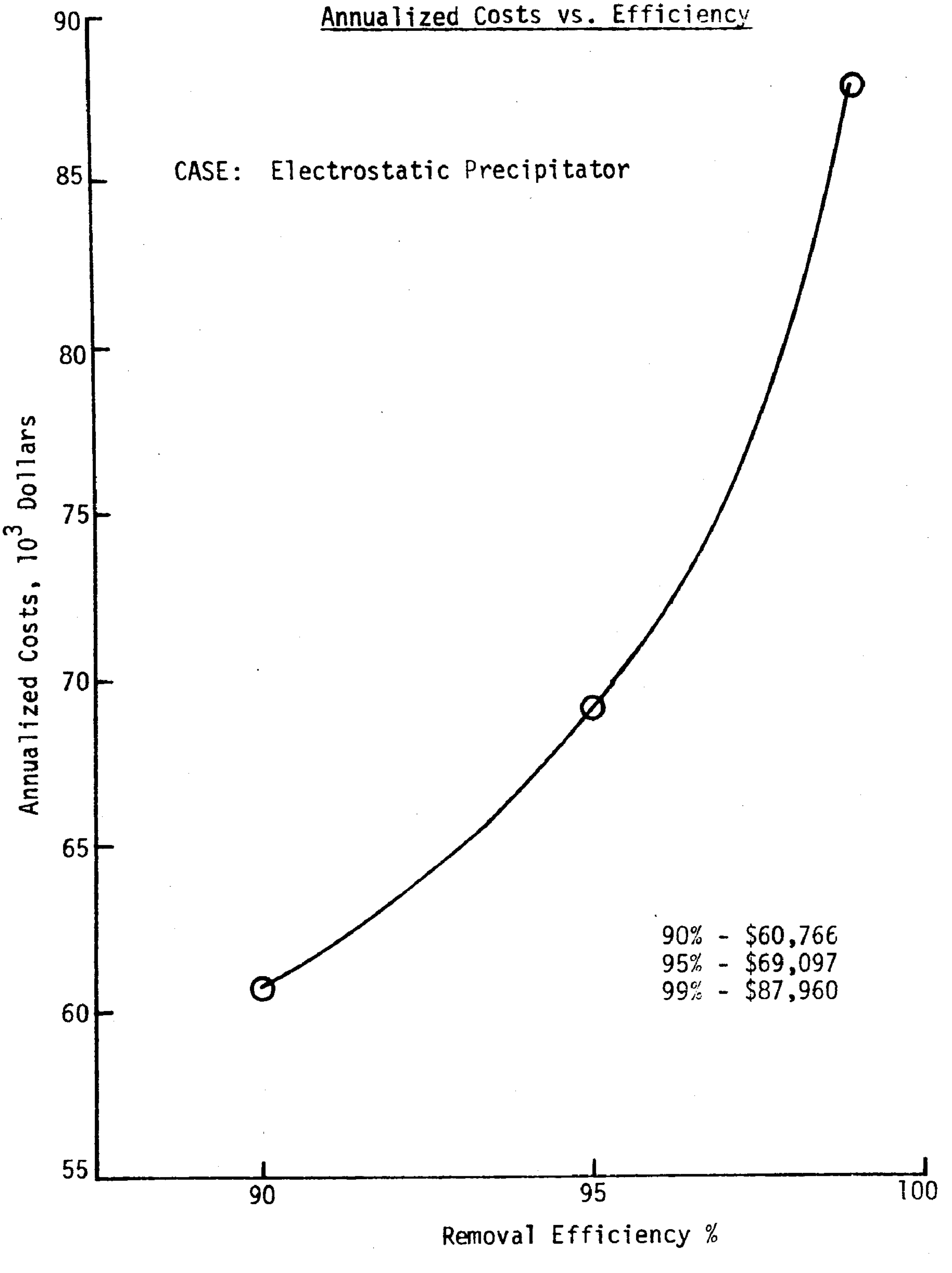


Table 28

Fabric Filter Costs Data

	A/C 2.9	A/C 5.8	A/C 8.9	A/C 11.3
Installed Costs X 10^3 Dollars & ($/ACFM)				
Nomex	244.87 (3.50)	133.59 (1.91)	109.56 (1.57)	99.96 (1.43)
Gore-Tex/Gore-Tex	267.80 (3.83)	145.06 (2.07)	114.81 (1.64)	102.71 (1.47)
Gore-Tex/Nomex	218.12 (3.12)	120.22 (1.72)	98.25 (1.40)	89.46 (1.28)
Dralon T	192.20 (2.75)	107.26 (1.53)	89.61 (1.28)	82.55 (1.18)
Teflon Felt	322.60 (4.75)	177.46 (2.54)	136.41 (1.95)	119.99 (1.71)
Annual Operating Costs X 10^3 Dollars & ($/ACFM)				
Nomex	14.57 (0.21)	16.93 (0.24)	15.82 (0.23)	15.49 (0.22)
Gore-Tex/Gore-Tex	30.53 (0.44)	20.07 (0.29)	21.40 (0.31)	22.92 (0.33)
Gore-Tex/Nomex	18.16 (0.26)	13.86 (0.20)	17.26 (0.25)	19.61 (0.28)
Dralon T	9.88 (0.14)	11.67 (0.17)	13.01 (0.19)	13.55 (0.19)
Teflon Felt	44.98 (0.64)	25.93 (0.37)	22.02 (0.31)	22.76 (0.33)
Total Annualized Cost of Contraol X 10^3 Dollars & ($/ACFM)				
Nomex	47.14 (0.67)	34.69 (0.50)	30.39 (0.43)	28.79 (0.41)
Gore-Tex/Gore-Tex	66.19 (0.95)	39.36 (0.56)	36.70 (0.52)	36.58 (0.52)
Gore-Tex/Nomex	47.17 (0.67)	29.85 (0.43)	30.33 (0.43)	31.50 (0.45)
Dralon T	35.15 (0.50)	25.93 (0.37)	24.93 (0.36)	24.52 (0.35)
Teflon Felt	89.22 (1.27)	49.53 (0.71)	40.16 (0.57)	40.90 (0.58)

Table 29

Electrostatic Precipitator Cost X 10^3 Dollars ($/ACFM)

	Efficiency		
	90%	95%	99%
Installed Costs	412.97 (5.90)	471.60 (6.74)	600.10 (8.57)
Operating Costs	5.84 (.083)	6.38 (.091)	8.15 (0.116)
T. Annualized Costs	60.77 (0.87)	69.10 (.99)	87.96 (1.26)

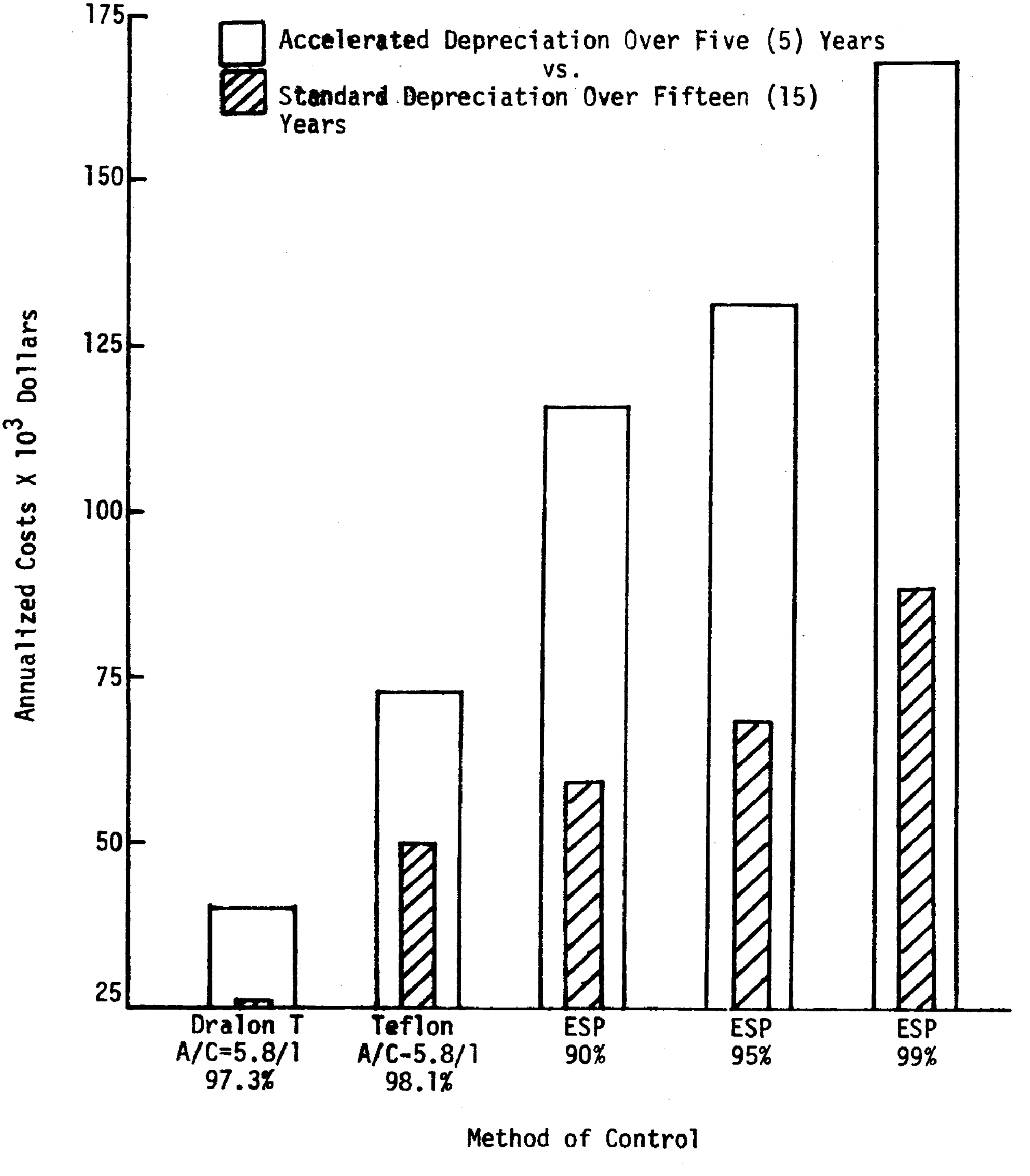
Table 30

Annualized Costs Based on Accelerated Depreciation

Case (A/C, Efficiency)	Installed Costs	Annual Operating Costs	Annualized Capital Costs	Total Annualized Costs Accelerated (Standard)
Dralon T (5.8/1, 97.3%)	107,260	11,670	28,600	40,260 (25,930)
Teflon (5.8/1, 98.1%)	177,460	25,930	47,310	73,240 (49,530)
ESP (90%)	412,970	5,840	110,100	115,940 (60,770)
ESP (95%)	471,590	6,380	125,730	132,100 (69,100)
ESP (99%)	600,100	8,150	159,990	168,130 (87,960)

Figure 48

Annualized Cost Comparison



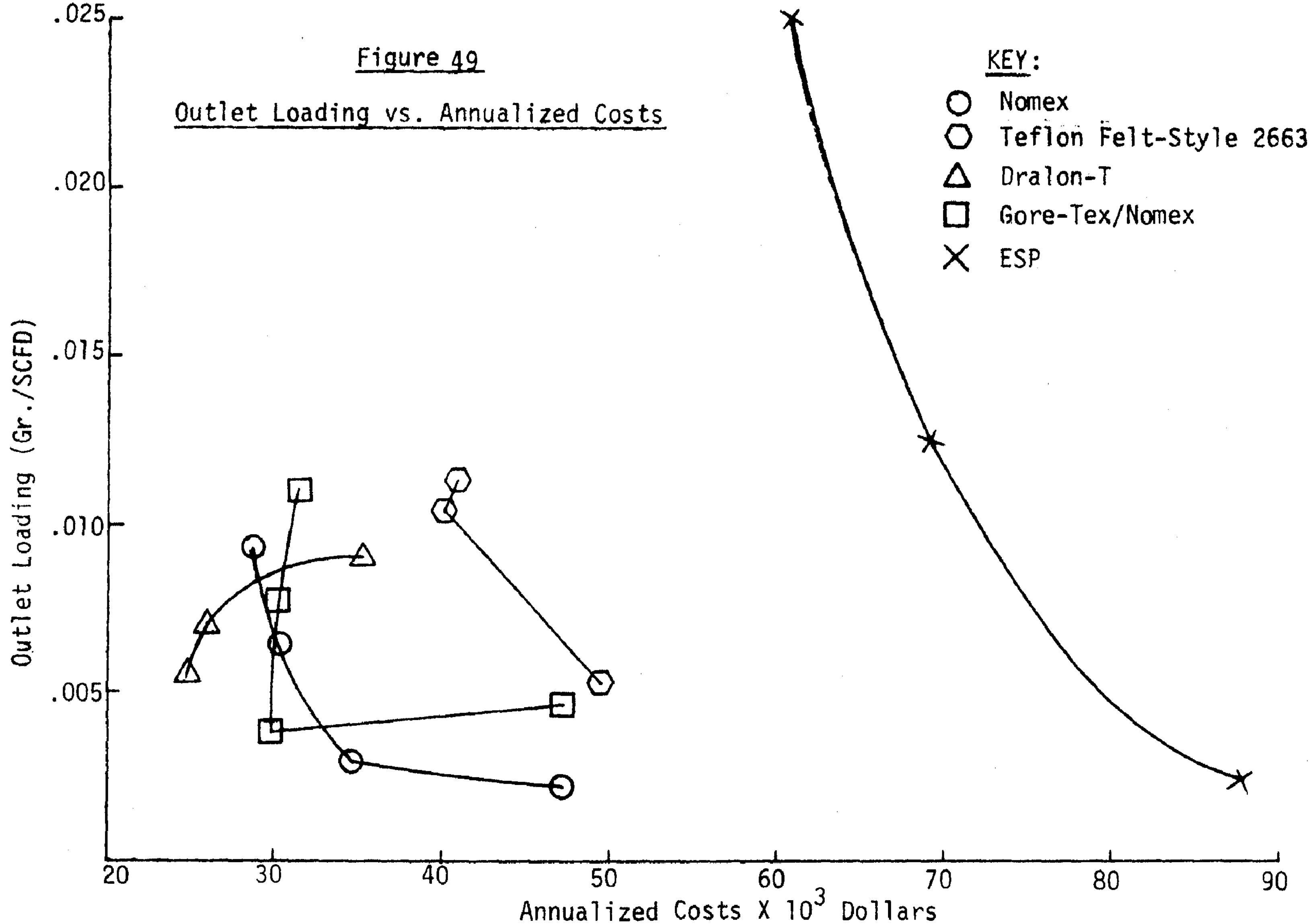


Figure 49

Outlet Loading vs. Annualized Costs

as a viable economical method of particulate control for industrial coal-fired stoker boilers.

DISCUSSION

The performance of the pilot plant indicates that fabric filtration is a viable control method for industrial size stoker boilers. A summary of overall performance for the four media evaluated is presented in Figures 48, 49 and 50 and Table 30. All media proved capable of exceeding State and Federal requirements for particulate removal. Nomex felt had the lowest outlet loading at each respective A/C ratio, while Teflon felt was capable of performing satisfactorily at A/C ratios as high as 14/1. Nomex and Gore-Tex operated at pressure drops between 2 and 6 inches of water while Teflon felt operated at pressure drops up to 7 inches at 14/1. The pressure drop curves for Nomex and Dralon T appear to be leveling off at increasing velocities and would indicate that even higher velocities than those evaluated might prove economically feasible. The efficiencies shown in Table 31 might be considered low for a baghouse, only Nomex achieved greater than 99% removal at an A/C of 6/1. However, since this apparent low efficiency is due in part to the low inlet concentration, the outlet concentrations are probably a better tool for evaluating overall performance. These outlet concentrations were less than 0.015 Gr./SCFD in all cases and less than 0.005 Gr./SCFD for the low and middle velocities for both Nomex and Gore-Tex.

As shown in the economic analysis, the operating costs for a baghouse are higher than those for an electrostatic precipitator. The higher baghouse cost is due to bag replacement. Therefore, bag life is really the critical factor in determining whether the fabric filter is economically competitive. On the basis of installed costs the baghouse costs are lower even for Teflon felt at an A/C of 2.9/1. This comparison is reflected in total annualized costs for the bag life assumption used where all cases of the fabric filter, except Teflon at 2.9/1, have lower costs than the ESP at 90% efficiency. The performance (outlet loading) versus annualized cost curve (Figure 47) really states the overall case for the fabric filter as a competitor, both technically and economically with ESP for control of particulate emissions from industrial size stoker boilers.

Figure 50

Outlet Concentration
vs.
Air-to-Cloth Ratio for Various Bag Materials

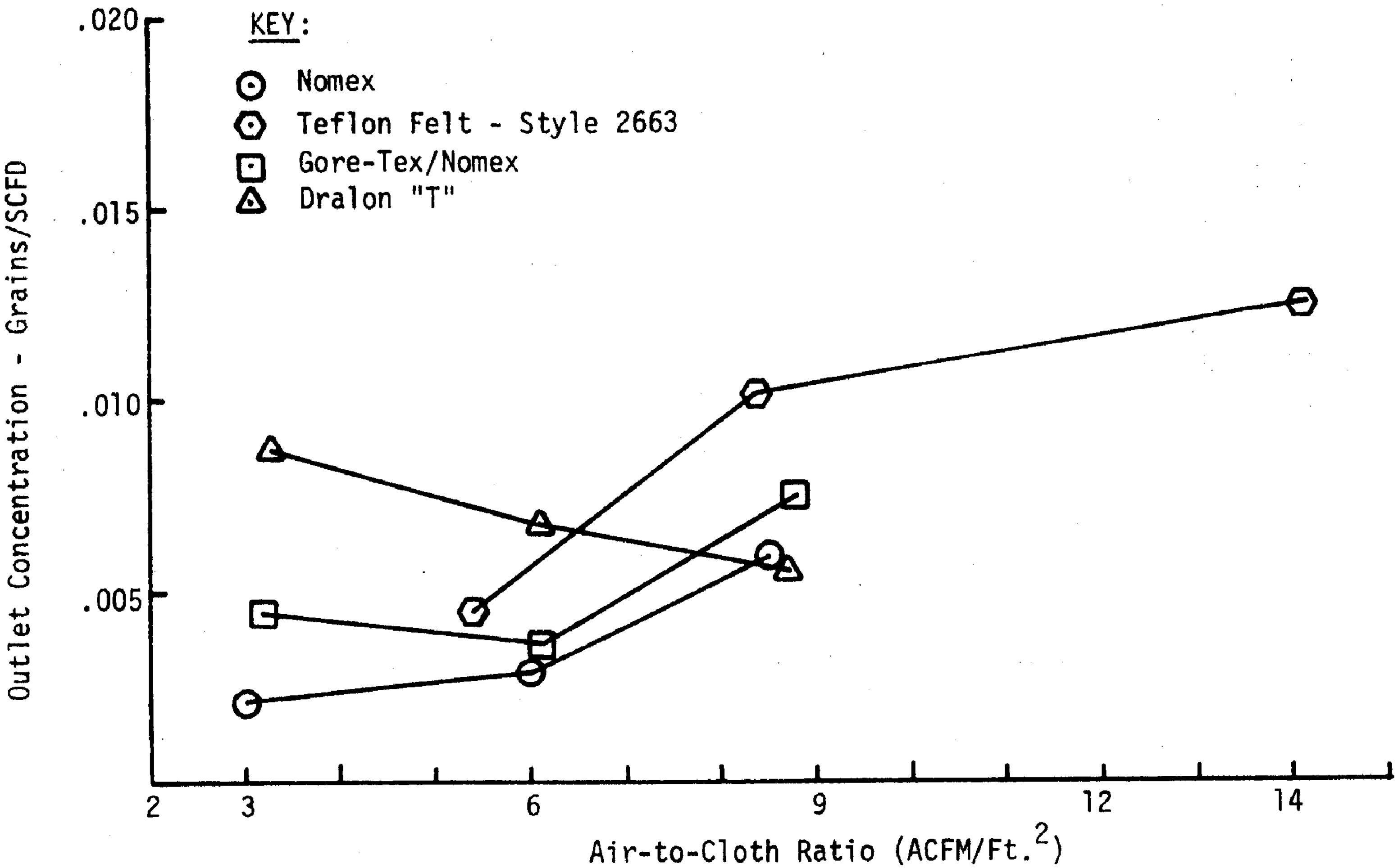


Figure 51

Penetration vs. Air-to-Cloth Ratio for Different Bag Materials

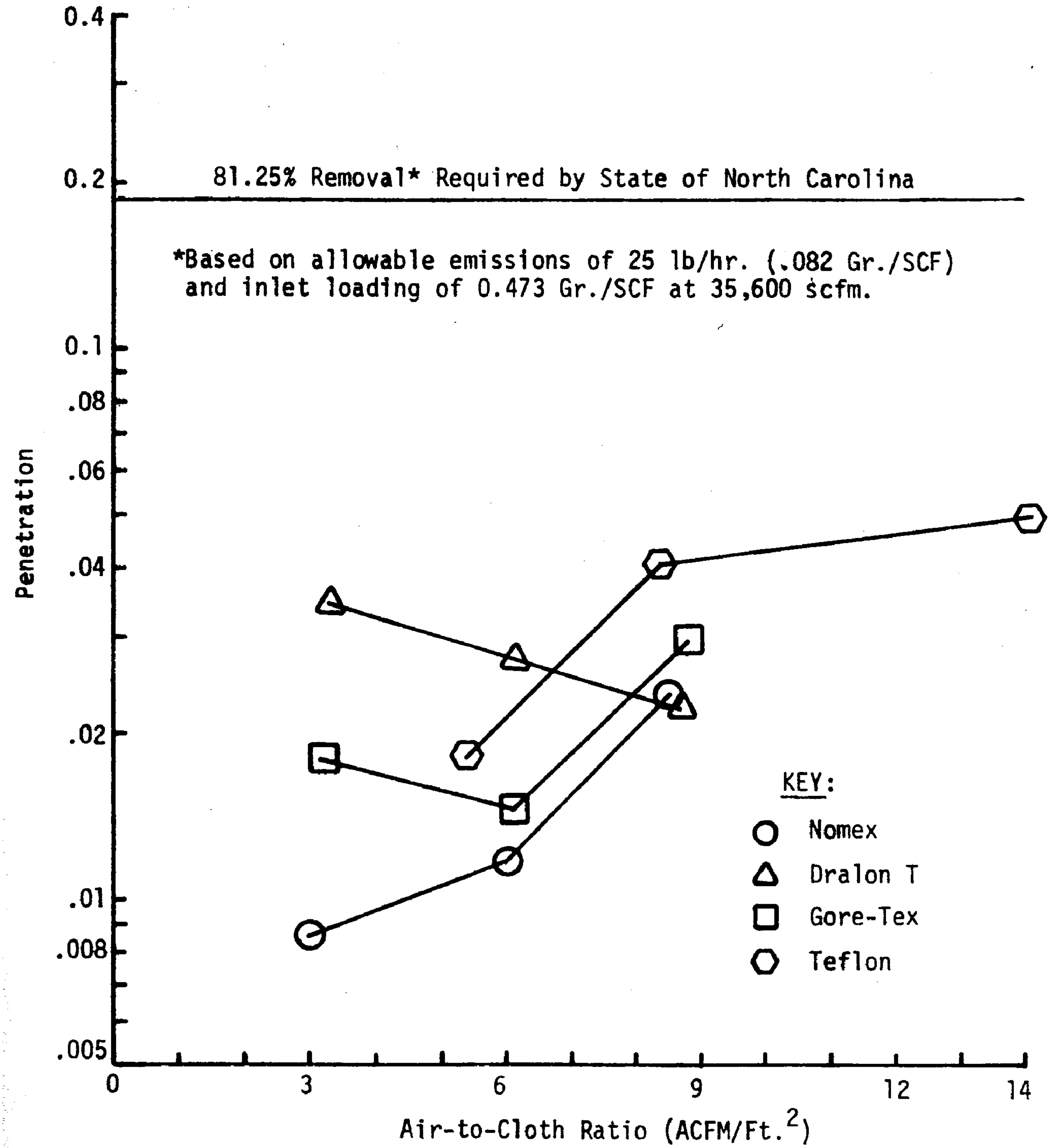


Figure 52

Comparison of Operating Pressures for Various Bag Materials

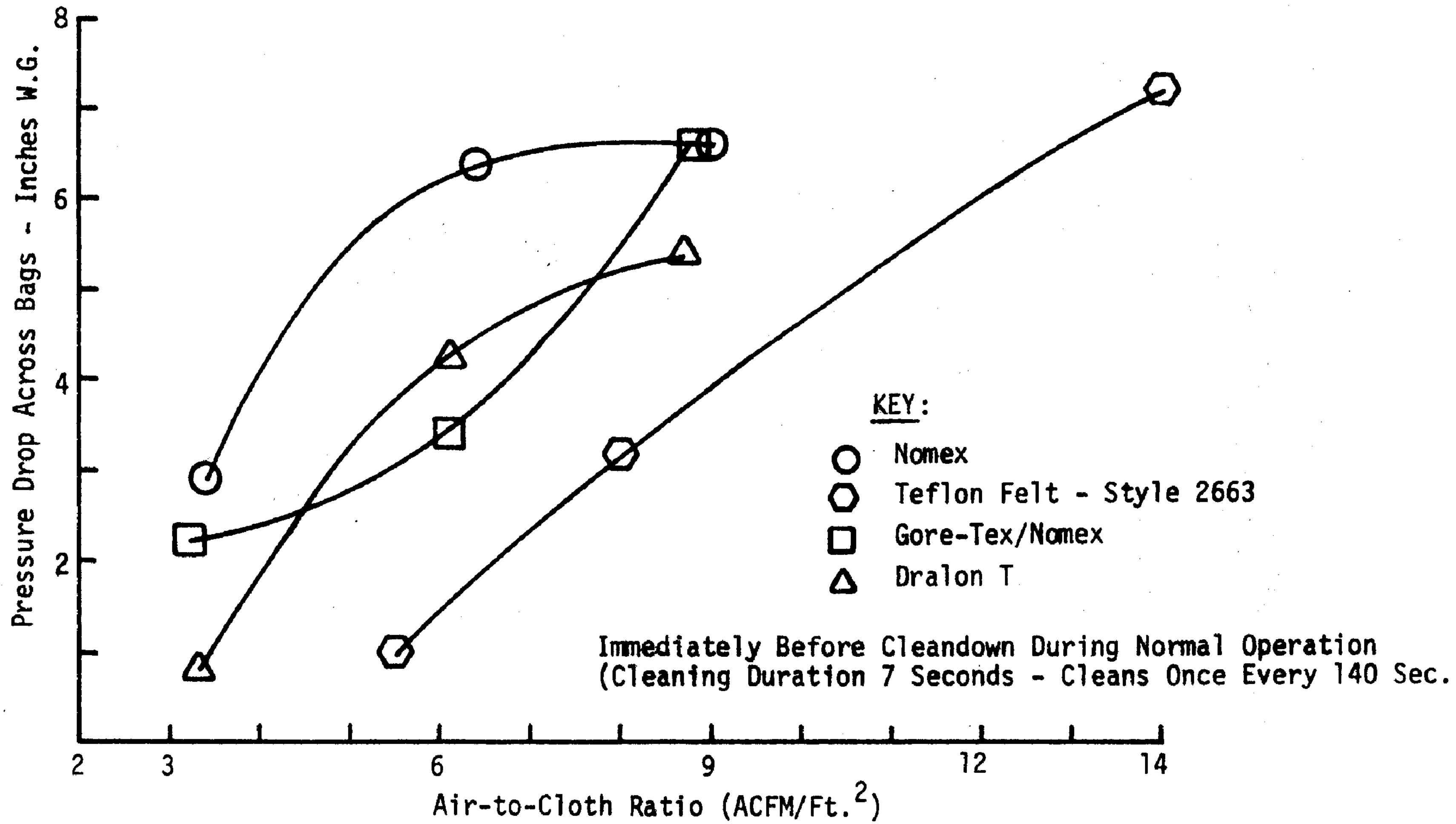


Table 31

Comparison of Particle Size Efficiencies for Various Bag Materials

Air-to-Cloth Ratio 6/1

Particle Diameter (Dp)* Microns	% Efficiency Nomex	Teflon Felt Style 2663**	Dralon T	Gore-Tex/Nomex
8.37	99.62	99.33	98.48	99.33
5.29	99.59	98.95	98.99	99.43
3.54	99.45	98.09	97.86	97.95
2.47	98.07	96.96	95.86	96.07
1.57	97.92	96.96	94.82	96.96
.79	97.44	90.23	89.07	96.28
.49	96.23	86.79	87.54	94.53
.36	95.00	79.10	78.66	97.27
< .36	96.52	92.32	94.49	97.97
Overall Efficiency	99.12	98.05	97.27	98.61

*Corrected for particle density and stack temperature.

**Teflon Felt, Style 2663 - A/C 5.4/1

All efficiencies based on the same inlet loadings and therefore assumes constant inlet conditions.

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APPENDIX

Appendix A-1

Units of Measures - Conversions
Experiment on Nomex and Teflon

UNITS OF MEASURE - CONVERSIONS

Environmental Protection Agency policy is to express all measurements in Agency documents in metric units. When implementing this practice will result in undue costs or lack of clarity, conversion factors are provided for the non-metric units used in a report. Generally, this report uses British units of measure. For conversion to the metric system, use the following conversions:

TO CONVERT FROM	TO	MULTIPLY BY
°F	°C	$\frac{5}{9}$ (°F-32)
ft	meters	0.304
ft^2	$meters^2$	0.0929
ft^3	$meters^3$	0.0283
ft/min (fpm)	centimeters/sec	0.508
ft^3/min	$centimeters^3$/sec	471.9
in	centimeters	2.54
in^2	$centimeters^2$	6.45
oz	grams	28.34
oz/yd^2	$grams/meter^2$	33.89
grains	grams	0.0647
$grains/ft^3$	$grams/meter^3$	2.288
lb force	dynes	4.44×10^5
lb mass	kilograms	0.453
lb/ft^2	$grams/centimeter^2$	0.488
in H_2O/ft/min	cm H_2O/cm/sec	5.00
$\frac{\text{in } H_2O/ft/min}{lb/ft^2}$	$\frac{\text{cm } H_2O/cm/sec}{gm/cm^2}$	10.24

Appendix A-1

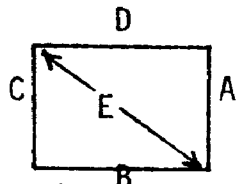
Experiment on Nomex Felt (HT)

Shrinkage, Weight Loss, Permeability - 10/25/74-11/12/74

Description:

Cut test swatch 6" X 6" - measured, weighed and ran perm at 0.5" WG.

Placed test swatch in oven at 300° F; remeasured, weighed and ran perms weekly.



Nomex (HT) Test Swatch

Results

Before 10/25	10/29	11/5	11/12
Wt. 11.49 grams	Wt. 10.73 gr.	Wt. 10.73 Gr.	Wt. 10.72 Gr.
A = 6 1/16"	A = 6 1/16"	A = 6 1/32"	A = 6 1/16"
B = 6	B = 6	B = 6	B = 6
C = 6	C = 6	C = 6	C = 6
D = 6	D = 5 15/16	D = 5 15/16	D = 5 15/16
E = 8 9/16	E = 8 9/16	E = 8½	E = 8½
Perm = 39.94 cfm/ft.^{2}	Perm = 40.18	Perm = 38.83	Perm = 43.24

Net Change

Wt. - 0.77 grams
A = None
B = None
C = None
D = 1/16"
E = 1/16"
Perm = + 3.3 cfm/ft.^{2}

Appendix A-1

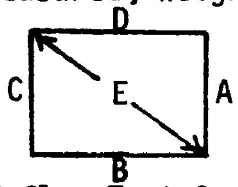
Experiment on Teflon Felt (26 oz.)

Shrinkage, Weight Loss, Permeability - 9/20/74-9/21/74

Description:

Cut test swatch 6" X 6" - measured, weighed and ran perm at 0.5", 1.0", 3.0", 5.0" WG.

Placed in oven at 300°F for 24 hours, cooled to ambient temperature in dessicator and remeasured, weighed and ran perms.



Teflon Test Swatch

Results

Before	After	Net Change
Wt. 19.1115 grams	Wt. 18.7870 grams	Wt. .3245 Grams
A = 6 1/32"	A = 5 3/4"	A = 9/32"
B = 6 1/32"	B = 5 5/16"	B = 3/32"
C = 6.0"	C = 5 23/32"	C = 9/32"
D = 6.0"	D = 5 7/8"	D = 4/32"
E = 9 9/16"	E = 9 7/16"	E = 4/32"

Δp	Perms cfm/ft^2	Δp	Perms cfm/ft^2	Δp	Perms cfm/ft^2
0.5	24.92	0.5	19.38	0.5	-5.54
1.0	49.84	1.0	38.41	1.0	-11.34
3.0	123.10	3.0	97.06	3.0	-26.04
5.0	784.88	5.0	142.6	5.0	-46.30

Appendix A-2

Teflon Felt Data - Style 2063

Teflon Felt - Style 2063

Sixteen Teflon felt bags were placed in Cell 2. (See Figure A-1 for bag positioning).

The Andersen sampler was utilized in obtaining in-situ particle size data at air-to-cloth levels of 5.2 to 1, 8 to 1 and 14 to 1. Inlet flue gas volumes ranged between 950 and 2600 ACFM. Because of the limited amount of Teflon cloth on hand, difficulty was experienced in trying to operate at the lower air-to-cloth levels. In order to effect an air-to-cloth ratio of 5 to 1, the main fan was throttled almost completely. The reverse air volume, although not used during sampling periods, was 3500 acfm.

The particle size distribution for the individual runs was averaged at each of the three levels of air-to-cloth. The comparison of this data is graphically displayed in Figure A-2. The mass mean particle diameters were 2, 3 and 4 microns for air-to-cloth ratios of 5.2, 8 and 14 to 1 respectively.

The size distribution curves indicate that about 50% of the particulate was less than 2 microns at the lowest air-to-cloth, while only 37% of the particulate by weight was less than 3 microns at 14 to 1.

Average outlet concentration cumulative percent and penetration by particle size are listed in Table A-1. Outlet concentration as a function of velocity is presented in Figure A-3.

Pressure drop versus air-to-cloth data is presented in Figure A-5 while examples of typical cleandown cycles are shown in Figure A-6. Although Teflon felt exhibited the highest dust penetration of the materials tested, it was capable of operating with the lowest pressure drops. As shown in Figures A-5 and A-6 it would be economically feasible to operate at even the highest air-to-cloth levels.

After fifty-two hours on stream the bags were inspected. They showed no signs of wear with only slight evidence of pearling in a 3/16" build-up of a friable dust.

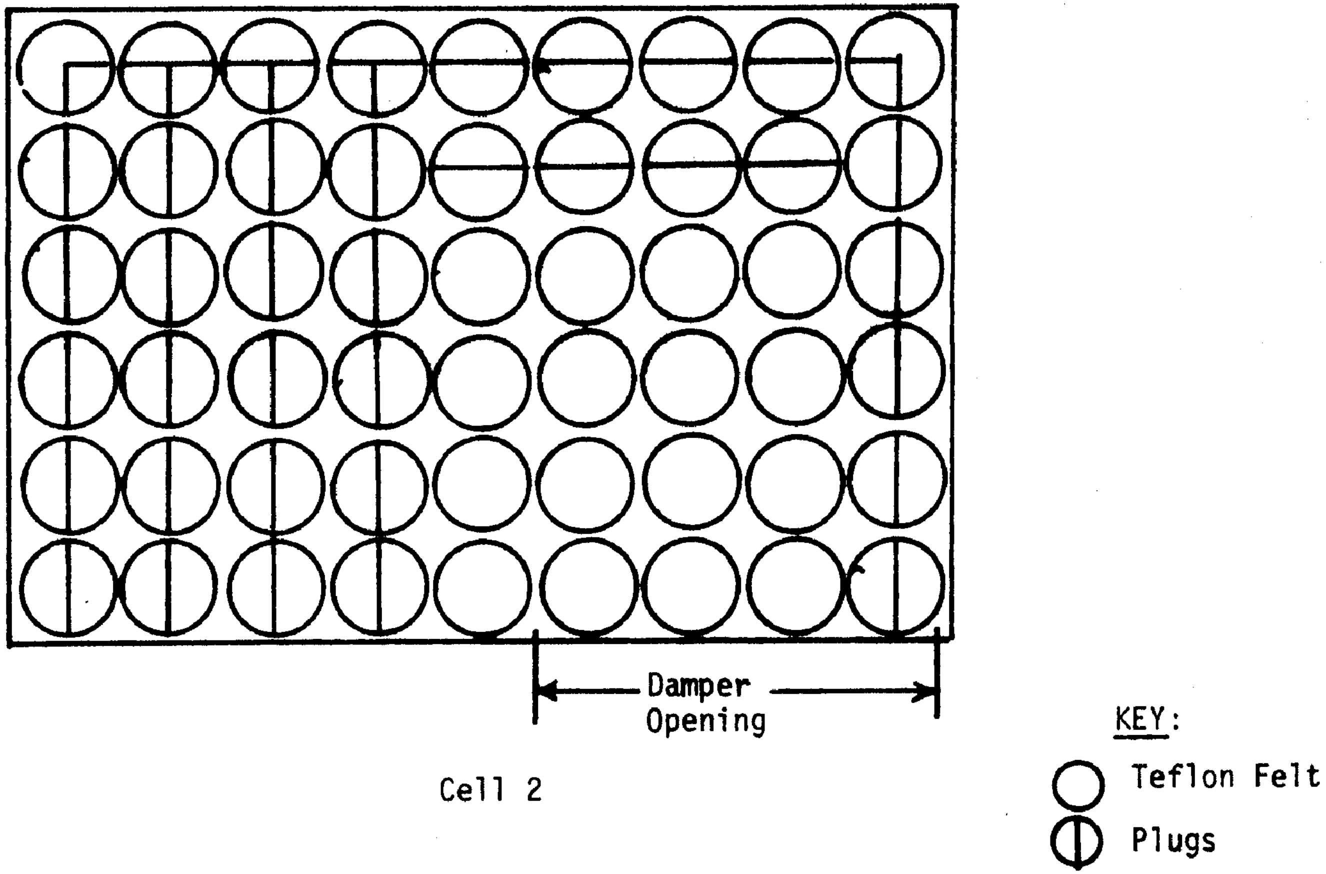


Figure A-1

Positioning of Teflon Felt Bags
Style 2063

Figure A-2

Outlet Particle Size Distribution

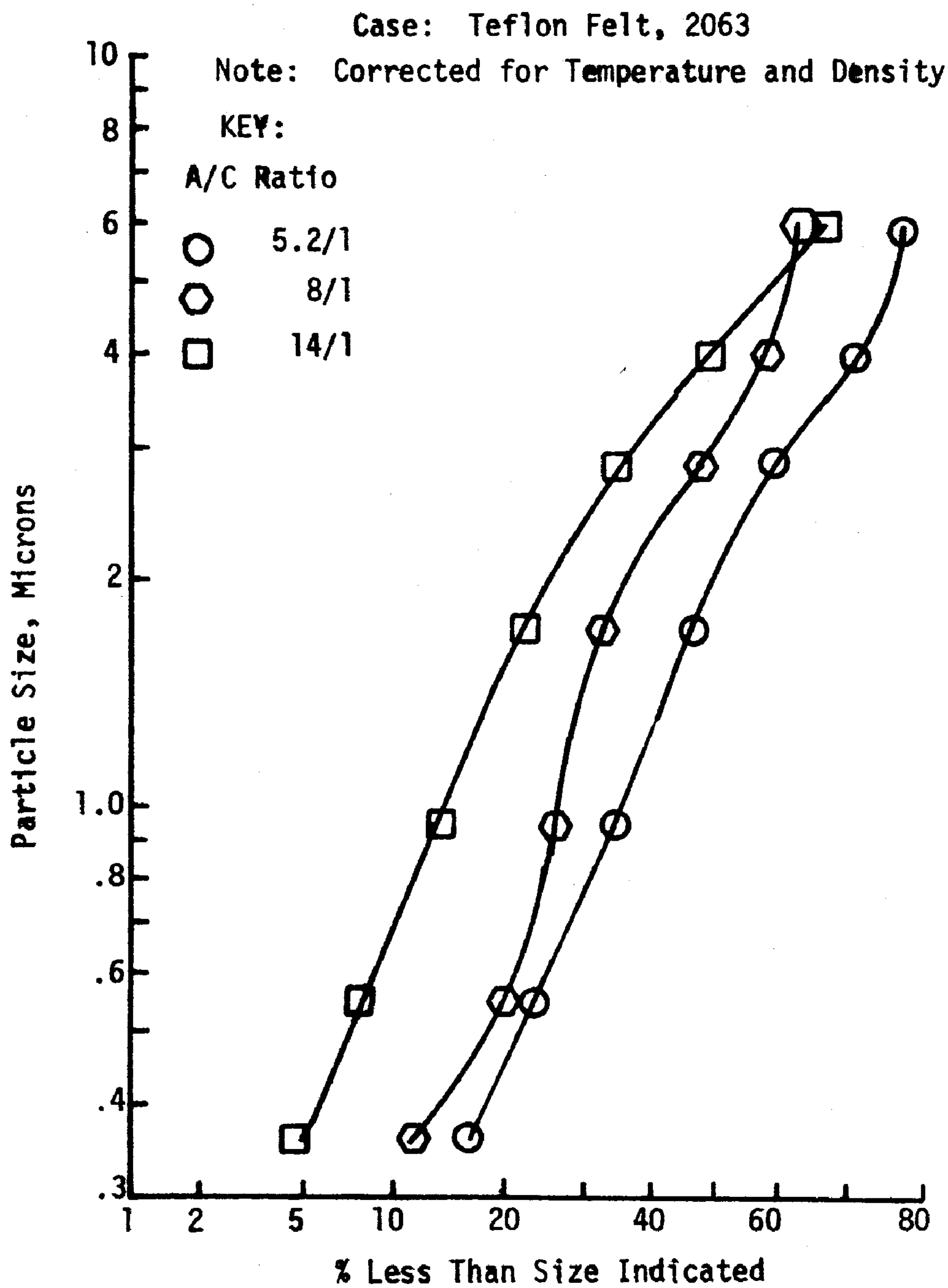


Table A-1

Outlet Concentration, Cumulative % and Penetration

Teflon Felt, Style 2063

Avg.[1] Part. Diam. um	Air-to-Cloth Ratio 5.2/1: Avg.[2] Outlet Conc. Gr./SCFD	Cuml.[3] %	Pene-[4] tration	Air-to-Cloth Ratio 8/1: Avg. Outlet Conc. Gr./SCFD	Cuml. %	Pene- tration	Air-to-Cloth Ratio 14/1: Avg. Outlet Conc. Gr./SCFD	Cuml. %	Pene- tration
> 9.37	.00325	100	.0223	.00142	100	.0098	.00967	100	.0665
5.87	.00084	77.69	.0218	.00019	63.49	.0049	.00512	67.17	.1330
3.98	.00184	71.92	.0696	.00041	58.61	.0155	.00434	49.79	.1642
2.84	.00176	59.29	.1368	.00058	48.07	.0451	.00359	35.06	.2789
1.72	.00181	47.21	.1418	.00026	33.16	.0204	.00257	22.87	.2014
.95	.00159	34.79	.3232	.00025	26.48	.0508	.00182	14.15	.3699
.55	.00109	23.88	.4037	.00033	20.05	.1222	.00092	7.97	.3407
.36	.00055	16.40	.1862	.00008	11.57	.0269	.00041	4.85	.1380
< .36	.00184	12.63	.4289	.00037	9.51	.0862	.00102	3.46	.2378
TOTAL	.01457		.0581	.00389		.0155	.02946		.1174

1. Corrected for particle density (2.6 grams/C.C.) and stack temperature.
2. At 5.2/1 three (3) tests averaged, at 8/1 two (2) tests averaged, at 14/1 two (2) tests averaged.
3. Percent of total outlet concentration less than size indicated.
4. Penetration based on average inlet concentration at corresponding impactor stages.

Figure A-3

Outlet Concentration by Particle Size
vs.
Air-to-Cloth Ratio

Case: Teflon Felt

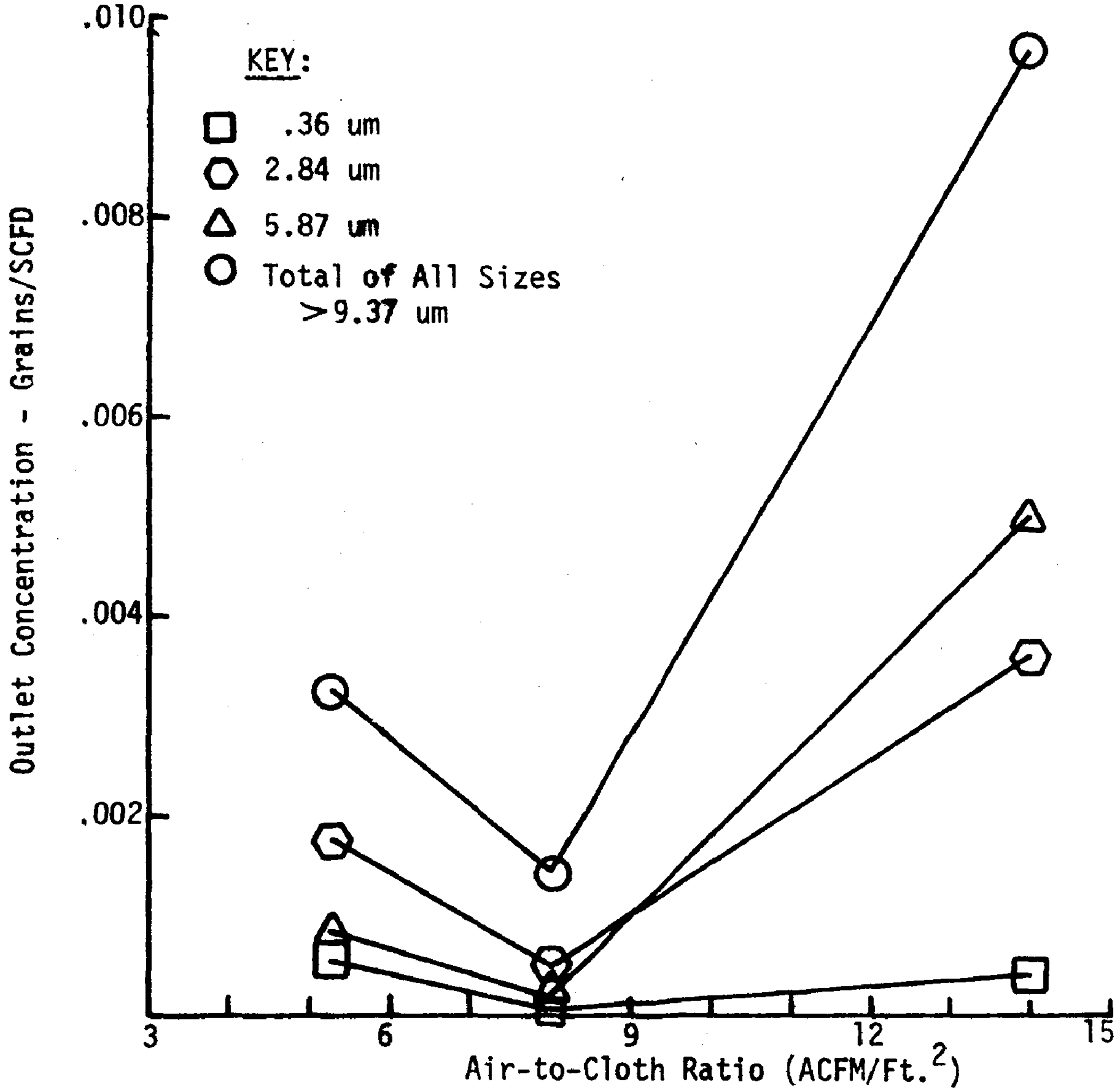


Figure A-4

Penetration vs. Particle Diameter

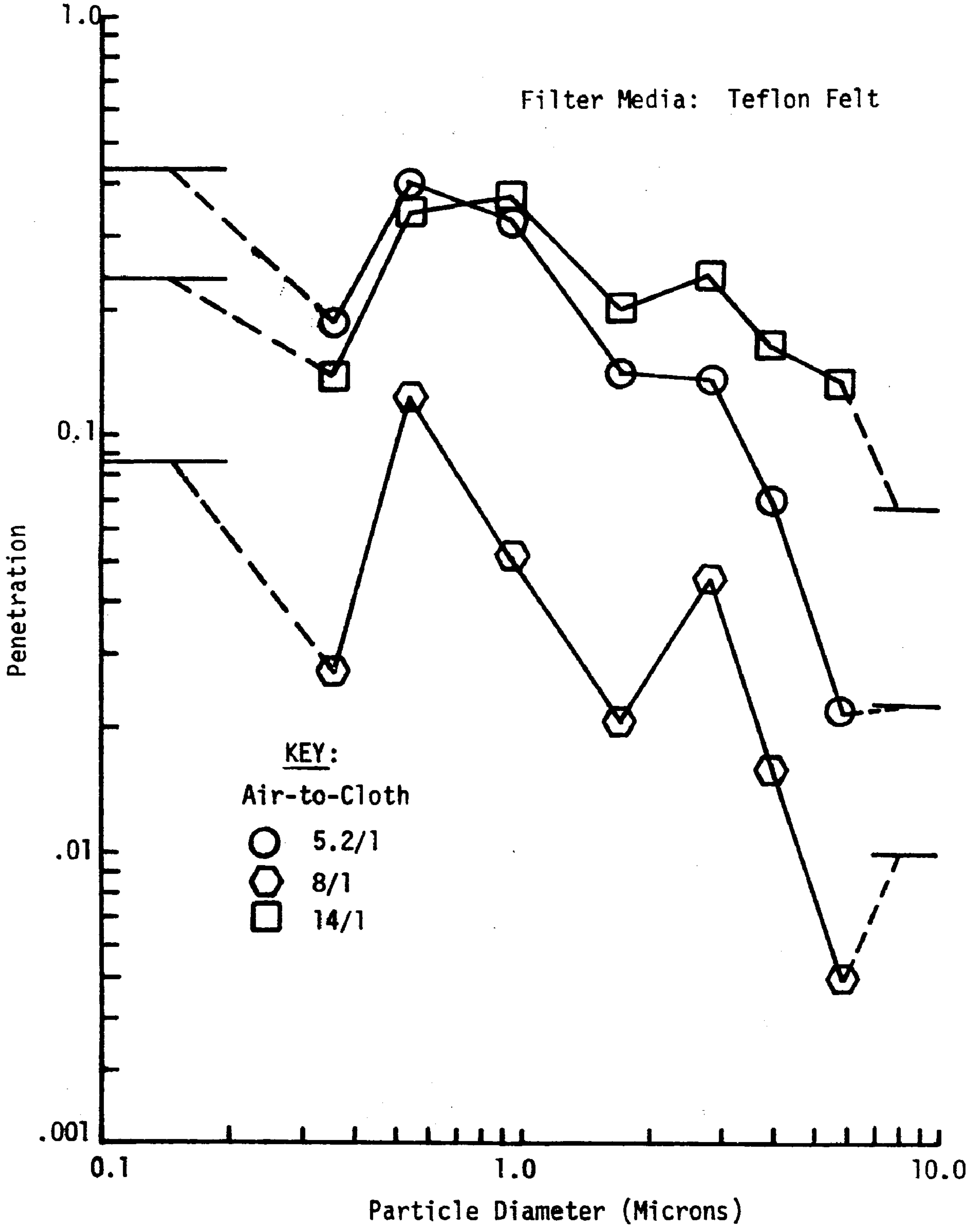


Figure A-5

Pressure Drop Across Bags
vs.
Air-to-Cloth Ratio

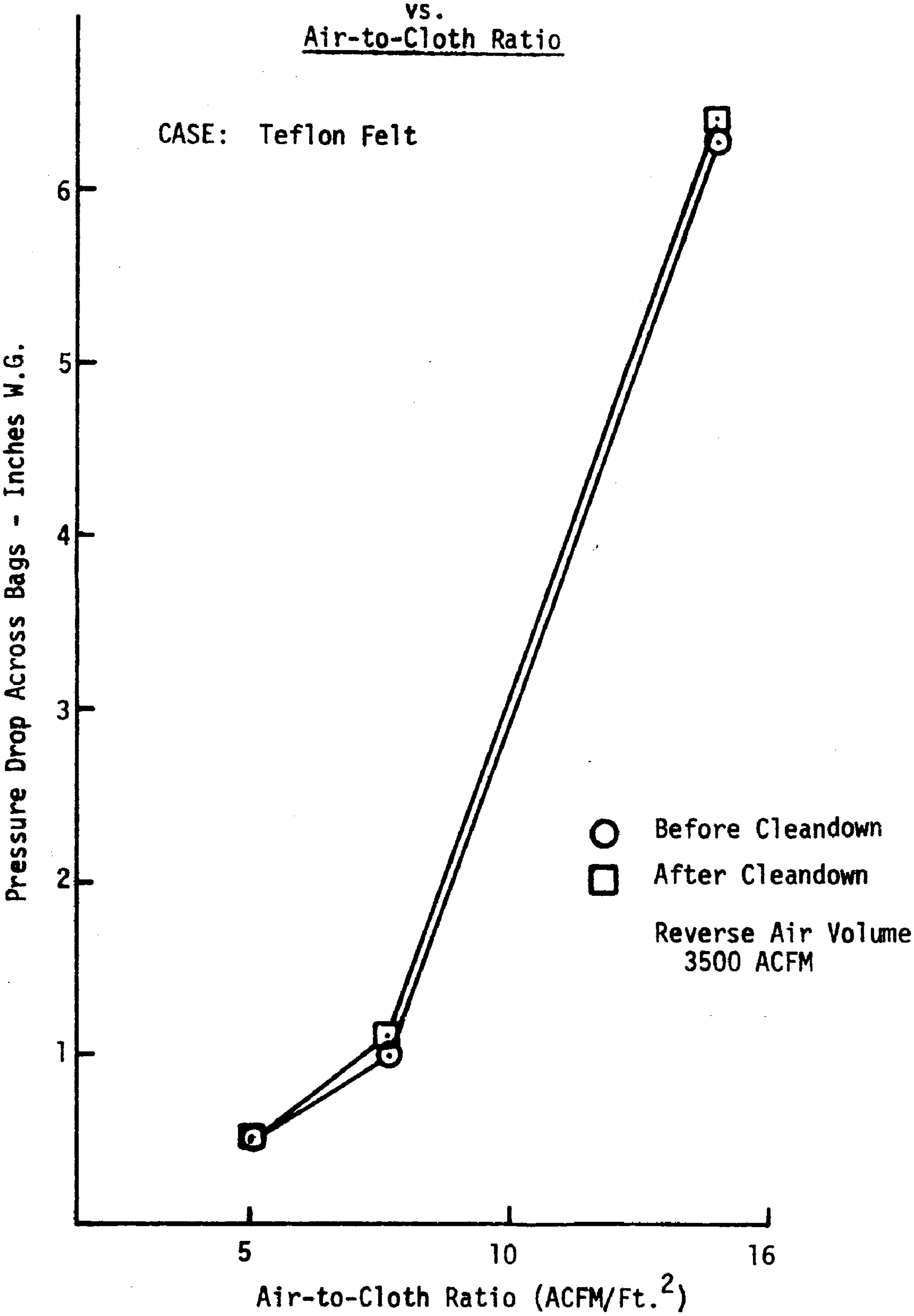
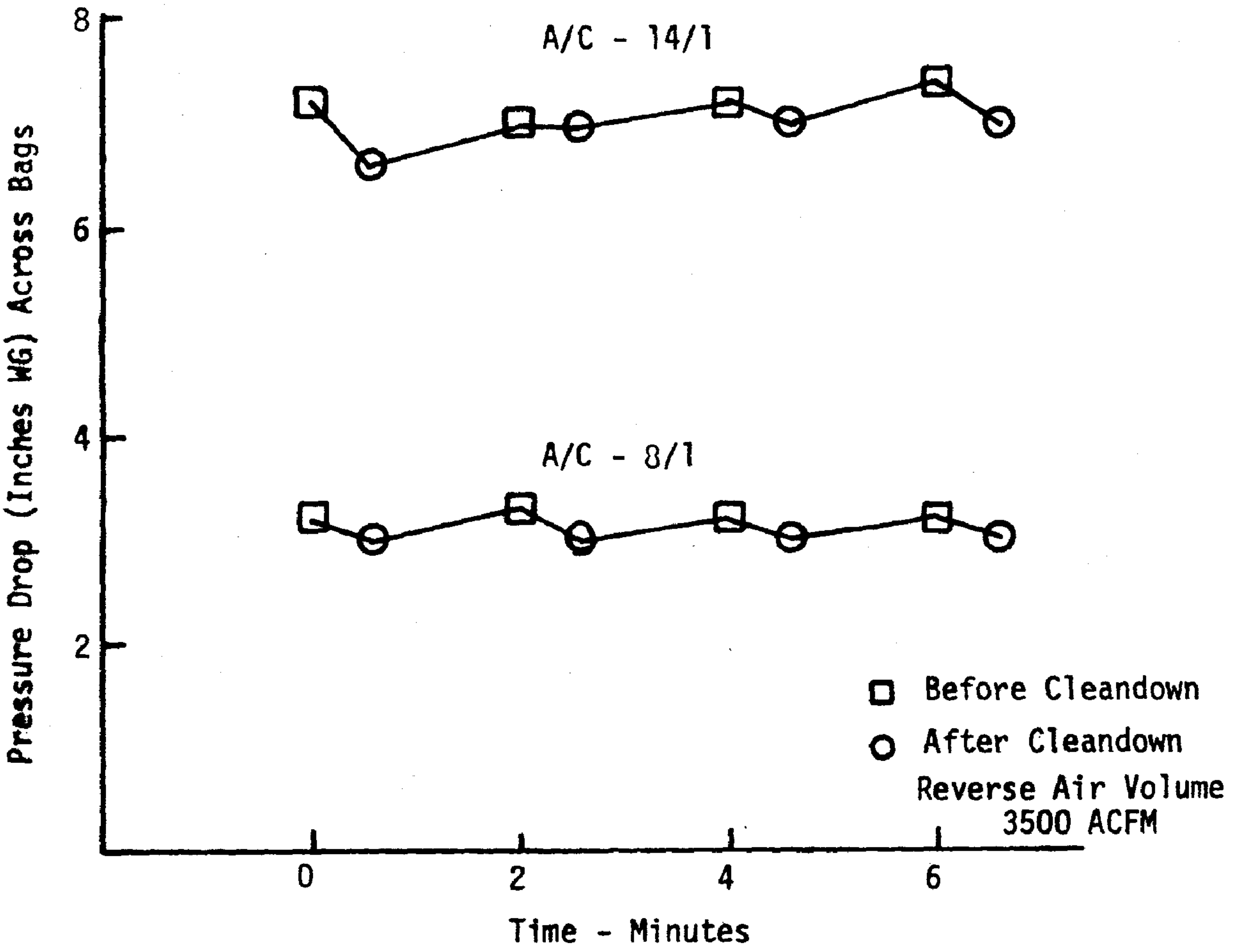


Figure A-6

Typical Cleaning Cycles

Teflon Felt



Appendix A-3

Pilot Plant Flow Data for Andersen
Tests No. 2-80
Particle Size Distribution Data
Fractional Loading Data

Table A-2
Pilot Plant Flow Data

Date & Time	And. Test No.	Main Slide Gate Position % Open	Flow Rate Q_F*	Flow Rate Q_R*	Air-to-Cloth Ratio (Ft./Min.) $(A/C)_F$	Air-to-Cloth Ratio (Ft./Min.) $(A/C)_R$	Temperature T_F (°F)	Temperature T_R (°F)	Bags Tested & Exposure (Hrs.) at Test Time		Pressure Drop Across Cell (In. H_2O) Cell 3	Pressure Drop Across Cell (In. H_2O) Cell 4
5/29 1150	2	100	2380	4374	6.9	12.7	160	100	Inlet		-	8.4
5/30	3								Inlet			
5/31 1050	4	100	2380	-	6.6	-	170	135	Inlet		-	7.6
6/6 1145	5	10	1475	-	8.0	-	130	-	TF	15	#2 4.6	-
6/6 1600	6	10	1475	-	8.0	-	120	-	TF	20	#2 4.6	-
6/7 1544	7	-	1677	-	9.1	-	120	-	Inlet		#2 2.8	-
6/8 1236	8	10	2496	-	14	-	150	-	TF	31	#2 7.3	-
6/10 1342	9	10	2563	2127	14	12	150	130	TF	36	#2 6.3	-
6/11 1627	10	5	943	-	5.2	-	110	-	TF	42	#2 0.5	-
6/12 1150	11	5	1017	-	5.2	-	120	-	TF	46	#2 1.1	-
6/12 1600	12	5	1017	-	5.2	-	120	-	TF	50	#2 1.0	-

*F - foreward flow i.e., flue gas
*R - reverse flow i.e., reverse air

TF = Teflon felt

Table A-2

Pilot Plant Flow Data
(continued)

Date & Time	And. Test No.	Main Slide Gate Position % Open	Flow Rate Q_F	Flow Rate Q_R	Air-to-Cloth Ratio (Ft./Min.) $(A/C)_F$	Air-to-Cloth Ratio (Ft./Min.) $(A/C)_R$	Temperature T_F (°F)	Temperature T_R (°F)	Bags Tested & Exposure (Hrs.) at Test Time		Pressure Drop Across Cell (In. H_2O) Cell 3	Pressure Drop Across Cell (In. H_2O) Cell 4
6/18 1056	13	5	1068	-	3.1	-	120	-	N	89	-	1.2
6/18 1540	14	5	1068	-	3.1	-	130	110	N	94	-	1.1
6/19 1035	15	5	975	-	2.9	-	125	105	N	98	-	0.9
6/19 1533	16	60	2120	-	6.1	-	175	140	N	103	-	7.1
6/20 1133	17	20	2094	-	6.1	-	155	-	N	108	-	4.2
6/21 1130	18	20	2060	-	6.1	-	185	-	Inlet		-	3.5
6/24 0945	19	20	1897	-	5.5	-	160	-	G	6	-	3.6
6/24 1435	20	20	2422	-	7.0	-	190	150	Aborted		-	2.8
6/25 1121	21	20	1988	-	6.0	-	180	140	G	14	-	2.9
6/25 1551	22	30	2171	-	6.5	-	195	145	G	19	-	4.5
6/26 0950	23	15	1198	-	3.6	-	143	-	G	23	-	2.5

N = Nomex
G = Gore-Tex

Table A-2

Pilot Plant Flow Data
(continued)

Date & Time	And. Test No.	Main Slide Gate Position % Open	Flow Rate Q_F	Flow Rate Q_R	Air-to-Cloth Ratio (Ft./Min.) $(A/C)_F$	Air-to-Cloth Ratio (Ft./Min.) $(A/C)_R$	Temperature T_F (°F)	Temperature T_R	Bags Tested	Exposure (Hrs.) at Test Time	Pressure Drop Across Cell, Cell 3 (In. H_2O)	Pressure Drop Across Cell, Cell 4 (In. H_2O)
6/26 1453	24	15	1258	–	3.7	–	160	–	G	28	–	2.7
7/9 1818	25	20	2082	–	6.2	–	190	–	G	36	–	4.0
7/10 1118	26	20	2088	3296	6.3	9.9	197	–	G	42	–	4.2
7/11 1125	27	70	3000	3222	9.0	9.7	195	160	G	52	–	6.9
7/12 1035	28	100	2867	3222	8.6	9.7	193	–	G	58	–	7.5
7/17 1003	29	80	2777	–	8.3	–	204	–	G	62	–	7.3
7/17 1500	30	5	1004	–	3.0	–	132	–	G	68	–	1.5
7/18 1519	31	100	3044	–	9.1	–	203	–	G	74	–	7.4
7/24 1056	32	5	789	–	2.7	–	140	130	G	84	–	1.8
7/24 1435	33	5	926	–	3.2	–	125	120	G	88	–	1.5
7/25 1030	34	20	1802	–	6.3	–	180	155	G	92	–	5.1

G = Gore-Tex

Table A-2

Pilot Plant Flow Data
(continued)

Date & Time	And. Test No.	Main Slide Gate Position % Open	Flow Rate Q_F	Flow Rate Q_R	Air-to-Cloth Ratio (Ft./Min.) $(A/C)_F$	Air-to-Cloth Ratio (Ft./Min.) $(A/C)_R$	Temperature T_F (°F)	Temperature T_R	Bags Tested & Exposure (Hrs.) at Test Time		Pressure Drop Across Cell (In. H_2O) Cell 3	Pressure Drop Across Cell (In. H_2O) Cell 4
7/25 1425	35	20	1761	-	6.1	-	180	160	G	96	-	5.5
7/26 1015	36	100	2613	-	9.1	-	208	-	G	100	-	7.8
7/26 1400	37	100	2547	-	8.9	-	182	-	G	104	-	8.3
7/29 1535	38	15	2107	5000	6.1	14	174	-	G	113	#2 2.0	-
7/30 1640	39	50	2972	-	8.7	-	200	-	N	120	-	6.7
7/31 1129	40	80	2812	3100	8.2	9.0	191	164	N	124	-	7.6
8/6 0745	41	80	6425	1420	9.3	2.1	223	185	N	128	5.7	6.3
8/6 1040	42	80	5909	1420	8.6	2.1	230	196	N	131	5.6	6.4
8/6 1330	43	80	5910	3160	8.6	4.6	230	198	N	135	4.8	5.2
8/7 0740	44	100	6670	3160	9.6	4.6	220	195	N	138	6.4	6.8
8/7 1033	45	100	6670	4000	9.6	5.8	220	195	N	141	4.8	6.0
8/7 1340	46	100	5390	4000	7.8	5.8	225	195	N	143	5.8	6.0

G = Gore-Tex
N = Nomex

Table A-2

Pilot Plant Flow Data
(continued)

Date & Time	And. Test No.	Main Slide Gate Position % Open	Flow Rate Q_F	Q_R	Air-to-Cloth Ratio (Ft./Min.) $(A/C)_F$	$(A/C)_R$	Temperature T_F (°F)	T_R	Bags Tested & Exposure (Hrs.) at Test Time		Pressure Drop Across Cell: Cell 3 (In. H_2O)	Cell 4
8/8 0750	47	80	4512	1400	6.5	2.1	200	150	N	147	6.0	6.1
8/8 1035	48	80	4512	1400	6.5	2.1	200	150	N	150	6.1	6.1
8/14 1110	49	80	4653	Off	6.7	–	212	175	Inlet		5.5	5.6
8/14 1110	50	80	4653	Off	6.7	–	212	175	Inlet		5.5	5.6
8/14 1400	51	80	4653	Off	6.7	–	205	170	Inlet		5.7	5.9
8/14 1400	52	80	4653	Off	6.7	–	205	170	Inlet		5.7	5.9
8/15 0800	53	60	4421	3100	6.4	4.5	200	165	N	164	5.0	5.0
8/15 1040	54	60	4421	3100	6.4	4.5	210	170	N	167	5.8	5.9
8/15 1350	55	60	4421	4000	6.4	5.8	200	170	N	171	5.7	5.8
8/16 0740	56	60	4421	4000	6.4	5.8	200	170	N	174	5.4	5.6

N = Nomex

Table A-2

Pilot Plant Flow Data
(continued)

Date & Time	And. Test No.	Main Slide Gate Position % Open	Flow Rate Q_F	Flow Rate Q_R	Air-to-Cloth Ratio (Ft./Min.) $(A/C)_F$	Air-to-Cloth Ratio (Ft./Min.) $(A/C)_R$	Temperature T_F (°F)	Temperature T_R (°F)	Bags Tested & Exposure (Hrs.) at Test Time		Pressure Drop Across Cell (In. H_2O) Cell 3	Pressure Drop Across Cell (In. H_2O) Cell 4
8/16 1035	57	20	2129	1400	3.1	2.1	170	140	N	177	3.1	3.0
8/20 0735	58	20	2313	1400	3.4	2.1	165	140	N	180	2.9	2.8
8/20 1100	59	20	2313	3160	3.4	4.6	160	140	N	183	2.7	2.6
8/20 1330	60	20	2313	3160	3.4	4.6	150	140	N	186	2.5	2.4
8/21 0730	61	60	2275	4000	3.3	5.8	150	125	N	190	2.2	2.2
8/21 1005	62	60	2275	4000	3.3	5.8	160	135	N	192	2.2	2.2
8/26 1150	63	30	2550	-	8.5	-	190	135	Aborted		-	5.6
8/26 1430	64	30	2550	-	8.5	-	175	135	DT	27	-	6.2
8/27 0730	65	30	2666	-	8.9	-	150	-	DT	30	-	5/4
8/27 1035	66	20	1817	-	6.1	-	162	-	DT	33	-	2.9

N = Nomex
DT = Dralon T

Table A-2

Pilot Plant Flow Data
(continued)

Date & Time	And. Test No.	Main Slide Gate Position % Open	Flow Rate Q_F	Q_R	Air-to-Cloth Ratio (Ft./Min.) $(A/C)_F$	$(A/C)_R$	Temperature T_F (°F)	T_R	Bags Tested & Exposure (Hrs.) at Test Time		Pressure Drop Across Cell: Cell 3 (In. H_2O)	Cell 4
8/27 1350	67	20	1817	-	6.1	-	170	-	DT	36	-	5.0
8/28 1135	68	20	1817	3810	6.1	13	-	-	DT	42	-	5.2
8/29 1110	69	10	997	-	3.3	-	130	-	DT	48	-	2.2
8/29 1400	70	10	997	-	3.3	-	140	-	DT	51	-	2.2
11/18 1405	71	10	3100	-	14	-	160	-	TF	25	3.5	-
11/19 0955	72	5	1760	-	7.9	-	120	-	TF	29	3.0	-
11/19 1355	73	5	1383	-	6.0	-	100	-	TF	34	1.0	-
11/19 1615	74	5	1383	-	6.0	-	80	-	TF	37	1.0	-
11/20 1145	75	10	3300	-	14.3	-	160	-	TF	40	6.8	-
11/20 1520	76	10	1830	-	8.0	-	130	-	TF	43	3.0	-
11/21 1140	77	10	3260	-	14.2	-	150	-	TF	47	7.8	-

DT = Dralon T
TF = Teflon felt

Table A-2

Pilot Plant Flow Data
(continued)

Date & Time	And. Test No.	Main Slide Gate Position % Open	Flow Rate Q_F	Q_R	Air-to-Cloth Ratio (Ft./Min.) $(A/C)_F$	$(A/C)_R$	Temperature T_F (°F)	T_R	Bags Tested & Exposure (Hrs.) at Test Time		Pressure Drop Across Cell, Cell 3 (In. H_2O)	Cell 4
11/21 1350	78	5	1930	-	8.4	-	125	-	TF	50	4.0	-
11/21 1555	79	5	1180	-	5.4	-	80	-	TF	52	1.8	-
11/22 0925	80	5	1180		5.4	-	90	-	TF	54	1.5	-

TF = Teflon felt

Table A-3

PARTICLE SIZE DISTRIBUTION FOR ANDERSEN TESTS

D R A L O N T

And. Run#	A/C Ratio	Particle Size Distribution								
64	8.5/1	>9.8	6.1	4.1	2.8	1.79	.92	.57	.39	<.39
65	8.9/1	>9.7	6.0	4.0	2.8	1.80	.92	.58	.38	<.38
66	6.1/1	>9.8	6.1	4.1	2.8	1.80	.92	.58	.38	<.38
67	6.1/1	>9.3	5.9	3.8	2.7	1.72	.88	.54	.36	<.36
68	6.1/1	>9.8	6.1	4.0	2.8	1.81	.92	.58	.36	<.36
69	3.3/1	>8.6	5.4	3.6	2.5	1.59	.82	.50	.34	<.34
70	3.3/1	>8.6	5.4	3.6	2.5	1.59	.82	.50	.34	.34
Total		65.6	41.0	27.2	18.9	12.10	6.20	3.85	2.55	2.55
Avg.		>9.37	5.86	3.89	2.7	1.73	.89	.55	.36	<.36

N O M E X F E L T : (Zero RA)

And. Run#	A/C Ratio	Particle Size Distribution								
13	3.1/1	>8.5	5.4	3.5	2.48	1.89	.79	.49	.33	<.33
14	3.1/1	>8.37	5.29	3.48	2.81	1.54	.79	.475	.32	<.32
15	2.9/1	>8.8	5.5	3.7	2.5	1.9	.83	.51	.35	<.35
16	6.1/1	>9.8	6.0	4.0	2.8	1.77	.91	.57	.37	<.37
17	6.1/1	>9.9	6.2	4.2	2.9	1.84	.95	.59	.40	<.40
39	8.7/1	>8.4	5.3	3.6	2.52	1.55	.80	.49	.33	<.33
40	8.2/1	>8.4	5.3	3.6	2.51	1.55	.80	.49	.33	<.33
38	6.1/1	>9.7	6.0	4.0	2.9	1.78	.91	.56	.38	<.38
Total		71.87	44.99	30.08	21.42	13.82	6.78	4.18	2.81	2.81
Avg.		>8.98	5.62	3.76	2.68	1.73	.85	.52	.35	<.35

G O R E - T E X

And. Run#	A.C Ratio	Particle Size Distribution								
19	5.5/1	>10.2	6.4	4.3	3.0	1.87	.97	.59	.41	<.41
21	6.0/1	>9.7	6.1	4.0	2.9	1.80	.91	.56	.38	<.38
22	6.5/1	>9.6	6.1	4.0	2.8	1.79	.92	.57	.38	<.38
23	3.6/1	>9.4	5.9	3.9	2.8	1.75	.90	.55	.37	<.37
25	6.2/1	>9.3	5.9	3.8	2.73	1.74	.88	.55	.36	<.36
26	6.3/1	>9.9	6.2	4.1	2.9	1.82	.94	.58	.39	<.39
27	9/1	>10.5	6.6	4.4	2.93	1.93	.99	.61	.41	<.41
28	8.6/1	>9.2	5.7	3.83	2.65	1.67	.871	.536	.36	<.36
32	2.7/1	>7.27	5.55	3.73	2.57	1.62	.847	.515	.35	<.35

Table A-3 (continued)

PARTICLE SIZE DISTRIBUTION FOR ANDERSEN TESTS

G O R E - T E X cont.

And. Run#	A/C Ratio	Particle Size Distribution								
33	3.2/1	>7.25	5.55	3.73	2.57	1.62	.847	.515	.35	<.35
34	6.3/1	>10.6	6.6	4.49	3.1	1.93	1.0	.62	.43	<.43
Total		102.9	66.6	44.28	30.95	19.54	10.08	6.20	4.19	4.19
Avg.		> 9.35	6.05	4.03	2.81	1.78	.92	.56	.38	<.38

T E F L O N F E L T (Style 2063)

And. Run#	A/C Ratio	Particle Size Distribution								
5	8/1	>8.96	5.66	3.69	2.63	1.65	1.05	.527	.329	<.329
6	8/1	>8.96	5.66	3.69	2.63	1.65	1.05	.527	.329	<.329
8	14/1	>9.3	5.98	3.99	2.79	1.79	.93	.54	.37	<.37
9	14/1	>10.8	6.5	5.0	3.66	1.89	.98	.603	.413	<.413
10	5.2/1	>9.2	5.79	3.82	2.7	1.7	.856	.54	.36	<.36
11	5.2/1	>9.04	5.6	3.79	2.66	1.66	.86	.53	.36	<.36
12	5.2/1	>9.3	5.9	3.9	2.8	1.7	.89	.55	.37	<.37
Total		65.56	41.09	27.88	19.87	12.04	6.62	3.82	2.53	2.53
Avg.		>9.37	5.87	3.98	2.84	1.72	.95	.55	.36	<.36

N O M E X F E L T (Three levels RA)

And. Run#	A/C Ratio	Particle Size Distribution								
41	9.3/1	>9.6	6.0	3.9	2.80	1.79	.91	.56	.37	<.37
42	8.6/1	>9.7	6.1	4.0	2.8	1.8	.92	.56	.38	<.38
43	8.6/1	>9.5	6.0	4.0	2.8	1.77	.91	.55	.38	<.38
44	9.6/1	>9.7	6.1	4.0	2.8	1.8	.92	.56	.38	<.38
45	9.6/1	>9.6	6.0	3.9	2.8	1.79	.91	.56	.37	<.37
46	7.8/1	>9.0	5.8	3.8	2.7	1.67	.86	.52	.35	<.35
47	6.5/1	>9.52	6.0	3.9	2.8	1.79	.91	.56	.37	<.37
48	6.5/1	>9.3	5.78	3.69	2.65	1.67	.89	.54	.36	<.36
53	6.4/1	>9.0	5.77	3.87	2.67	2.04	.86	.53	.36	<.36
54	6.4/1	>9.0	5.77	3.87	2.67	2.04	.86	.53	.36	<.36
55	6.4/1	>9.0	5.77	3.87	2.67	2.04	.86	.53	.36	<.36
56	6.4/1	>9.0	5.77	3.87	2.67	2.04	.86	.53	.36	<.36
57	3.1/1	>9.57	6.0	3.96	2.8	1.85	.91	.56	.37	<.37
58	3.4/1	>9.16	5.81	3.83	2.66	1.71	.87	.53	.36	<.36

Table A-3 (continued)

PARTICLE SIZE DISTRIBUTION FOR ANDERSEN TESTS

N O M E X F E L T (Three levels RA) cont.

And. Run#	A/C Ratio	Particle Size Distribution								
59	3.4/1	>9.3	5.88	3.83	2.72	1.73	.88	.55	.35	<.35
60	3.4/1	>9.3	5.88	3.83	2.72	1.73	.88	.55	.35	<.35
61	3.3/1	>9.16	5.81	3.83	2.66	1.71	.87	.53	.36	<.36
62	3.3/1	>9.16	5.81	3.83	2.66	1.71	.87	.53	.36	<.36
Total		167.57	106.05	69.78	49.05	32.68	15.95	9.78	6.55	6.55
Avg.		>9.31	5.89	3.88	2.73	1.82	.89	.54	.36	<.36

T E F L O N F E L T (Style 2663)

And. Run#	A/C Ratio	Particle Size Distribution								
77	14.2/1	>8.27	5.15	3.52	2.51	1.56	.77	.49	.32	<.32
78	8.4/1	>8.25	5.19	3.53	2.46	1.59	.785	.479	.32	<.32
79	5.4/1	>8.53	5.43	3.62	2.45	1.55	.81	.50	.34	<.34
80	5.5/1	>8.75	5.55	3.65	2.55	1.63	.83	.51	.35	<.35
81	14/1	>8.08	5.14	3.42	2.39	1.51	.76	.46	.31	<.31
Total		41.88	26.46	17.74	12.36	7.84	3.96	2.44	1.64	1.64
Avg.		>8.38	5.29	3.55	2.47	1.57	.79	.49	.33	<.33

Table A-4
FRACTIONAL LOADING FOR ANDERSEN TESTS*

NOMEX FELT (Zero RA)

And. Run#	Air-To-Cloth = 3/1				Air-To-Cloth = 6/1				Air-To-Cloth = 8.5/1		
	13	14	15	Avg.	16	17	38	Avg.	39	40	Avg.
Fractional Loadings	.00068	.00040	.00085	.00064	.00043	.00059	.00120	.00074	.00228	.00114	.00171
	.00027	.00014	.00010	.00017	.00015	.00018	.00031	.00021	.00080	.00047	.00064
	.00030	.00043	.00022	.00032	.00011	.00022	.00078	.00037	.00135	.00083	.00109
	.00030	.00037	.00019	.00029	.00011	.00037	.00031	.00026	.00085	.00045	.00065
	.00018	.00040	.00022	.00027	.00022	.00048	.00075	.00048	.00094	.00075	.00084
	.00012	.00032	.00016	.00020	.00025	.00019	.00024	.00023	.00039	.00025	.00032
	.00006	.00017	.00010	.00011	.00014	.00026	.00062	.00034	.00036	.00050	.00043
	.00009	.00009	.00006	.00008	.00007	.00015	.00007	.00010	.00006	.00008	.00007
	.00006	.00015	.00006	.00008	.00011	.00037	.00017	.00022	.00016	.00022	.00019
Total	.00206	.00247	.00196	.00216	.00159	.00281	.00445	.00295	.00719	.00469	.00594

TEFLON FELT (Style 2063)

And. Run#	Air-To-Cloth = 5.2/1				Air-To-Cloth = 8/1			Air-To-Cloth = 14/1		
	10	11	12	Avg.	5	6	Avg.	8	9	Avg.
Fractional Loadings	.00400	.00290	.00284	.00325	.00224	.00060	.00142	.00573	.01362	.00967
	.00065	.00088	.00098	.00084	.00015	.00022	.00019	.00435	.00590	.00512
	.00142	.00198	.00213	.00184	.00025	.00057	.00041	.00305	.00562	.00434
	.00103	.00185	.00241	.00176	.00025	.00091	.00058	.00275	.00443	.00359
	.00116	.00185	.00241	.00181	.00021	.00032	.00026	.00198	.00316	.00257
	.00090	.00162	.00224	.00159	.00018	.00032	.00025	.00111	.00253	.00182
	.00071	.00114	.00142	.00109	.00009	.00057	.00033	.00050	.00133	.00092
	.00065	.00057	.00044	.00055	.00006	.00009	.00008	.00019	.00063	.00041
	.00149	.00299	.00104	.00184	.00040	.00035	.00037	.00042	.00162	.00102
Total	.01201	.01578	.01591	.01457	.00383	.00395	.00389	.02008	.03884	.02946

*All values are Grains/SCFD

Table A-4 (continued)

FRACTIONAL LOADING FOR ANDERSEN TESTS

T E F L O N F E L T (Style 2663)

And. Run#	77	81	Avg.	79	80	Avg.	78
	Air-To-Cloth = 14.1/1			Air-To-Cloth = 5.4/1			Air-To-Cloth = 8.4/1
Fractional Loadings	.00362	.00281	.00321	.00087	.00095	.00091	.00257
	.00086	.00072	.00079	.00035	.00047	.00041	.00082
	.00106	.00108	.00107	.00041	.00044	.00043	.00108
	.00075	.00084	.00080	.00035	.00055	.00045	.00108
	.00086	.00078	.00082	.00048	.00054	.00051	.00082
	.00060	.00078	.00069	.00038	.00066	.00052	.00087
	.00161	.00060	.00110	.00024	.00047	.00036	.00072
	.00111	.00072	.00092	.00035	.00058	.00046	.00093
	.00468	.00126	.00297	.00052	.00054	.00053	.00134
Total	.01515	.00959	.01237	.00395	.00520	.00458	.01023

D R A L O N T

And. Run#	70	60	Avg.	66	67	68	Avg.	64	65	Avg.
	Air-To-Cloth = 3.3/1			Air-To-Cloth = 6.1/1				Air-To-Cloth = 8.7/1		
Fractional Loadings	.00124	.00121	.00122	.00218	.00149	.00239	.00202	.00145	.00143	.00144
	.00098	.00113	.00106	.00029	.00027	.00061	.00039	.00039	.00065	.00052
	.00124	.00164	.00144	.00037	.00044	.00061	.00048	.00050	.00061	.00055
	.00118	.00147	.00133	.00048	.00061	.00071	.00060	.00046	.00057	.00051
	.00101	.00127	.00114	.00071	.00088	.00103	.00087	.00071	.00075	.00073
	.00087	.00096	.00092	.00089	.00071	.00121	.00094	.00075	.00072	.00074
	.00056	.00065	.00061	.00066	.00054	.00079	.00066	.00046	.00064	.00055
	.00048	.00045	.00046	.00052	.00031	.00061	.00048	.00032	.00036	.00034
	.00045	.00056	.00050	.00037	.00020	.00057	.00038	.00021	.00022	.00022
Total	.00801	.00934	.00868	.00647	.00545	.00853	.00682	.00525	.00595	.00560

Table A-4 (continued)

FRACTIONAL LOADING FOR ANDERSEN TESTS

G O R E - T E X

And. Run#	27	28	Avg.	23	32	33	Avg.
	Air-To-Cloth = 8.8/1			Air-To-Cloth = 3.2/1			
Fractional Loadings	.00156	.00189	.00173	.00086	.00072	.00054	.00071
	.00034	.00131	.00082	.00040	.00038	.00074	.00051
	.00097	.00201	.00149	.00050	.00110	.00089	.00083
	.00059	.00096	.00078	.00083	.00061	.00057	.00067
	.00114	.00134	.00124	.00069	.00075	.00069	.00071
	.00046	.00026	.00036	.00053	.00029	.00034	.00039
	.00088	.00048	.00068	.00030	.00052	.00040	.00040
	.00021	.00003	.00012	.00016	.00006	.00009	.00010
	.00030	.00016	.00023	.00023	.00015	.00009	.00016
Total	.00645	.00844	.00745	.00450	.00458	.00435	.00448

Air-To-Cloth = 6.1/1

And. Run#	19	21	25	26	22	34	Avg.
Fractional Loadings	.00219	.00142	.00036	.00037	.00064	.00198	.00116
	.00023	.00025	.00007	.00011	.00021	.00011	.00016
	.00061	.00032	.00033	.00033	.00050	.00060	.00045
	.00069	.00046	.00030	.00041	.00057	.00097	.00057
	.00073	.00032	.00026	.00033	.00043	.00093	.00050
	.00050	.00025	.00020	.00011	.00032	.00045	.00031
	.00035	.00017	.00013	.00015	.00018	.00079	.00029
	.00008	.00011	.00007	.00007	.00003	0	.00006
	0	.00011	.00007	.00033	.00014	.00037	.00017
Total	.00538	.00341	.00179	.00221	.00302	.00620	.00367

Table A-4 (continued)

FRACTIONAL LOADING FOR ANDERSEN TESTS

N O M E X F E L T (3 levels of RA) Air-To-Cloth = 3.4/1

	RA = 1400			RA = 3100			RA = 4000		
And. Run#	57	58	Avg.	59	60	Avg.	61	62	Avg.
Fractional Loadings	.00129	.00123	.00126	.00118	.00102	.00110	.00107	.00111	.00109
	.00057	.00026	.00041	.00031	.00035	.00033	.00027	.00041	.00034
	.00054	.00039	.00046	.00028	.00031	.00029	.00027	.00034	.00031
	.00014	.00023	.00019	.00014	.00017	.00016	.00027	.00030	.00029
	.00061	.00036	.00048	.00021	.00021	.00021	.00030	.00037	.00033
	.00054	.00029	.00041	.00024	.00021	.00022	.00027	.00030	.00028
	.00036	.00023	.00030	.00011	0	.00006	.00010	.00030	.00020
	.00061	.00016	.00039	.00014	.00011	.00013	.00017	.00017	.00017
	.00043	.00010	.00027	0	.00014	.00007	.00017	0	.00009
Total	.00509	.00325	.00417	.00261	.00252	.00257	.00289	.00330	.00310

N O M E X F E L T (3 levels of RA) Air-To-Cloth = 6.4/1

	RA = 1400			RA = 3100			RA = 4000		
And. Run#	47	48	Avg.	53	54	Avg.	55	56	Avg.
Fractional Loadings	.00170	.00097	.00133	.00134	.00230	.00182	.00086	.00128	.00107
	.00094	.00098	.00096	.00062	.00095	.00078	.00053	.00095	.00074
	.00073	.00078	.00076	.00055	.00092	.00073	.00060	.00128	.00094
	.00073	.00088	.00080	.00058	.00089	.00073	.00071	.00071	.00071
	.00048	.00026	.00037	.00040	.00081	.00061	.00053	.00078	.00065
	.00048	.00049	.00049	.00058	.00057	.00058	.00057	.00047	.00052
	.00003	.00003	.00003	.00029	.00050	.00040	.00057	.00044	.00051
	.00042	.00039	.00041	.00076	.00032	.00054	.00050	.00037	.00044
	.00017	.00003	.00010	.00037	.00021	.00029	.00029	.00057	.00043
Total	.00568	.00481	.00525	.00549	.00747	.00648	.00516	.00685	.00601

Table A-4 (continued)

FRACTIONAL LOADING FOR ANDERSEN TESTS

N O M E X F E L T (3 levels of RA) Air-To-Cloth = 8.9/1

And. Run#	RA = 1400			RA = 3100			RA = 4000		
	41	42	Avg.	43	44	Avg.	45	46	Avg.
Fractional Loadings	.00374	.00270	.00322	.00243	.00210	.00226	.00284	.00221	.00252
	.00139	.00142	.00141	.00091	.00112	.00102	.00119	.00115	.00117
	.00150	.00222	.00186	.00162	.00188	.00175	.00172	.00090	.00131
	.00160	.00131	.00145	.00102	.00271	.00187	.00113	.00115	.00114
	.00192	.00127	.00159	.00120	.00315	.00217	.00084	.00022	.00053
	.00032	.00044	.00038	.00046	.00094	.00070	.00060	.00070	.00065
	.00061	.00076	.00069	.00060	.00058	.00059	.00007	.00006	.00007
	0	.00015	.00008	.00063	.00043	.00053	.00042	.00042	.00042
	.00001	.00029	.00020	.00028	.00011	.00020	0	.00003	.00002
Total	.01119	.01056	.01088	.00915	.01302	.01109	.00881	.00684	.00783

Appendix A-4

ESP Installed Cost Basis
Sample Calculations for Operating
and Annualized Cost

APPENDIX A-4

Electrostatic Precipitator Installed Cost Basis

Budgetary quotations for electrostatic precipitators were solicited from several of the leading ESP manufacturers. Listed below are the design parameters furnished with the requests for quotations.

General Design Parameters

1. Coal Analysis - See Table 9
2. Emission Rates:

35,000 acfm/Boiler	- 70,000 acfm Total
Particulates, 130 Lbs/Hour/Boiler	- 260 lbs./Hour Total
SO_2	- 250-500 ppm
SO_3	- 3-6 ppm
CO_2	- 9.5%
CO	- 0%
O_2	- 10%
N_2	- 80%
Temperature	- 350° F
Moisture	- 5.0% By Volume

3. Particle Size of Ash:

Particle Diameter Microns	Percent Less Than Size Indicated
6.4	49
4.2	38
2.8	27
1.8	18
0.94	12
0.58	8
0.38	7

51% of particles are greater than 6.4 microns.

APPENDIX A-4

ELECTROSTATIC PRECIPITATOR

Operating and Annualized Cost Calculations

Formula for calculating theoretical operating and annualized cost of control were taken from: Edminsten, N.G. and Bunyard, F.L., "A Systematic Procedure for Determining the Cost of Controlling Particulate Emissions from Industrial Sources", JAPCA V20 N7, p. 446, July 1970.

I. Electrostatic Precipitator Operating Cost:

$$G = S\,[JHK + M]$$

Where,

G = Theoretical Annual Operating Cost

S = Design Capacity, ACFM

J*= Power Required, Kilowatts/ACFM

H = Annual Operating Time, 6240 Hours

K = Power Costs, $/KWH

M = Maintenance Costs, $/ACFM

*Does not include power for main fan.

At 90% efficiency,

$$G = 70{,}000\,[(.00019)\,(6240)\,(.0175) + .02]$$

$$G = 70{,}000\,(.040748)$$

$$G = \$2{,}852$$

At 95% efficiency,

$$G = 70{,}000\,[(.00026)\,(6240)\,(.0175) + .02]$$

$$G = 70{,}000\,(.048392)$$

$$G = \$3{,}387$$

At 99% efficiency,

$$G = 70{,}000\,[(.0004)\,(6240)\,(.0175) + .03]$$

$$G = 70{,}000\,(.07368)$$

$$G = \$5{,}158$$

Main fan costs, $(F) = S\left[\frac{.7457}{6356E} PHK\right]$

Where,

S = Design Capacity, ACFM

.7457 = A Constant (1 Horsepower = 0.7457 Kilowatts)

E = Fan Efficiency, 60%

P*= Pressure Drop, Inches of Water

H = Annual Operating Time, 6240 Hours

K = Power Cost, $/KWH

$$F = 70{,}000\left[\frac{.7457}{(6356)(.6)}(2)(6240)(.0175)\right]$$

$$F = 70{,}000\ [.042705]$$

$$F = \$2{,}989$$

*Assumes 0.5 inches for ESP plus 1.5 inches for inlet duct, etc.

∴ Total Annual Operating Costs = G + F

at 90% Efficiency, $2,852 + $2,989 = $5,841

at 95% Efficiency, $3,387 + $2,989 = $6,376

at 99% Efficiency, $5,158 + $2,989 = $8,147

II. Electrostatic Precipitator Annualized Costs

Total annualized cost of control is equal to the annual operating cost plus the annualized capital cost.

Annualized Capital Cost* = 0.133 X Installed Cost

Total Annualized Cost = 0.133 X Installed Cost + Operating Cost

at 90% Efficiency = (0.133) (412,970) + 5,841
= 54,925 + 5,841
= $60,766

at 95% Efficiency = (0.133) (471,588) + 6,376 = $69,097

at 99% Efficiency = (0.133) (600,100) + 8,147 = $87,960

*See fabric filter case (Page 167) for annualized capital cost assumptions.

Appendix A-4

Fabric Filter
Operating and Annualized Costs

Sample Calculations

Formula for calculating theoritical operating and annualized cost of control were taken from: Edminsten, N.G. and Bunyard, F.L., "A Systematic Procedure for Determining the Cost of Controlling Particulate Emissions from Industrial Sources", JAPCA V20 N7, p. 446, July 1970.

I. Fabric Filter Operating Cost:

Case - Teflon Felt at A/C = 5.8/1

$$G = S \left[\frac{0.7457}{6356E} PHK + M\right]$$

Where: G = Theoretical annual cost for operation and maintenance

S = Design capacity, acfm

P = Pressure drop, inches of water

E = Fan efficiency, assumed to be 60% (expressed as 0.60)

0.7457 - A constant, 1 horsepower = .7457 kilowatt

H = Annual operating time, 6240 hours (24 hours/day X 5 days/week X 52 weeks/year = 6240 hours/year)

K = Power costs, $/KWH

M = Maintenance cost, $/ACFM (based on 25% bag replacement per year)

In this case:

S = 70,000 acfm

P = 3.8 Inches of Water

E = 60%

H = 6,240 Hours

K = $0.0175/KWH

M = (No. of bags in house X 25% replacement rate X cost per bag) ÷ S

Sample Calculations
(continued)

$$M = \frac{1080 \text{ Bags} \times .25 \times \$75/\text{Bag}}{70{,}000 \text{ acfm}} = \$.29/\text{ACFM}$$

Assuming a 60% fan efficiency reduces the above equation for G to:

$$G = S\ (195.5 \times 10^{-6}\ PHK + M)$$

Substituting the figures above yields:

$$G = 70{,}000\ (195.5 \times 10^{-6} \times 3.8 \times 6240 \times .0175 + .29)$$

$$= 70{,}000\ (.0918 + .2893)$$

$$= 70{,}000\ (.3811)$$

$$= 25{,}929$$

II. Total annualized cost of control is equal to the annual operating cost plus the annualized capital cost.

Annualized Capital Cost = 0.133 X Installed Costs

Assumptions:

1. Purchase and installation costs are depreciated over fifteen (15) years.
2. The straight line method of depreciation (6 2/3% per year) is used.
3. Other costs called capital charges are assumed to be equal to the amount of depreciation. Therefore, depreciation plus other capital charges amount to 13 1/3 percent of the initial capital costs of the equipment.

In this case: Teflon Felt at A/C = 5.8/1

Total annualized cost of control = .133 X Installed Costs + Operating Costs

= .133 X 177,460 + 25,929

= 23,602 + 25,929

= 49,531

Appendix A-5

Kerr Boiler Sheets for August 8th, 15th, 16th, 20th and 21st. Corresponds to Andersen Test Numbers 47 and 48 and 53 thru 62. Testing Nomex felt at A/C ratio of 6/1 and 3/1 at three levels of reverse air.

BOILER LOG SHEET

G 8 1974 — SHIFT — OPERATOR — HELPER

STEAM 1 2 METER — COAL 1 2 — MAKE UP 1 2 — CAL. NO. — RCVR. EMPTY — CHEM. FED — K-SEL — ADJUNCT — SULFITE — CAUSTIC

FLOW	34		46	48	44	46	46	50	54	56		
F. W. PRES.	190		230	220	225	225	230	220	230	210		
TEMP.	212	212	210	210	210	210	210	210	210	210	210	211
F. G. TEMP.: A. H. IN	540	552	560	560	550	560	570	570	580	590	567	551
OUT	310	331	320	320	310	320	340	320	320	350	323	327
AIR TEMP.: A. H. OUT	360	377	350	350	350	350	360	360	360	370	356	366
INSIDE	82	83	X									83
OUTSIDE	68	71	X									71
DRUM WATER LEVEL	0		0	0	0	0	0	0	0	0		
DRAFT F. D. OUT	1.6	1.6	2.2	2.4	2.3	2.2	1.6	2.2	3.0	2.4	2.3	2.4
WINDBOX	.5	.6	.7	.8	.8	.8	.3	.6	.9	.5	.7	.6
FURNACE	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1
A. H. IN	.8	.9	.8	.8	.7	.7	.7	.8	.9	.9	.8	.9
OUT	2.4	3.6	4.0	4.0	3.8	3.8	3.8	4.2	5.2	4.8	4.2	3.9
I. D. IN	5.0	5.3	6.5	6.5	6.0	6.0	6.0	7.0	8.0	8.0	6.7	6.0
O. F. AIR PRESSURE	2.0		.2	.2	.2	.2	.2	.2	.2	.2		
CIND. RTN. PRES.	23.6		28.0	28.0	28.0	28.0	28.0	28.0	28.0	27.6		
MASTER AIR PRESSURE	38		38	38	38	38	38	38	38	38		
CHEM. FEED BLR.	2		2	2	2	2	2	2	2	2		
F. W. HTR.	X		X									
F. W. PUMP ELEC. #1	✓		X									
#2	X		✓	✓	✓	✓	✓	✓	✓	✓		
STEAM	X		X									
BLOW OFF VALVE SETTING	48		7	7	7	7	7	7	7	7		
RCVR. PUMP #1	X		✓	✓	✓	✓	✓	✓	✓	✓		
#2	X		X									
AIR COMP. #1	X		X									
#2	X		X									
#3	X		✓	✓	✓	✓	✓	✓	✓	✓		
CITY WATER PRES.	78		X									
TEMP.	82	82	X									82
I. D. DAMPER	20		32	32	32	32	32	35	38	40		
FAN BRNGS.	✓		✓	✓	✓	✓	✓	✓	✓	✓		
MOTOR REGULAR	✓		✓	✓	✓	✓	✓	✓	✓	✓		
STAND BY	✓		✓	✓	✓	✓	✓	✓	✓	✓		
F. D. FAN BRNGS.	✓		✓	✓	✓	✓	✓	✓	✓	✓		
DAMPER	40		50	50	50	50	45	50	50	52		
FUEL FEED	90		90	95	90	90	90	95	95	95		
O. F. AIR	15.0		60	65	60	60	60	65	65	65		
STKR. BRNG. WTR.	✓		✓	✓	✓	✓	✓	✓	✓	✓		
F. W. HTR. PRES.	X		2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0		
TEMP.	X		220	220	220	220	220	220	220	220		
VENT	X		✓	✓	✓	✓	✓	✓	✓	✓		
F. G. ANAL CO2												

BOILER LOG SHEET

AUG 8 1976 — SHIFT — OPERATOR — HELP

TIME	3:30	AVG.	3:30	4	5	6	7	8	9	10	AVG.	AVG.
STEAM PRES.	150	150	150	150	150	150	150	150	150	150	150	150
FLOW	36		46	46	42	46	44	46	48	48		
F. W. PRES.	205		225	225	235	235	225	230	225	220		
TEMP.	210	210	210	210	210	210	210	210	210	210	210	210
F. G. TEMP.: A. H. IN	560	532	560	560	540	550	560	560	560	560	556	544
OUT	340	323	330	330	320	320	320	320	320	320	320	322
AIR TEMP.: A. H. OUT	370	356	366	360	350	360	360	360	360	360	358	357
INSIDE	90	88	X									
OUTSIDE	78	75	X									
DRUM WATER LEVEL	0		+1/2	+1/2	+1/2	+1/2	+1/2	+1/2	+1/2	+1/2		
DRAFT F. D. OUT	1.6	1.6	1.6	1.8	1.6	1.6	1.6	2.0	2.4	1.6	1.6	1.6
WINDBOX	.4	.4	.4	.5	.5	.3	.4	.6	.8	.3	.4	.4
FURNACE	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1
A. H. IN	.9	.8	.7	.7	.6	.7	.7	.7	.8	.8	.7	.7
OUT	3.8	3.4	3.6	3.6	3.2	3.8	3.6	3.8	4.2	4.0	3.7	3.5
I. D. IN	6.0	5.1	5.5	5.5	5.6	6.0	6.0	6.0	6.5	6.5	5.8	5.4
O. F. AIR PRESSURE	2.0		.2	.2	.2	.2	.2	.2	.2	.2		
CIND. RTN. PRES.	23.4		27.8	27.8	27.8	27.6	27.6	27.6	27.8	28.0		
MASTER AIR PRESSURE	38		38	38	38	38	38	38	38	38		
CHEM. FEED BLR.	2		2	2	2	2	2	2	2	2		
F. W. HTR.	X		X									
F. W. PUMP ELEC. #1	✓		X	✓	✓	✓	✓	✓	✓	✓		
#2	X		✓									
STEAM	X		X									
BLOW OFF VALVE SETTING	48		7	7	7	7	7	7	7	7		
RCVR. PUMP #1	X		✓	✓	✓	✓	✓	✓	✓	✓		
#2	X		X									
AIR COMP. #1	X		X									
#2	X		X									
#3	X		✓	✓	✓	✓	✓	✓	✓	✓		
CITY WATER PRES.	82		X									
TEMP.	80	80	X									
I. D. DAMPER	25		30	30	28	32	30	32	35	32		
FAN BRNGS.	✓		✓	✓	✓	✓	✓	✓	✓	✓		
MOTOR REGULAR	✓		✓	✓	✓	✓	✓	✓	✓	✓		
STAND BY	✓		✓	✓	✓	✓	✓	✓	✓	✓		
F. D. FAN BRNGS.	✓		✓	✓	✓	✓	✓	✓	✓	✓		
DAMPER	50		45	48	45	45	45	50	50	48		
FUEL FEED	85		85	85	85	90	85	90	90	85		
AIR	14.5		55	55	55	60	65	60	60	55		
STKR. BRNG. WTR.	✓		✓	✓	✓	✓	✓	✓	✓	✓		
F. W. HTR. PRES.	X		2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0		
TEMP.	X		210	220	220	220	220	220	220	220		
VENT	X		✓	✓	✓	✓	✓	✓	✓	✓		

STEAM 1 2 METER — COAL 1 2 — MAKE UP 1 2 — EMPTY CHEM. — SULFITE — CAUSTIC

BOILER LOG SHEET

SHIFT — OPERATOR — HELPER

STEAM METER 1 2 — COAL 1 2 — MAKE UP 1 2 — CAR NO. — RCVD — EMPTY — CHEM. FED — K-G.L. — ADJUNCT — SULFITE — CAUSTIC

STEAM PRES.	150	150	150	150	150	150	150	150	150	150	150	150
FLOW	34		44	48	48	46	46	48	44	50		
F. W. PRES.	200		225	215	215	225	215	230	235	230		
TEMP.	210	210	210	210	210	210	210	210	210	210	210	210
F. G. TEMP.: A. H. IN	550	550	550	560	570	560	560	560	550	560	560	555
OUT	330	331	320	320	326	320	320	330	320	330	322	326
AIR TEMP.: A. H. OUT	360	360	360	360	360	360	360	360	360	360	360	360
INSIDE	88	92	X									92
OUTSIDE	70	78	X									78
DRUM WATER LEVEL	-1/2		+1/2	0	+1/2	+1/2	+1/2	+1/2	+1/2	+1/2		
DRAFT F. D. OUT	2.0	2.0	1.8	2.4	2.6	2.6	1.8	2.0	2.0	1.8	2.1	2.0
WINDBOX	.6	.6	.5	.7	.9	1.0	.5	.6	.7	.4	.6	.6
FURNACE	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1
A. H. IN	.9	.9	.7	.8	.8	.7	.7	.7	.7	.8	.7	.8
OUT	4.0	4.0	3.8	4.2	4.2	3.8	3.8	4.0	3.8	4.4	4.0	4.0
I. D. IN	6.0	6.0	6.0	6.5	6.5	6.0	6.0	6.0	6.0	7.0	6.2	6.1
O. F. AIR PRESSURE	2.0		.2	.2	.2	.2	.2	.2	.2	.2		
CIND. RTN. PRES.	23.4		27.6	27.6	27.8	27.6	27.4	27.4	27.6	27.6		
MASTER AIR PRESSURE	38		38	38	38	38	38	38	38	38		
CHEM. FEED BLR.	2		2	2	2	2	2	2	2	2		
F. W. HTR.	X		X									
F. W. PUMP ELEC. #1	✓		X									
#2	X		✓	✓	✓	✓	✓	✓	✓	✓		
STEAM	X		X									
BLOW OFF VALVE SETTING	48		7	7	7	7	7	7	7	7		
RCVR. PUMP #1	X		✓	✓	✓	✓	✓	✓	✓	✓		
#2	X		X									
AIR COMP. #1	X		X									
#2	X		X									
#3	X		✓	✓	✓	✓	✓	✓	✓	✓		
CITY WATER PRES.	76		X									
TEMP.	82	82	X									82
I. D. DAMPER	28		28	35	35	32	32	32	30	40		
FAN BRNGS.	✓		✓	✓	✓	✓	✓	✓	✓	✓		
MOTOR REGULAR	✓		✓	✓	✓	✓	✓	✓	✓	✓		
STAND BY	✓		✓	✓	✓	✓	✓	✓	✓	✓		
F. D. FAN BRNGS.	✓		✓	✓	✓	✓	✓	✓	✓	✓		
DAMPER	52		42	50	52	50	48	48	48	50		
FUEL FEED	80		85	90	90	85	85	90	95	85		
O. F. AIR	14.0		55	60	60	55	55	60	65	55		
STKR. BRNG. WTR.	✓		✓	✓	✓	✓	✓	✓	✓	✓		
F. W. HTR. PRES.	X		2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0		
TEMP.	X		220	220	220	220	220	220	220	220		
VENT.	X		✓	✓	✓	✓	✓	✓	✓	✓		

BOILER LOG SHEET

BOILER NO.	1		2									PLANT
TIME	3:30	AVG.	3:30	4.	5.	6.	7.	8.	9.	10	AVG.	AVG.
STEAM PRES.	150	150	150	150	150	150	150	150	150	150	150	150
FLOW	34		46	46	48	46	46	44	46	48		
F. W. PRES.	205		235	220	230	220	225	235	235	230		
TEMP.	210	210	210	210	210	210	210	210	210	210	210	210
F. G. TEMP.: A. H. IN	540	546	560	560	560	565	560	550	560	560	558	552
OUT	330	330	320	320	320	320	320	320	320	330	328	329
AIR TEMP.: A. H. OUT	360	368	360	360	360	360	360	360	360	360	360	364
INSIDE	90	91	X									91
OUTSIDE	80	79	X									79
DRUM WATER LEVEL	0		+1/2	+1	+1/2	+1/2	+1	+1/2	+1/2	+1/2		
DRAFT F. D. OUT	1.8	1.9	1.8	2.2	2.6	1.6	2.0	1.8	2.4	1.6	2.0	1.4
WINDBOX	.6	.6	.4	.6	.9	.3	.6	.6	.8	.3	.5	.5
FURNACE	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1
A. H. IN	.9	.9	.8	.7	.8	.7	.7	.7	.7	.7	.7	.8
OUT	4.0	4.0	4.0	3.6	4.4	3.8	4.0	3.6	4.0	4.0	3.9	3.9
I. D. IN	6.0	6.0	6.0	5.5	7.0	6.0	6.0	5.5	6.0	6.0	6.0	6.0
O. F. AIR PRESSURE	2.0		.2	.2	.2	.2	.2	.2	.2	.2		
CIND. RTN. PRES.	23.4		27.6	27.6	27.4	27.4	27.4	27.8	27.8	27.8		
MASTER AIR PRESSURE	38		38	38	38	38	38	38	38	38		
CHEM. FEED BLR.	2		2	2	2	2	2	2	2	2		
F. W. HTR.	X		X									
F. W. PUMP ELEC. #1	✓		X									
#2	X		✓	✓	✓	✓	✓	✓	✓	✓		
STEAM	X		X									
BLOW OFF VALVE SETTING	48		7	7	7	7	7	7	7	7		
RCVR. PUMP #1	X		✓	✓	✓	✓	✓	✓	✓	✓		
#2	X		X									
AIR COMP. #1	X		X									
#2	X		X									
	X		✓	✓	✓	✓	✓	✓	✓	✓		
CITY WATER PRES.	80		X									
TEMP.	82	82	X									82
I. D. DAMPER	28		32	30	38	32	32	30	32	32		
FAN BRNGS.	✓		✓	✓	✓	✓	✓	✓	✓	✓		
MOTOR REGULAR	✓		✓	✓	✓	✓	✓	✓	✓	✓		
STAND BY	✓		✓	✓	✓	✓	✓	✓	✓	✓		
F. D. FAN BRNGS.	✓		✓	✓	✓	✓	✓	✓	✓	✓		
DAMPER	52		48	48	52	45	48	48	50	45		
FUEL FEED	85		85	90	90	85	90	85	95	90		
O. F. AIR	14.5		55	60	60	55	60	55	65	60		
STKR. BRNG. WTR.	✓		✓	✓	✓	✓	✓	✓	✓	✓		
F. W. HTR. PRES.	X		2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0		
TEMP.	X		220	220	220	220	220	220	220	220		
VENT	X		✓	✓	✓	✓	✓	✓	✓	✓		

BOILER LOG SHEET

DATE AUG 16 1974 — SHIFT — OPERATOR — STEAM METER — COAL — MAKE UP — CAR NO. — RCVD. — EMPTY — CHEM. FED — CAUSTIC

BOILER NO.	1		2									PLANT
TIME	7:30	AVG.	7:30	8	9	10	11	12	1	2	AVG.	AVG.
STEAM PRES.	150	150	150	150	150	150	150	150	150	150	150	150
FLOW	36		48	48	50	54	44	44	44	44		
F. W. PRES	220		235	230	230	235	235	235	235	235		
TEMP.	212	212	212	212	212	212	212	212	212	212	212	212
F. G. TEMP.: A. H. IN	520	531	575	565	580	580	550	560	555	540	565	548
OUT	310	316	330	325	330	320	330	330	325	325	326	326
AIR TEMP.: A. H. OUT	360	361	360	360	360	380	365	350	360	360	369	362
INSIDE	54	88	x									88
OUTSIDE	72	75	x									75
DRUM WATER LEVEL	+1		0	+1/2	0	+1	+2	+1/2	+1/2	+1/2		
DRAFT F. D. OUT	1.4	1.5	1.[illegible]	1.7	2.0	2.2	1.2	1.6	1.5	1.4	1.8	1.6
WINDBOX	.4	.5	.6	.5	1.0	.5	.2	.4	.5	.2	.4	.4
FURNACE	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1
A. H. IN	.8	.9	.9	.7	.9	.9	.7	.7	.7	.7	.7	.8
OUT	3.8	3.9	7.0	4.4	4.8	4.8	3.4	3.5	3.8	3.8	4.4	4.1
I. D. IN	6.0	6.0	7.0	6.5	7.5	7.5	5.5	6.0	6.0	6.0	6.7	6.3
O. F. AIR PRESSURE	2.0		.2	.2	.2	.2	.2	.2	.2	.2		
CIND. RTN. PRES.	23.6		27.8	27.8	27.8	27.8	27.8	27.5	27.8	27.[illegible]		
MASTER AIR PRESSURE	38		38	38	38	38	38	38	38	38		
CHEM. FEED BLR.	2		2	2	2	2	2	2	2	2		
F. W. HTR.	x		x									
F. W. PUMP ELEC. #1	✓		x									
#2	x		✓	✓	✓	✓	✓	✓	✓	✓		
STEAM	x		x									
BLOW OFF VALVE SETTING	[illegible]		7	7	7	7	7	7	7	7		
RCVR. PUMP #1	x		✓	✓	✓	✓	✓	✓	✓	✓		
#2	✓		x									
AIR COMP. #1	x		x									
#2	x		x									
#3			✓	✓	✓	✓	✓	✓	✓	✓		
CITY WATER PRES.	78		x									
TEMP.	82		x									82
I. D. DAMPER	25		35	35	40	40	35	30	30	30		
FAN BRNGS.	✓		✓	✓	✓	✓	✓	✓	✓	✓		
MOTOR REGULAR	✓		✓	✓	✓	✓	✓	✓	✓	✓		
STAND BY	✓		✓	✓	✓	✓	✓	✓	✓	✓		
F. D. FAN BRNGS.	✓		✓	✓	✓	✓	✓	✓	✓	✓		
DAMPER	50		50	50	55	50	50	50	50	45		
FUEL FEED	90		90	85	90	85	90	90	90	90		
O. F. AIR	150		60	55	60	55	60	60	60	60		
STKR. BRNG. WTR.	✓		✓	✓	✓	✓	✓	✓	✓	✓		
F. W. HTR. PRES.	x		2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0		
TEMP.	x		220	220	220	220	220	220	220	220		
VENT	✓		✓	✓	✓	✓	✓	✓	✓	✓		

BOILER LOG SHEET

BOILER NO.											
TIME	3:30	AVG.	3:30	4	5	6	7	8	9	10	AVG.
STEAM PRES.	150		150	150	150	150	150	150	150	150	[illegible]
FLOW	22		40	38	38	36	47	38	3[illegible]	3[illegible]	
F. W. PRES.	230		230	230	210	215	215	230	235	210	
TEMP.	210		210	210	210	210	210	210	210	210	210
F. G. TEMP.: A. H. IN	510		550	540	540	540	560	540	540	520	541
OUT	310		320	320	320	320	320	320	320	310	316
AIR TEMP.: A. H. OUT	330		360	350	350	360	360	350	350	330	350
INSIDE	90		X								90
OUTSIDE	84		X								77
DRUM WATER LEVEL	+2		+1/2	+1/2	+1/2	+1/2	+1/2	+1/2	+1	+1/2	
DRAFT F. D. OUT	2.0		1.8	1.8	2.0	1.6	1.8	2.0	2.2	2.4	1.9
WINDBOX	.5		.4	.5	.6	.4	.5	.6	.7	.9	.5
FURNACE	.1		.1	.1	.1	.1	.1	.1	.1	.1	.1
A. H. IN	.9		.7	.7	.7	.7	.7	.7	.7	.7	.7
OUT	3.8		3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8
I. D. IN	6.0		6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
O. F. AIR PRESSURE	2.0		.2	.2	.2	.2	.2	.2	.2	.2	
COND. RTN. PRES.	23.4		27.8	27.8	27.8	27.8	27.6	27.6	27.6	27.8	
MASTER AIR PRESSURE	38		38	38	38	38	38	38	38	38	
CHEM. FEED BLR.	3		2	2	2	2	2	2	2	2	
F. W. HTR.	X		X								
F. W. PUMP ELEC. #1	✓		X								
#2	X		✓	✓	✓	✓	✓	✓	✓	✓	
STEAM	X		X								
BLOW OFF VALVE SETTING	7/8		7	7	7	7	7	7	7	7	
RCVR. PUMP #1	X		✓	✓	✓	✓	✓	✓	✓	✓	
#2	X		X								
AIR COMP. #1	X		X								
#2	X		X								
#3	✓		✓	✓	✓	✓	✓	✓	✓	✓	
CITY WATER PRES.	82		X								
TEMP.	50		X								
I. D. DAMPER	25		32	32	32	32	32	32	32	32	
FAN BRNGS.	✓		✓	✓	✓	✓	✓	✓	✓	✓	
MOTOR REGULAR	✓		✓	✓	✓	✓	✓	✓	✓	✓	
STAND BY	✓		✓	✓	✓	✓	✓	✓	✓	✓	
F. D. FAN BRNGS.	✓		✓	✓	✓	✓	✓	✓	✓	✓	
DAMPER	58		48	48	50	45	48	48	50	60	
FUEL FEED	80		85	95	90	90	95	90	90	90	
O. F. AIR	14.0		55	65	60	50	65	60	60	[illegible]	
STKR. BRNG. WTR.	✓		✓	✓	✓	✓	✓	✓	✓	✓	
F. W. HTR. PRES.	X		200	200	200	200	200	200	200	200	
TEMP.	X		220	220	230	220	220	220	220	220	
VENT	X		✓	✓	✓	✓	✓	✓	✓	✓	

STEAM · METER · COAL · MAKE UP · SHIFT · OPERATOR · HELPER · CHEM. F.D K-GEL · ADJUNCT · SULFITE · CAUSTIC

11.04 11.52 I. S. 81

BOILER LOG SHEET

DATE AUG 20 1974 SHIFT

OPERATOR

HELPER

BOILER NO.	1		2									PLANT
TIME	7:30	AVG.	7:30	8	9	10	11	12	1	2	AVG.	AVG.
STEAM PRES.	150	150	150	150	150	150	150	150	150	[illegible]	150	150
FLOW	32		42	44	46	50	50	52	50	48		
F. W. PRES.	210		235	240	240	230	235	230	210	210		
TEMP.	212	212	210	210	210	210	210	210	210	210	[illegible]	211
F. G. TEMP.: A. H. IN	540	540	550	550	550	550	550	550	550	550	551	545
OUT	315	320	320	320	320	320	320	320	320	[illegible]	320	320
AIR TEMP.: A. H. OUT	380	382	360	360	360	360	360	360	360	[illegible]	[illegible]	371
INSIDE	84	86	X									86
OUTSIDE	70	74	X									74
DRUM WATER LEVEL	+1		+1	+1	+1	+1	+1	+1	+1			
DRAFT F. D. OUT	1.4	1.6	2.0	2.2	2.6	1.6	1.8	2.4	2.2	2.4	2.1	1.8
WINDBOX	.6	.5	.6	.6	.8	.4	.4	.7	.7	.8	.6	.5
FURNACE	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1
A. H. IN	.8	.9	.7	.7	.8	.7	.8	.9	.8	.8	.8	.8
OUT	.4	3.7	4.0	4.0	4.4	4.0	4.4	4.6	4.4	4.4	4.3	4.0
I. D. IN	5.0	5.3	6.5	6.5	7.0	6.5	7.0	7.5	7.0	7.0	6.9	6.1
O. F. AIR PRESSURE	1.8		.2	.2	.2	.2	.2	.2	.2	.2		
CIND. RTN. PRES.	23.6		27.8	27.8	27.8	27.8	27.8	27.8	27.8	27.8		
MASTER AIR PRESSURE	38		38	38	38	38	38	38	38	38		
CHEM. FEED BLR.	[illegible]		2	2	2	2	2	2	2	2		
F. W. HTR.	X		X									
F. W. PUMP ELEC. #1	✓		X									
#2	X		✓	✓	✓	✓	✓	✓	✓	✓		
STEAM	X		X									
BLOW OFF VALVE SETTING	[illegible]		8	8	8	8	8	8	8	8		
RCVR. PUMP #1	X		✓	✓	✓	✓	✓	✓	✓	✓		
#2	X		X									
AIR COMP. #1	X		X									
#2	X		X									
#3	X		✓	✓	✓	✓	✓	✓	✓	✓		
CITY WATER PRES.	76		X									
TEMP.	84	84	X									84
I. D. DAMPER	25		40	40	38	35	35	40	38	35		
FAN BRNGS.	✓		✓	✓	✓	✓	✓	✓	✓	✓		
MOTOR REGULAR	✓		✓	✓	✓	✓	✓	✓	✓	✓		
STAND BY	✓		✓	✓	✓	✓	✓	✓	✓	✓		
F. D. FAN BRNGS.	✓		✓	✓	✓	✓	✓	✓	✓	✓		
DAMPER	50		55	55	50	48	48	50	50	48		
FUEL FEED	90		90	90	90	90	90	95	95	90		
O. F. AIR	15.0		55	55	55	55	55	60	60	55		
STKR. BRNG. WTR.	✓		✓	✓	✓	✓	✓	✓	✓	✓		
F. W. HTR. PRES.	X		2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0		
TEMP.	X		220	220	220	220	220	220	220	220		

METER	BLR. NO.	END	BEGIN	DIFF.	EVAP.
STEAM	1	[illegible]	[illegible]	[illegible]	
	2	[illegible]	[illegible]	[illegible]	
METER					
COAL	1	[illegible]	[illegible]	[illegible]	
	2	[illegible]	[illegible]	[illegible]	
MAKE UP	1				%
	2				%
CAR NO.					
RCVD.					
EMPTY					
CHEM. FED	K-GEL				
	ADJUNC				
	SULFIT				
	CAUST				

BOILER LOG SHEET

TIME	3:30	AVG.	330	4	5	6	7	8	9	10	AVG.	AVG.
STEAM PRES.	150	150	150	150	150	150	150	150	150	150	150	150
FLOW	36		46	44	46	42	40	34	32	30		
F. W. PRES.	205		235	225	230	230	226	245	250	245		
TEMP.	210	210	210	210	210	210	210	210	210	210	210	210
F. G. TEMP.: A. H. IN	550	547	560	560	560	550	550	540	540	540	550	548
OUT	330	320	320	320	320	320	320	310	310	310	316	318
AIR TEMP.: A. H. OUT	360	350	360	360	360	360	360	350	350	350	356	353
INSIDE	90	91	X									91
OUTSIDE	80	78	X									78
DRUM WATER LEVEL	+2		+1/2	+1/2	+1/2	+1/2	+1/2	+1/2	+1/2	+1/2		
DRAFT F. D. OUT	1.6	1.9	1.8	1.6	2.0	1.4	1.6	2.0	2.2	1.6	1.7	1.8
WINDBOX	.5	.4	.4	.4	.4	.3	.4	.6	.7	.3	.4	.4
FURNACE	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1
A. H. IN	.9	.8	.7	.6	.7	.6	.6	.7	.7	.7	.6	.7
OUT	3.8	3.7	3.8	3.4	3.6	3.6	3.2	3.8	3.8	3.8	3.6	3.6
I. D. IN	5.5	5.4	6.0	5.5	6.0	5.5	5.0	6.0	6.0	6.0	5.7	5.5
O. F. AIR PRESSURE	1.8		2	2	2	2	2	2	2	2		
CIND. RTN. PRES.	23.2		27.4	27.4	27.6	27.6	27.8	28.0	28.0	28.0		
MASTER AIR PRESSURE	38		38	38	38	38	38	38	38	38		
CHEM. FEED BLR.	2		2	2	2	2	2	2	2	2		
F. W. HTR.	X		X									
F. W. PUMP ELEC. #1	✓		X									
#2	X		✓	✓	✓	✓	✓	✓	✓	✓		
STEAM	X		X									
BLOW OFF VALVE SETTING	38		8	8	8	8	8	8	8	8		
RCVR. PUMP #1	✓		✓									
#2	X		X									
AIR COMP. #1	X		X									
#2	X		X									
#3	X		✓	✓	✓	✓	✓	✓	✓	✓		
CITY WATER PRES.	80		X									
TEMP.	84	84	X									
I. D. [illegible]	25		32	30	22	30	28	32	32	32		[illegible]
FAN BRNGS.	✓		✓	✓	✓	✓	✓	✓	✓	✓		
MOTOR REGULAR	✓		✓	✓	✓	✓	✓	✓	✓	✓		
STAND BY	✓		✓	✓	✓	✓	✓	✓	✓	✓		
F. D. FAN BRNGS.	✓		✓	✓	✓	✓	✓	✓	✓	✓		
DAMPER	50		48	42	48	42	42	48	50	45		
COAL FEED	90		90	85	90	85	85	85	85	85		
O. F. AIR	15.0		60	55	60	55	55	55	55	55		
STKR. BRNG. WTR.	✓		✓	✓	✓	✓	✓	✓	✓	✓		
F. W. HTR. PRES.	X		2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0		
TEMP.	X		220	220	220	220	220	220	220	220		
VENT	X		✓	✓	✓	✓	✓	✓	✓	✓		
F. G. [illegible]												

SHIFT OPERATOR HELPER

STEAM METER COAL MAKE UP CAR NO. RCVD. EMPTY CHEM. FED

BOILER LOG SHEET

BOILER NO.	7:30	AVG.	7:30	8	9	10	11	12	1	2	AVG.	PLANT AVG.
TIME	7:30	AVG.	7:30	8	9	10	11	12	1	2	AVG.	AVG.
STEAM PRES.	150	150	150	150	150	150	150	150	150	150	150	150
FLOW	44		44	46	46	48	48	44	54	48		
F. W. PRES.	195		225	230	240	230	225	225	225	230		
TEMP.	212	212	210	210	210	210	210	210	210	210	210	211
F. G. TEMP.: A. H. IN	585	580	580	580	580	590	590	580	590	590	585	583
OUT	320	320	320	320	320	330	330	320	330	330	325	323
AIR TEMP.: A. H. OUT	360	359	360	360	360	370	370	360	370	370	365	362
INSIDE		[illegible]	X									87
OUTSIDE		77	X									77
DRUM WATER LEVEL	[illegible]		+1	+1	+1	+1	+1	+1	+1	+1		
DRAFT F. D. OUT	[illegible]	1.7	2.0	2.2	2.0	2.4	2.4	1.8	1.8	1.8	2.0	1.8
WINDBOX	[illegible]	.5	.6	.6	.6	.4	.4	.5	.5	.4	[illegible]	.5
FURNACE	[illegible]	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1
A. H. IN	[illegible]	.9	.8	.7	.7	.8	.8	.7	.7	.8	.7	.8
OUT	[illegible]	3.8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4.2	4.0
I. D. IN	[illegible]	6.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5	[illegible]	6.7	6.3
O. F. AIR PRESSURE	[illegible]	[illegible]	.2	.2	.2	.2	.2	.2	.2	.2		
CIND. RTN. PRES.			27.6	27.6	27.6	27.6	27.6	27.6	27.6	27.8		
MASTER AIR PRESSURE	38	[illegible]	38	38	38	38	38	38	38	38		
CHEM. FEED BLR.	[illegible]		2	2	2	2	2	2	2	2		
F. W. HTR.	[illegible]		X									
F. W. PUMP ELEC. #1	✓		X									
#2	X		✓	✓	✓	✓	✓	✓	✓	✓		
STEAM	X		X									
BLOW OFF VALVE SETTING	38		5	5	8	8	8	8	8	5		
RCVR. PUMP #1	X		✓	✓	✓	✓	✓	✓	✓	✓		
#2	X		X									
AIR COMP. #1	X		X									
#2	X		X									
#3	X		✓	✓	✓	✓	✓	✓	✓	✓		
CITY WATER PRES.			X									
TEMP.			X									50
I. D. DAMPER	[illegible]		40	40	32	35	35	30	42	35		
FAN BRNGS.	✓		✓	✓	✓	✓	✓	✓	✓	✓		
MOTOR REGULAR	✓		✓	✓	✓	✓	✓	✓	✓	✓		
STAND BY	✓		✓	✓	✓	✓	✓	✓	✓	✓		
F. D. FAN BRNGS.	✓		✓	✓	✓	✓	✓	✓	✓	✓		
DAMPER			55	55	50	50	48	48	58	45		
FUEL FEED			95	95	90	95	95	95	95	85		
O. F. AIR	[illegible]		60	60	60	60	60	60	60	60		
STKR. BRNG. WTR.	✓		✓	✓	✓	✓	✓	✓	✓	✓		
F. W. HTR. PRES.	X		2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0		
TEMP.	[illegible]		226	220	228	220	226	220	220	220		

DATE SHIFT OPERATOR RELIEVER RCVD. EMPTY CHEM. FED K-GEL ADJUST SULFITE CAUST

STEAM 1 2 METER COAL 1 2 MAKE UP 1 2 CAR NO.

METER LR. NO. END BEGIN DIFF. EVAP.

BOILER LOG SHEET

BOILER NO.	1		2									PLANT
TIME	330	AVG.	3:30	4	5	6	7	8	9	10	AVG.	AVG.
STEAM PRES.	150	150	150	150	150	150	150	150	150	150	150	150
FLOW	22		42	46	44	46	44	46	42	44		
F. W. PRES.	[illegible]		225	225	230	225	225	230	235	225		
TEMP.	210	210	210	210	210	210	210	210	210	210	210	210
F. G. TEMP.: A. H. IN	540	541	570	570	570	570	570	560	560	570	567	554
OUT	310	310	320	320	320	320	320	320	310	320	318	314
AIR TEMP.: A. H. OUT	330	330	360	360	360	350	350	340	340	340	350	340
INSIDE	94	92	X									92
OUTSIDE	84	80	X									[illegible]
DRUM WATER LEVEL	+1		+½	+½	+½	+½	+½	-½	-½	-½		
DRAFT F. D. OUT	1.[illegible]	1.9	1.6	2.0	2.0	1.8	1.6	1.8	1.8	1.6	1.7	1.8
WINDBOX	.5	.5	.4	.6	.7	.4	.3	.3	.6	.4	.4	.4
FURNACE	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1
A. H. IN	.9	.9	.7	.7	.7	.7	.7	.7	.7	.7	.7	.8
OUT	3.[illegible]	2.8	3.6	4.0	3.8	4.0	3.8	3.8	3.6	3.8	3.8	3.8
I. D. IN	6.0	6.0	5.5	6.5	6.0	6.0	6.0	6.0	.	6.0	6.0	6.0
O. F. AIR PRESSURE	[illegible]		.2	.2	.2	.2	.2	.2	.2	.2		
CIND. RTN. PRES.	2		27.4	27.4	27.4	27.6	27.6	27.6	27.8	28.0		
MASTER AIR PRESSURE	38		38	38	38	38	38	38	38	38		
CHEM. FEED BLR.			2	2	2	2	2	2	2	2		
F. W. HTR.			X									
F. W. PUMP ELEC. #1	✓		X									
#2			✓	✓	✓	✓	✓	✓	✓	✓		
STEAM			X									
BLOW OFF VALVE SETTING	[illegible]		8	8	8	8	8	8	8	8		
RCVR. PUMP #1	X		✓	✓	✓	✓	✓	✓	✓	✓		
#2	X		X									
AIR COMP. #1	X		X									
#2	[illegible]		X									
#3	X		✓	✓	✓	✓	✓	✓	✓	✓		
CITY WATER PRES.	52		X									
TEMP.	[illegible]	84	X									84
I. D. [illegible]	25		32	32	32	35	32	32	30	32		
FAN BRNGS.			✓	✓	✓	✓	✓	✓	✓	✓		
MOTOR REGULAR			✓	✓	✓	✓	✓	✓	✓	✓		
STAND BY			✓	✓	✓	✓	✓	✓	✓	✓		
F. D. FAN BRNGS.			✓									
DAMPER	55		48	48	50	48	48	48	48	45		
FUEL FEED	85		85	90	90	85	85	90	90	85		
O. F. AIR	145		55	60	60	55	55	60	60	55		
[illegible] BRNG. WTR.			✓	✓	✓	✓	✓	✓	✓	✓		
F. W. HTR. PRES.	X		2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0		
TEMP.	X		220	220	220	220	[illegible]	[illegible]	[illegible]	[illegible]		
VENT	X		✓	✓	✓	✓	✓	✓	✓	✓		

Appendix A-6

Statistical Analysis

Appendix A-6

Statistical Analysis

A statistical analysis was conducted to determine if there was a significant relationship between outlet loading and air-to-cloth ratio (velocity thru the filtering media). This analysis was done in two parts. First, the outlet loading data for each of the four bag materials was analyzed with respect to the three levels of velocity tested. Second, the outlet loading data for Nomex felt at three levels of reverse air for each of three levels of velocity was analyzed.

One-sided and two-sided tests for variance were employed utilizing the F-test for significance. The outlet loading data was organized as shown in Table A-5. Then the one-sided test for variance was conducted for each bag material. Following is an example calculation for the case of Nomex felt.

$$T_L = (.0021) + (.0025) + (.0020) = .0066$$

$$T_M = (.0016) + (.0028) + (.0045) = .0089$$

$$T_H = (.0072) + (.0047) = .0119$$

$$T_G = T_L + T_M + T_H = .0274$$

Where T_L = total of the outlet loading values at low velocity

T_M = total of the outlet loading values at medium velocity

T_H = total of the outlet loading values at high velocity

T_G = total of the outlet loading values at all three velocities

Calculate $SS_T = (.0021)^2 + (.0025)^2 \text{ +------+ } (.0047)^2$

$$SS_T = .000119$$

Where SS_T = Sum of squares of the outlet loading values at all three velocities.

Calculate SS_E, variation within velocities

Where, $SS_E = SS_T - \frac{T_L^2}{3} + \frac{T_M^2}{3} + \frac{T_H^2}{2}$

$$SS_E = .000119 - (.000015 + .000026 + .000071)$$

$$SS_E = .000119 - .000112$$

$$SS_E = .000007$$

Calculate SS_V, variation between velocities

Where, $SS_V = \frac{T_L^2}{3} + \frac{T_M^2}{3} + \frac{T_H^2}{2} + \frac{T_G^2}{8}$

$$SS_V = \frac{.000044}{3} + \frac{.000079}{3} + \frac{.000142}{2} - \frac{.000751}{8}$$

$$SS_V = .000015 + .000026 + .000071 - .000094$$

$$SS_V = .000018$$

Set-up an analysis of variance table as follows:

Analysis of Variance Table

Variance	Source of Variation	Sum of Square	Degrees of Freedom	Mean Squares
SS_V	Between Velocities	.000018	2	.000009
SS_E	Within Velocities	.000007	5	.0000014

Then, the F-test gives

$$F = \frac{.000009}{.0000014} = 6.43$$

Conclusion: The F- Statistic is found to be significant at the 0.05 level of significance.

Appendix A-6

(continued)

The results of similar computation employing the one-sided test for the other three bag materials as well as Nomex felt are shown in Table A-9. Also included in Table A-9 are the results obtained when the one-sided test is applied to the Nomex felt data for three levels of reverse air (RA).

The two-sided test for variance was utilized to evaluate the Nomex felt data at three levels of reverse air for each of three velocities. This allows determination of the significance of reverse air and velocity upon outlet loading simultaneously and also significance of interactions.

The computations for the two-sided test proceed as follows:

		Reverse Air L	Reverse Air M	Reverse Air H
Velocity	L	.0051 .0032	.0026 .0025	.0029 .0033
Velocity	M	.0057 .0048	.0055 .0075	.0056 .0068
Velocity	H	.0112 .0106	.0091 .0133	.0088 .0068

$SS_E = .0000013$

Source of variation in the table will appear as follows:

Source	d.f.	SS
Between RA Levels	2	SS_{RA}
Between Velocities	2	SS_V
Interaction	4	SS_I
Error	9	SS_E
Total	17	SS

Where SS_T is corrected for mean.

$$SS_{RA} = (.0112 + .0106 + .0057 + .0048 + .0051 + .0033)^2 \div 6 + (.0092 + .0130 + .0055 + .0075 + .0026 + .0025)^2 + 6 + (.0088 + .0068 + .0052 + .0069 + .0029 + .0033)^2 \div 6 - (0.1149)^2 \div 18$$

$$SS_{RA} = (.0407)^2 \div 6 + (.0403)^2 \div 6 + (.0339)^2 \div 6 - (.1149)^2 \div 18$$

$$SS_{RA} = .000276 + .000271 + .000192 - .000733$$

$$SS_{RA} = .000006$$

$$SS_V = (.0197)^2 \div 6 + (.0356)^2 \div 6 + (.0596)^2 \div 6 - (.1149)^2 \div 18$$

$$SS_V = (.000065 + .000211 + .000592 - .000733)$$

$$SS_V = .000135$$

$$SS_T = .000899 - (.1149)^2 \div 18$$

$$SS_T = .000905 - .000733$$

$$SS_T = .000166$$

$$SS_I = SS_T - (SS_E + SS_V + SS_{RA})$$

$$SS_I = .000166 - (.000018 + .000135 + .000006)$$

$$SS_I = .000166 - .000154$$

$$SS_I = .000012$$

Analysis of Variance Table:

	Mean Squares	F
RA	$SS_{RA} \div 2 = .000003$	$MS_{RA}/MS_E = 2.14$
Vel.	$SS_V \div 2 = .0000675$	$MS_V/MS_E = 48.2$
Int.	$SS_I \div 4 = .000003$	$MS_I/MS_E = 2.14$
Error	$SS_E \div 9 = .0000014$	

F Test for RA is not significant at 0.10 level.
F Test for V is significant at 0.001 level.
F Test for I is not significant at 0.10 level.

Appendix A-6
(continued)

The following conclusions can be drawn:

1. The one-sided test for variance shows a significant change in outlet loading with a change in velocity (A/C ratio) for each bag material except Teflon felt - Style 2663. This does not say that the 2663 Teflon outlet loadings are not valid, only that the number of tests was too few to show significance. A time trend appears in the data which may partially explain the change in loading with change in velocity. Therefore, from the analysis we cannot actually conclude that an increase in velocity produced an increase in outlet loading.

2. The two-sided test for variance for the case of Nomex felt at three levels of reverse air shows a very significant change in outlet loading with a change in velocity. The reverse air and interaction between reverse air and velocity are not signifcant. However, the F-statistic is large enough to indicate the relationship may be there but is not demonstrated due to degrees of freedom; i.e. sample size.

3. The one-sided test for variance for the case of Nomex felt at three levels of reverse air shows a significant change in outlet loading with a change in reverse air at the high velocity. However, the relationship is not found significant at low or medium velocity. This explains why the interaction F-statistic was relatively large. That is there is an interaction but only at the high velocity.

4. Finally, the high significance of the two sided test for increased loading with increased velocity reinforces the signifcance demonstrated in the one-sided test for each bag material.

Appendix A-6
(continued)

4. (continued)
   It can be concluded that the complication of time trend, while present, does not preclude reliability of the data.

Table A-5

Tabulation of Data for Statistical Analysis

Andersen Test No.	Air-to-Cloth Ratio ACFM/Ft.^{2}	Outlet Loading GR/SCFD	Outlet Loading^2
		Nomex Felt	
15	2.9	.0020	.000004
13	3.1	.0021	.000004
14	3.1	.0025	.000006
16	6.1	.0016	.000003
17	6.1	.0028	.000008
38	6.1	.0045	.000020
39	8.7	.0072	.000052
40	8.2	.0047	.000022
		.0274	.000119
		Teflon Felt - Style 2063	
10	5.2	.0120	.000144
11	5.2	.0158	.000250
12	5.2	.0159	.000253
5	8.0	.0038	.000014
6	8.0	.0040	.000016
8	14	.0201	.000404
9	14	.0388	.001505
		.1104	.002586
		Teflon Felt - Style 2663	
79	5.4	.0040	.000016
80	5.5	.0052	.000027
78	8.4	.0102	.000105
77	14.2	.0152	.000230
81	14	.0096	.000092
		.0442	.000470

Table A-5 (cont'd)

Tabulation of Data for Statistical Analysis

Andersen Test No.	Air-to-Cloth Ratio ACFM/Ft.^{2}	Outlet Loading GR/SCFD	Outlet Loading^2
	Gore-Tex/Nomex		
32	2.7	.0046	.000021
33	3.2	.0044	.000019
23	3.6	.0045	.000020
19	5.5	.0054	.000029
21	6.0	.0034	.000012
25	6.2	.0018	.000003
26	6.3	.0022	.000005
34	6.3	.0062	.000038
22	6.5	.0030	.000009
28	8.6	.0084	.000071
27	9.0	.0065	.000042
		.0504	.000269
	Dralon T		
69	3.3	.0093	.000087
70	3.3	.0080	.000064
66	6.1	.0065	.000042
67	6.1	.0055	.000030
68	6.1	.0085	.000073
64	8.5	.0053	.000028
65	8.9	.0060	.000035
		.0491	.000359

Table A-5 (cont'd)

Tabulation of Data for Statistical Analysis

Andersen Test No.	Air-to-Cloth Ratio ACFM/Ft.	Reverse Air Level/ACFM	Outlet Loading GR/SCFD	Outlet Loading^2
		Nomex Felt		
41	9.3	1420	.0112	.000125
42	8.6	1420	.0106	.000112
43	8.6	3160	.0092	.000085
44	9.6	3160	.0130	.000169
45	9.6	4000	.0088	.000077
46	7.8	4000	.0068	.000046
			.0596	.000614
47	6.5	1400	.0057	.000032
48	6.5	1400	.0048	.000023
53	6.4	3100	.0055	.000030
54	6.4	3100	.0075	.000056
55	6.4	4000	.0052	.000027
56	6.4	4000	.0069	.000048
			.0356	.000216
57	3.1	1400	.0051	.000026
58	3.4	1400	.0033	.000011
59	3.4	3160	.0026	.000007
60	3.4	3160	.0025	.000006
61	3.3	4000	.0029	.000008
62	3.3	4000	.0033	.000011
			.0197	.000069
			.1149	.000899

Table A-6

Analysis of Variance Table

Variance	Source of Variation	Sum of Squares	Degrees of Freedom	Mean Squares	F-Statistic	Conclusion
Teflon Felt - Style 2063						
SS_V	Between Velocities	.000661	2	.000331	7.2	Significant at .05 level
SS_E	Within Velocities	.000184	4	.000046		
Gore-Tex/Nomex						
SS_V	Between Velocities	.000022	2	.000011	5.5	Significant at .05 level
SS_E	Within Velocities	.000016	8	.000002		
Dralon T						
SS_V	Between Velocities	.000010	2	.000005	5	Significant at 0.10 level
SS_E	Within Velocities	.000004	4	.000001		
Nomex Felt						
SS_V	Between Velocities	.000018	2	.000009	6.43	Significant at .05 level
SS_E	Within Velocities	.000007	5	.0000014		

Table A-6 (cont'd)

Analysis of Variance Table
(continued)

Variance	Source of Variation	Sum of Squares	Degrees of Freedom	Mean Squares	F-Statistic	Conclusion
Teflon Felt - Style 2663						
SS_V	Between Velocities	.000063	2	.000032	4.0	Not Significant
SS_E	Within Velocities	.000016	2	.000008		
Nomex Felt at Low Velocity - 3 Levels of RA						
SS_V	Between RA Levels	.000002	2	.000001	0.7	Not Significant
SS_E	Within RA Levels	.000013	9	.0000014		
Nomex Felt at Medium Velocity - 3 Levels of RA						
SS_V	Between RA Levels	.000002	2	.000001	0.7	Not Significant
SS_E	Within RA Levels	.000013	9	.0000017		
Nomex Felt at High Velocity - 3 Levels of RA						
SS_V	Between RA Levels	.000014	2	.000007	5.0	Significant at .05 level
SS_E	Within RA Level	.000013	9	.0000014		
Nomex Felt - 3 Levels of Velocity - Assuming RA Constant						
SS_V	Between Velocities	.000135	2	.0000675	33.8	Significant at .001 level
SS_E	Within Velocities	.000031	15	.000002		

Table A-6 (cont'd)

Analysis of Variance Table
(continued)

Variance	Source of Variation	Sum of Squares	Degrees of Freedom	Mean Squares	F-Statistic	Conclusion
Nomex Felt at 3 Velocities and 3 Levels of Reverse Air						
SS_{RA}	Between RA Levels	.000006	2	.000003	2.14	Not Significant
SS_V	Between Velocities	.000135	2	.0000675	48.2	Significant at .001 level
SS_I	Interaction	.000012	4	.000003	2.14	Not Significant
SS_E	Error	.000013	9	.0000014	-	---

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

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3. RECIPIENT'S ACCESSION NO.

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5. REPORT DATE
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7. AUTHOR(S) John D. McKenna, John C. Mycock, and William O. Lipscomb

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16. ABSTRACT The report gives results of a pilot scale investigation to determine the technoeconomic feasibility of applying a fabric filter dust collector to coal fired industrial boilers. It extends and confirms preliminary work reported in July 1974. The pilot facility, on a slip stream of a 60,000 lb/hr boiler, was capable of handling 11,000 acfm at an air-to-cloth (A/C) ratio of 6/1. Filter media evaluated were Nomex felt, Teflon felt (two styles), Gore-Tex, and Dralon-T. Fractional efficiency was determined using an Andersen inertial impactor for the four filter media at three A/C levels. The effect of reverse air volume on outlet loading and pressure drop across the bags was evaluated for Nomex felt. Nomex felt achieved the lowest outlet dust concentrations while Teflon felt operated at the lowest pressure drop. All media tested achieved outlet loadings well within allowable limits. Higher collection efficiencies were achieved with Nomex felt by discontinuing reverse air cleaning. Varying the volume of reverse air from 1400 to 4000 acfm had little effect on removal efficiency. Increasing the amount of air used for cleaning does reduce the pressure drop across the bags. Installed annual operating and total annualized costs for a fabric filter and an electrostatic precipitator, capable of handling 70,000 acfm of flue gas from a coal fired boiler, are presented. A full scale demonstration is anticipated.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Air Pollution	Boilers	Air Pollution Control	13B
Filtration	Dust Collectors	Stationary Sources	07D
Filter Materials	Feasibility	Fabric Filters	13K, 14A
Coal	Tetrafluoroethylene	Nomex	21D
Combustion	Resins	Teflon	21B, 11I
Industrial Heating		Gore-Tex, Dralon-T	13A

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