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FABRIC FILTRATION ANALYSES FOR THREE UTILITY BOILER FLYASHES

Final Report

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ABSTRACT

A major objective of this program was to augment the present data base for modeling fabric filter systems designed for the control of inhalable particulate (IP) emissions from coal-fired boilers. Emphasis was placed on the determination of K_2, the flyash specific resistance coefficient and a_c, a parameter describing fabric cleanability. Fabric filter design, operating, and performance data were analyzed with the assistance of utility personnel from Harrington and Monticello Stations in Texas and Kramer Station in Nebraska. Supplementary laboratory determinations of K_2 were made for flyashes produced by the above facilities because K_2 values could not be estimated from field data alone. Based on laboratory tests it was determined that flyash surface deposits underwent negligible porosity changes for fabric pressure losses <2000 N/m^2. Additionally, a simple field procedure was developed to measure K_2 directly with the aid of heat resistant membrane filters and a Method 17 in-situ sampling probe. Detailed analyses and modeling trials indicated that K_2 and a_c estimates developed from routine compliance or acceptance tests were too rough for dependable modeling although providing useful guidelines. Estimated K_2 values ranged from 0.89 to 3.79 N-min/g-m while a_c values varied from 0.01 to 0.52. Special pilot tests and equipment is the recommended approach to obtain "modeling quality" data inputs.

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FIGURES

FIGURES (continued)

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TABLES (continued)

ENGLISH AND METRIC EQUIVALENCIES FOR KEY FILTRATION PARAMETERS

	Units		
	Metric	English	Equivalency
Filter resistance	N/m^2	in. H_2O	249 N/m^2 = 1 in. water
Filter drag	N min/m^3	in. H_2O min/ft	817 N min/m^3 = 1 in. water min/ft
Velocity	m/min	fpm	0.305 m/min = 1 fpm
Volume flow	m^3/min	cfm	0.0283 m^3/min = 1 cfm
Fabric area	m^2	ft^2	0.093 m^2 = 1 ft^2
Areal density	g/m^2	lb/ft^2	4882 g/m^2 = 1 lb/ft^2
Specific resistance coefficient	N min/g-m	in. H_2O min ft/lb	0.167 N min/g-m = 1 in. H_2O min ft/lb
Dust concentration	g/m^3	$grains/ft^3$	2.29 g/m^3 = 1 $grain/ft^3$

ACKNOWLEDGMENTS

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SECTION 1

EXECUTIVE SUMMARY

BACKGROUND AND STATEMENT OF PURPOSE

The expectation that the control of particulate emissions from the combustion of coal in utility, industrial, and commercial boiler applications will entail progressively stricter emissions regulations suggests that fabric filter systems will assume a more pronounced role in the future. For those situations where fabric failure as the result of thermal stressing, chemical corrosion, or moisture condensation cannot be avoided, electrostatic precipitation and/or wet scrubbing may provide acceptable alternatives in certain applications.

The ease with which a new fabric filter system can be brought on-line often depends more upon good luck than the application of solid design and operating principles. There are many reasons for the occurence, and frequently the persistence, of field shakedown problems although lack of information certainly plays a key role. In some cases, there may not be a full understanding of the process to be controlled or exactly what takes place during the operation of a large multi-chambered fabric filter system. Furthermore, even when the system designer is properly informed from the technical perspective, there may be an unfortunate lack of solid quantitative data relating to the key parameters determining the overall filter system performance.

With the present availability of experimental modeling techniques for predicting filter system operation, there exists a developing capability to eliminate much of the guess work in filter design by augmenting the data and experience inventories of the reputable fabric filter vendors and designers. On the other hand, the surface has barely been scratched in two areas dealing with fabric pressure losses encountered with many dust fabric combinations (defined by the specific resistance coefficient of the dust, K_2, and the ease with which a dust may be removed from the fabric during its cleaning). In current modeling approaches, the degree of cleaning has been defined by the dimensionless term, a_c, that specifies the fraction of the total fabric surface from which the superficial or dislodgable dust layer has been removed.

The critical problem at present is that numerical values for K_2 and a_c have been measured for relatively few dust/fabric combinations and the capability to calculate accurately K_2 and a_c based solely upon theoretical considerations is non-existent. Direct measurement of the above terms is advocated, preferably by well controlled laboratory experiments and, given the opportunity, by specially designed field tests on full scale equipment. A study now in progress, EPA Contract No. 68-02-3151, is intended (a) to develop useful relationships between coal assays and the filterability of their flyash emissions and (b) to increase the data base for typical K_2 and a_c values for U.S. coal flyashes.

The primary purpose of the present program is to examine alternative approaches for obtaining improved or new estimates of K_2 and a_c values typifying real field situations. It has been proposed that for selected field operating conditions and with prior estimates either for K_2 or a_c, the steady-state filtration parameters such as air-to-cloth ratio, inlet dust concentration, baghouse temperature, total number of compartments, number of compartments cleaned at one time, cleaning frequency and cleaning duration can be used to estimate either a_c or K_2. If the available data do not suffice to make individual estimates of K_2 and a_c, various compatible $[K_2\text{-}a_c]$ pairs for these parameters may be inferred from the steady-state field operating and performance parameters. The above approach is of little value, however, unless supporting evidence can be obtained to narrow the range of the resultant pairs.

It was recognized at the outset of this study that the use of raw field data without the advantage of special equipment modifications or controlled changes in operating mode could not be expected to produce other than interim working values serving as temporary guidelines until more sophisticated measurements could be performed. It was also suspected and later demonstrated that certain groupings of field data that initially proved promising were not amenable to analysis. On the other hand, it was believed that if the determination or assumption of rational values for K_2 and a_c based upon laboratory tests or comparable field measurements led to predicted pressure loss values in fair agreement with field observations, the viability of supporting modeling procedures would have been validated. It was recognized that the laboratory estimates for K_2 based upon the re-dispersion of dust hopper flyash samples followed by the development of drag-fabric loading curves suffer from the particle size simulation problems always present when a bulk dust sample is re-aerosolized. Hence, the laboratory estimates of K_2 may differ from the values associated with the freshly deposited flyash.

In the presentation of technical data, we have adhered to metric units with their still commonly used English counterparts shown in parenthesis. However, raw field data have been given in their "as received" English form for convenient reference to the original sources. Additionally certain formulas appear in the text that are designed to compute the values of selected variables in metric units.

PROGRAM RESULTS

Laboratory Measurements

The laboratory phase of this program involved the determination of K_2 values at typical field filtration velocities for coal flyash samples supplied by the baghouse operators of three co-operating utility groups, Southwestern Public Service Company (SPS), Harrington Station; Texas Utilities Generating Group (TU), Monticello Station; and the Nebraska Public Power District, Kramer Station. Flyash samples were filtered on used but cleaned woven glass fabrics such as those commonly used in the field while observing the changes in pressure loss as the dust accumulated (mainly upon the fabric surface) to areal densities up to $\sim 800\ g/m^2$. Average K_2 values for the re-aerosolized flyash were 2.75, 0.89 and 3.79 N-min/g-m, respectively for SPS, TU and Kramer Stations. Limited tests at two velocities showed that K_2 values for the SPS flyash were dependent upon filtration velocity but to a lesser extent than estimated in earlier studies for a cyclone boiler flyash.

A very significant outgrowth of the laboratory test program were the results of concurrent K_2 measurements in which membrane filters (HA Millipore) were used as the substrate for the deposited flyash layer. It was observed that the slopes of the pressure loss/fabric loading curves were almost completely linear from their origins (zero dust loading) to the maximum dust loading. First, the characteristic concave-down form normally found with woven glass fabrics during the early fabric loading period was no longer present because there is no preliminary pore filling phase such as found with most woven media. What is measured as an overall pressure loss for the flyash membrane filter combination is the simple algebraic sum of two series-connected resistances to gas flow. Second, a frequently observed slightly upward curvature noted previously with some flyash/glass fabric combinations was not seen with the membrane filter substrate. Because of the linear slope, it appears that the flyash layers per se undergo no compression due to increased pressure gradient over nominal ranges, up to $1500\ N/m^2$. Conversely, the observed curvature is probably related mainly to the compression of the less resilient fabric substrate.

Field Data Analyses and Modeling

The results of the analysis of field performance data from the co-operating power stations indicated that because essentially continuous cleaning was required at all plants, no meaningful field estimates of K_2 were possible. Only in those instances where extended filtration intervals without cleaning allow for the development of a uniformly distributed dust layer can K_2 be infered directly from field operating data. Accordingly, no determination of the cleaning parameter a_c was possible from the field data alone because the estimation of a_c requires that K_2 be known unless the unlikely situation exists where a direct measurement of the fraction of the surface dust dislodged (a_c) has been made. Therefore, it was necessary to use the laboratory generated K_2 values not only to characterize their field counterparts (with their recognized limitations), but also to determine the cleaning parameter a_c.

The above technique was applied to selected data sets that appeared to represent the steady-state filtration conditions for which the GCA fabric filter model has been designed. By treating the above values of K_2 and a_c as data inputs in conjunction with design, operating, and cleaning parameters customarily used in the modeling process, predicted values were generated for average pressure loss and dust penetration properties for the field systems. In view of the assumptions involved, the relatively good agreement between observed and predicted pressure losses (roughly a 10 to 40 percent error) appears to justify the analytical approach.

The level of agreement is somewhat deceptive, however, because the initial calculation of a_c is based upon the field operating parameters, including pressure loss, as well as an independent K_2 measurement. It is emphasized that the primary objective of this program was to derive field estimates of a_c (and possibly K_2) for dust/fabric combinations not previously studied in detail at the pilot plant level. Hence, the extent to which a confirming prediction of pressure loss agrees with the actual field measurement indicates the reasonableness of the a_c value.

However, in applying the modeling relationship for filter system design or diagnostic purposes, it must be realized that casual estimates of either K_2 or a_c at the ±50 percent level can lead to large variations in predicted performance and/or estimated air/cloth requirements. Because of the mathematical role played by a_c in predictive modeling, predicted pressure losses are highly sensitive to small changes in a_c, particularly when a_c is in the 0.1 range.

A second observation arising from the field analyses was that the computed values of a_c in some cases fell below the 0.1 value constituting the lower limit for model application. (Actually the model will function with a_c entries of less than 0.1, but will treat them mathematically as if they were 0.1). Although this problem was solvable by long-hand approximation techniques, it is recommended that the model application be broadened by reducing the lower limit for a_c.

The unique cleaning approach used by Kramer Station, which often results in variable cleaning and filtration intervals, represents a practical advance in adjusting the available filtration capacity to variable boiler load and variable inlet concentrations. However, the present model structure is not directly amenable to handling the above operating mode unless the system variability can be established beforehand.

CONCLUSIONS AND RECOMMENDATIONS

Laboratory Measurements

In the following section, conclusions and recommendations pertaining to the laboratory measurements program are presented.

1. The non-linearity observed with pressure loss versus fabric loading curves with many glass fabrics results from compression of the fabric and not the dust cake over the typical ranges of pressure loss <2000 N/m^2 (8 in. water) encountered in the field. Although the degree of curvature involved does not lead to serious computational error for most flyashes, the capability to distinguish between substrate compression and dust compression will facilitate the modeling of other dust/fabric combinations.

2. The technique of using a membrane filter as the dust collecting substrate provides a simple, economical means for direct field measurement of K_2. A filter circle consisting of Teflon or other appropriate membrane material mounted in an in-stack filter holder with provisions to measure pressure loss across the filter over a 30 to 60 minute sampling period and to determine the resulting flyash weight gain by subsequent removal of the filter from the holder will enable simultaneous estimates of both K_2 and local mass concentration. In contrast to similar measurements with woven fabrics or other substrates where the initial curve path is always curvilinear, the membrane approach requires only two pressure measurements, initial and final, and a net dust weight to establish the slope (and K_2) for the pressure-fabric loading curve.

Field Data Analyses and Modeling

The attempts to estimate a_c and/or K_2 values for various flyash/fabric combinations based upon the analyses of steady-state field performance data and the use of computer modeling techniques has led to the following conclusions and recommendations:

1. K_2 values could not be determined from the field data provided by the co-operating utilities because continuous cleaning was required to keep system pressure loss within pre-set bounds.

2. The need to use laboratory estimates of field K_2 values introduces errors relating to probable differences in particle size parameters. Use of the field K_2 technique involving Teflon membrane filters and in-stack collection of the flyash as a conventional testing procedure would greatly improve the accuracy of K_2 measurements and hence the reliability of modeling predictions. It is recommended that this technique be used for future measurements.

3. The estimation of a_c values from a combination of laboratory K_2 measurements and typical field measurements associated with compliance test data supplemented by inlet (uncontrolled effluent) concentrations depends not only upon the representativeness of the K_2 value but also upon the accuracy of measured field operating parameters, such as pressure loss, air flow, inlet concentration, and adherence to indicated cleaning parameters.

4. Except for rough estimates of the probable behavior of a given flyash/fabric combination, the results of the current analyses demonstrate the need for specialized measurements programs based upon laboratory or field pilot scale testing to determine accurately the values for the K_2 and

a_c parameters. It is not recommended that these terms be computed from theoretical considerations except for guideline purposes until the dust permeability and adhesion phenomena can be described in terms of practically and easily measured parameters.

5. The apparent occurrence of a_c values less than the present lower limit of 0.1 set for the GCA filtration model suggests minor changes in the model structure. It is recommended that these changes be implemented, based on future field tests.

6. Those dust fabric/combinations, which, in conjunction with certain filtering and cleaning parameters cause small a_c values, will produce the greatest errors in predictive modeling because of the inherent sensitivity of pressure loss to small changes in a_c in the low, $\sim$0.1, a_c range.

7. The present model structure is not designed to predict variable system behavior where, due to rapid load shifts and possibly concurrent changes in inlet loading, the system never achieves a steady-state condition. The model can be used on a step by step basis to predict moderate variability in system behavior when sufficient time is allowed for near steady state to be established and the nature of the system variability is known beforehand.

SECTION 2

INTRODUCTION

BACKGROUND

Fabric filtration appears as a logical candidate for control of particulate emissions from both utility and industrial coal-fired boilers in those situations where ash properties preclude cost competitive applications of electrostatic precipitation. However, the present data bases are limited and those systems recently installed are still undergoing major shakedowns with the likelihood that some changes will be made in both design and operating parameters. In addition, the proposed installation of large scale filter systems for $\geq$ 250 Mw (elec) boilers, requires that extreme caution be used in choosing design and operating conditions. The capability to perform predictive modeling, which has seen only limited field validation, can reduce significantly the guesswork involved in constructing filter systems.

PRESENT MODELING CAPABILITIES

At the present time, field measurements performed at three utilities: Bow, New Hampshire; Nucla, Colorado; and Sunbury, Pennsylvania[1,2,3] appear to be predicted within reasonable levels by the GCA fabric filtration model for collapse and reverse flow and mechanically shaken systems.[4,5,6,7,8] A comparison of estimates of the fabric cleaning parameter, a_c, by laboratory and field measurements showed good agreement in view of the technical difficulties involved in developing these data.[7] Note that a_c values for the power stations cited above tend to lie close to the laboratory-based experimental curve, Figure 1. Similarly, mass penetration and fabric resistance properties for Nucla, Colorado and Sunbury, Pennsylvania coal-fired utility boilers were also predicted with acceptable accuracy according to the measured and predicted values shown in Table 1.[4]

Additionally, use of the model to predict operating losses to be expected at the Amarillo Station of the Southwestern Public Service Company (SPS) has indicated high pressure losses, ~10 to 12 in. water, (2.5 to 3.0 kPa) which were consistent with field observations. Because these computations were based upon a combination of pilot tests performed in the field plus estimates of certain parameters where there were doubts as to their accuracy or representativeness, the excellent agreement between predicted and observed pressure losses has been accepted with due caution.

Actually, the data base for determining the values for two parameters essential to the modeling procedure, a_c (the fraction of filter surface

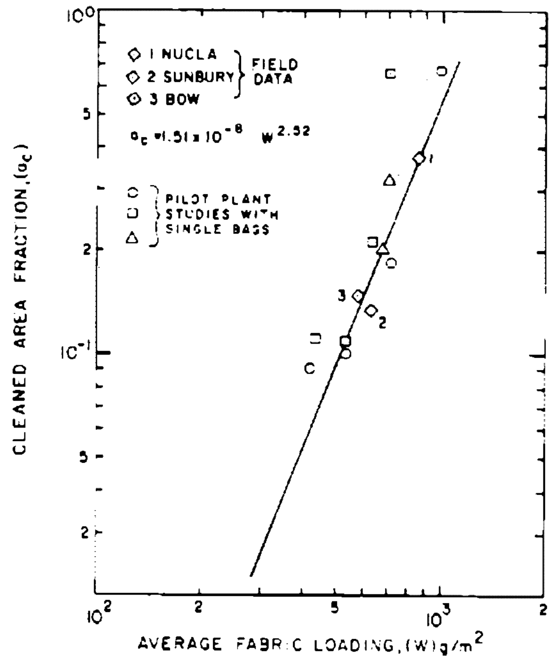

Figure 1. Cleaned area fraction versus filter dust loading or interfacial adhesive force. Coal flyash (MMD = 4.2 μm, σ_g = 2.44) with woven glass (Sunbury type) fabric.[7]

TABLE 1. MEASURED AND PREDICTED PERFORMANCE FOR WOVEN GLASS BAGS WITH COAL FLYASH[4]

	Percent penetration	
	Measured[a]	Predicted[a]
Nucla, Colorado	0.21	0.19 (1.52)[b]
Sunbury, Pennsylvania	0.15	0.20
	Resistance-kPa	
	Measured	**Predicted**
Nucla, Colorado		
Average, cleaning and filtering	1.03	0.97
During cleaning only	1.7	1.52
Maximum just before cleaning	1.16	1.16
Minimum just after cleaning	0.85	0.72
Sunbury, Pennsylvania		
Average, cleaning and filtering	0.64	0.62
During cleaning only	0.71	0.66
Maximum just before cleaning	0.71	0.66
Minimum just after cleaning	0.56	0.57

[a]Averaged over cleaning and filtering cycles.

[b]During cleaning cycle only.

cleaned) and K_2 (the specific resistance coefficient of the dust of interest) is very limited. Furthermore, the immediate prospects for providing improved estimates of these variables, short of direct measurements, are contingent upon the results of continued laboratory and field research such as the EPA sponsored study now in progress at GCA/Technology Division, "Development and Evaluation of Improved Fine Particulate Filter Systems," EPA Contract No. 68-02-3151.

Therefore, an important facet of the present program is to examine field and laboratory data from as many sources as possible to provide improved estimates for the modeling parameters.

CRITICAL MODELING PARAMETERS

The core model proposed by Dennis and Klemm for predicting system pressure drag across fabric filters used to control flyash emissions from coal-fired boilers is represented in Equation 1[5]

$$S = \left(\sum_{i=1}^{n} \frac{a_c}{S_c} + \frac{a_{u1}}{S_{u1}} \cdots \frac{a_{ui}}{S_{ui}} \right)^{-1} A \qquad (1)$$

where S and A refer to overall drag and filter area, respectively, i designates the i^{th} fractional area a_i and its associated properties, n is the total number of elemental areas making up the whole surface, and the subscripts c and u refer to the <u>cleaned</u> and <u>uncleaned</u> filter areas, respectively. Equation 1 describes the behavior of a large, multicompartmented baghouse that undergoes sequential chamber cleaning in accordance with a fixed time cycle or pre-set limiting pressure loss. As a result, although the pressure losses are essentially the same across each compartment, the local gas flow through each compartment is dictated by the instantaneous dust holding (which depends upon when the compartment was last cleaned). The drag through any section of the filter surface over which the fabric dust loading is uniformly distributed is

$$S = S_E + K_2 W \qquad (2)$$

where S is the total filter drag, S_E the effective residual drag, K_2 the specific resistance coefficient for the dust, and W the fabric dust loading in mass per unit area.

<u>Specific Resistance Coefficient</u>

The K_2 value for any dust is readily determined on an experimental basis provided that the fabric dust loading, W, is uniform. However, W is often not uniform because of frequent cleaning in many field applications. Thus, routine field testing used to assess baghouse performance may not provide sufficient data for correct estimates of K_2.

If one attempts to calculate K_2 based upon theoretical considerations by way of various modifications of the classical Kozeny-Carman relationship; i.e.:

$$K_2 = 1.6\ \mu S_0^2\ (1-e)/\rho_p e^3 \tag{3}$$

where μ is the gas viscosity, e the cake porosity, ρ_p the discrete particle density, and S_0 the specific surface parameter for the size distribution, the results will at best be only within ±50 percent of actual measured values;[5] hence, the advisability of determining K_2 by direct measurement whenever possible.

Cleaning Parameter, a_c

Except for special testing procedures involving direct weighing of filter bags immediately before and after cleaning, the cleaning parameter a_c must be determined by indirect means for filter systems using bag collapse and low velocity reverse flow <1.5 m/min for dust removal. Furthermore, there are not sufficient data to determine dust release properties based upon the fundamental adhesion relationship between the overlying dust layer and the fabric substrate.

If the K_2 value for a specific dust can be established, it is possible to use the data deriving from routine acceptance, compliance or performance tests to make a practical estimate of the cleaning parameter.

$$a_c = 1 - \frac{W_p - \Delta W - W_R}{W_p - W_R} \quad \text{(metric units)} \tag{4}$$

In the above case, W_p is the estimated (uniformly distributed) fabric loading corresponding to the resistance P_m; i.e., the overall system maximum pressure signaling the start of cleaning, ΔW is the average increase in fabric loading over the filtration interval, and W_R is the residual fabric loading for the cleaned regions of the fabric. By means of Equation 5 below, W_p can be determined on the basis of the assigned operating values for P_m and filtration velocity, V provided that the K_2 value has been established.

$$W_p = (P_m/V - S_E)/K_2 \tag{5}$$

PROGRAM OBJECTIVES

The major objectives of this study were to augment the existing data base (a) for identifying specific problem areas encountered in fabric filtration applications for control of flyash emissions from coal-fired boilers and (b) to suggest how these problems might be solved. The program was also intended to encourage the use of mathematical models in both the design and analysis of filter system behavior by providing improved definition of the variables appearing in the model and by demonstrating the merits of the modeling approach by further field validation. Additionally, laboratory tests were planned to estimate certain filtration parameters whose field estimations suggest the need for refinement or validation.

SCOPE OF WORK

To realize the full value of current modeling capabilities, regardless of the filter system type, certain controlling parameters were investigated in the field and/or laboratory because there were no accurate means to predict these parameters from theoretical considerations alone.

Dust deposit resistance to gas flow as defined by K_2 and the degree of cleaning, a_c, as defined by the relationship between dust adhesion and separating forces were computed on a basis of direct measurement, a combination of laboratory and field measurements, or by trial and error approaches.

Documentation of overall boiler and filter system operations including relevant input parameters was carried out to provide a rational basis for assessing system performance as well as flagging specific problems detracting from system effectiveness.

UTILITY BOILERS STUDIED IN MODEL VALIDATIONS

Southwestern Public Service Company (SPS) — Harrington Station Boiler No. 2, Amarillo, Texas[9,10,11,12]

Boiler and Fuel Parameters--

Harrington Station is a pulverized coal burning installation with two 350 Mw_e boilers now on line and a third unit under construction. A combination of electrostatic precipitation and scrubbing is used with Boiler No. 1 whereas a baghouse is the control device for Harrington No. 2 boiler. The present fuel consists of a Wyoming coal with the following properties: 0.3 to 0.4 percent sulfur, 5 to 7 percent ash and a heating value (as received) of 8425 Btu/lb. The boiler functions as a peak loaded unit that cycles throughout the day in accordance with the electrical demand. Best estimates of fabric filter system availability since it became operational on Boiler No. 2 in June 1979 are roughly 90 percent. It is expected that a significant improvement in availability will be observed once selections of filter fabrics and key operating parameters are decided.

Flyash Control Equipment--

The Boiler No. 2 baghouse was designed and constructed to operate with a fabric pressure loss of roughly 4 in. water and a flange-to-flange loss of 5 in. water. The flyash control system consists of two identical baghouses, designated as the East and West units, each containing 14 compartments; see Figure 2. Each compartment contains 204 bags, 30 ft 8 in. long and 11.5 in. in diameter, manufactured from a glass twill. The original bags were designated as W.W. Criswell 445-04, a 10.5 oz/yd^2 twill with a silicone-graphite coating. A different Criswell weave, 442-57 DC2 with a Teflon B coating was used in later tests. At the design air-to-cloth ratio of 3.4 afpm, total gas flow for the Harrington No. 2 baghouse is a nominal 1.6×10^6 acfm at baghouse temperatures ranging from 320° to 380°F.

Although the original operating plan called for the pressure actuated, sequential cleaning of all compartments in groups of two, with varying periods when all compartments would remain on-line, unexpectedly high fabric

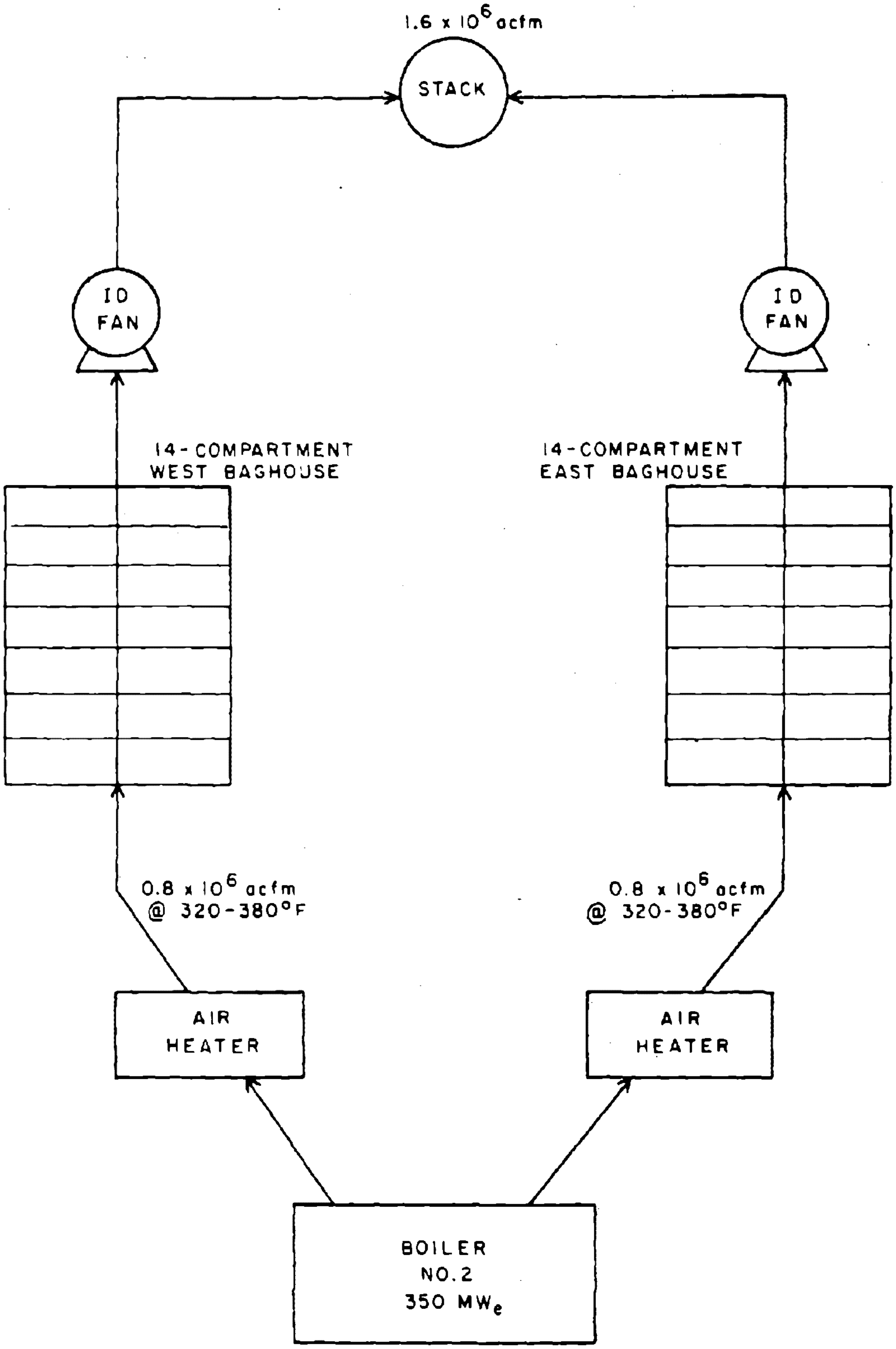

Figure 2. Boiler and control equipment configuration for Harrington, Station, Southwestern Public Service Company, Amarillo, Texas.

pressure losses prevented the latter operating mode. Consequently, the actual cleaning regimen typifies a time-controlled system wherein the sequential cleaning of compartments is constantly repeated. Thus, the steady-state pressure loss conditions will depend upon inlet concentration, air-to-cloth ratio and the fabric cleanability as influenced by any changes in flyash properties. During normal operation, 2 minutes are required for the concurrent cleaning of one West and one East baghouse compartment such that the overall cleaning cycle takes 28 minutes. The actual data inputs representing the essential information used in the model validation analyses are listed in Section 4 for selected operating periods.

During the first year of field operation, the observed SPS pressure losses ranged from 8 to 10 and 10 to 12 in. water, respectively, for the fabric and flange-to-flange resistance parameters. In fact, the continuous monitoring system showed occasional pressure losses even higher than the levels cited above. Insofar as particulate emissions were concerned, the discharges were well below the compliance level; i.e., 0.035 versus 0.1 $lb/10^6$ Btu. Excessive pressures and bag replacement problems experienced during shakedown were attributed to (a) cleaning procedures, (b) a finer ash than anticipated, (c) electrostatic charge effects, (d) variations in mass loadings and coal ash characteristics, and (e) the glass fabric properties.

Several steps were taken (with measurable improvements noted) to solve the excess pressure loss problem. These included the substitution of different fabrics, careful attention to bag tensioning, changes in the mechanical shaking parameters and installation of a flow control on the deflation system. Although the multifaceted program to improve both system performance and availability is proving effective, it has led to data outputs that make difficult the analysis of some baghouse data for modeling purposes. In subsequent sections of this report, we have indicated that the number of periods depicting steady-state operation with the same bag type used in all compartments are quite limited.

Kramer Station, Bellevue, Nebraska[13,14,15,16]

Boiler and Fuel Parameters--

Kramer Station consists of four pulverized coal, peaking boilers, three designed for ∿25 Mw_e operation and a single 37.5 Mw_e unit. Prior to installation of the present baghouse, the particulate control equipment consisted of mechanical, cyclonic-type collectors designed to remove approximately 83 percent of the flyash at a maximum pressure loss of 3.3 in. water. Several types of coal have been burned with the most recent supply a Kemmerer, Wyoming coal having a heating value of 10,000 Btu/lb and with sulfur and ash contents of 0.5 to 0.8 percent and 3.2 to 4.2 percent (as received). Although several control options had been considered, such as electrostatic precipitators, scrubbers, filters or combinations of the above, it was elected to burn a low sulfur coal, thus minimizing the SO_x emission problem followed by the selection of fabric filtration for flyash removal because of the recognized difficulties in capturing flyash from low sulfur coals with electrostatic precipitators. It was also decided to use the existing mechanical collectors in a standby, parallel-flow configuration, should the need for emergency repair and/or plant turndown arise. The above approach also assures a broad (unfractionated range in particle size for the flyash depositing on the fabric as opposed to the narrower size spectrum afforded by an upstream, series-connected cyclone. In many cases, the removal of the coarser particles appears to increase dust cake resistance to gas flow. The only noted difference in the operation of the four boilers is that the use of a dolomitic limestone-precoat with Baghouse (Boiler) No. 1 has led to a consistently higher fabric pressure loss. The possibility of moisture pick-up on the limestone was considered by Kramer personnel to explain the higher operating pressure loss. Flyash was used to pre-coat systems 2, 3, and 4 prior to fire-up procedures.

Flyash Control Equipment--

The baghouses for Boiler Nos. 1, 2, and 3 are similar, each designed to handle 122,000 acfm at design flow with a total of 720 Teflon coated fiberglass bags* housed in 10 sequentially-cleaned (collapse and reverse flow) compartments. The filter unit for Boiler No. 4 is basically the same except that it consists of 1152 bags housed in 16 compartments and filters a flue gas flow of 192,000 acfm at temperatures in excess of 325°F. The reverse flow rate per compartment is 14,400 acfm in all cases. The schematic arrangement for the Kramer bahouses is shown in Figure 3. Although the basic bag designs were very similar to those used by SPS and Texas Utilities, 4 anti-deflation rings were sewn inside each bag, starting 6 ft from the top and 5 ft apart. No cleaning augmentation by mechanical shaking is provided for the Kramer systems.

A unique bag cleaning approach is used whereby the normal cleaning cycle is interrupted if baghouse pressure loss exceeds the preset level of 5 to 6 in. water following the cleaning of one compartment. The normal cleaning cycle allows for approximately 9 minutes of filtration between cessation of one compartment's cleaning and the initiation of the next compartment's cleaning. If the preset pressure loss is exceeded after any compartment has been cleaned, this 9 minute interval is reduced to zero and the baghouse cleans constantly until the pressure loss is reduced below the preset limit. It should also be noted that once the pressure loss has been decreased to a point below the allowable maximum, the system will operate with all compartments on line for a 9 minute period before corrective cleaning is initiated. Therefore, in the event of very sudden increases or decreases in concentration, greater than average excursions from average pressure loss conditions will take place.

Following the usual gamut of shakedown problems, many of which were primarily of a mechanical or electrical nature — electrical circuitry, solenoid valves, current limiting switches — the system has evolved to a relatively maintanance free operation. Specific details for the design and operating parameters persisting during the modeling intervals are given in Section 4.

Texas Utilities, Monticello Station, Units 1 and 2[17]

Boiler and Fuel Parameters--

Two boilers rated at 575 Mw_e (Units 1 and 2) and one 750 Mw_e boiler (No. 3) constitute the Monticello Station equipment. Units 1 and 2 are controlled by a combination of electrostatic precipitators and fabric filters

*Fabric Filters, Inc., 25 ft, 4 in. long, 12 in. diameter.

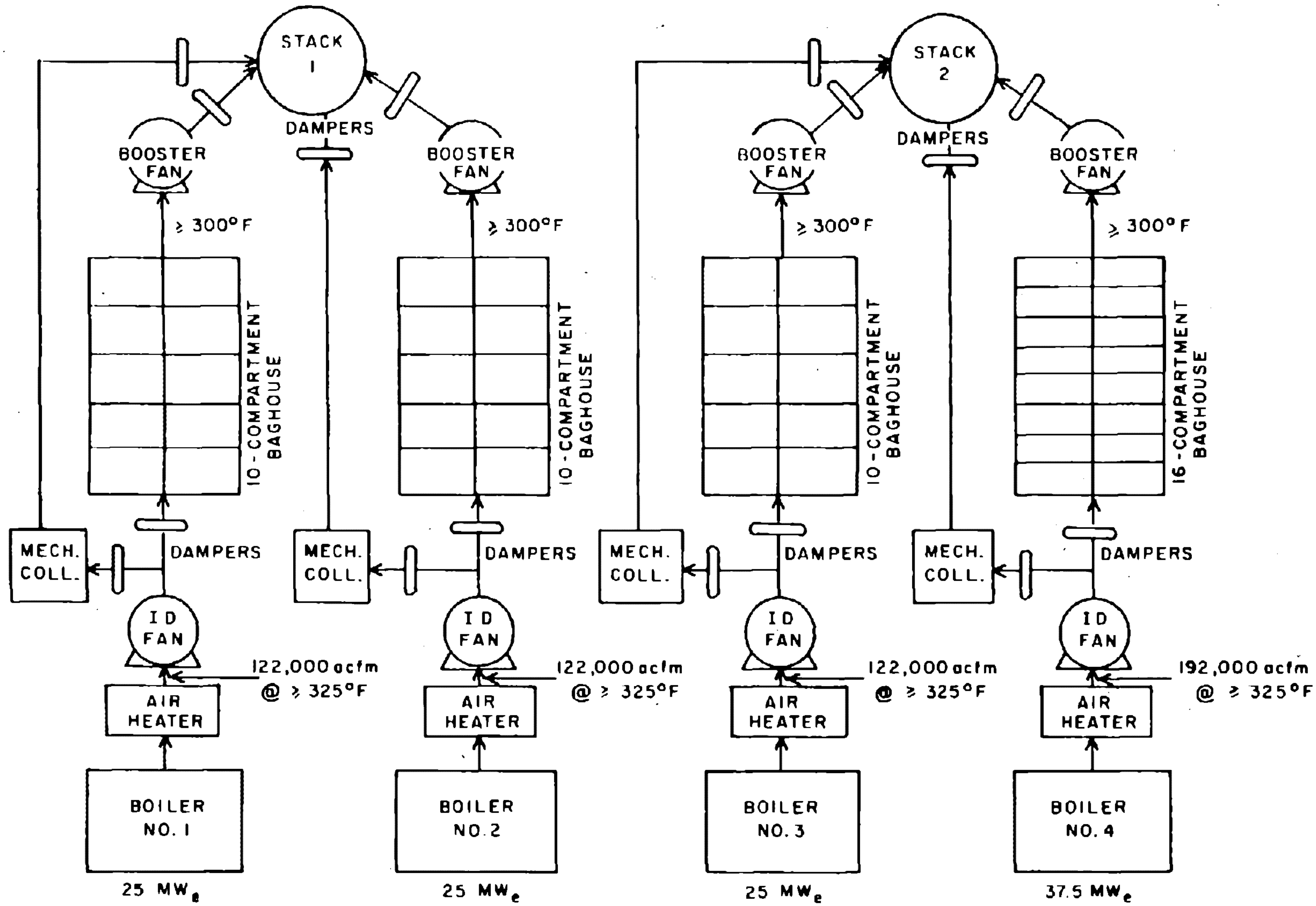

Figure 3. Boiler and control equipment configurations for Kramer Station, Nebraska Public Power District, Bellevue, Nebraska.

operating in parallel while Unit 3 uses a series-connected ESP and scrubbing system. All boilers are designed for base-loaded operations with the firing of pulverized Texas lignites having the following analyses: heating values of 5400 to 6450 Btu/lb, sulfur contents ranging from 0.75 to 1.3 percent, and very high ash contents, 16 to 28 percent (as received basis).

During early shakedown operations, baghouse availability was less than 90 percent and visible emissions in excess of 30 percent opacity suggested a possible need for boiler derating. Fabric pressure losses in excess of design levels plus inadequate collection of the fine particles contributing to excessive opacities by the electrostatic precipitators operating in parallel with glass fabric filters appeared to be the major problem. Note that the Texas Air Control Board (TACB) limits plume opacity to 30 percent.

Flyash Control Equipment--

The fabric filters currently installed on Boilers 1 and 2 are retrofit systems whose major role is to greatly reduce the gas flow through the original precipitators such that the ESP treated fraction will produce a reduced effluent concentration. The physical arrangement for the combined fabric filter-ESP systems is shown in Figure 4. The remaining flue gas that passes through the filter (initially expected to be 80 percent of the total flue gas emissions) after re-combining with the ESP effluent, was expected to provide a resultant emission with concentrations well below the 0.3 $lb/10^6$ Btu level set by the Texas Air Control Board (TACB). Two baghouses operating in parallel, each consisting of 18 individual compartments with 204 bags, 30.5 ft long and 11.5 in. in diameter constituted the filtration equipment. Because of high operating pressure losses, both A and B Baghouses are cleaned simultaneously such that two out of a total of 36 compartments are always in the cleaning mode.

During preliminary testing, the glass bags were identified as W.W. Criswell 445-04, 3 × 1 twill with a weight of 10.5 oz/yd^2 and a silicone-graphite surface treatment. However, several types of bags were tested and, at the present time, the boiler No. 1 filter system uses a Criswell bag described as No. 442-57 DC2 with a 10 percent Teflon B surface treatment. Bags are installed with the warp side out (or on the clean side) which means that the dust should be less readily dislodged from the interior (filtering) surface. The actual fabrics in use when field data were used for modeling analyses are indicated in Section 4 of this report. The nominal flue gas rate for both boilers 1 and 2 is 2.3×10^6 acfm at 380°F. With ~80 percent of the total gas flow passing through the baghouses, the design air-to-cloth ratio is 2.74 afpm with 36 compartments on line and 3.08 afpm with 32 compartments on line (2 out for cleaning and 2 on standby to allow rapid maintenance with minimal pressure loss fluctuations). Although the design flange-to-flange operating pressure loss was 7 to 8 in. water, the actual values were nearer to 11 to 12 in. water when 80 percent of the gas flow was directed through the baghouse. Some reduction in pressure loss occured when only 61 percent of the flow was handled by the baghouse although the result of this compromise led to excessive plume opacity (>30 percent according to TACB measurements). Pressure loss problems were believed to result in part from unexpectedly high K_2 values for the dust although electrostatic charge phenomena were also suspected. After extensive shakedown tests with different fabrics, the boiler now operates at

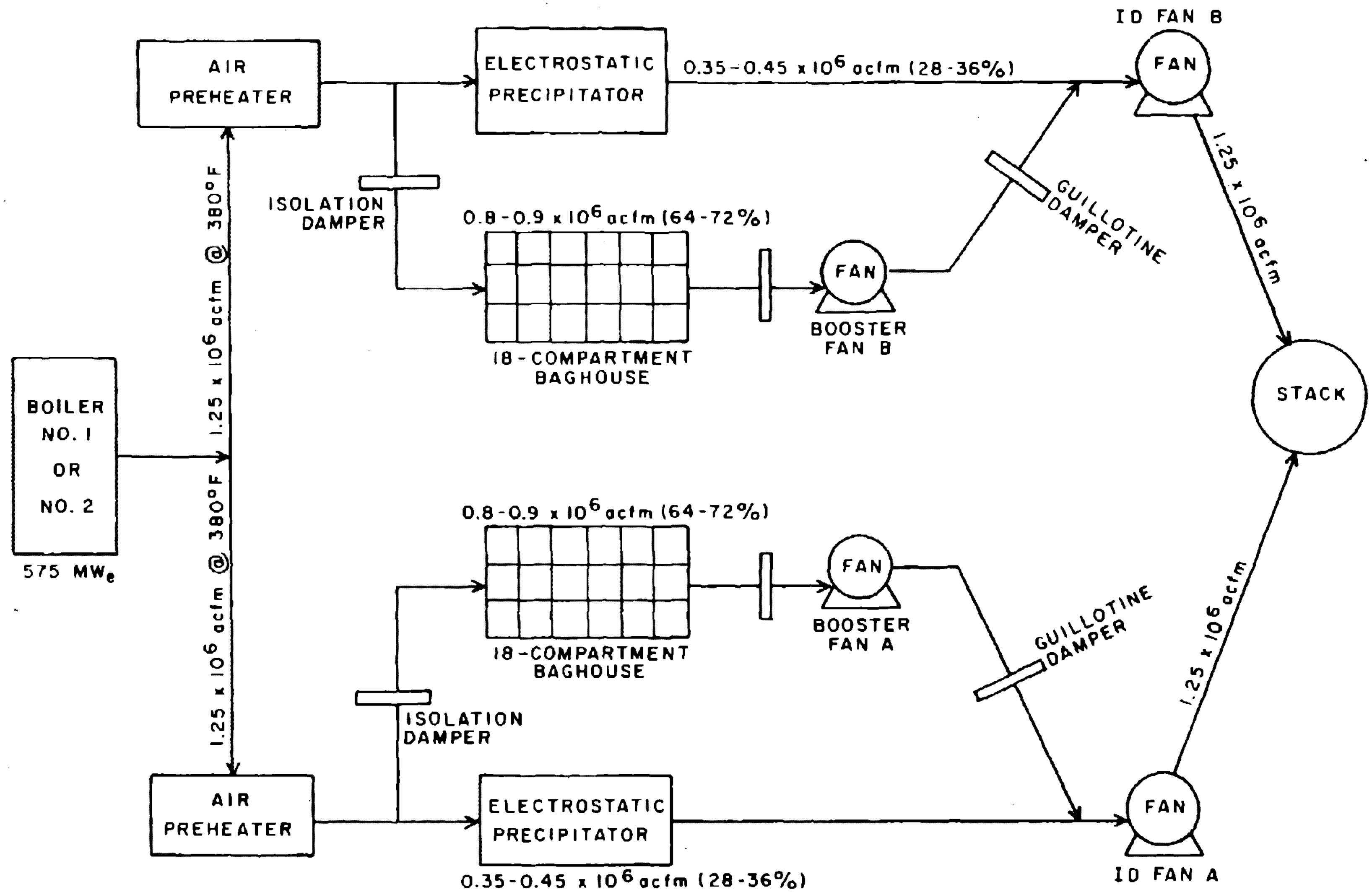

Figure 4. Boiler and control equipment configuration for Monticello Station, Texas Utilities Generating Co., Mount Pleasant, Texas.

rated load with roughly 72 percent of the flow through the baghouses as originally planned. Concurrently, the TACB 30 percent opacity limit is usually met. It is pointed out that the opacity problem arises from the fraction of the flue gas flow that passes through the electrostatic precipitators before rejoining the baghouse effluent whose opacity is far below the allowable level.

Operating and design parameters relating to the modeling analyses are provided in Section 4.

SECTION 3

LABORATORY PROGRAM: EQUIPMENT, TECHNICAL PROCEDURES, AND TEST RESULTS

EQUIPMENT AND TECHNICAL PROCEDURES

Bench Scale Filtration Equipment

The laboratory program was designed so that filter performance tests involving fabric resistance characteristics and particle size properties could be carried out on a bench scale system. This system is fully described in a previous report.[5] While it is recognized that dimensional or dynamic similarity cannot always be satisfactorily attained, the bench scale approach offers such advantages as higher measurement precision and reduced testing time.

The test assembly used in this program operates with a filtration area of approximately 345 cm^2 (15 cm × 23 cm). A rigid, steel picture frame assembly functions as the actual filter holder, enabling the filter panel to be removed for weighing and subsequent replacement. The framed filter panel is held in a vertical position between inlet and exit manifolds (as shown in Figure 5) with no physical support or backing behind the fabric. The flat inlet distribution manifold section ensures a vertical air flow, parallel to the filtering surface, as is the case in a typical field installation. By reducing the depth of the manifold to approximately 2.5 cm, a vertical velocity sufficient to support flyash particles of 30 µm aerodynamic diameter is attained (based on an air-to-cloth ratio of 0.61 m/min, or 2 fpm).

Flyash enters the system through an inlet pipe that discharges into a hopper section below the inlet manifold. The inlet pipe diameter enlarges prior to entering the hopper to minimize particle impaction losses on the opposite hopper wall. Samples of the upstream aerosol for particle size analysis and for alternative K_2 measurement (see below) are withdrawn through the top of the inlet manifold. The probe opening is located opposite the center of the fabric panel. On the clean air side of the system, the entire fabric filter effluent is passed through a glass fiber filter prior to flow measurement, so that fabric collection efficiency can be determined.

Both the filtration system and the dust generation system (described below) are electrically grounded (to the extent expected in the field) to reduce the possibility of electrostatic particle losses and to minimize the potential impact of electrical charge on dust cake structure.

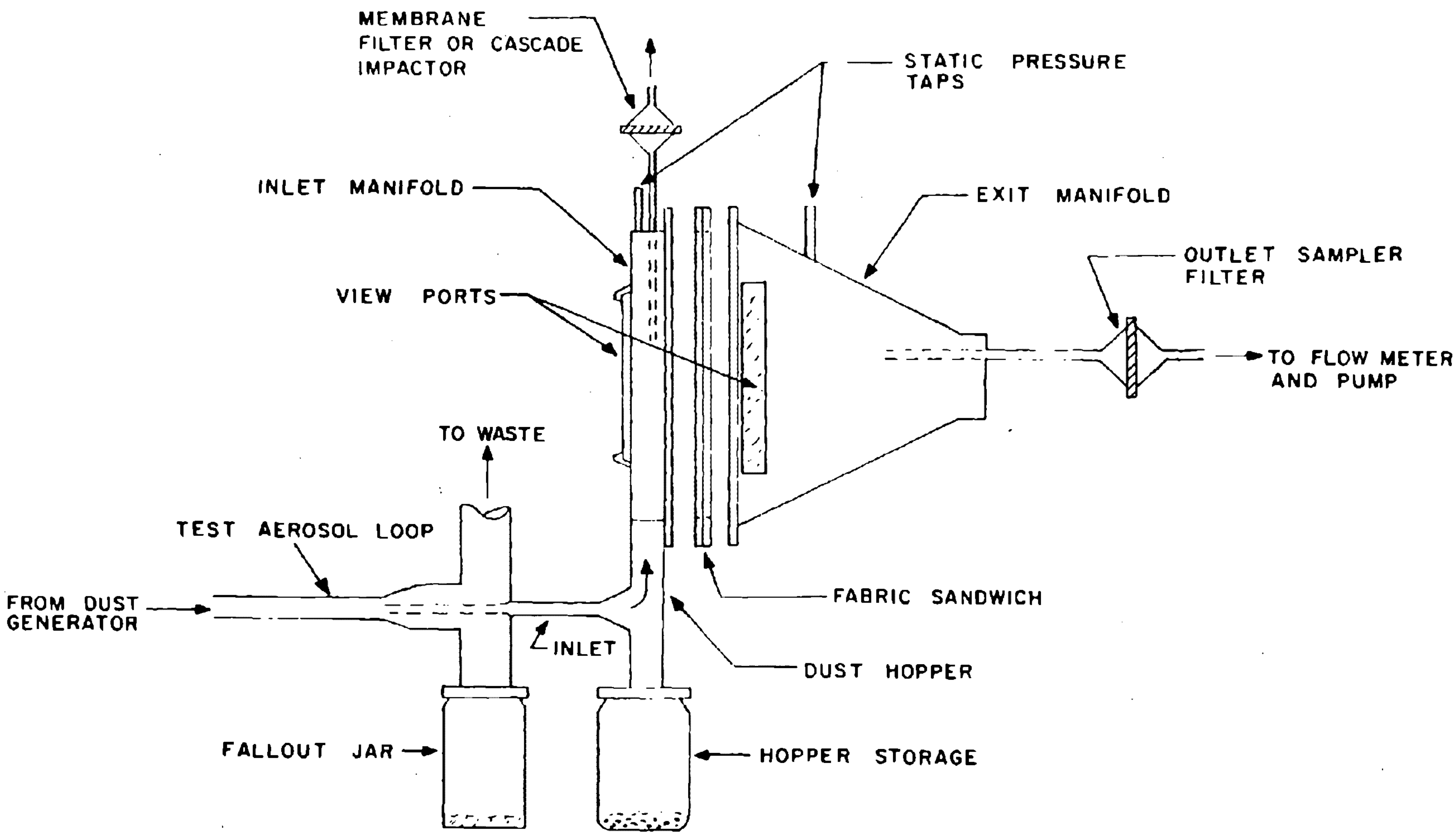

Figure 5. Fabric filter test assembly.[5]

Dust Generation Apparatus

Test aerosols are generated with an NBS dust feeder,[18] a device that provides a regulated dust feed over a delivery range of approximately 0.1 to 2 grams/min. After discharging from a small storage hopper onto a slowly rotating spur gear, the dust (or flyash) is transported to an aspirating tube leading to a compressed air ejector. A clean, dried compressed air supply of about 0.11 m^3/min (4 acfm) at 276 kPa (40 psig) first entrains and then redisperses the dry dust by the high velocity (sonic) shearing action in the nozzle. The well dispersed dust is injected into an aerosol test loop resulting in a combined air flow, compressed plus entrained air, of 0.23 m^3/min (8 acfm).

Excess air from the test loop is vented to a waste gas treatment system. The aerosol sample for the test equipment is extracted by means of a probe attached to the filter system inlet pipe. By varying the probe diameter, it is possible to extract an isokinetic sample (±10 percent) from the test loop for fabric air-to-cloth ratios ranging from 0.45 to 1.70 m/min (1.5 to 5.6 fpm). The above procedure ensures that flyash size properties will be unaffected by the extraction flow rate over the range of experimental filtration velocities used in filter testing. A schematic drawing of the filter test assembly is shown in Figure 5.

Test Aerosols

Flyash samples from the baghouse hoppers were obtained from each of the three utility fabric filter users assisting in the study — Nebraska Public Power District, Kramer Station, Bellevue, Nebraska; Texas Utilities Generating Company, Monticello Station, Mt. Pleasant, Texas; and Southwestern Public Service Company, Harrington Station, Amarillo, Texas.

Prior to analysis, flyash samples were mixed and sieved through an ASTM 120 mesh (125 µm pore size) sieve to remove any coarse material present. This step was followed by storage in a 100°C drying oven prior to use. The conditioned flyashes were then redispersed by the NBS dust generator described previously.

Filtration Media and K_2 Measurement

Two types of filtration media were used in the laboratory program. The 15 cm × 23 cm fabric panel consisted of a new, unused section of Menardi-Southern 601 TUFLEX woven glass fabric with 10 percent Teflon B coating. Air was drawn through the fabric panel with a rotary vane sampling pump. Instantaneous air flow was monitored with an orifice meter while the total volume filtered was measured by a dry test meter, corrected to pressure-temperature conditions at the fabric surface.

Static pressure taps on both the inlet and outlet manifolds allowed for determination of pressure loss across the fabric at frequent intervals. The fabric panel and frame were periodically removed from the test assembly and weighed to determine the mass of flyash accumulated. This procedure was carried out without serious disruption of the dust cake surface. By assuming a constant dust feeder output and inlet loading, and by using the frequent pressure loss readings, intermediate points (between actual panel weighings) on the drag versus dust loading curve were obtained.

At least one K_2 measurement was carried out at the air-to-cloth ratio expected in the field for each of the three flyash samples.[9,15,17] The air-to-cloth ratios at Kramer Station and Monticello Station were similar (∿ 0.6 m/min), while the air-to-cloth ratio for Harrington Station was higher (∿ 1.0 m/min). To facilitate a velocity-independent comparison of all three flyash samples, K_2 for the Harrington Station flyash was determined at the lower air-to-cloth ratio as well.

Upon completion of each test, the fabric panel was cleaned by a two-stage process. First, the dust cake was removed by rapping the panel frame on a flat surface, with the filtering side of the panel facing downward. Next, the panel and frame were shaken by hand about 20 times at two cycles per second to remove any additional loosely deposited flyash. This cleaning process produced residual dust loadings ranging from 20 to 56 grams/m^2, with an average value of 39 grams/m^2. The above values were in good agreement with previously determined residual dust holdings. Insofar as could be seen by direct observation, complete removal of the superficial or dislodgable dust layer was accomplished.

During each fabric filter test, flyash was also collected on a membrane filter (Millipore Corporation, type HA, 0.45 μm pore size, effective area 9.62 cm^2), by extracting the aerosol sample from a point opposite the center of the fabric panel. Flow through the membrane filter was held constant by means of a calibrated critical flow orifice having a diameter that provided a face velocity essentially the same as that for the woven glass fabric panel.

Static pressure taps on either side of the membrane filter holder were also provided to record pressure loss during the test. The initial pressure loss across the clean membrane filter ranged from 920 to 1920 N/m^2 (3.7 to 7.7 inches H_2O), depending on the filtration velocity. This initial reading was subtracted from all subsequent readings to obtain values for incremental pressure loss, which were used to construct a drag versus dust loading curve.

Because of the fragility of the membrane filter and its dust cake, it was not possible to remove the filter from its holder for weighing at intermediate points during the testing. To obtain intermediate points on the drag versus dust loading curve, it was necessary to assume that the rate of dust accumulation on the membrane filter was proportional to that of the fabric panel. In this way, the final dust loading on the membrane filter could be apportioned over each of the test intervals.

Particle Size Measurement

The particle size properties of each flyash were measured with an Andersen Mark III cascade impactor using glass fiber collection substrates. The impactor inlet was modified by attaching a straight, 25 cm long, 0.8 cm i.d. probe to the inlet cone. With this arrangement, the impactor could be mounted in a vertical position above the inlet manifold, as shown in Figure 5.

Samples of the inlet aerosol were extracted from a location opposite the center of the fabric test panel.

Impactor flow rates were kept at approximately 0.020 m^3/min (0.7 acfm), and instantaneous and cumulative flow measurements were made with a calibrated orifice meter and dry test meter, respectively. To maintain similar size properties between the aerosol extracted from the test loop for particle size analysis and that extracted for K_2 measurement, a total flow of 0.023 m^3/min (0.81 acfm) was sampled, with the excess air passing through the fabric panel. The total flow corresponds to the required extraction for K_2 measurement at 0.64 m/min (2.1 ft/min), the filtration velocity at which most tests were conducted.

Because the concentration of the inlet aerosol averaged 4 grams/m^3, short sampling times (of the order of one minute) were required. Duplicate measurements were made for each flyash sample. Standard procedures[19] for impactor clean-up were followed. Substrates and filters were weighed on a Mettler balance to 0.01 mg and constant weights (to within 0.1 mg) were recorded to 0.1 mg for calculations. The manufacturer's calibration data for the inertial impaction parameter ($\sqrt{\Psi}$) and stage jet diameters were used to calculate individual stage cut diameters by an iterative procedure.[20]

EXPERIMENTAL RESULTS

Filtration Parameters

Experimentally determined filtration parameters for the three field flyash samples are presented in Table 2. For the Menardi-Southern glass fabric panel, residual drag (S_R) and dust loading (W_R) were determined from the cleaned panel pressure loss and weight at the start of each test. Residual dust loadings were sufficiently small such that the initial pressure losses were generally less than 25 N/m^2 (0.1 inch H_2O).

TABLE 2. LABORATORY DETERMINATIONS OF K_2, S_E, S_R, AND W_R FOR THREE UTILITY FLYASHES USING GLASS FABRIC AND MEMBRANE FILTERS

Test[a] dust	Fabric filter[b]					Membrane filter[c]	
	Face velocity (m/min)	K_2 (N-min/g-m)	S_E (N-min/m³)	S_R (N-min/m³)	W_R (g/m²)	Face velocity (m/min)	K_2 (N-min/g-m)
SPS	0.61	2.82	54	29	36	0.62	2.85
SPS	0.62	2.30	84	32	46	0.63	2.76
SPS	1.02	3.12	64	17	20	1.08	3.27
TU	0.64	0.89	81	31	37	0.67	1.12
NPPD	0.63	3.79	-68	40	56	0.62	3.77

[a] SPS = Southwestern Public Service Company, Harrington Station.
TU = Texas Utilities Generating Company, Monticello Station.
NPPD = Nebraska Public Power District, Kramer Station.

[b] Menardi-Southern Division of United States Filter Corporation, Style 601 TUFLEX woven glass fabric with 10% Teflon B coating.

[c] Millipore Corporation, Type HA 0.45 μm pore size, 47 mm diameter.

Filter drag versus dust loading curves (Figures 6 through 10) were constructed for each of the filtration tests. The raw data from which the smooth curves in the text were constructed appear in Appendix A, Figures A1 through A4. These data are the basis for the characteristic curvilinear form of the drag/filter loading curves when a cleaned fabric is returned to service. The flyash-fabric specific resistance coefficient (K_2) for each curve was obtained from the slope of a line that was fitted (by the method of least squares) to the test interval endpoints and the estimated point at which drag increase becomes essentially linear with areal density. Extrapolation of this line to a zero dust loading provided an estimate of effective residual drag, S_E.

At the common filtration velocity of approximately 0.6 n/min (2.0 fpm), flyash-fabric K_2 levels varied over a four-fold range; 0.89 N-min/g-m for the Texas Utilities, Monticello Station (TU) sample to 3.79 N-min/g-m for the Nebraska Public Power, Kramer Station (NPPD) sample. The only flyash evaluated at more than one filtration velocity was the sample from Southwestern Public Service, Harrington Station (SPS). Filtration velocity exerted only a moderate effect on K_2. For a 67 percent increase in filtration velocity (from 0.61 m/min to 1.02 m/min), there was an 11 percent increase in K_2 (from 2.82 N-min/g-m to 3.12 N-min/g-m). The velocity-K_2 relationship is indicated in Figure 11 for filtration velocities of 0.61 and 1.02 m/min.

Effective residual drag (S_E) values, with one exception, were in the range of 50 to 100 N min/m^3. The one value which fell outside this range, -68 N min/m^3, has no physical meaning except to provide a reference point for determination of curve slope. It is possible that the negative S_E value may have resulted from incomplete fabric cleaning. A higher residual dust loading, W_R, would have shifted the drag versus dust loading curve to the right, thereby further decreasing S_E.

Figures 6 through 10 also provide incremental drag versus dust loading curves for the simultaneously run Millipore HA membrane filter measurements. In order to show more clearly the relationship between the woven glass fabric and membrane filter curves, the axes of the membrane filter curves were displaced. This was accomplished by adding the fabric S_R and W_R values to each point on the membrane filter curve, thus creating a common origin.

The flyash-membrane filter specific resistance coefficients (K_2) shown in Table 2 were again obtained from the slopes of linear regression lines based on the method of least squares fit. For each test, the data points consisted of the measured initital and final drag and the dust loading, supplemented by the calculated intermediate points at the end of each test interval.

The flyash-membrane filter K_2 values were generally in good agreement with the flyash-fabric K_2 values. A greater than three-fold range in K_2 was observed among the three field flyash samples; 1.12 N-min/g-m for the TU sample to 3.77 N-min/g-m for the NPPD sample.

As shown in Figure 11, the moderate velocity-K_2 relationship noted for the SPS flyash with woven glass fabric as the substrate was also noted for the membrane filter tests. A 74 percent increase in filtration velocity

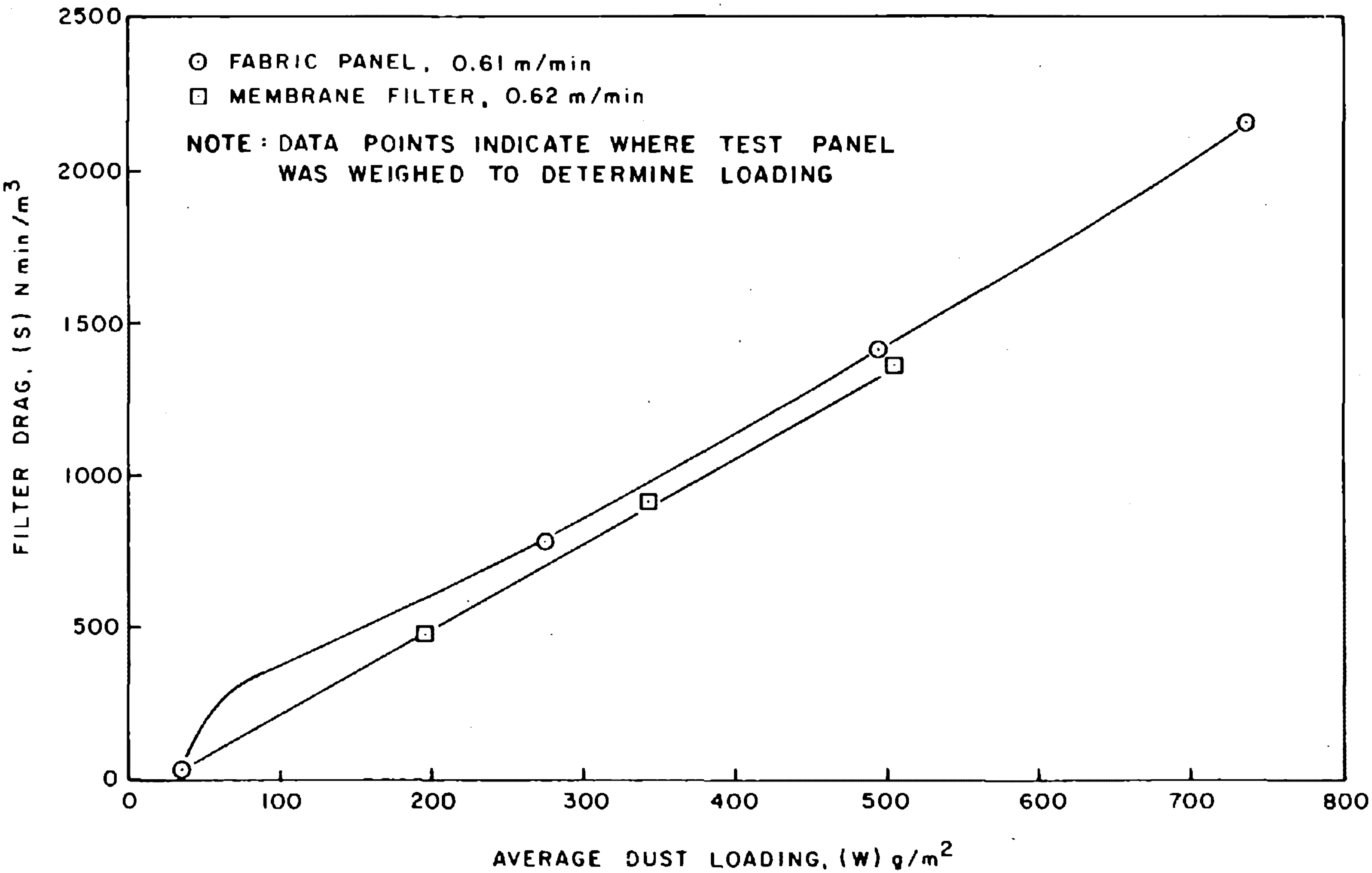

Figure 6. Drag versus average dust loading for woven glass fabric panel and HA membrane filter with Southwestern Public Service resuspended flyash at approximately 0.61 m/min face velocity. (See Figure A-1.)

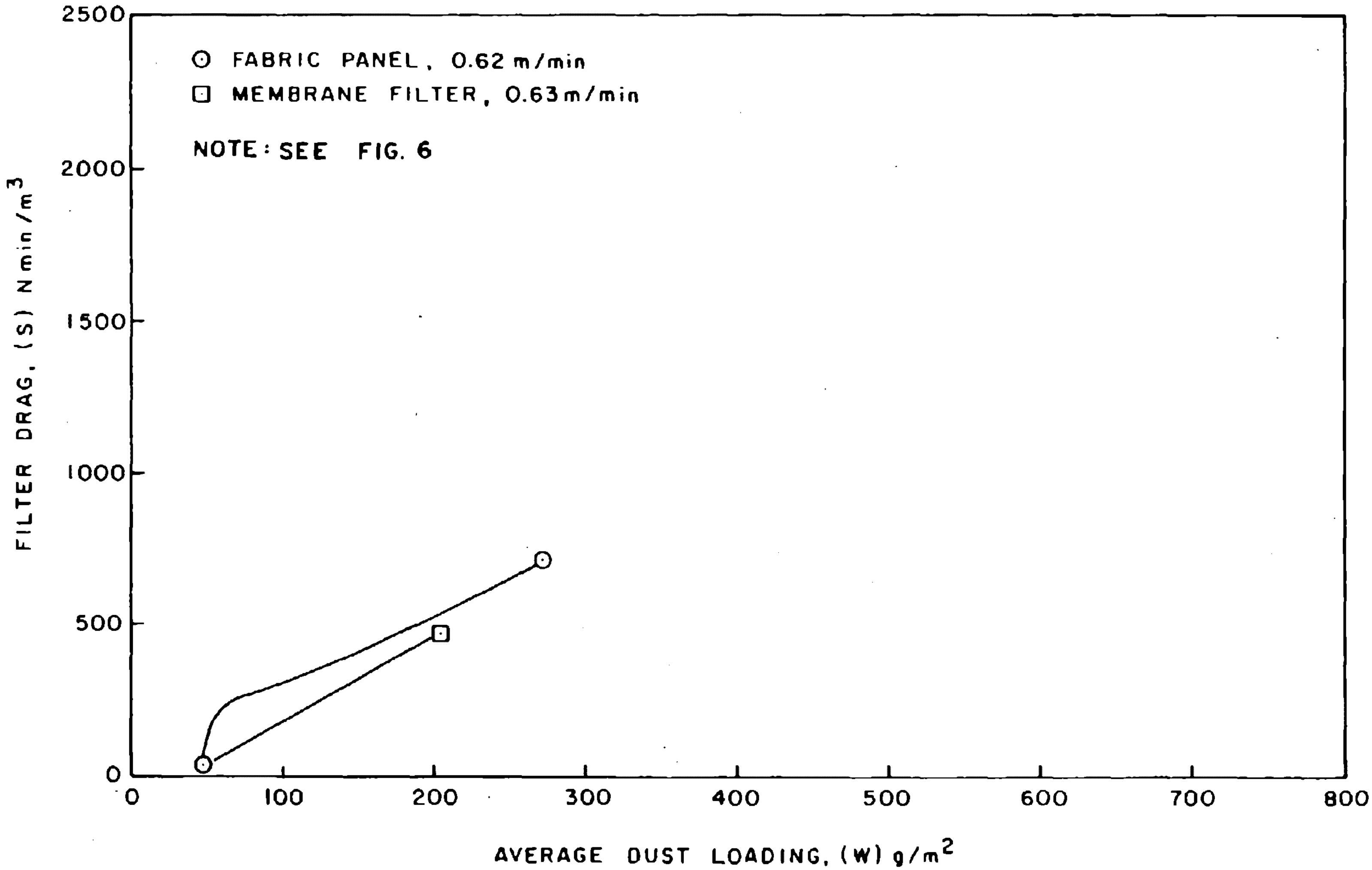

Figure 7. Drag versus average dust loading for woven glass fabric panel and HA membrane filter with Southwestern Public Service resuspended flyash at approximately 0.61 m/min face velocity. (See Figure A-4.)

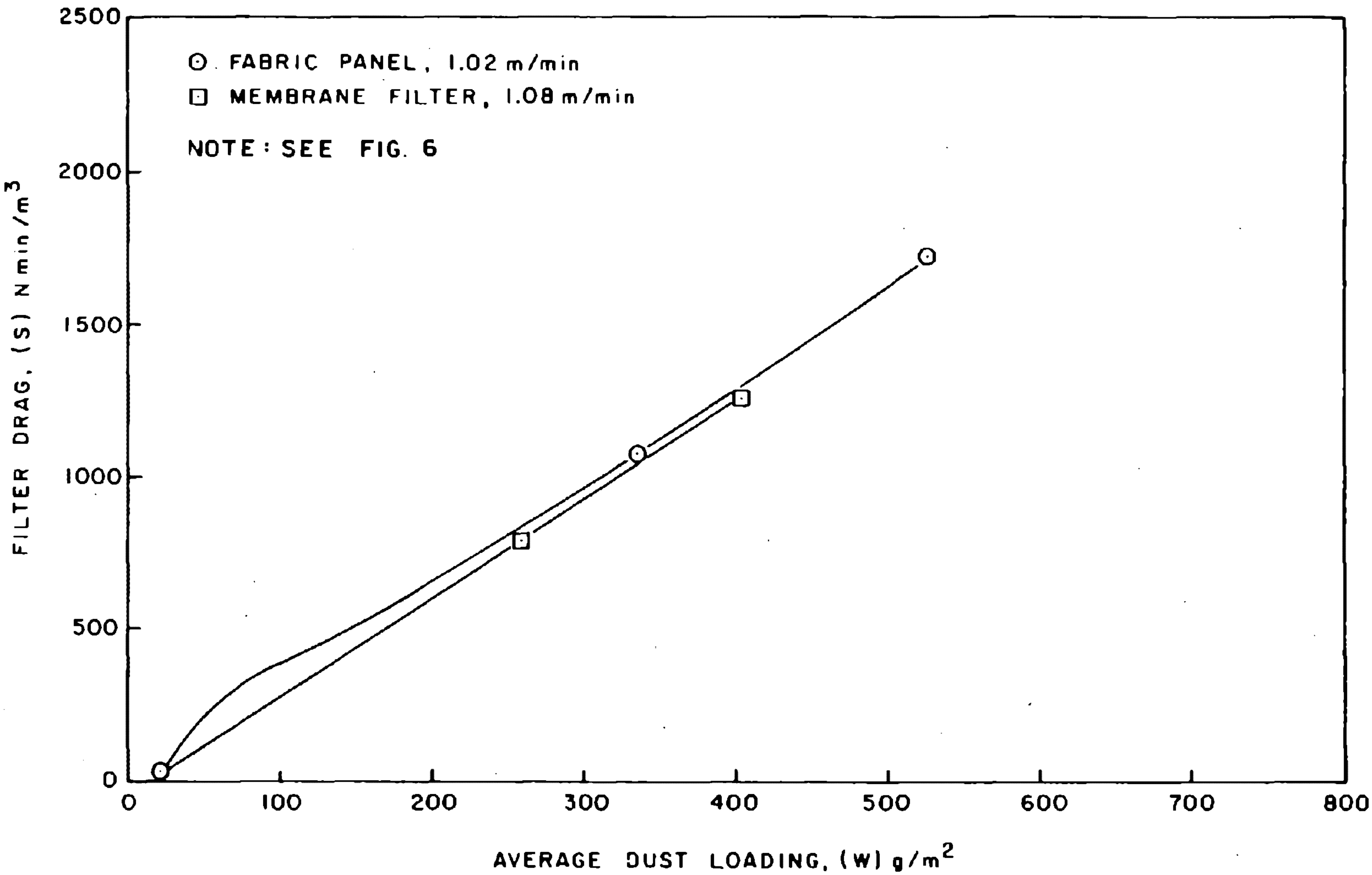

Figure 8. Drag versus average dust loading for woven glass fabric panel and HA membrane filter with Southwestern Public Service resuspended flyash at approximately 1.04 m/min face velocity. (See Figure A-1.)

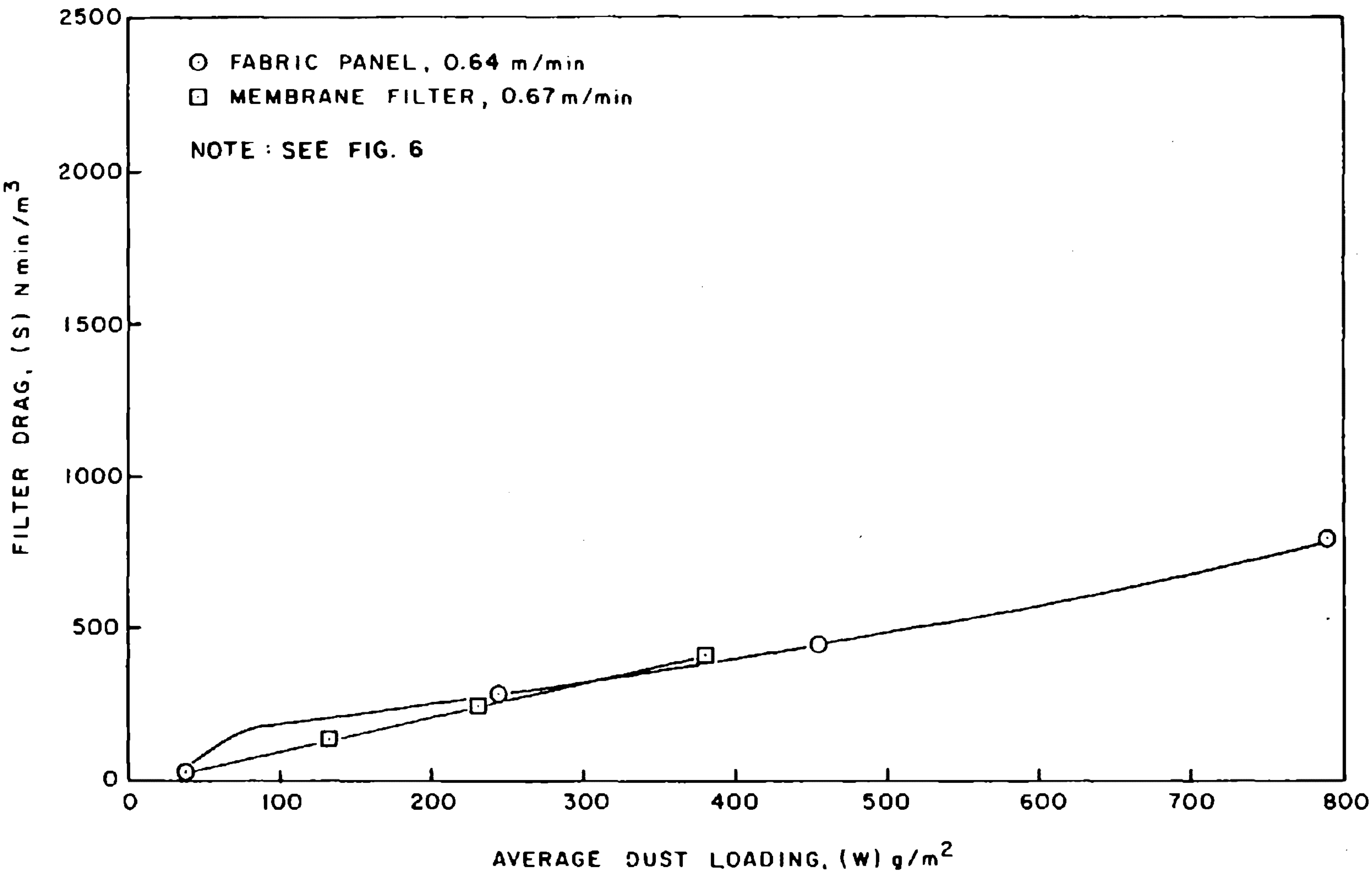

Figure 9. Drag versus average dust loading for woven glass fabric panel and HA membrane filter with Texas Utilities resuspended flyash at approximately 0.64 m/min face velocity. (See Figure A-2.)

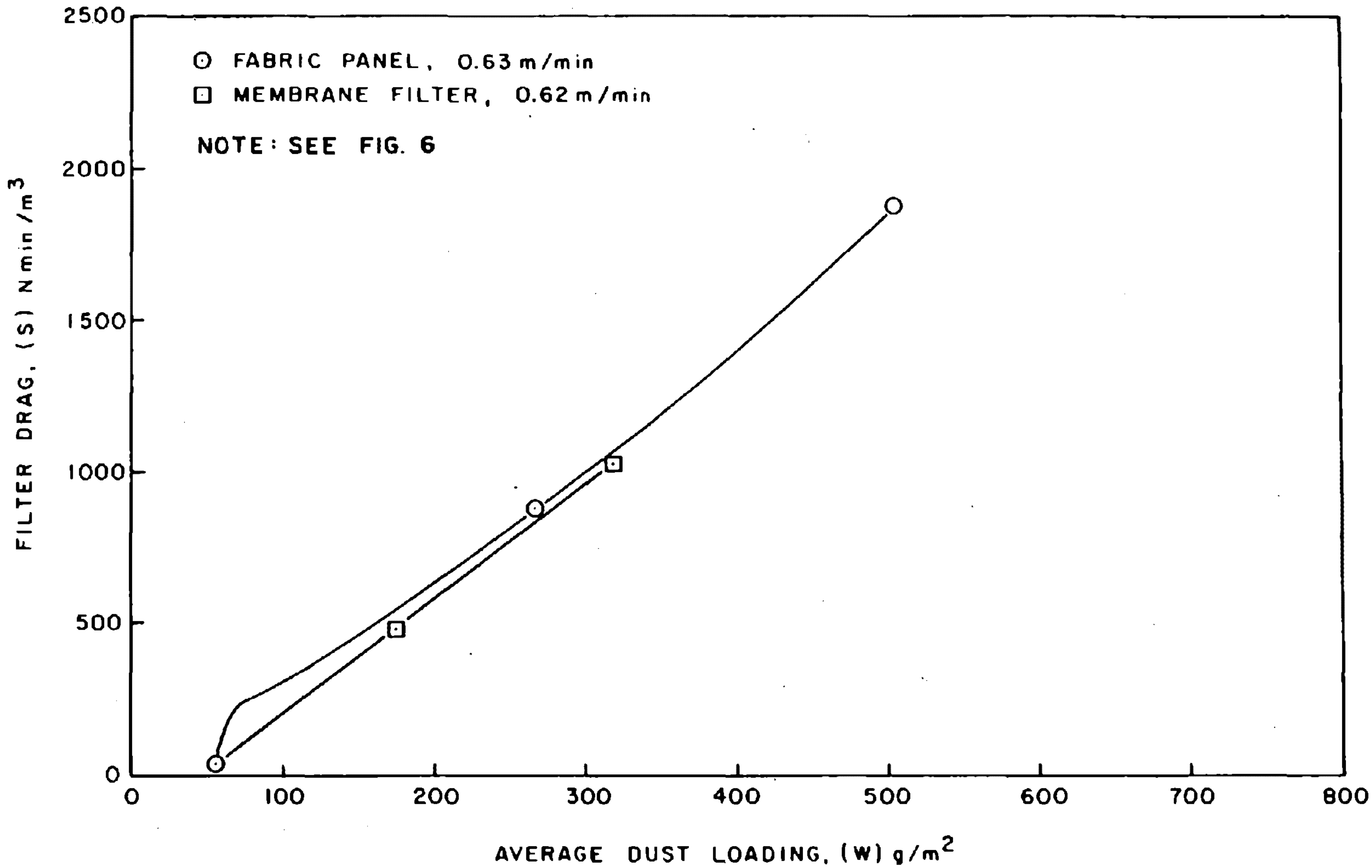

Figure 10. Drag versus average dust loading for woven glass fabric panel and HA filters with Nebraska Public Power District resuspended flyash at approximately 0.64 m/min face velocity. (See Figure A-3.)

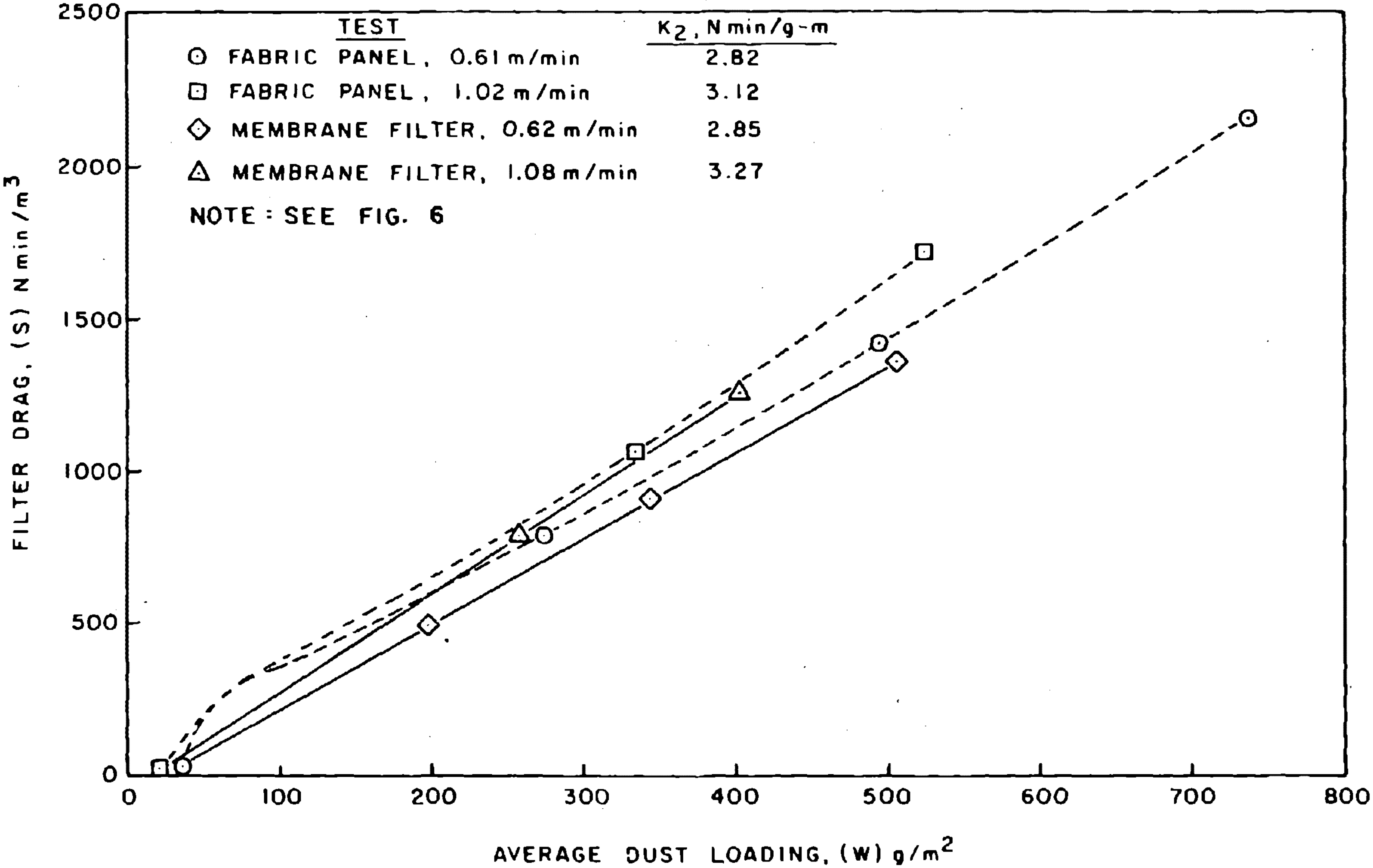

Figure 11. Effect of filtration velocity on specific resistance coefficient (K_2). Southwesterm Public Service flyash with woven glass fabric panel and HA membrane filter.

(from 0.62 m/min to 1.08 m/min) caused only a 15 percent increase in K_2 (from 2.85 N-min/g-m to 3.27 N-min/g-m).

Particle Size Properties

Cumulative particle size distributions were plotted on log-probability paper for the two impactor sizings performed for each sampling of the resuspended flyash. Samples were collected immediately before the fabric test panels, Figure 5. A straight line was fitted by eye to each plot and values for aerodynamic mass median diameter (aMMD) and geometric standard deviation (σ_g) were obtained from the curve. The cumulative size distributions for the three flyash samples are shown in Figures 12 through 14. Aerodynamic mass median diameters ranged from 5.9 μm (NPPD sample) to 9.7 μm (TU sample), with the geometric standard deviation falling between 2.3 and 2.8. The observed aMMD and σ_g values fall within the range expected for redispersed flyash from pulverized coal-fired utility boilers.

SIGNIFICANCE OF FINDINGS

Comparison of K_2 Measurements on Woven Glass Fabric and Membrane Filter Media

An examination of the filter drag versus dust loading curves for the woven glass fabric and membrane filter media (Figures 6 through 10) reveals the following differences and similarities:

- absence of an intermediate zone of cake formation for membrane filter flyash deposits
- a linear drag versus dust loading curve for membrane filter media versus a curvilinear relationship for the woven glass fabric
- comparable K_2 values for flyashes deposited on the two types of media in each of the five tests.

Although the laboratory program was not aimed directly at investigating the preceding phenomena, the end results are important from both the theoretical and practical viewpoints.

Early Cake Formation--

The initial nonlinear portions of the drag versus dust loading curves, characterized by sharp increases in drag for small increments of dust accumulation, are often observed for woven fabrics, particularly those without heavily napped surfaces. The surface of a new fabric is characterized by depressed regions at the junctures of the warp and fill yarns with an overlay of projecting fibers in areas where bulked or staple yarns are present such as evidenced by the Menardi-Southern glass fabric.*

*The Menardi-Southern glass fabric media used for testing consists of multifiliment warp yarns with bulked fill yarns.

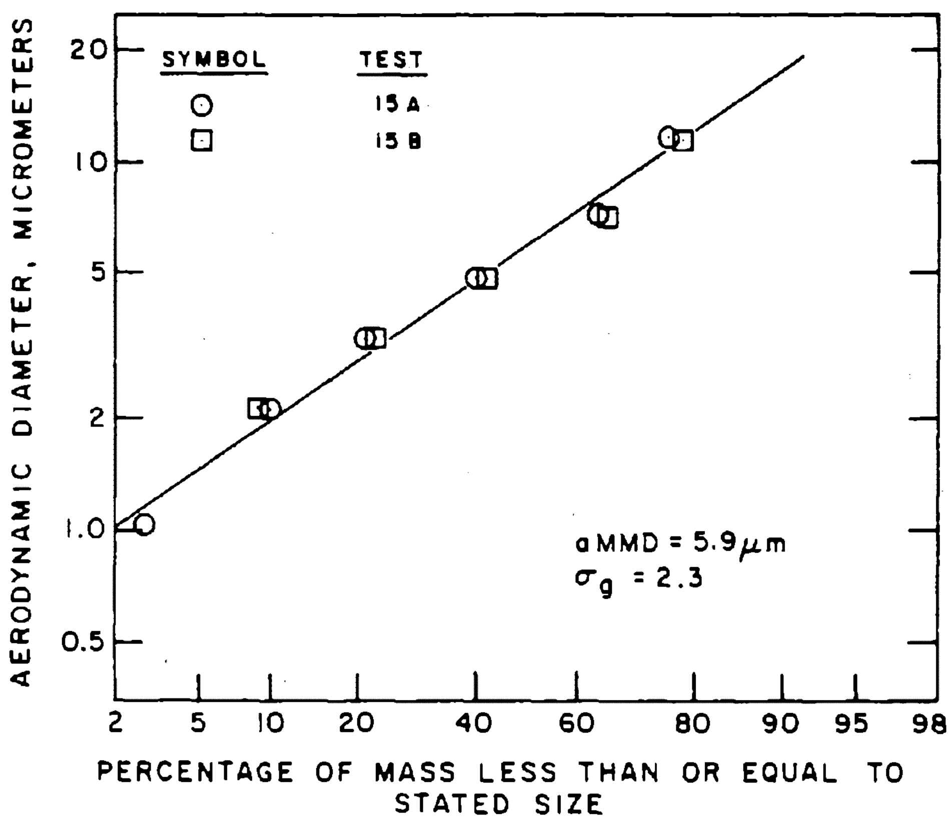

Figure 12. Particle size distribution for Nebraska Public Power District resuspended flyash, Andersen Mark III impactor measurements. (See Figure 5).

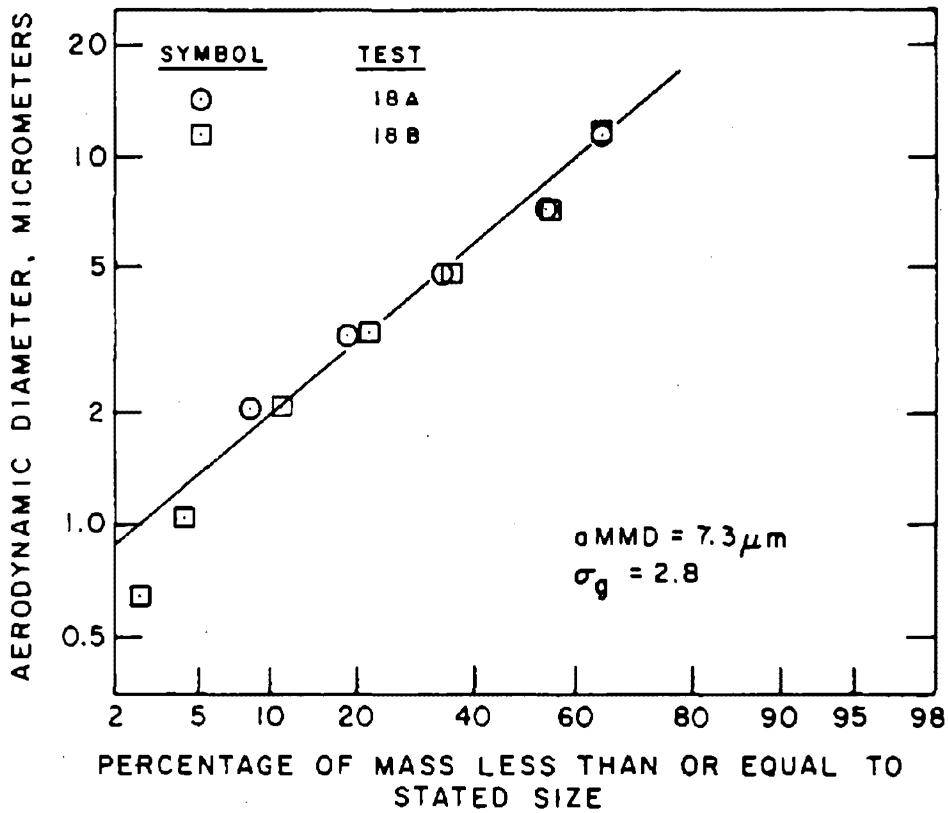

Figure 13. Particle size distribution for Southwestern Public Service resuspended flyash, Andersen Mark III impactor measurements. (See Figure 5).

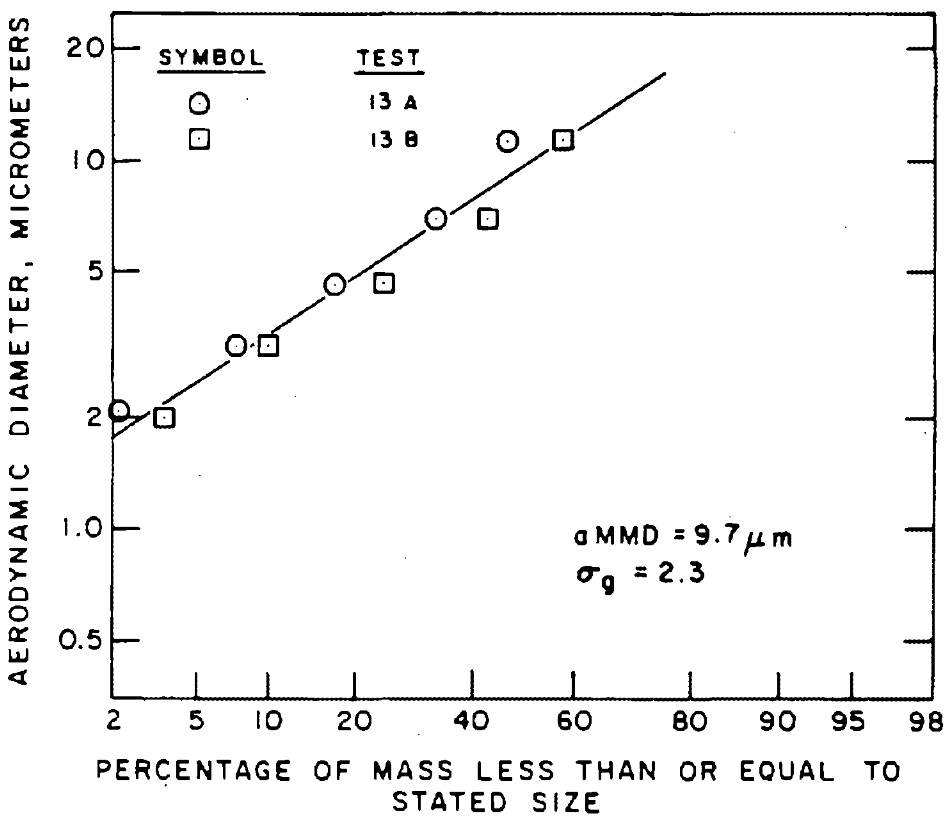

Figure 14. Particle size distribution for Texas Utilities resuspended flyash, Andersen Mark III impactor measurements. (See Figure 5).

At the start of filtration, dust deposits within and upon this loose yarn substrate. The higher pore velocities and greater dust cake thickness per unit mass of deposited dust at the inception of filtration are largely responsible for the inititally concave downward shape of the drag versus dust loading curve. After the fabric depressions have been completely filled and a pronounced surface dust deposit formed, the drag versus dust loading curve in most cases assumes a near linear path.

For fabrics composed entirely of tightly woven multifilament yarns, the zone of early cake formation is much less pronounced, probably because of shallower surface depressions. The membrane filters used in the testing represent an even more extreme situation. The membrane filter is essentially a sieving or screening device for the preponderance of particles in the approaching flyash aerosol. Because of the small pore diameter ($\sim$0.45 μm for the Millipore HA filters), particles are collected almost entirely upon the membrane surface, such that a sharp line of demarkation exists between the filter and the dust layer with little evidence of an intermediate pore-filling region. Hence no zone of early cake formation was seen in any of the membrane filter performance curves generated during current testing.

Form of Drag Versus Dust Loading Curves--

In addition to lacking a zone of early cake formation, membrane filter performance curves differ from their fabric counterparts in another important aspect. What is referred to in the literature as the region of homogeneous cake filtration (i.e., the linear or near linear portion of a drag-loading curve) was shown to be almost completely linear with a membrane filter substrate. Conversely, a slight but consistent concave upward curve form was exhibited for flyash deposits on the woven glass medium, Figures 6 through 10. The repetitious nature of the above phenomena precludes the liklihood of experimental error.

The woven glass fabric curves, which were developed from several measured drag and dust loading points, displayed a constantly increasing slope from point to point following the transient zone of early cake formation. Additionally, the estimated intermediate points, based on an assumption of constant inlet loading (as shown in Figures A1 through A4 in Appendix A), also show a concave upward trend. While the assumption of constant inlet loading may be questionable because of the inherent variability of any dust dispersing apparatus, it is improbable that dust feed deviations would always follow a pattern such as to generate the curve forms discussed here.

As previously noted, weighing of the membrane filters and sample holder at intermediate points during a test was not possible because of cake fracture problems. As a result, all intermediate points are based on the assumption of constant inlet loading plus the additional assumption of proportional dust accumulation on the two types of filter media. However, all five curves constructed on the basis of these assumptions show a striking adherence to a linear form (minimum coefficient of correlation, $r = 0.999$). Erroneous or invalid assumptions would not be expected to produce such a consistent relationship.

The phenomenon of a nonlinear filtration curve for woven fabrics may have gone unrecognized or unreported for a number of reasons. Difficult to control dust feeders in conjunction with limited pressure loss measurements for any one dust-fabric combination might conceal nonlinearity. Failure to carry filtration to a sufficiently high fabric dust loading can also obscure the tendency for curvature. Most important, unless the curvature is extremely pronounced, the construction of a linear "best fit" is convenient from the computational viewpoint, and probably well within the error boundaries for measurements of this type. The linearizing approach has been applied to several filtration curves for woven glass fabrics found in the literature.[21,22]

Since systematic error is probably not a valid explanation for the observed curvature of the fabric pressure loss or drag versus dust loading curves, some other mechanism must be found. Dust cake compaction has been suggested as a cause of nonlinearity with some dusts.[23] As the dust cake builds up, incoming particles may slip past previously deposited particles or force them further into the dust cake. In view of the large void volume, greater than 70 percent for most dust cakes, such an explanation is not unreasonable. The result of cake compaction or compression is a gradual decrease in porosity accompanied by a resultant increase in pressure loss for equal increments of dust deposit.

If such a phenomenon were solely responsible for the observed nonlinearity in the glass fabric curves, one should expect a similar nonlinearity in the membrane filter curves, since both filters were loaded simultaneously under nearly identical conditions. The extreme linearity of the membrane filter curves suggests that cake compaction is not the explanation. While the possibility of some cake compaction is acknowledged, no visual evidence is shown for the membrane filter results.

Hence, a more likely explanation for the fabric nonlinearity, given the linearity of the membrane filter curves, is the probable compression of the fabric substrate, in particular the bulked fill yarns with their residual dust holdings. Even when dust deposition has progressed such that the entire fabric surface is covered, up to surface loadings of 800 g/m^2, occasional fibers from the fill yarns can be found projecting through the dust cake. It is suggested, therefore, that the fiber presence may tend to increase slightly the dust cake porosity during the early stages of filtration until overcome by cake compression as the pressure loss increases. This would explain the slightly lower slopes (or incremental K_2 levels) at low to moderate surface loadings. However, once the cake compresses to the porosity found on the membrane filter, any further rise in apparent K_2 levels must be related to compression within the fabric substrate itself. The final concave (up shape of the nonlinear pressure) loss-fabric loading curves is attributed mainly to substrate compression.

Although the drag versus dust loading relationship for woven glass fabric was consistently curvilinear, the extent of concavity was small enough to enable a reasonable straight-line approximation for K_2. In fact, the minimum correlation coefficient (r) obtained from the linear regression method used to estimate K_2 was 0.99.

Similarity of Calculated K_2 Values on Fabric and Membrane Filters--

Despite the basic differences in form between the woven glass fabric and membrane filter performance curves, the K_2 values calculated for the two media by linear approximation were in good agreement (Table 2). The K_2 values for the surface deposit on the two substrates agreed to within 5 percent for three of the five filtration tests. For the remaining two tests, flyash-membrane filter K_2 values ranged from 20 to 26 percent higher. One of these tests (20 percent) however, was terminated while the substrate dust loading was still relatively low, 270 g/m^2 (see Figure 7). Had the filtration cycle been extended, it is expected that the upward concavity of the fabric curve would have continued while the membrane curve would have maintained an essentially linear path. Calculated K_2 values for the two media might then have shown better agreement.

Inspection of Figures 6 through 10 shows that the slopes (i.e., K_2 values) of the filtration curves for the two media are not radically different over the dust loading range of 300 to 600 g/m^2. The significance of this finding is that field fabric loadings generally center about this range. Hence, the use of an appropriate membrane filter is suggested as a convenient method for making field K_2 determinations.

One of the problems in working with simulated dust clouds generated by redispersion of bulk samples is that conditions — temperature, size properties, electrostatic charge, etc. — for the field aerosol never can be reproduced exactly in the laboratory. For this reason, the applicability of laboratory-determined parameters, such as K_2, is always open to question. A technique for field determination of K_2 values based upon in-stack collection of flyash on high-temperature membrane filters (Method 17 approach), coupled with concurrent measurement of pressure loss across the filter, should provide improved estimates of K_2, thereby enhancing the value of the fabric filter predictive models.

A high correlation was observed between K_2 values determined on membrane filters and on the type of Menardi-Southern woven glass fabric used in the present tests. Measured K_2 values for the same flyash collected on two commonly used woven glass fabrics were identical in previous bench scale tests.[5] In addition, the K_2 values developed from flyash collection upon other fabrics (i.e., cotton and Dacron) were approximately the same.[5] Since most woven glass fabrics used for flyash collection are structurally very similar, it appears that membrane filters should afford a convenient means for K_2 determinations in the field.

Effect of Velocity on K_2

Previous investigators have observed a moderate dependence of K_2 on filtration velocity. While the actual relationship between K_2 and filtration velocity in field installations may depend upon many factors, bench and pilot scale studies have generally shown that K_2 is proportional to filtration velocity raised to a fractional power ranging from 0 to 1.0,[5,23,24] with the 0 to 0.5 range best describing more recent measurements.[5,23]

Results from the current testing, fall within 0 to 0.5 range, although only one of the flyash samples (SPS) was filtered at more than one velocity. A comparison of K_2 values for the first and third SPS tests in Table 2* indicates a proportionality to velocity raised to the 0.20 and 0.25 powers, for woven glass fabric and membrane filter media, respectively.

Effect of Particle Size on K_2

The Kozeny-Carman theory predicts an inverse square relationship between K_2 and the particle diameter characterizing the ratio of surface area to unit volume;[24] i.e.,

$$K_2 \propto 1/d_{sv}^2$$

This relationship can also be expressed in terms of a specific surface parameter, S_o, which relates to the surface to volume ratio for the solids contained in a given volume.

$$S_o^2 \propto 1/d_{sv}^2$$

For a polydisperse aerosol, the specific surface parameter can be calculated from the equation

$$S_o = \frac{6\ d_s^2}{d_v^3}$$

where d_s and d_v are the diameters of average surface and average volume, respectively. For a log-normal distribution of known mass median diameter and geometric standard deviation, both d_s and d_v are readily computed by the Hatch-Choate equations.[25]

S_o values were calculated for each of the three field flyash samples, using the MMD and σ_g values from Figures 12 through 14 (a discrete particle density of 2.0 g/cm^3 was assumed in converting aMMD to MMD). Table 3 shows flyash-fabric K_2 values for each flyash filtered at ∿0.6 m/min, along with calculated S_o^2 values for each flyash.

The S_o^2 values shown in Table 3 were plotted on a graph showing earlier flyash measurements used to explore the K_2-S_o^2 relationship, Figure 15.[5] The results demonstrate that particle size distribution plays a very large role in determining K_2 despite the possibility of variations in other flyash properties that bear upon K_2 estimation; e.g., shape, individual particle density, and electrical charge. Although the data are limited, the K_2-S_o^2 relationship for the present flyashes follows the trend observed for the earlier measurements. Note that the size parameters for the N.H. Public Service flyash vary in accordance with the dust generating characteristics of each experimental system.

*As discussed above, the flyash-fabric K_2 value for the second SPS test is considered artificially low because of the low fabric loading.

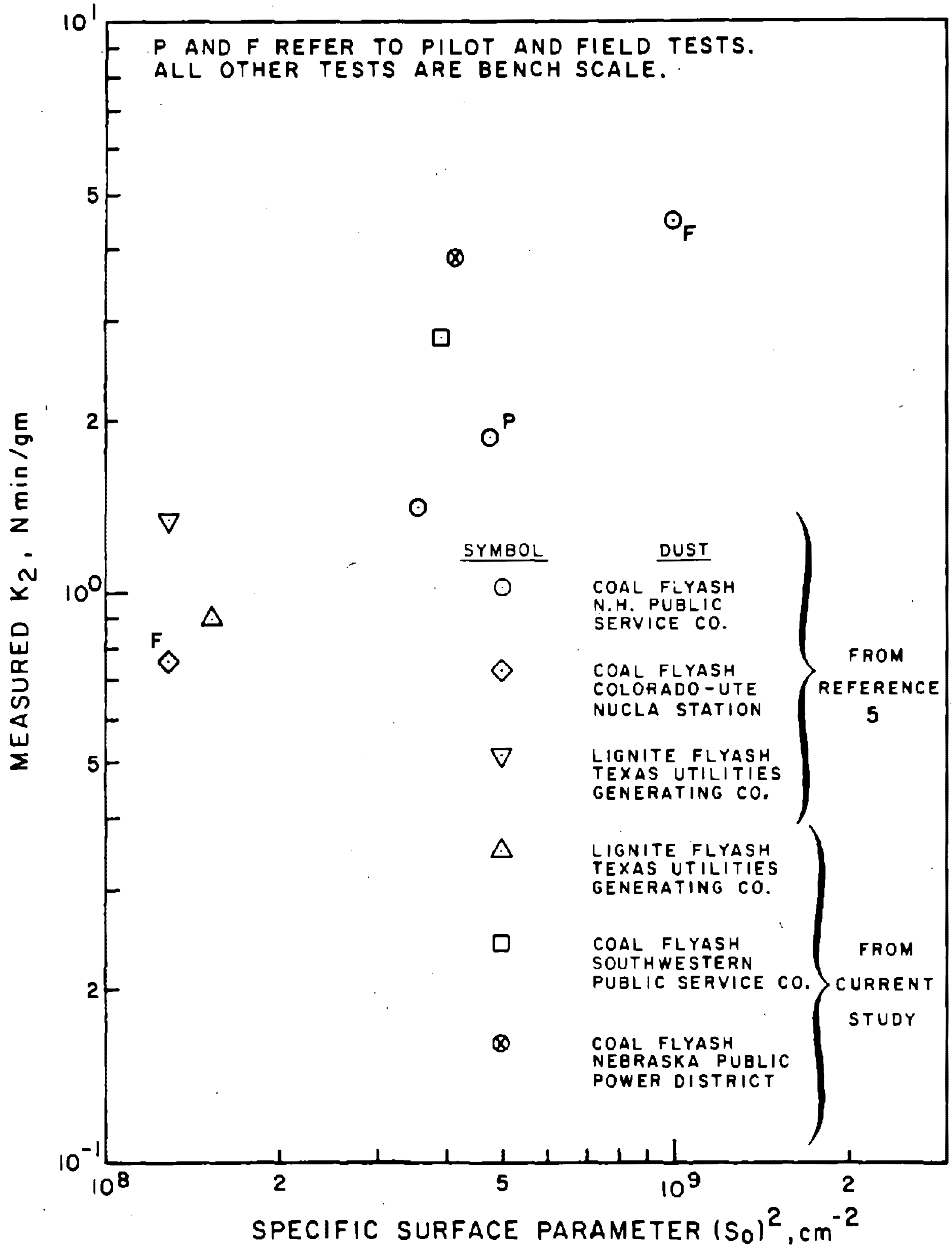

Figure 15. Specific resistance coefficient (K_2) versus specific surface parameter $(S_o)^2$, from Andersen impactor sizing, for various flyashes.

TABLE 3. SPECIFIC RESISTANCE COEFFICIENT (K_2) AND SPECIFIC SURFACE PARAMETER (S_o^2) FOR TEST DUSTS FILTERED AT 0.6 m/min FACE VELOCITY

Test dust	K_2 $\left(\frac{N\text{-min}}{g\text{-m}}\right)$	S_o^2 (cm^{-2})
TU	0.89	1.53×10^8
SPS	2.82	3.90×10^8
NPPD	3.79	4.14×10^8

Effect of Relatively Humidity on K_2

Although relative humidity was not controlled in the five tests reported here (recorded levels ranged from 25 to 53 percent*), no conclusive effect of relative humidity on K_2 was observed. Two of the five tests were carried out over three day periods. For one test (Test No. 11, Appendix A), relative humidity increased from 41 to 53 percent over the test intervals. For the second test (Test No. 14, Appendix A), a decrease in relative humidity from 52 to 32 percent was recorded. Flyash-fabric K_2 increased with successive test intervals during both tests. This observation is better explained by a gradually decreasing fabric substrate-dust cake interaction and fabric compression, as postulated above, than by the effects of changing relative humidity.

Because of their linear form, the membrane filter drag curves provide a better indication of humidity effects. Table 4 shows the calculated K_2 values for the dust cakes accumulated during four separate time intervals for two tests. During each interval, SPS flyash was filtered for 90 to 100 minutes at a filtration velocity of 0.62 or 0.63 m/min (approximately 2.05 fpm). K_2 values varied by only 5 percent (2.76 to 2.90 N-min/g-m) over a more than two-fold range of relative humidity (25 to 53 percent).

In any earlier study, Dennis et al.[5] reported that no perceptible changes in K_2 and flyash penetration were noted during filtration with Dacron fabrics over the relative humidity range 16 to 42 percent. Poor and good electrical grounding did not alter the results. Therefore, it is difficult to reconcile the above findings with those of Durham and Harrington[26] and Ariman and Helfritch[27] who report significant reductions in K_2 as relative humidity increases. In the first case,[26] K_2 was not determined on the basis of a uniform dust deposit, while changes in airborne particulate size caused by differential

*Relative humidity data are presented in Table A1, Appendix A.

settling may have magnified the K_2 changes described by Ariman and Helfritch.[27] It is also important to note that humidity and electrical charge effects can be readily confused with respect to their possible effects on dust deposits. Since preliminary model validation tests had suggested that electrical charge and humidity effects may play sufficiently similar roles in many field situations to allow them to be grouped with more readily measured parameters, the conflicting data appearing in the literature emphasize the need for rigidly controlled tests to clarify the roles of charge and humidity.

TABLE 4. EFFECT OF CHANGING RELATIVE HUMIDITY ON FLYASH—MEMBRANE FILTER K_2[a]

Test number	% relative humidity	K_2 $\left(\frac{\text{N-min}}{\text{g-m}}\right)$
11A	41	2.87
11B	43	2.90
11C	53	2.79
17A	25	2.76

[a]Results for SPS flyash at a filtration velocity of 0.62-0.63 m/min.

Experimentally Derived W_R, S_R, and S_E Values

Experimentally derived values for residual drag (S_R), residual dust loading (W_R), and effective residual drag (S_E) are all based upon a completely cleaned, new fabric surface with less than 100 hours use. As will be discussed later in this report, new fabric values for these parameters do not describe the state of well-used fabrics where W_R, S_E, and S_R values are much higher.

SECTION 4

ANALYSES OF OPERATING DATA

ESTIMATION OF FABRIC FILTER SYSTEM PERFORMANCE

A complete description of fabric filter performance requires that the following parameters be defined unless K_2 and/or a_c have been previously determined.

- inlet and outlet particulate concentrations
- volumetric gas flow
- baghouse pressure loss
- baghouse design parameters
- outlet particle size properties

Particulate concentrations are necessary for the determination of fabric loadings (W), fabric loading rate (W/t), and baghouse particulate collection efficiency. Volumetric gas flow in conjunction with the effective fabric area determines the operating air-to-cloth ratio of the baghouse, ($m^3/min/m^2$). Continuous pressure loss measurements reflecting pressure changes during filtration and fabric cleaning intervals aid in determining the fraction of fabric surface cleaned as defined by the cleaning parameter, (a_c). However, the observed change in pressure loss over an extended filtering period (with no cleaning interruptions) wherein a nearly uniform surface dust loading can be established, provides the best means to estimate a_c or K_2. In actual practice, the above conditions may not be encountered except for moderate inlet concentrations of a dust whose K_2 value is relatively low. The baghouse design parameters necessary for the modeling analyses are the total filtration area, the number of compartments, and the frequency and intensity of cleaning. The various procedures used to calculate both K_2 and a_c are described in detail in earlier modeling studies. However, in order to appreciate how these concepts relate specifically to the analyses of the present field data, the key steps in their computation are reviewed here. It must be noted that the specific resistance coefficient (K_2) can only be estimated with confidence under the following circumstances.

First, for pressure or time controlled cleaning cycles where lengthy intervals of filtration exist between cleaning cycles, K_2 can be estimated from the rate of pressure drop increase over the final third (roughly) of the filtering period after the surface dust loading has again approached a nearly uniform distribution. The above procedure is considered valid provided that the average fabric loading just before the next cleaning is three to four times larger than that for a single bag immediately after cleaning. When the filtration period is not long enough to establish a linear rise; i.e., gross differences still prevail between surface loading at various points on the fabric, K_2 must be estimated by other methods.

A second approach for estimating K_2 is possible when cleaning is continuous and when a_c is known or very large (≈70 to 100 percent). The above situation rarely occurs except with multifilament weaves that display excellent dust release properties but usually poor efficiency characteristics. Although K_2 may, in theory, be estimated without considering a_c in the above situation, its estimated value is still subject to error since assumptions about the effective drag, S_E, and the form of the drag versus loading curve are required. Determination of the cleaning level, a_c, can be made under circumstances similar to those described previously with the more reliable estimates associated with pressure and time-controlled cleaning systems having lengthy periods of filtration. The calculation process is reasonably straightforward since the following quantities are readily determinable:

- The amount of dust removed from the fabric — which equals that deposited over the complete filtration cycle.

- The amount of dust on the fabric just before cleaning — which can be computed when K_2 and the cycle time are known and provided that the assumption of uniform dust distribution over the fabric surface is valid.

If, on the other hand, the length of the filtration period is not sufficient to establish a uniform distribution, the calculation of a_c becomes more difficult. First, K_2, whose magnitude must be known to compute a_c, cannot be estimated with confidence. Second, it then becomes necessary to establish the actual dust loading distribution when a non-uniform distribution exists so that the fabric dust loading just before cleaning can be calculated. When cleaning is performed on a continuous basis, a similar approach must be taken since an uneven load distribution exists throughout the baghouse.

Based upon the preceding discussion, there exists only one set of circumstances where <u>both a_c and K_2</u> can be estimated from operating data alone; i.e., pressure- or time-controlled cleaning systems with extended periods of filtration between cleanings. In all other cases, one of the two parameters must be known. However, a partial analysis can be performed in which the results indicate possible <u>sets</u> of K_2 and a_c values.

The analyses of SPS Harrington Station data fell within the latter category, until subsequent laboratory measurements by GCA yielded the drag versus loading relationship for the dust. The first of two analyses was based on operating data alone while the second analysis entailed the use of both operating data and the laboratory-determined drag — loading relationships. Detailed discussions of the analytical approach and the results of its application are presented later in this section. Since both methods required the use of operating field data, a review of the availability and reliability of the data is presented next.

AVAILABILITY AND ASSESSMENT OF OPERATING DATA, HARRINGTON STATION, SOUTHWESTERN PUBLIC SERVICE COMPANY

Three sources of operating data were available for the detailed analyses of the Harrington Station Fabric filter system. The first two were the results of compliance-type tests performed by GCA[12] and SPS[28] while the third consisted of output from a computerized, automated data logging system used by SPS to monitor selected filter and boiler operating parameters for characterizing system performance.

The performance tests, which were carried out in accordance with EPA Methods 2 and 5 included measurement of inlet and outlet gas flows, inlet and outlet particulate loadings, particle size distributions, flue gas analyses, and associated boiler operating parameters. Aside from providing the information necessary to define baghouse performance; e.g., pressure loss and efficiency characteristics, these data may also be used to verify the accuracy of the automated data monitoring system.

The SPS automated data logging system continuously records SO_2, NO_x, O_2 and particulate concentrations, and volumetric gas flows in the inlets and outlets of the East and West baghouses and in the single stack serving both collectors. Flue gas temperatures and duct static pressures are also monitored at the inlets and outlets of the two baghouses. In addition, operating load levels (Mw_e), fuel firing rates, and cleaning mode and frequency are continuously monitored and stored either as direct inputs or derived values based upon data inputs. The various data inputs are summarized and stored for retrival on an hourly basis.

The computerized system, which came on-line during September 1978, underwent debugging and calibration until December 1978. During these months, the only data considered reliable by SPS were temperature and flow measurements. Since pressure loss data are necessary for an evaluation of the system, the data recorded prior to the end of November could not be used to assist in the filter model validation efforts. As discussed in Section 2, SPS instituted a bag replacement program in January 1979 as part of an effort to reduce operating pressure losses while simultaneously providing the required gas handling capacity and effluent properties. Since several bag types were often installed in the same or adjacent compartments, there is no way that the behavior of any single bag type can be determined. Thus, all test data developed under the above conditions have little value from the modeling perspective unless applied to a system which replicates the bag arrangements used by SPS (a highly unlikely situation). A complete rebagging of both baghouses was carried out in June of 1979. With the exception of two compartments, the same bag type was installed in the West baghouse. Thus, by discounting the effect of two odd compartments, the data collected after June 1979 for the West baghouse can be used for model assessments. However, because the East baghouse was rebagged with several test fabrics, data from this source are not suitable for model development.

Data for the month of November 1979 and the July-August period 1979 were considered by SPS to be accurate and representative of system behavior. However, certain entries appearing in the fabric filter system log were, according to SPS, inaccurate with the more serious errors associated with the inlet and outlet particulate loadings.

REVIEW OF OPERATING DATA

Particulate Concentrations

A summary of particulate concentration data is presented in Table 5 based on stack sampling measurements by GCA and SPS. Note that during GCA test 6, a mixture of coal and gas was fired and that during SPS Test 3, no sootblowing was performed. A number of conclusions may be drawn from the entire test series. First, the particulate concentrations differ between the East and West side baghouses, but with no consistent pattern. Second, with regard to the SPS tests, the concentration is higher, as expected, during sootblowing. Finally, a comparison of measured and expected (based on 80 percent carry over of coal ash) concentrations shows that only two tests (SPS 1 and 2) showed particulate concentrations anywhere near the theoretical levels.

TABLE 5. MEASURED AND PREDICTED UNCONTROLLED FLYASH CONCENTRATIONS, HARRINGTON NO. 2 BOILER, SOUTHWESTERN PUBLIC SERVICE, GCA AND SPS TESTS

Test number	Inlet concentrations — grains/Sft^3			Theoretical[b]
	East baghouse	West baghouse	Weighted average[a]	
GCA/Technology Division[12]				
1[c]	1.03	1.57	1.36	2.76
2[c]	0.99	1.68	1.41	2.44
3[c]	1.34	1.20	1.26	2.89
4[c]	2.21	1.36	1.66	2.94
5[c]	1.53	1.02	1.26	2.27
6[d]	1.36	2.36	1.97	2.32
Average, Tests 1-5	1.42	1.37	1.39	2.66
Southwestern Public Service[28]				
1[c]	2.28	2.74		2.39
2[c]	2.04	2.56		2.24
3[e]	1.67	1.63		2.59
Average, Tests 1-2	2.16	2.65		2.32

[a] Based on East and West concentrations and gas flows in each branch.

[b] Assumes 80 percent of coal ash appears as flyash (computed by GCA).

[c] Continuous sootblowing.[29]

[d] Partial gas firing.

[e] No sootblowing.

The discrepancy between the measured GCA results and the theoretical concentrations may be due to (1) settlement in the air preheater hoppers and throughout the inlet ducts between the air preheaters and the baghouse, (2) a loss of ash-forming material in the pulverizer due to rejection of pyrite and associated material and/or (3) an accidental loss of particulate material from the sampling trains when removing the probe or changing its location due to the relatively high negative static pressure in the duct and because of its vertical alignment.

Although estimates of inlet concentrations were obtainable from the SPS fabric filter system log (FFSL), program operational problems led to uncertainties in the data outputs. Since the above data as well as those developed from actual stack sampling did not appear dependable, we elected to estimate inlet loadings directly based upon current log entries for fuel ash content (6 percent), firing rate, 80 percent carryover as flyash, and the measured flue gas flow. Additionally, since the difference in concentration between East and West cannot be readily determined, the assumption was made that equal amounts of particulate matter enter each baghouse. In reduced form, the inlet concentration per section may be calculated as follows:

$$C_i = 12,815\ T/Q_i \qquad (4)$$

where C_i = inlet concentration, g/m^3
T = tons/hr of coal fired
Q_i = actual gas glow rate through East or West sections, acfm

<u>Volumetric Gas Flow Rates</u>

A study was performed to determine which data should be used to determine the actual operating gas flow rates without which estimates of baghouse performance are not possible. Hourly entries for average flow rates given in the FFSL and estimates based upon GCA flow measurements are summarized in Table 6. Three procedures were used to generate the gas flow data: (1) measurements by EPA Method 2, (2) continuous measurement by "anubar" instrumentation that were recorded in the SPS log and (3) by mass balance based upon fuel consumption rate and excess air statistics.

Inspection of computations based upon Method 2 measurements suggests a maldistribution of flow between the East and West side baghouses. The same conclusion can be drawn by examining the continuous measurements recorded in the FFSL. Based on discussions with plant personnel, this phenomenon is real and <u>not</u> due to measurement errors. The gas flow pattern is cyclonic at the point where the flow partitions between East and West compartments such that more flue gas enters the West baghouse. Since the ratio of the outlet flows as determined by Method 5 performance tests and distribution as reported by the FFSL also confirm the non-uniform flow, the FFSL data appear reliable.

The GCA measurements also indicate significant flow differences between the inlets and outlets of both baghouses. Flow also appears lower through the East baghouse and higher through the West baghouse. It is suspected that problems with the sampling locations noted in the original field test report

TABLE 6. FLUE GAS STATISTICS FOR HARRINGTON NO. 2 BOILER (SPS) BASED ON GCA STACK MEASUREMENTS, SPS INSTRUMENTATION AND FUEL BURNING RATES

	Test number[a]					
	H-2-1	H-2-2	H-2-3	H-2-4	H-2-5	H-2-6
Station load, Mw_e	362.0	361.9	362.4	362.0	362.1	301.7
Coal consumption tons/hr	196.2	197.8	199.7	194.2	190.3	158[b]
Coal - higher heating value, Btu/lb	8850	8744	8487	8502	8594	8709
Flue gas rate[c] $\times 10^{-3}$ dscfm						
GCA, East inlet[d]	263	312	380	290	399	302
GCA, West inlet[d]	488	510	475	474	396	331
GCA, East outlet[d]	385	391	367	384	396	331
GCA, West outlet[d]	411	432	463	428	395	332
GCA, total inlet[d]	751	822	855	764	864	694
GCA, total outlet[d]	796	823	830	812	791	663
SPS, East outlet[e]	420	431	428	417	409	356
SPS, West outlet	443	448	447	439	428	380
SPS, total outlet	863	879	875	856	837	736
Theoretical, total outlet[f]	800	840	743	782	782	660
% difference, GCA versus theoretical flow	-1	-2	5	4	1	0[g]
% difference SPS (Anubar) versus measures flow (Method 2)	8	7	5	5	6	11

[a] GCA test designation.[12]

[b] Partial gas firing with load variations.

[c] 68°F.

[d] By GCA, Method 2.[12]

[e] By SPS, in-line "Anubar" measurement from FFSL.

[f] Based on fuel firing rate, F factors and O_2 data.

[g] Actual difference <0.5%.

may be the cause. For example, flow disturbances were located within one diameter of the measurement locations for both up and downstream tests and an obstruction in the West outlet duct prevented a complete velocity traverse.

The last two lines in Table 6 show comparison between (a) measured and theoretical flows and (b) FFSL printout and measured values. Measured flow rates were consistently within 5 percent of theoretical levels and the flow rates recorded by the FFSL were generally within 10 percent of the Method 2 measurements. The FFSL data were used to determine the flow rates in the modeling analyses.

Baghouse Pressure Loss

The only source of baghouse pressure loss data was the information given in the FFSL as averaged hourly values for the East and West baghouse.

Baghouse Face Velocity

The filtration velocity, V_i (m/min), is determined from the actual gas flow, Q_i (acfm), and the filtration area, A_f; i.e., $V_i = Q_i/A_f$ where the average fabric area is about 26,000 ft^2 or in reduced form:

$$V_i \text{ (m/min)} = 1.172 \times 10^{-6} Q_i \text{ (acfm)} \quad (5)$$

SELECTION OF DATA

In the preceding sections, the types of data available and their respective sources have been discussed. Since the analysis of baghouse data for modeling applications depends upon measurements representing "steady state" operation, it is imperative that the proper information be chosen. Thus, a review of the data with respect to load variations must be made in order to find periods of "steady state" operation since many boilers are expected to operate under variable load conditions.

Reference to Figure 16, which indicates the coal firing rate for Harrington Boiler No. 2 for November 21 and 22, 1978, shows that over the time spans 2200/11/21 through 0600/11/22 and 0900 through 2000/11/22 the boiler firing rates (and load levels) are fairly constant. It should be noted, however, that a constant load level firing rate does not necessarily mean that the baghouse has arrived at steady-state conditions. Although step increases or decreases in boiler load to a new level will be rapidly followed by corresponding changes in velocity (provided that no significant changes in air-to-fuel ratio or gas temperature take place), additional time may be required for the system pressure loss characteristics to reach the new steady state conditions. In fact, if the periods of constant load are not long enough, the baghouse may never reach true steady-state. The boiler load variations shown in Figure 16 for the period 0100, November 21 through 2400, November 22 reflect intervals of both constantly varying load and relatively stable loads. Except for the hourly trends where some pressure loss changes appear to be out of phase with boiler load and/or filtration velocities, the velocity and pressure loss curves follow quite rapidly any change in boiler load level.

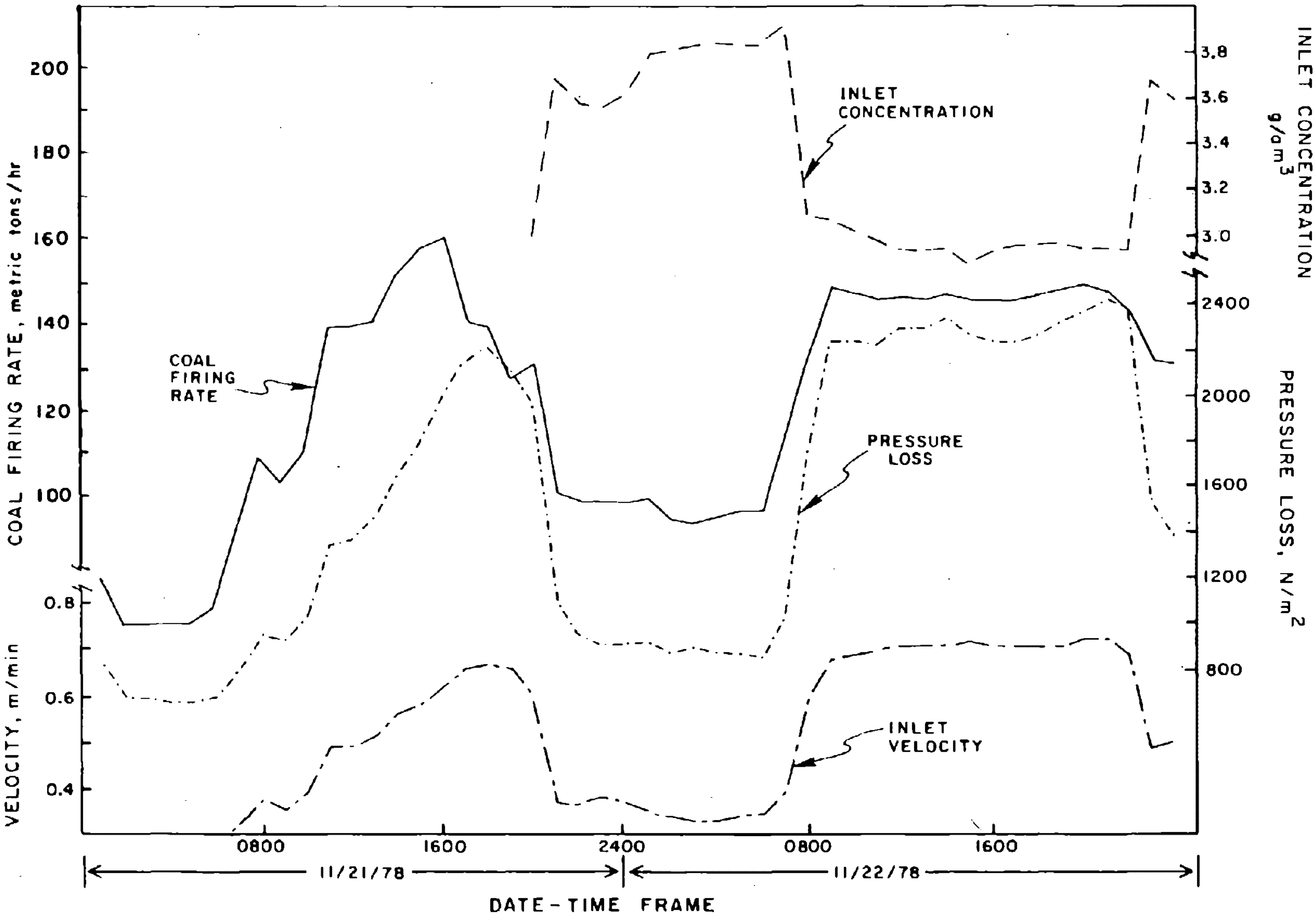

Figure 16. Boiler firing rate and East baghouse operating parameters for indicated time interval, Harrington No. 2 Boiler (SPS).

It is comparatively easy to explain why pressure loss changes will either lag or exceed those reported for changes in load levels. If, for example, the boiler load level and the arrival rate of the surface dust loading increase, it will take some finite time for the fabric loading to reach its equilibrium and maximum cleaning rate for the new load level. Thus, the cleaning would not be able to keep up with the increase in surface loading for a length of time determined by the actual fabric dust accumulation rate. Conversely, with a reduction in boiler load level, fabric cleaning will lead to a more rapid decrease in pressure loss until the equilibrium fabric surface loading is reached for the new operating conditions. It should be noted that the slopes of increasing or decreasing pressure-time traces are always steeper than those for the velocity-time curves. This follows from the fact that pressure varies as the square of the velocity provided that there are no significant differences in gas temperature or flyash loadings for the periods being compared.

Inspection of the concentration-time curve appears to present some anomalies until one takes into account that the actual deviations from mean concentration are only about ±10 percent. In cases where small increases in excess air accompany load reductions, the measured particulate concentrations at constant gas temperature would be expected to decrease and vice versa. On the other hand, significant decreases in gas temperature are often associated with boiler turndown such that the particulate concentration reported at the lower temperature will actually show an increase. The above interactions are reflected in the inlet concentration versus time curve shown in Figure 16.

The fact that there exists a very close parallel between velocity and pressure loss changes on the one hand and boiler load levels on the other indicates that changing load conditions can be modeled as well as steady-state conditions provided that the boiler load versus time relationship is known beforehand. For many peaking boilers, it appears quite reasonable that the daily power demands would follow the same pattern and thus, adapt readily to modeling.

For the purpose of the present study, however, it is preferred to deal only with those data blocks where boiler load level is constant and indisputably representative of steady-state conditions.

Three such time periods and their related operating conditions are listed in Table 7 for SPS boiler operation at approximately 40 percent full load. Two additional data sets are provided for near full load operation although there are doubts as to how well they describe steady-state conditions. In the case of the July 1979 tests, several bag types were installed in the East baghouse whereas W.W. Crisswell (Teflon B) bags were used in all but one compartment of the West baghouse (the latter contained Menardi Southern 601-T bags).

PRELIMINARY ANALYSIS OF K_2 AND a_c

As stated previously, the SPS field testing data did not provide sufficient information for the independent determination of K_2 and a_c. It is again emphasized that the field data are in no way deficient because of this limitation. The problem is that the routine measurements used to establish mass

TABLE 7. STEADY-STATE OPERATING PARAMETERS, HARRINGTON NO. 2 BOILER (SPS) AT 40 PERCENT AND APPROXIMATELY FULL LOAD OPERATION

Time period	Boiler load MW_e	East baghouse: Velocity m/min	East baghouse: Inlet concentration g/m^3	East baghouse: Pressure loss N/m^2	West baghouse: Velocity m/min	West baghouse: Inlet concentration g/m^3	West baghouse: Pressure loss N/m^2
1. 11/20/78 (0400-0600)	158	0.350	3.49	670	0.335	3.65	700
2. 11/29/78 (0100-0500)	158	0.359	3.47	670	0.371	3.36	750
3. 11/30/78 (0100-0500)	153	0.356	3.36	660	0.363	3.30	730
Average (1 through 3)	156	0.355	3.44	667	0.356	3.43	733
11/22/78 (1000-1700)	351	0.795	2.95	2270	0.800	2.93	2120
07/31/79[a] (1200-2100)	324	0.798	3.05	1530	0.687	3.58	1400

[a] Several bag types installed in East baghouse. Thus data represent a mix of bags.

emissions, pressure loss and size properties were not designed to furnish the special inputs needed for model development. Therefore, preliminary analyses were carried out with the expectation that they would yield several possible combinations of K_2 and a_c values, rather than finite solutions. The results of these exploratory analyses are discussed in the following paragraphs.

The method for estimating a_c from the operating data of a continuously cleaned system is summarized here. Continuous cleaning means that following the sequential cleaning of all compartments (∿ 30 minutes for 14 compartments) the process is resumed immediately with 1/14 of the total fabric area out of service at all times. The fractional area cleaned is defined as

$$a_c = 1 - \frac{W_p - \Delta W - W_R}{W_p - W_R} \tag{6}$$

which reduces to

$$a_c = \frac{\Delta W}{W_p} \tag{7}$$

when W_R is much less than $W_p - \Delta W$

a_c = fractional area cleaned
W_p = fabric dust loading just prior to cleaning
ΔW = amount of dust removed during cleaning, which is also the amount added during filtration
W_R = residual fabric dust loading

The amount of dust added (and removed) from a compartment (ΔW) over an entire cleaning cycle; i.e., the sequential cleaning of all compartments, is the product of the inlet dust concentration (C_i), the filtration or face velocity (V_i), and the cleaning cycle time (t_c). Thus, the numerator of Equation 7 is readily defined. The dust loading on a compartment just prior to cleaning, however, must be estimated. The approach used here is to estimate the first average loading across the entire baghouse from the average pressure loss and second the distribution of loadings across the baghouse. This procedure, in conjunction with the assumption of a linear loading distribution, permits the development of the following set of equations:

$$\overline{P} = P_E + K_2 \left(\overline{W}_p - W_R\right) V_i \; n/(n-1) \tag{8}$$

$$\overline{W}_p = W_p - C_i V_i \; (t_c/2) \; n/(n-1) \tag{9}$$

where
$\overline{P}$ = average pressure loss
P_E = effective pressure loss = $S_E V_i$
n = number of compartments
$\overline{W}_p$ = average loading across bag
K_2 = specific resistance coefficient at actual operating conditions

Combining Equations 7 through 9 yields

$$\overline{P} = P_E + K_2 \left(\frac{1}{a_c} - \frac{n}{2n-2}\right) C_i V_i^2 \; t_c \; n/(n-1) \tag{10}$$

which, by rearrangement, provides a means to determine a_c if K_2 is known or vice versa since all other terms in the equation are calculable from available data.

$$a_c = \frac{2K_2\ C_i V_i^2\ t_c}{2(P - P_E)\ (n-1)/n + K_2\ C_i\ V_i^2\ t_c\ n/(n-1)} \qquad (11)$$

Although P_E (or S_E) may not be known, a reasonable estimate of this parameter may be inferred from other systems for which S_E is known. In general, a rough S_E estimate will not cause large errors unless the average operating pressure loss is very low. A summary of the parameters used in conjunction with Equation 11 in the preliminary analyses is given in Table 8. The operating parameters (C_i, V_i and $\overline{P}$) for the low load conditions are the averages for the East and West baghouses given in Table 5. The parameters for the medium load situation are also averages of the East and West values, while the high load condition refers to the West side only. A value of 300 N-min/m^3 was assumed for S_E based on test data for similar dust/fabric combinations. Earlier tests at SPS with the Mobile Fabric Filter System yielded an S_E value of 275 N-min/m^3.

TABLE 8. EXPERIMENTAL VALUES USED IN PRELIMINARY ESTIMATES OF a_c AND K_2, HARRINGTON NO. 2 BOILER (SPS)

Variable	Boiler load level		
	Low	Medium	High
C_i (g/m^3)	3.44	3.32	2.93
V_i (m/min)	0.355	0.743	0.800
$\overline{P}$ (N/m^2)	700	1465	2120
t_c (min)	28	28	28
n	14	14	14
S_E (N-min/m^3)[a]	300	300	300
T (°C)	133	157	165
$(S_E)_t$ N-min/m^3[b]	370	350	390

[a] Assumed value at 25°C.

[b] Corrected to operating temperature.

The results of the preliminary analysis of the three data sets are presented in Table 9. The first column gives the assumed or trial value for K_2 at the operating temperature and velocity of the data set (low, medium or high load) under investigation. Inspection of Table 9 leads to the following conclusions:

- First, a_c is approximately linearly related to K_2, which indicates that the second term in the denominator of Equation 8 is much smaller than the first term.

- Second, for identical K_2 values, a_c levels at the high boiler loads are less than those at the medium levels, which appears contrary to previous findings; i.e., higher boiler loads lead to increased fabric loading and higher a_c values, Figure 1.

TABLE 9. PAIRED VALUES FOR K_2 AND a_c SATISFYING OBSERVED PRESSURE LOSSES AT INDICATED BOILER LOAD LEVELS, HARRINGTON NO. 2 BOILER (SPS)

Specific resistance coefficient K_2 (N-min/g-m)[a]	Cleaning parameter, a_c (dimensionless)		
	Low load[b]	Medium load[b]	High load[b]
0.5	0.01	0.02	0.01
1.0	0.02	0.04	0.03
2.0	0.04	0.07	0.05
3.0	0.06	0.11	0.07
4.0	0.08	0.14	0.10
5.0	0.09	0.17	0.12
6.0	0.11	0.21	0.14
7.0	0.13	0.24	0.16
8.0	0.15	0.26	0.19
9.0	0.16	0.24	0.21
10.0	0.18	0.32	0.23

[a] At operating temperature and face velocity.

[b] Refers to boiler output.

The rationale for an increase in a_c with higher loading is that with all other variables held constant (including the time between bag or compartment cleanings) a greater fabric loading must accumulate during the filtration period. Since more dust is present just before cleaning, the separating force is larger and, in turn, more dust is dislodged from the fabric (hence a larger a_c value).

Generally, this criterion appears to be satisfied when the low and high boiler load conditions are compared but not for the medium and high values as stated above. There exists a number of possible explanations for this difference. During high load operations the type of fabric used was different from that used during the low and medium load situations. Thus, there could be a distinct difference between dust-fabric adhesion properties and, hence, cleanability.

Another possibility is that steady-state may not have been reached during the medium load time period. This would result in a lower pressure loss and, hence, higher values for a_c. Another factor that can influence a_c estimation is the inlet concentration, C_i, which along with increasing load level, should produce greater a_c values. Note that the indicated K_2 values reflect the operating conditions at each load situation. Thus, if a velocity effect exists (as has been noted previously with other dusts), the a_c values on a single line cannot be compared directly for the low to high load operations. In this instance, however, even if K_2 were to vary as the square root of the face velocity, the actual increase from medium to high load operations would produce less than a 10 percent increase. It is concluded, therefore, that velocity effects cannot explain the "abnormally" low a_c values at high boiler loads. It is further concluded that there is a tremendous range of potential values for K_2-a_c combinations that will satisfy the pressure predicting conditions of Equation 11. Therefore, unless one term or the other is known, there is little likelihood of estimating the other. In the next section, data analyses based upon prior information for K_2 are discussed.

ESTIMATION OF a_c FROM SPS OPERATING DATA

Various laboratory tests were performed to determine approximate K_2 values for the SPS flyash. The technical procedures used and the interpretation of these measurements have been described in Section 3. Because the laboratory tests involved the redispersion of bulk flyash sampled from the SPS baghouse hoppers, it is recognized that the estimates of particle size parameters and K_2 are subject to error. Ordinarily, it is expected that such laboratory measurements will indicate coarser size properties and possibly lower K_2 values because even high pressure compressed air dust generators ($\sim$ 90 psig) fail to provide complete breakup of agglomerated particles. Key properties for the SPS flyash are summarized in Table 10.

TABLE 10. SUMMARY OF FILTRATION PARAMETERS FOR SPS FLYASH BASED ON LABORATORY TESTS AT 25°C

Test	Substrate	V_i (m/min)	K_2 (N-min/g-m)	S_E (N-min/m^3)	S_R (N-min/m^2)	W_R (g/m^3)
11	Glass fiber[a]	0.61	2.98	25	36	29
12	Glass fiber	1.03	3.13	75	20	17
11	Membrane filter[b]	0.61	2.85	—	—	—
12	Membrane filter	1.08	3.26	—	—	—

[a]Woven glass, Menardi-Southern.

[b]HA Millipore filter.

Based upon measurements at two face velocities, the laboratory tests on the SPS dust indicate that K_2 was less dependent upon face velocity than had been determined for other flyashes; i.e., $K_2 = f(V)^{0.2-0.25}$ rather than $f(V)^{0.5}$ as noted for the GCA flyash.[5] The above variance is believed to reflect differences in flyash properties and not errors in measuring techniques. Laboratory measurements also indicated lower values for residual (effective) drag, S_E, because the test medium had seen only brief service. Allowing for the fact that all filter media experienced a slow but gradual increase in interstitial dust deposits over their service life, we have elected to assume a higher and more conservative value for S_E, $\sim$ 300 N-min/m^3. The measurements presented in Table 10 represent less than two days fabric use such that the residual dust holding, S_R, and the effective residual dust holding, S_E, are well below their quasi-steady-state levels. The negative S_E intercept is merely a mathematical convenience for defining the curve of best fit for the drag-fabric loading relationships.

The use of HA membrane filters as the flyash substrate revealed that dust cake properties per se underwent little change over the range of pressure loss and fabric loading levels studied. Therefore, it appears that it is the compression (and hence, reduced porosity) of the woven glass fabric and not the dust layer that causes the slightly concave upward shape noted during laboratory drag versus loadings measurements (Figures 6 through 10). In actual practice, whatever the reason for the concavity, it can be readily defined mathematically. However, force fitting to a linear relationship is generally acceptable for current modeling purposes.

Since (a) the effect of velocity on K_2 appeared to be relatively small for the SPS flyash and (b) the range of average velocities for the field tests under investigation was encompassed by the laboratory tests, a linear relationship was assumed for the drag versus loading curve. This led to selection of 3.0 N-min/g-m as the average K_2 value at 25°C and 25 N-min/m^3 as the effective residual drag, S_E. Based upon the design and operating parameters given in Table 11, wherein the K_2 values have been corrected to their equivalent levels at operating baghouse temperatures, the a_c values calculated from Equation 11 were 0.07, 0.13 and 0.10 for boiler firing at low, medium, and high load levels, respectively. Adjusted S_E values were essentially the same, 31 to 33 N-min/m^3 regardless of firing rate. The fact that a_c values do not continue to increase with boiler load may be due to the lower dust loading at high load, differences in fabric, or some parameter change not detected during the test periods of interest. It has been demonstrated in the past studies that the dust dislodging forces and a_c will increase for a fixed cleaning mode when the thickness of the dust; i.e., the fabric loading, is increased.

The a_c values along with the relevant operating parameters shown in Table 11 were used in the computer model to calculate the SPS system performance characteristics summarized in Table 12. Predicted pressure losses were between 40 and 75 percent lower than the actual measured values. In the low load case, low estimates may be due to one of the model's limitations; i.e., the model operation is restricted to a_c values equal to or greater than 0.1. Therefore, although the computer program will function for a_c entries of less than 0.1 values, a_c will be processed as if it were exactly 0.1. The result is that the model will automatically predict a lower pressure loss in such cases. With respect to the medium and high load predicitons, however, the low a_c estimate must be explained by some other mechanisms.

TABLE 11. INPUT PARAMETERS FOR MODEL VALIDATION, HARRINGTON NO. 2 BOILER, SPS WITH SLIGHTLY USED FABRIC

Parameter	Low load	Medium load	High load
Number of compartments	14	14	14
Cleaning cycle time (min)	28	28	28
Individual compartment cleaning time (min)	1.9	1.9	1.9
Reverse flow velocity (m/min)	1.54	1.54	1.54
Average face velocity (m/min)	0.355	0.687	0.798
Gas temperature (°C)	133	157	165
Inlet dust concentration[a] (g/m^3)	3.44	3.58	2.94
Specific cake resistance, K_2[a] (N-min/g-m)	3.77	3.87	3.98
Effective drag, S_E[a] ($N\text{-}min/m^3$)	31	32	33
Residual loading, W_R (g/m^2)	28	28	28
Fractional area cleaned, a_c[b]	0.07[c]	0.13	0.10

[a]Reported at actual operating temperatures and gas flows.

[b]a_c computed from Equation 11.

[c]Computer program converts this value to 0.10 for subsequent calculations.

TABLE 12. PERFORMANCE PREDICTIONS FOR SPS, HARRINGTON NO. 2 BOILER WITH SLIGHTLY USED FABRIC

Load level	Average pressure loss[a] (N/m^2)		Fractional[b] penetration
	Predicted	Measured	
Low	400[c]	700	0.0036
Medium	1000	1400	0.0047
High	1400	2200	0.0058

[a]Based on S_E values for slightly used fabrics, 31 to 33 $N\text{-}min/m^3$.

[b]Average penetration by GCA tests, 0.005-0.006.[12]

[c]Based on computer value of 0.1 for a_c.

The difference between the predicted a_c value for low load operation and that which would have resulted had the model been designed to operate over the range (a_c = 0.05 to 1) has been estimated by an equation developed during earlier model sensitivity studies; i.e.,

$$\overline{P} = \ln \left[1 + \frac{K_2C_iV_i^2t_c\ (2n-1)/(2n-2)}{\frac{K_2C_iV_it_c}{S_E + K_2C_iV_it_c\ (1-a_c/a_c)}} \right] \qquad (12)$$

in which average pressure loss is related to system design and operating parameters. The units for the indicated variables remain as defined previously in Equations 8 through 11 and Table 8 for actual temperature and flow conditions. By substitution of the same parameters used to generate the model output summarized in Table 13, in conjunction with the previously calculated a_c values of 0.07 and 0.10, pressure loss data were developed for low boiler operation.

The data presented in Table 13 may be interpreted as follows: first, Equation 12 provides a good pressure loss estimate relative to the more sophisticated model solution. For an a_c input of 0.1, the Equation 12 value is only 15 percent greater than that deriving from the model. Second, if the cleaning parameter is actually 0.07 as computed from Equation 11, the pressure loss based on Equation 12, 666 N/m^2, is in reasonable agreement with the measured value of 700 N/m^2. Despite the approximations involved, the above analysis suggests that the model disagreement under low load conditions may be at least partly due to the lower limit (0.1) set for a_c. If further field trials indicate that low cleaning levels, $a_c<0.1$ are very common, the model will be revised to take this situation into account.

TABLE 13. ESTIMATION OF MODEL ERROR IN PREDICTING PRESSURE LOSS WHEN a_c VALUES ARE LESS THAN 0.1

Cleaning parameter, a_c	Average pressure loss, N/m^2		
	Computed from equation	Computed by model	Actual measured value
0.07	666	400	700
0.10	462	400	700

The preceding analysis cannot be applied to medium and high load conditions because the calculated a_c values are already within the 0.1 to 1.0 range. Predicted pressure losses for the medium and high load cases, respectively, were roughly 29 and 36 percent lower than the measured values.

Since the model assumes that K_2 varies as the square root of the filtration velocity whereas present tests suggested a lesser exponent; i.e., $K_2 = F\ (V)^{0.2-0.25}$, the velocity effect was suspected as a possible cause of the low predicitons. However, when the model was actually adjusted so that the velocity dependency was eliminated altogether; i.e., K_2 is constant, the predicted pressure loss for the medium load level was found to be the same as that forecast when the velocity exponent was 0.5.

Therefore, the fact that the input parameters in Table 13 included a very low value for S_E, ∿ 31 N-min/m^3, was examined as a possible cause of low model predictions. Based upon prior laboratory and field measurements, it had been noted that S_E values in the range of 300 N-min/m^3 at 25°C were not uncommon for fabrics that had been in service from 1 to 2 years. In terms of overall pressure loss across the filter, the difference between 30 and 300 N-min/m^3 for S_E translates to a pressure loss increase of 183 N/m^2 (∿ 0.75 in. w.c.) for a filter system with a face velocity of 0.61 m/min (2 ft/min). Thus, although the high S_E selection is conservative, its impact on overall system pressure is comparatively small, (<10 to 15 percent). New estimates of a_c were made by means of Equation 12 for low, medium, and high load conditions assuming the S_E value to be 300 N/min/m^3, Table 14.

TABLE 14. CALCULATED OPERATING AND PERFORMANCE PARAMETERS FOR HARRINGTON NO. 2 BOILER (SPS) FOR AN S_E VALUE OF 300 N-min/m^3

Load level	S_E[a] (N-min/m^3)	a_c[b]	Average pressure loss, N/m^2		Percent[d] pressure loss deviation	Fractional penetration
			Predicted	Measured[c]		
Low	370	0.08	580	700	-17	0.0033
Medium	380	0.16	1080	1400	-23	0.0037
High	390	0.11	1600	2200	-27	0.0042

[a] S_E corrected to Table temperature from 300 N-min/m^3 at 25°C.

[b] a_c computed from Equation 11.

[c] From Table 12.

[d] Percent deviation from measured value.

According to Table 14, it appears that the assumption of a higher S_E value (which may be more in line with the estimated service life of the SPS bags) brings the model pressure loss predictions into closer agreement with the measured (field test) values. A comparison of the flyash penetration levels given in Tables 12 and 14 shows relatively small changes in emissions. A direct relationship, however, is indicated between penetration and a_c which is consistent with increased dust removal from the fabric. It should be noted, however, that with both a_c and S_E undergoing change, the end result could be either an increase or decrease in flyash penetration.

With respect to the effect of increased S_E or pressure loss, basic theory suggests that if the substrate pressure loss is increased with no change in the amount (W) and K_2 properties of the overlying dust layer, the overall fabric pressure loss should also increase. However, these effects are not necessarily directly additive for sequentially cleaned multicompartment systems as demonstrated in prior model sensitivity studies.

AVAILABILITY AND ASSESSMENT OF OPERATING DATA, KRAMER STATION, NEBRASKA PUBLIC POWER DISTRICT

A considerable part of the operating data for Kramer Station has been obtained from plant log sheets and strip charts. These data include coal consumption and steam production rates, baghouse inlet temperatures, pressure drops across each compartment and overall baghouse pressure drop. As mentioned earlier in this section, two additional pieces of information are necessary to appraise baghouse resistance characteristics; gas flow rate and the inlet (or uncontrolled) particulate concentration. Outlet particulate concentration is also necessary to define baghouse collection efficiency for the aerosol. The latter information (flow rate and inlet and outlet concentrations) was provided for some time periods by several field tests performed at Kramer Station.

Shortly after the baghouses were placed in service, compliance tests were performed (May 1977) that provided data on gas flow, temperature, and outlet concentrations. During the same time frame, acceptance tests provided similar data as well as estimates of inlet particulate concentration. Compliance tests were performed for each stack rather than for Boilers 1 through 4 whereas acceptance tests were performed only on Boilers 1 and 4. The result of these tests along with all relevant details are described in References 13 through 16.

In addition to the compliance and acceptance tests cited above, special performance tests were conducted on the Kramer baghouses by MRI* under contract to the Electric Power Research Institute (EPRI). Partial results for the October 1977 and May 1978 tests are reported in References 14 through 16. A final EPRI report is now in preparation that will provide information on baghouse outlet and inlet concentrations, efficiency, all gas flows and steam generation rates, and plume opacity.

Finally, operating data were also obtained for more recent time periods, July 13, 1979 and January 22, 1980, when no concurrent stack measurements were performed. The July date was chosen since on that date an "urge" test was performed. During this period the boilers were operated at maximum load (actually 20 percent over the design level). One reason for selecting the January date was that the Boiler 2 load level was reasonably constant throughout the day. The only information sources for these tests were the plant log sheets and strip charts.

In general, all the time periods for which data were considered for analysis reflect fairly steady boiler load levels over at least 3 or 4 hours of

*Meteorological Research, Inc., Altadena, California.

operation. Two of the acceptance tests, however, were run over a much shorter (1 hour) period. The data also represent a broad range of operating conditions and operational exploration. It was observed, for example, as will be discussed in the following sections, that baghouse operating procedures have undergone modifications as more field experience accrued. The available data are included in the time periods listed in Table 15.

TABLE 15. DATA AVAILABILITY AND CUMULATIVE BAGHOUSE SERVICE PERIODS

Data available	Cumulative on-line service
May, 1977	<1 month
October, 1977	5 months
May, 1978	1 year
June, 1979	2 years

A compilation of the operating data extracted from plant log sheets, strip charts and various reference sources 13 through 16 is presented in Table 16. With the exception of the tests ending with "avg" all test numbers were assigned by CCA. Inlet gas flow rates were available only for the compliance and/or acceptance test data. All outlet particulate concentration and collection efficiency data reported for EPRI tests were used to calculate the inlet concentration. Two sources of information were available for baghouse pressure drop as well as the pressure drops through the individual compartments. Baghouse pressure loss is also recorded continuously for each baghouse on strip chart recorders. The numbers appearing in parentheses under the flange to flange pressure drop present strip chart data. These values were essential to determine the reliability of the pressure drops shown on the log sheets since pressure drop is manually recorded every 3 hours in some cases. Furthermore, the log sheet values are instantaneous readings that do not necessarily represent the average pressure drop for the time interval of interest. Finally, steam generation rates were obtained from both the log sheets and supporting references 14 through 16, whichever appeared the most appropriate for a given analysis.

Volumetric Gas Flow Rate

When flue gas flow rates were not available for the time periods of interest, they were estimated from other data such as boiler steam rates which were indicated for nearly all time periods. Since steam flow is roughly proportional to fuel firing rate and fuel firing rate in turn relates almost directly to flue gas flow, the volumetric gas flow could then be determined from the boiler steam flow. Although other factors, such as coal heating value, moisture content, and excess air also affect gas flow rate, these factors could not be taken into account over the short term for modeling purposes. However, these factors were not considered to detract from the accuracy of the flow rate estimates any more than the possible error contributed from the need to

TABLE 16. AVAILABLE OPERATING AND PERFORMANCE DATA FOR KRAMER STATION

			Baghouse inlet measurements			Pressure loss in. water			
Test code	Boiler	Date	Flow (10^3 acfm)	Temperature[b] (°F)	Particulate[c] concentration (gr/acf)	Average[b] across compartments	Flange[d] to flange	Steam rate (10^3 lb/hr)	Particulate collection efficiency (percent)[a]
2-avg	1	5/77	133.4	336	0.424	5.7	8.3	240[b]	98.9
3-avg	1	5/77	127.7	329	1.637	4.8	7.5	214[b]	99.1
C	1	10/77	116.2		0.593		7 (6.5)	210.0[a]	99.85
D	1	10/77	106.5		0.574		5.5 (6.0)	197.0[a]	99.77
E	1	10/77	92.9		0.342		5 (4.5)	154.0[a]	99.66
R	1	7/79		380		4.0	5.5 (5.5)	236[b]	
S	2	7/79		365		2.8	4.8 (4.5)	244[b]	
V	2	1/80		325		4.2	5.2	163[b]	
A	3	10/77	90.9		0.563		4	159.5[a]	99.77
B	3	10/77	130.9		0.605		6	216.0[a]	99.90
1	3	5/78			0.752	2.6	3.4	137[a]	99.89
2	3	4/78			0.605		5.0	160[a]	99.86
3	3	5/78			0.656			208[a]	99.92
4	3	5/78			0.738	2.4	3.3	140[a]	99.96
5	3	5/78			0.302	2.5	3.5	185[a]	99.90
6	3	5/78			1.23	3.8	5.3	214[a]	99.98
T	3	7/79		375		4.3	6.9 (6.6)	257[b]	
5-avg	4	5/77	202.8	372	0.278	6.0	7.5	320[b]	98.7
6-avg	4	5/77	213.7	388	1.002	7.0	8.3		99.0
U	4	7/79		405		2.7	3.6 (3.6)	362[b]	

Note: Data reported in "as recieved" English units.

[a]From Reference 3.

[b]From Kramer Station log sheets.

[c]From References 1, 2, and 3. October 1977 and May 1978 values calculated from outlet concentration and efficiency.

[d]Numbers not in parentheses are from Kramer Station log sheets; numbers in parentheses are from baghouse pressure loss strip charts.

average hourly steam flow rates over 3 to 4 hour periods. The relationship between steam flow and gas flow was established by plotting the indicated gas flows versus their associated steam flows for Boilers 1, 2, and 3. The design flow for the above boilers is 122,000 acfm at 22,000 lb/hr steam (0.55 acfm per lb steam). For boiler 4 the flow increases to 192,000 acfm at 330,000 lb/hr steam (0.58 acfm per lb steam). Boiler 4 operating data were not used for flow estimates, however, because the steam rates appeared to differ from those of the three smaller boilers. The flow estimating relationship for Boilers 1 through 3 was determined to be:

$$Q \text{ (acfm)} = 0.54 \times S \text{ (lb/hr steam)} + 9000 \text{ acfm}$$

The actual design rate was used to estimate the required flow data for Boiler 4, when actual flow data were not available.

Inlet Concentration

Baghouse inlet concentrations were available only for time periods when actual performance tests were conducted. The remaining inlet concentrations were assumed to be the same as those deriving from actual measurements. A summary of the assigned concentrations is presented in Table 17.

TABLE 17. BEST ESTIMATES OF INLET FLYASH CONCENTRATIONS, KRAMER STATION

Inlet flyash concentration, gr/acf			
Boiler number	Date	Assigned value	Based on coal ash content
1	7/79	0.6 (1.37)[a]	0.70 (1.59)
2	7/79	0.6 (1.37)	0.66 (1.51)
2	1/80	0.6 (1.37)	0.76 (1.74)
3	7/79	0.6 (1.37)	0.67 (1.54)
4	7/79	0.4 (0.92)	0.69 (1.58)

[a]Concentration in g/am^3.

[b]Based on coal firing rate, 3.9 percent ash and 80 percent carryover.

A value of 0.6 gr/acf was assigned as the inlet concentration for Boilers 1 through 3. However, a lower value was assigned to Boiler 4 since compliance and acceptance measurements indicated that the inlet concentration to Boiler 4 was about 30 percent lower than that for Boiler 1. According to the estimates of inlet concentrations based upon coal ash content and an 80 percent carryover, the assigned inlet concentrations are roughly 80 to 90 percent of the coal ash derived values for Boilers 1 through 3 and about 60 percent of the ash value for Boiler 4.

Baghouse Pressure Drop

As noted earlier, pressure drop data were provided by plant log sheets and strip chart recorders. The Kramer log sheets indicate the overall baghouse pressure drop given by fluid manometer readings, overall baghouse pressure drop excerpted from recorder strip chart, and individual compartment pressure loss based on conventional manometer. Information is usually entered on the log sheets every 1 to 3 hours, although more frequent entries were made during some test periods. Reference to Table 16 shows that the pressure drops obtained from log sheets and strip chart records are in good agreement. Since the pressure drops of concern for the modeling analyses should be those across the bags alone, any losses attributable to ductwork or manifolding effects should be excluded. Despite the fact that pressure taps for estimation of overall or flange-to-flange pressure loss do not include much ductwork or manifolding, distinct differences are indicated between the former values and the fabric losses alone, Table 18. In a previous study, similar differences have been cited for Kramer Station[15] as shown in Table 18.

TABLE 18. FLANGE TO FLANGE (OVERALL) PRESSURE LOSSES VERSUS INDIVIDUAL COMPARTMENT PRESSURE LOSSES

	Pressure loss, inches water			
	Boiler 1	Boiler 2	Boiler 3	Boiler 4
Flange-to-flange	8.0	6.2	4.8	6.0
Compartment	6.8	5.0	3.9	4.5
Difference (Duct and manifold loss)	1.2	1.2	0.9	1.5

Based upon the data appearing in Tables 16 and 18, when overall baghouse pressure loss constitutes the only data input, 1 inch water is subtracted from the former value to estimate the pressure loss through the dust-laden fabric alone.

Cleaning Cycle

The general aspects of cleaning cycles have been discussed in Section 2 of this report. However, the performance analyses of the Kramer Station baghouse requires that the exact cleaning cycle used during each test period be defined since Kramer Station has employed at least four different cleaning cycles. A summary of the various cleaning cycles is presented in Table 19.

The off-line times shown in Table 19 represent the period when one compartment undergoes cleaning, whereas the on-line time depicts the time when all compartments are filtering. Since the cleaning cycles for the Kramer Baghouses are partially controlled by pressure loss (see Section 2), a baghouse may, in fact, operate with several permutations of off-line/on-line conditions. For example, if a baghouse is operating under the 11 min. 25 sec. cleaning cycle and pressure loss exceeds the preset limit, the cleaning cycle will shift to a "constantly cleaning" mode (the 58 sec. cycle). Since this situation represents a highly variable cleaning process, it cannot be analyzed via the steady state approach. The time scale on the pressure drop strip charts was sufficiently resolvable to determine whether or not a variable cleaning rate had been in effect. It is cautioned that in the application of any test data, it is important to observe not only the actual test data, but also to determine whether pressure conditions were such as to drive the system into a constantly cleaning mode.

TABLE 19. SUMMARY OF CLEANING CYCLES USED AT KRAMER STATION

	Time per compartment			
	May 1977	September 1977	October 1977	May 1978
Off-line[a]	58 sec	1 min 18 sec	1 min 25 sec	1 min 25 sec
On-line[b]	0 sec	2 min	4 min	10 min
Total	58 sec	3 min 18 sec	5 min 25 sec	11 min 25 sec

[a]Refers to compartment undergoing cleaning.

[b]All compartments filtering.

Filtration Velocity

Filtration velocity (metric units) was computed from the volumetric gas flow (English units) at baghouse inlet conditions and the total filtration area:

$$V(m/min) = \frac{0.02832\ Q\ (acfm)}{A}$$

where $A = 6{,}706\ m^2$ for Baghouse 1, 2, and 3.
$A = 10{,}745\ m^2$ for Baghouse 4.

Selection and Reduction of Operating Data

Based on inspection of the Table 16 data, most tests present sufficient information for a steady-state analysis. Test 3 (avg) on Boiler 1 in May 1977 could not be used since the time frame was less than 1 hour. The same logic applied to a subsequent test on Boiler 4 conducted in May 1977, Test 6 (avg). The measurement interval for July 13, 1979 for Boiler 1 (Test R) could not be used since the baghouse cleaning was carried with a combination of the 11 min. 25 sec. cleaning cycle and the 58 sec. cycle. Finally, Test 3 of May 1978 on Boiler 3 was excluded because of missing pressure loss data. The remaining test information was reduced by the techniques described in this section to a form suitable for analysis. The results of the data reductions are summarized in Table 20. Note that the cleaning cycle time shown in Table 20 refers

TABLE 20. SUMMARY OF KRAMER STATION OPERATING DATA REDUCED FOR MODELING ANALYSES

Test Code	Boiler	Date	Inlet concentration, (g/am^3)	Velocity V (am/min)	Pressure loss, $\bar{P}$, (N/m^2)	Total cycle time, t_c, (min)	Gas temperature (°C)
2-avg	1	5/77	0.97	0.563	1420	9.7	164
C	1	10/77	1.36	0.491	1500	9.7[a]	166
D	1	10/77	1.31	0.450	1120	9.7[a]	166
E	1	10/77	0.78	0.392	1000	9.7[a]	149
S	2	7/79	1.37	0.60	700	114.2	185
V	2	1/80	1.37	0.41	670	114.2	163
A	3	10/77	1.29	0.380	750	54.2	149
B	3	10/77	1.39	0.553	1250	9.7[a]	166
1	3	5/78	1.72	0.351	650	9.7	149
2	3	5/78	1.39	0.401	1000	9.7	149
4	3	5/78	1.09	0.357	600	114.2	149
6	3	5/78	2.82	0.528	950	114.2	166
T	3	7/79	1.37	0.63	1075	9.7[a]	191
5-avg	4	5/77	0.64	0.535	1500	15.5	189
4	4	7/79	0.92	0.560	675	182.7	208

Note: All units expressed in Metric system for data reductions.

[a]Indicates that the normal cleaning cycle reverted to continuous cleaning and remained at that level for the entire test period.

to the time span embracing the sequential cleaning of all 10 or all 16 compartments, respectively. The cleaning times that are footnoted, Table 20, are "constantly cleaned" cycles which were initated by high pressure losses on the dates in question. Had pressure losses not exceeded the pre-set value, the normal cleaning cycles would have been those shown in Table 19. It is also emphasized that some of the EPRI tests were purposely forced into a constantly-cleaned mode for experimental purposes.

Analysis of K_2 and a_c

Based on the preliminary analyses of Southwestern Public Service (SPS) data, concurrent development of K_2 and a_c parameters was not possible for the Kramer baghouses. Therefore, the value of K_2 used in modeling calculations was that determined by laboratory measurement (see Section 3), 3.7 N-min/g-m at $25^{o}C$ and 0.61 m/min. In order to estimate a_c, an additional piece of information is required; i.e., the effective drag, S_E. Since the laboratory tests were performed on relatively new fabrics with only minor plugging, S_E values were estimated from prior measurements with a similar fabric for various service lives.[5] Typical S_E levels for new, less than 6 months service, and 2 years field use are 60, 115 and 352 N-min/m^3 respectively. Based on the above values the following estimates of S_E were applied to the Kramer baghouses:

Boilers 2, 3, and 4

- approximately 1 month service - 150 N-min/m^3
- approximately 6 months service - 350 N-min/m^3

Boiler 1

- approximately 1 month service - 550 N-min/m^3
- approximately 6 months service - 550 N-min/m^3

The reason for the higher S_E value for the Boiler 1 baghouse was the higher pressure drop reported for this baghouse. Boiler 1 generally operates at a pressure drop roughly 1 inch water greater than that for the other units at the same operating conditions.[15] At 0.61 m/min face velocity, this translates to a drag value of about 400 N-min/m^3. Although it is recognized that the relationship between S_E and overall pressure loss is not linear, 400 N-min/m^3 were added to the S_E value of 150 N-min/m^3 corresponding to 1 month of service. It is suspected by Kramer personnel that the lime precoat on Boiler 1 is responsible for this difference. The same value was also applied to Boiler 1 for the October 1977 tests (after 6 months service), the assumption here being that either no flyash has deposited interstitially in the fabric or that any flyash that has deposited, has in effect, displaced an equilavent amount of limestone. For Boilers 2, 3, and 4 the values shown for 1 month service were applied to the May 1977 tests, whereas the 6 month values were applied to all other tests.

Values of a_c, Table 21, were estimated from the data presented in Table 20, the previously mentioned K_2 and S_E values, and Equation 11. The results seem to indicate that the cleaning cycle time is more important in determining

a_c than the boiler load level, neglecting for the moment any concurrent changes in such variables as inlet concentration and pressure loss. For example, for Tests 2 and A the steam flows were almost identical although the cleaning cycles were different. Thus, for a time interval of $t_c = 9.7$ minutes, a_c was estimated as 0.01 while for 54.2 minutes it appears as 0.07. This argument is apparently contradicted by Tests 5 and 6. However, the inlet concentration for Test 6 was about 3 times greater than that for Test 5 and the gas flow was also somewhat higher. In essence, Tests 5 and 6 demonstrate that the amount of dust added during a cleaning cycle; i.e., the product of concentration, velocity and cleaning cycle time is the controlling factor in determining a_c. This is to be expected since a_c reflects the amount of dust removed (which equals the amount added) divided by the total amount on a bag before cleaning.

TABLE 21. ESTIMATED a_c VALUES FOR THE KRAMER STATION BAGHOUSES

Test code	Boiler	Date	Steam flow (10^3 lb/hr)	Total cycle time, (min)	Calculated a_c (fractional)
2-avg	1	5/77	240	9.7	0.02
C	1	10/77	210	9.7[a]	0.01
D	1	10/77	197	9.7[a]	0.01
E	1	10/77	154	9.7[a]	0.01
S	2	7/79	244	114.2	0.52
V	2	1/80	162	114.2	0.21
A	3	10/77	160	54.2	0.07
B	3	10/77	216	9.7[a]	0.02
1	3	5/78	137	9.7	0.02
2	3	5/78	160	9.7	0.01
4	3	5/78	140	114.2	0.20
5	3	5/78	185	114.2	0.17
6	3	5/78	214	114.2	0.47
T	3	7/79	257	9.7[a]	0.04
5-avg	4	5/77	320	15.5	0.01
4	4	7/79	362	182.7	0.49

[a]Indicates that the normal cleaning cycle was overridden by high pressure loss, see Table 19.

This is not meant to imply that the pressure limit aspect of the cleaning cycle is unimportant. If the preset pressure limit is exceeded during the normal cleaning cycle, the system reverts to the "constantly-cleaning" mode which automatically provides more frequent cleaning. However, for at least one full cycle, the value of a_c would be the same (regardless of the type of cleaning cycle) since the amount of dust on a bag prior to cleaning will determine how much dust is removed from the bag in a deflate-reverse flow system. During subsequent cycles, however, less dust will be removed because the deposit thickness will be less just before cleaning. With continued filtration, the system will eventually achieve a steady state whereby the amount of dust added over the period representing a complete cleaning and filtering cycle equals that removed. Since less material accumulates over 10 minutes than during 54 minutes, less removal is required to maintain steady-state. The a_c values shown in Table 21 are "steady-state" values.

Model Validation

During the analyses of the SPS data discussed in the first part of this section, it became apparent that a_c values of less than 0.1 would require modifications to the existing model to obtain accurate results. In light of the fact that many of the a_c values estimated from the Kramer data were considerably less than 0.1, the need for adjustments was further demonstrated. Although external corrections were applied to the SPS results when a_c values slightly less than 0.1 were encountered, it is undesirable to apply the same approach for a_c values as low as 0.01 or 0.02. The principal objection is the high sensitivity to fabric pressure loss in the low a_c range. Therefore, only a selected number of tests results and associated derived data were used in the Kramer validation study. The actual values used in the modeling analyses are those which were presented in the preceding section, Tables 20 and 21. The results of the analyses are presented in Table 22. With the exception of Test A, all a_c values for the tests in Table 22 were greater than 0.1. Although the a_c value for Test A was 0.07, the model automatically treats it as 0.1. The result is that the predicted pressure loss is lower than that predicted had the actual value of 0.07 been used in a model capable of operating at $a_c = 0.07$. Therefore, the difference between predicted and actual pressure drops is correspondingly greater as shown in Table 22.

With the exception of Test A, predicted pressure losses are in good agreement with the measured values with a minimum deviation of +4 percent for Test U and a maximum deviation of-22 percent for Test 4. It appears that the greatest differences between actual and predicted pressure losses occur for the low a_c values as indicated in Figure 17. Although it might be argued that these differences are due to random errors in the input data, if one assumes that the operating data have the same accuracy from one test to the next, a real relationship appears to exist. If so, it must be assumed that the model becomes less accurate for low values of a_c, a supposition that is confirmed by previous studies[30] that show pressure drop is more sensitive to a_c variations when a_c is small.

The model predictions of penetration are not as accurate as those of pressure loss for the Kramer Station Baghouses. In fact, the Kramer baghouses appear to be vastly more efficient than predicted by the model. Although not analyzed in this study, other tests at Kramer indicated efficiencies of 99.97 to 99.99 percent for Boiler 3 when operating at 50 to 90 percent of full load with no cleaning.[15] The large differences between predicted and actual penetration have not as yet been resolved.

TABLE 22. MODEL VALIDATION TESTS BASED ON KRAMER STATION DATA

Test code	Boiler	Date	Pressure drop, N/m^2			Penetration, percent		a_c
			Predicted	Actual	Actual/predicted	Predicted	Actual	
S	2	7/79	745	700	0.94	0.61	—	0.52
V	2	1/80	570	670	1.18	0.34		0.21
A[a]	3	10/77	525	750	1.43	0.39	0.23	0.07
4	3	5/78	490	600	1.22	0.29	0.04	0.20
5	3	5/78	545	625	1.15	0.51	0.10	0.17
6	3	5/78	800	950	1.19	0.35	0.02	0.47
U	4	7/79	700	675	0.96	0.60	—	0.49

[a] a_c value of 0.07 - all other tests had a_c values greater than 0.1.

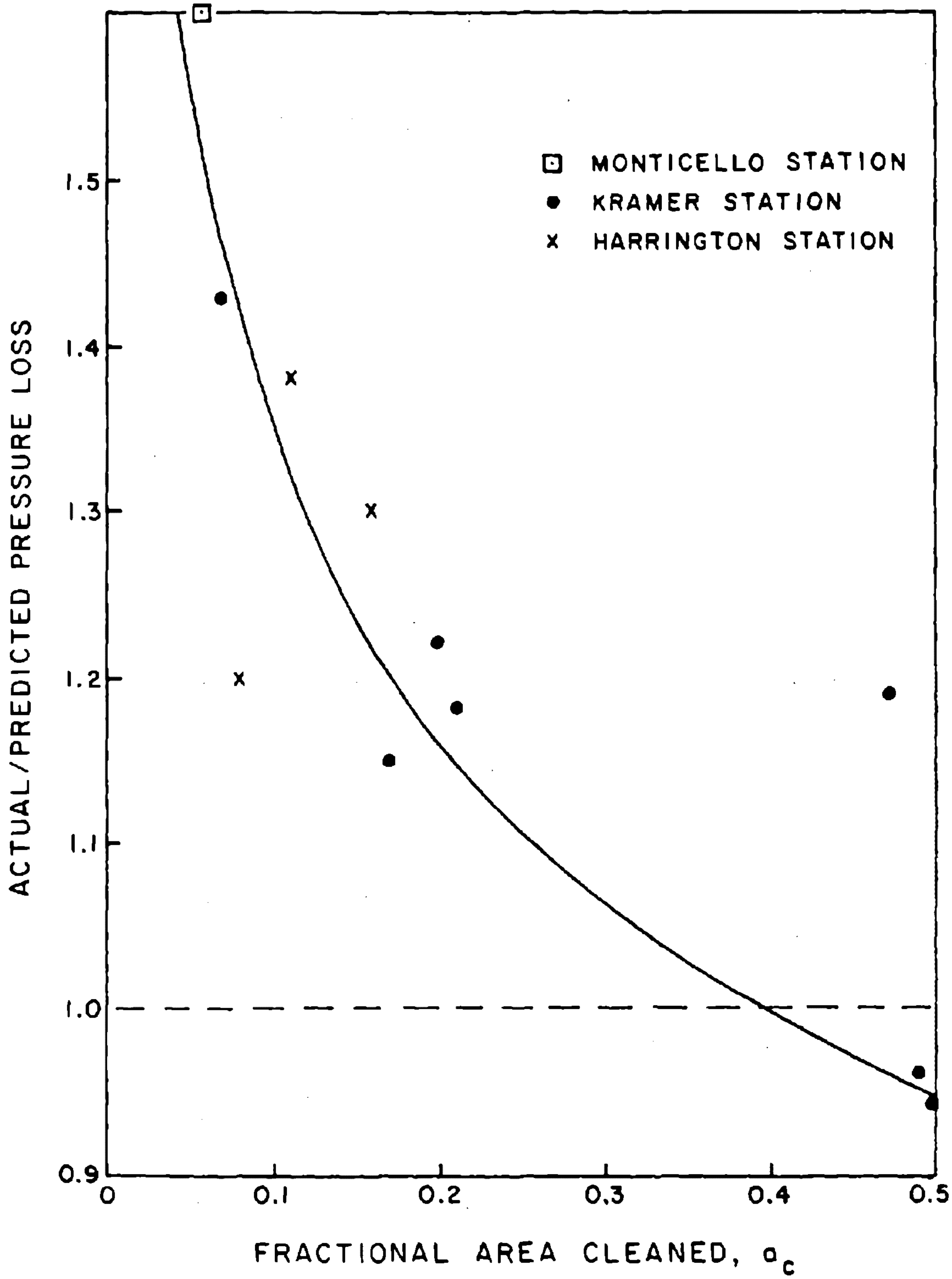

Figure 17. Relationship between accuracy of pressure loss predictions and a_c.

AVAILABILITY AND SELECTION OF OPERATING DATA, MONTICELLO STATION, TEXAS UTILITIES GENERATING COMPANY

Design and operating parameters for Boilers 1 and 2 at Monticello Station were supplied by TU personnel during a GCA plant inspection and in subsequent telephone communications with the engineers responsible for the direction of baghouse operations. The information used in the modeling analyses presented here reflect the most recent reporting of baghouse design, operating, and performance parameters. Table 23 provides a listing of the key data inputs used to describe current boiler and cleaning system operating characteristics.

TABLE 23. DESIGN AND OPERATING PARAMETERS FOR BOILERS 1 AND 2, MONTICELLO STATION, SINGLE BOILER STATISTICS

	Range	Average
Lignite firing rate	411-496 tons/hour	454 tons/hour
Coal ash content	16-28 percent	22 percent
Amount of coal ash appearing as flyash	—	65 percent
Total gas flow, ESP plus filter	—	2.3×10^6 acfm
Total baghouse flow, Sections A and B	—	1.7×10^6 acfm
Total filtration area	—	6.7×10^5 ft^2
Filtration velocity	2.39-2.69 afpm	2.54 afpm
Baghouse pressure loss		
Boiler No. 1	10-12 in H_2O	11 in H_2O
Boiler No. 2	10.5-11 in H_2O	10.8 in H_2O

Reduction of Operating Data

In reducing the design and operating data for the baghouse system, the average values for coal firing rate (454 tons/hr), coal ash content (22 percent), ash carryover (65 percent), and volumetric gas flow rate at baghouse temperature (2.3×10^6 acfm) were used to computer the resultant flyash particulate loading (6.6 gr/acf or 15.1 g/am^3) in the gas streams entering the two sections of each boiler baghouse system. The average filtration velocity was estimated as 2.54 afpm (0.77 am/min), based upon the average baghouse flow and total filtration area shown in Table 23. Similarly, an average pressure loss value of 11 in. water was selected for modeling studies.

The cleaning cycle for the Monticello baghouses is designed to take each compartment off-line for 2.5 minutes. After returning the just-cleaned compartment to the filtration mode, the isolation of the next compartment to be cleaned is delayed for 1.25 minutes. Thus, a total of 67.5 minutes is required for the sequential cleaning of 18 compartments during which time all compartments are on-line for 22.5 minutes and 17 compartments on-line for the remaining 45 minutes.

As in the case of Kramer Station, insufficient field data were available for the concurrent determination of K_2 and a_c. Thus, the value of K_2 used in the present analysis, 1.0 N-min/g-m (at 25°C and 0.65 m/min), was that derived from the laboratory measurements discussed in Section 3 of this report. An assumed S_E value of 350 N-min/m^3 was chosen as a representative effective residual fabric drag describing the fabric properties after extended field service. The bases for this selection were prior GCA laboratory measurements on related flyash/glass fabric combinations.[5]

The total filtration capability for each boiler consists of two separate baghouses, A and B, each containing 18 separate compartments. Furthermore, the levels of operating pressure loss have been sufficiently high, ~10-12 in. H_2O, to require continuous or back-to-back cleaning. Since two compartments, one from Section A and one from Section B are isolated simultaneously, the baghouse system can be analyzed as if it were made up of 18 sequentially cleaned compartments. Hence, in the summary of test parameters used for calculating a_c levels, the number of separate compartments is effectively 18. In Table 24, the necessary design and operating parameters needed to compute a_c by means of Equation 11 and also those required to operate the filtration model have been combined with the specific application designated by the codings a_c and M.

TABLE 24. SUMMARY OF DESIGN AND OPERATING PARAMETERS USED FOR ESTIMATION OF a_c AND COMPUTER MODEL ANALYSES, MONTICELLO STATION

Parameter description	Application[a]		Numerical value
	M	a_c	
Number of compartments	M	a_c	18
Cleaning cycle duration	M	a_c	67.5 minutes
Time to clean one compartment	M		2.5 minutes
Reverse flow volume	M		Not used
Cleaning cycle initiation	M		Continuous cleaning
Baghouse temperature	M	a_c	177°C
Inlet concentration	M	a_c	15.1 g/am^3
K_2 (25°C and 0.65 m/min)	M	a_c	1.0 N-min/g-m
S_E (25°C)	M	a_c	350 N-min/m^3
W_R	M		73 g/m^2
Filtration velocity	M	a_c	0.77 m/min
Average pressure loss (measured)		a_c	2750 N/m^2

[a]M designation means Model Input.
a_c designation means use for a_c computation by Equation 11.

Since Monticello Station is a baseload plant with only minor variations in load level, a steady-state analysis can be performed. Furthermore, since the bags in each section are essentially the same type and all have seen the same service time, a representative estimate of a_c appears possible. The method used for estimating a_c has been presented in preceding sections of this report dealing with the Harrington and Kramer baghouses. Based upon the data shown in Table 24, the estimated a_c value calculated by Equation 11 is 0.32 for the Monticello filter system. Despite the limitation of the estimating procedures, an a_c value of 0.32 in conjunction with a corresponding K_2 value of 1.0 appears consistent with similar data reported for the Nucla, Colorado system; i.e., 0.37 for a_c and a value of 0.76 N-min/g-m for K_2. By using the a_c value of 0.32 in conjunction with the other parameters required for a computer model prediction of filter pressure loss and dust penetration characteristics given in Table 24, the following results were obtained (see Table 25).

TABLE 25. COMPARISON OF MEASURED AND PREDICTED FILTER SYSTEM PERFORMANCE FOR MONTICELLO STATION

	Predicted[a]	Measured
Pressure loss, N/m^2 [b]	1735	2750
Penetration, percent	0.8	No data

[a] Based on GCA Fabric Filtration Model.[8]

[b] Pressure loss across fabric.

According to Table 25, the measured pressure loss is approximately 60 percent greater than one might expect based upon the modeling input information appearing in Table 24. Several reasons can be offered for the poor agreement between predicted and measured values. The very limited amount of data used in these analyses automatically detracts from its statistical significance. Additionally, the field and laboratory observation of electrical charge effects not detected with three other flyashes involved in this study represent another critical unknown quantity. It is suspected, although we have no supporting evidence, that the charge properties may cause the K_2 values estimated in the laboratory to be erroneously low relative to the field values. Therefore, there seems to be a critical need to determine K_2 values by an in-situ method such as that proposed in Section 3 of this report. Insofar as attempting to apply even the most advanced of the current theories for predicting K_2 values from fundamental principles, it is believed that an accuracy of ±50 percent represents the best that could be expected at the present time.

Samples of the tabular printout from the computer analyses of the Monticello, Kramer, and Harrington Station data are presented in Appendix B.

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APPENDIX A

SUPPORTING DATA FOR LABORATORY MEASUREMENTS

TABLE A-1. DATA SUMMARY FOR LABORATORY FILTRATION MEASUREMENTS

Test number	Date	Test dust[a]	Ambient % relative humidity	Fabric filter: Face velocity (m/min)	Fabric filter: Inlet concentration[b] (g/m³)	Fabric filter: K_2[c] $\left(\frac{N\cdot min}{g\cdot m}\right)$	Fabric filter: % Penetration[d]	Membrane filter: Face velocity (m/min)	Membrane filter: Inlet concentration[b] (g/m³)	Membrane filter: K_2[c] $\left(\frac{N\cdot min}{g\cdot m}\right)$
11A	11-05-79	SPS	41	0.61	4.32	2.40		0.62		2.87
11B	11-06-79	SPS	41	0.62	3.94	2.86	0.038	0.62	2.80	2.90
11C	11-07-79	SPS	53	0.61	4.34	3.09		0.62		2.79
12A	11-09-79	SPS	45	1.02	4.10	2.93	0.145	1.08	3.07	3.25
12B	11-09-79	SPS	45	1.01	4.60	3.40		1.08		3.3[illegible]
14A	11-27-79	TU	52	0.64	2.71	0.68		0.67		1.15
14B	11-29-79	TU	36	0.64	2.80	0.76	-0.029	0.67	1.43	1.13
14C	11-30-79	TU	32	0.64	4.27	1.05		0.67		1.09
16A	01-02-80	NPPD	30	0.63	4.45	3.33	0.023	0.62	2.73	3.75
16B	01-02-80	NPPD	30	0.63	4.74	4.15		0.62		3.79
17A	02-22-80	SPS	25	0.62	1.63	2.30	0.053	0.63	2.54	2.76

[a] SPS = Southwestern Public Service, Harrington Station.
TU = Texas Utilities Generating Company, Monticello Station.
NPPD = Nebraska Public Power District, Kramer Station.

[b] Inlet concentration is defined as flyash accumulation on a filter surface per volume of air drawn through the filter. Material which falls out or deposits prior to reaching the filter surface is neglected. Since the membrane filters could be weighed only at the beginning and end of each

[c] For each test interval, K_2 is defined by a linear approximation of the drag versus dust loading curve. For the initial fabric test intervals, the point at which the drag versus dust loading curve begins to level off has been used as the starting point for this approximation.

[d] Fabric penetration results are presented as average values over the entire test. (Most penetration occurs during the initial test interval prior to dust cake formation. Measurements made during Test No. 11 showed a 0.109% penetration over the initial test interval and an average penetration of 0.001% for the final two intervals)

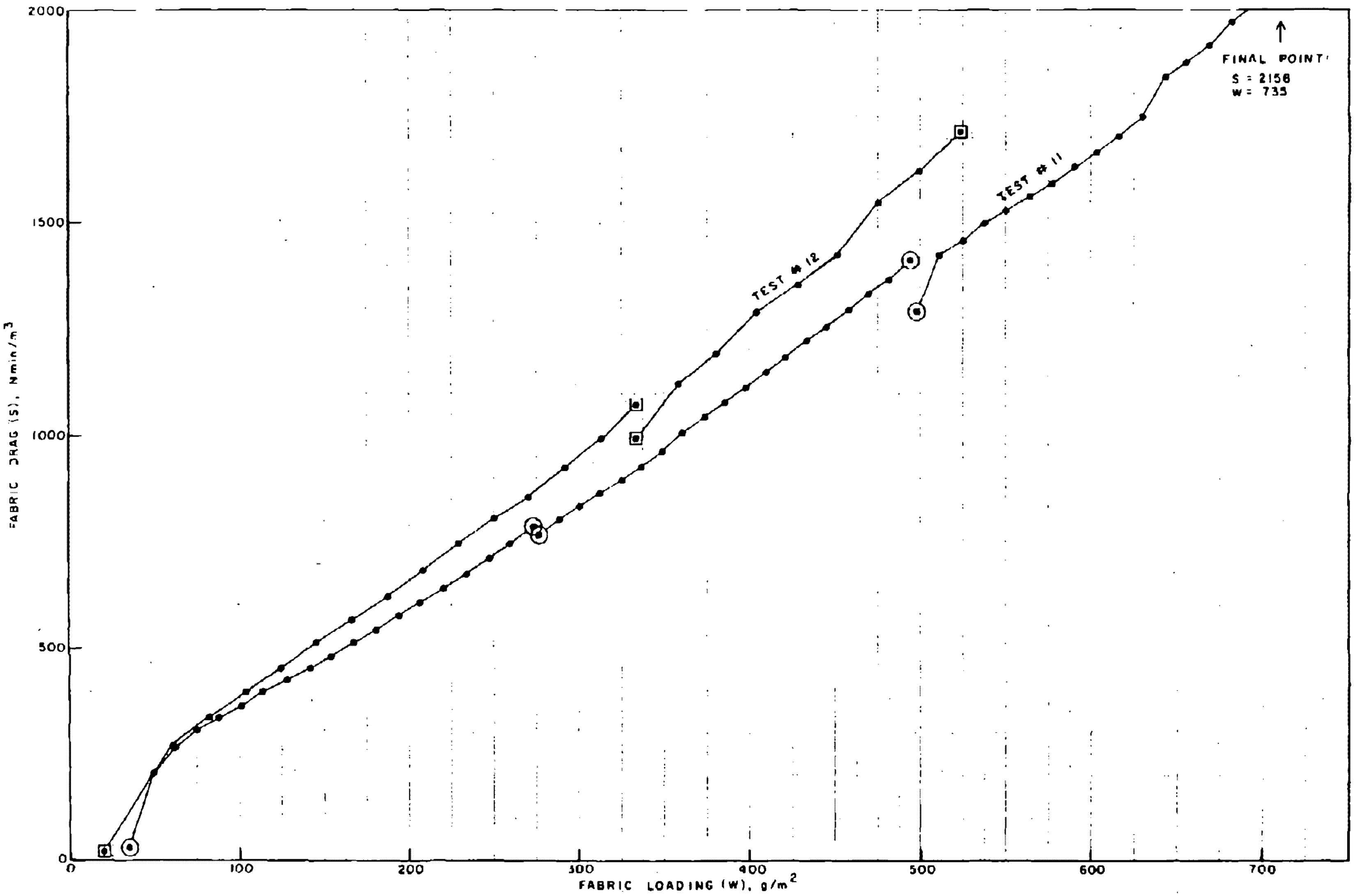

Figure A-1. Tests No. 11 and No. 12 Southwestern Public Service Flyash, face velocities of 0.61 and 1.02 m/min, respectively.

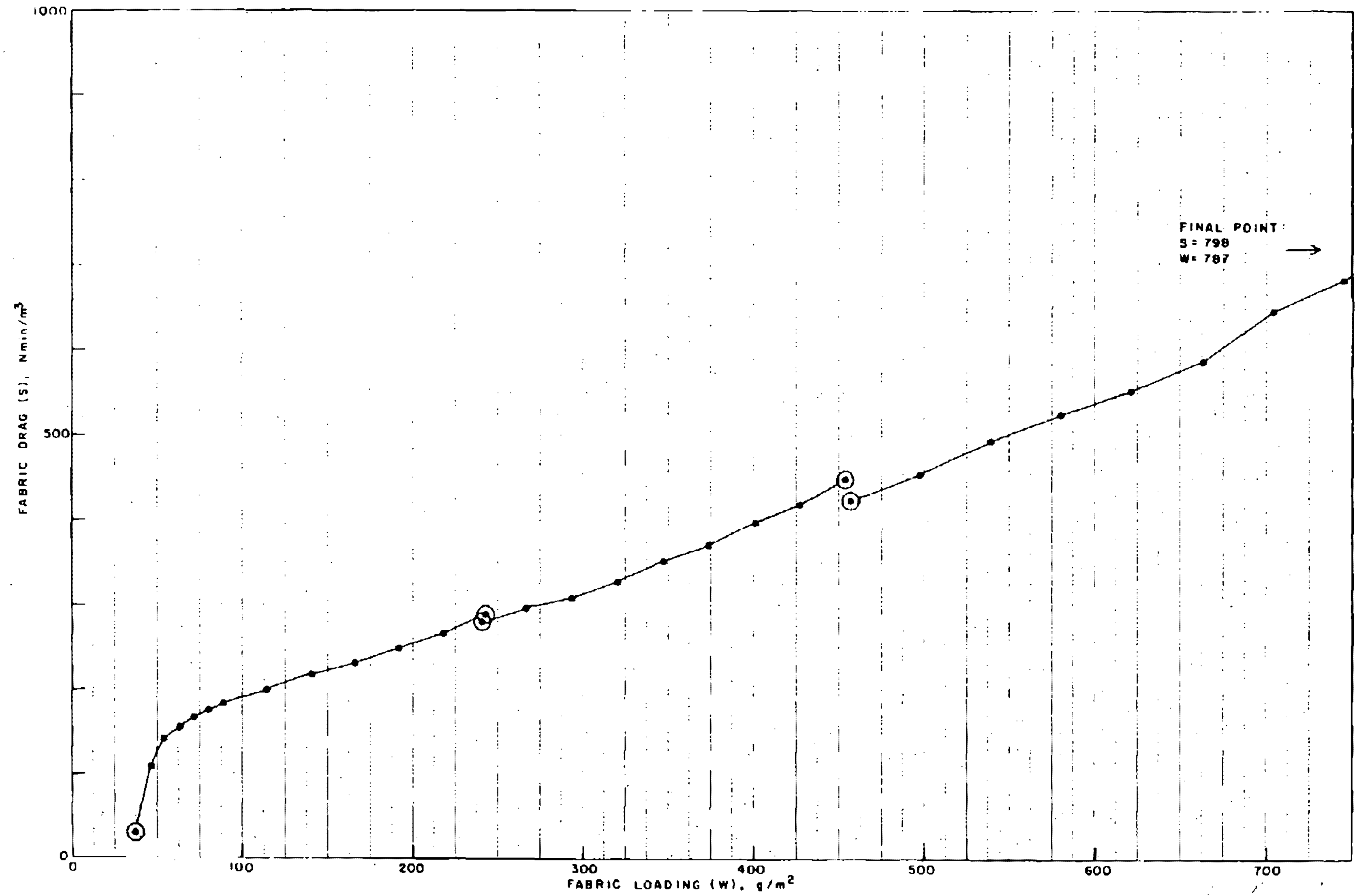

Figure A-2. Test No. 14 Texas Utilities Generating Company Flyash, face velocity = 0.64 m/min.

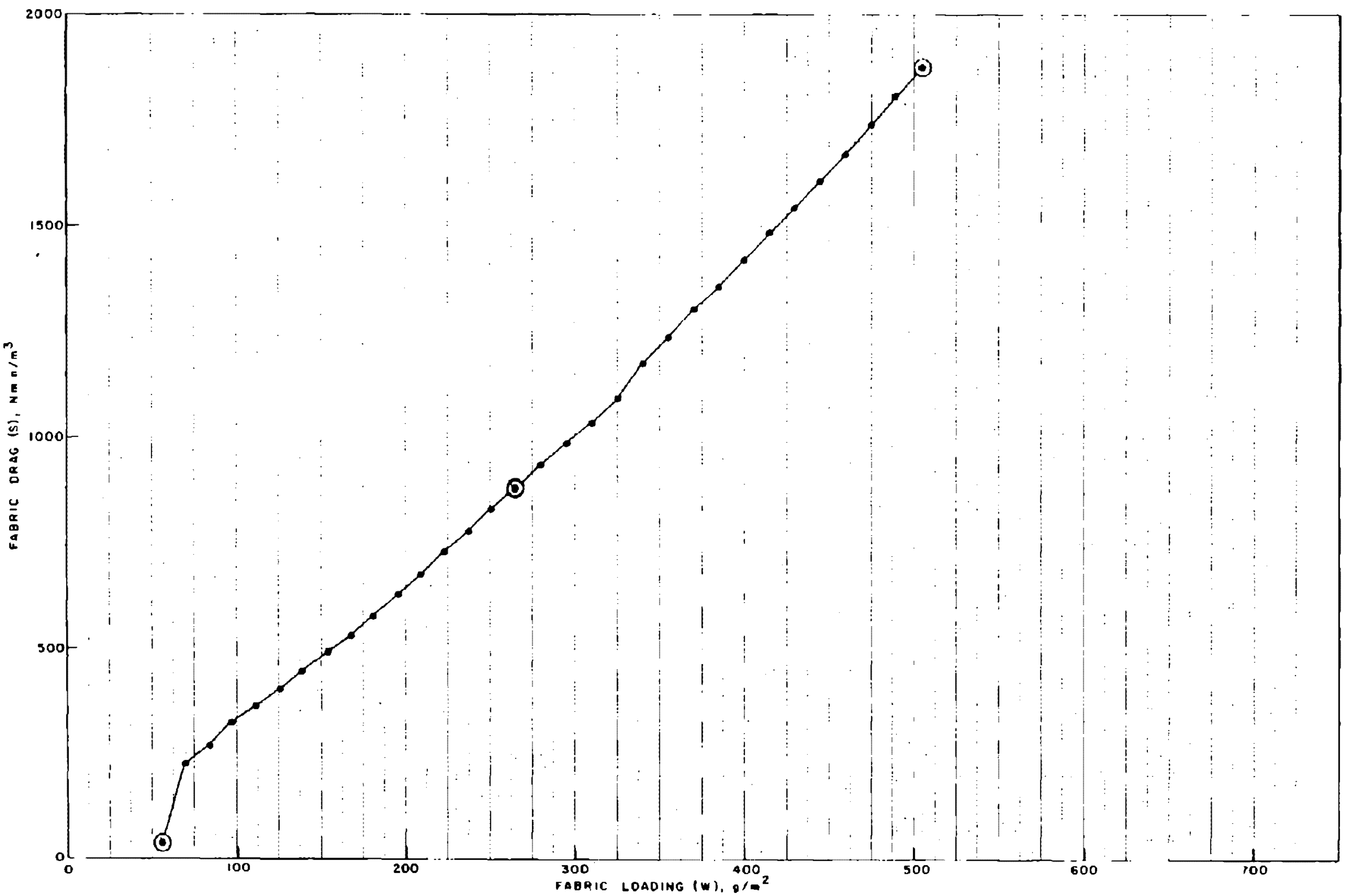

Figure A-3. Test No. 16 Nebraska Public Power District Flyash, face velocity = 0.63 m/min.

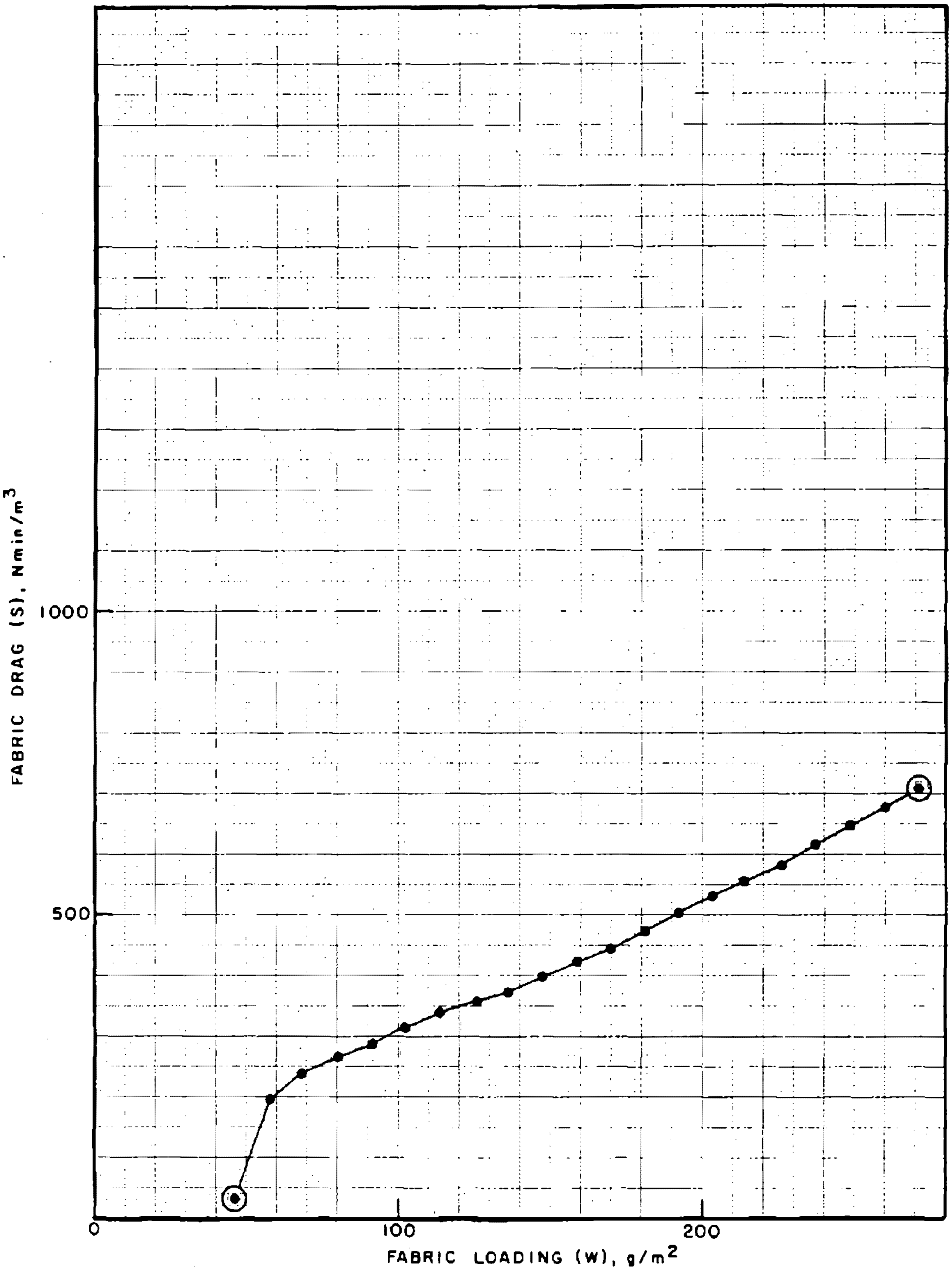

Figure A-4. Test No. 17 Southwestern Public Service Flyash, face velocity = 0.62 m/min.

APPENDIX B

SAMPLE PRINTOUT SHEETS FROM COMPUTER MODELING OF FABRIC FILTER PERFORMANCE

TABLE B-1. SOUTHWEST PUBLIC SERVICE SIMULATION - LOW LOAD - $S_E = 25$ N-min/m^3

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**************************************************************************************

SUMMARY OF INPUT DATA FOR BAGHOUSE ANALYSIS

**************************************************************************************

SOUTHWEST PUBLIC SERVICE - MEDIUM LOAD DATA


BASIC DESIGN DATA
     NUMBER OF COMPARTMENTS             14
     COMPARTMENT CLEANING TIME           1.9          MINUTES
       (OFF LINE TIME)
     CLEANING CYCLE TIME                28.0          MINUTES
     CONTINUOUSLY CLEANED SYSTEM
     REVERSE FLOW VELOCITY              1.5400        M/MIN

OPERATING DATA
     AVERAGE FACE VELOCITY              0.6870        M/MIN
     GAS TEMPERATURE                    157.          DEGREES CENTIGRADE
     INLET DUST CONCENTRATION            3.58         G/M3
          MEASURED AT                   157.          DEGREES CENTIGRADE

FABRIC AND DUST PROPERTIES

     SPECIFIC RESISTANCE, K2             3.87         N-MIN/G-M
          MEASURED AT                   157.          DEGREES CENTIGRADE
                                        0.6870        M/MIN
     EFFECTIVE RESIDUAL DRAG, SE         32.          N-MIN/M3
          MEASURED AT                   157.          DEGREES CENTIGRADE
     RESIDUAL LOADING, WR                28.0         G/M2


SPECIAL PROGRAM INSTRUCTIONS
     MAX NUMBER OF CYCLES MODELED       20
     ACCURACY LEVEL                     0
     TYPE OF RESULTS REQUESTED          SUMMARY /

     FRACTIONAL AREA CLEANED, AC      0.12
```

TABLE B-1 (continued)

CALCULATED VALUES

INLET DUST CONCENTRATION CORRECTED TO OPERATING TEMPERATURE	3.58	G/M3
FABRIC AND DUST CAKE PROPERTIES CORRECTED FOR GAS VISCOSITY		
SPECIFIC CAKE RESISTANCE, K2	3.65	N-MIN/G-M
EFFECTIVE DRAG, SE	134.	N-MIN/M3
FRACTIONAL AREA CLEANED, AC	0.12	
TIME INCREMENT	0.50	MINUTES
SYSTEM CONSTANT W*	0.0	G/M2

TABLE B-1 (continued)

****

RESULTS OF BAGHOUSE ANALYSIS

****

SOUTHWEST PUBLIC SERVICE - MEDIUM LOAD DATA

FOR 28.00 MINUTES OPERATION, CYCLE NUMBER 11

AVERAGE PENETRATION=	4.81E-03
AVERAGE PRESSURE DROP=	1026.70 N/M2
AVERAGE SYSTEM FLOW=	0.7830 M/MIN
MAXIMUM PENETRATION=	9.51E-03
MAXIMUM PRESSURE DROP=	1117.74 N/M2

FOR 28.00 MINUTES OPERATION, CYCLE NUMBER 12

AVERAGE PENETRATION=	4.78E-03
AVERAGE PRESSURE DROP=	1021.45 N/M2
AVERAGE SYSTEM FLOW=	0.7830 M/MIN
MAXIMUM PENETRATION=	9.46E-03
MAXIMUM PRESSURE DROP=	1110.97 N/M2

FOR 28.00 MINUTES OPERATION, CYCLE NUMBER 13

AVERAGE PENETRATION=	4.77E-03
AVERAGE PRESSURE DROP=	1017.76 N/M2
AVERAGE SYSTEM FLOW=	0.7830 M/MIN
MAXIMUM PENETRATION=	9.42E-03
MAXIMUM PRESSURE DROP=	1106.17 N/M2

TABLE B-2. SOUTHWEST PUBLIC SERVICE - MEDIUM LOAD - S_E = 25 N-min/m^3

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*****************************************************************************************

SUMMARY OF INPUT DATA FOR BAGHOUSE ANALYSIS

*****************************************************************************************

SOUTHWEST PUBLIC SERVICE- LOW LOAD DATA


BASIC DESIGN DATA
     NUMBER OF COMPARTMENTS              14
     COMPARTMENT CLEANING TIME            1.9           MINUTES
       (OFF LINE TIME)
     CLEANING CYCLE TIME                 28.0           MINUTES
     CONTINUOUSLY CLEANED SYSTEM
     REVERSE FLOW VELOCITY               1.5400         M/MIN

OPERATING DATA
     AVERAGE FACE VELOCITY               0.3550         M/MIN
     GAS TEMPERATURE                     133.           DEGREES CENTIGRADE
     INLET DUST CONCENTRATION             3.44          G/M3
          MEASURED AT                    133.           DEGREES CENTIGRADE

FABRIC AND DUST PROPERTIES

     SPECIFIC RESISTANCE, K2              3.77          N-MIN/G-M
          MEASURED AT                    133.           DEGREES CENTIGRADE
                                         0.3550         M/MIN
     EFFECTIVE RESIDUAL DRAG, SE          31.           N-MIN/M3
          MEASURED AT                    133.           DEGREES CENTIGRADE
     RESIDUAL LOADING, WR                 28.0          G/M2


SPECIAL PROGRAM INSTRUCTIONS
     MAX NUMBER OF CYCLES MODELED        20
     ACCURACY LEVEL                      0
     TYPE OF RESULTS REQUESTED           SUMMARY /

     FRACTIONAL AREA CLEANED, AC       0.06
```

TABLE B-2 (continued)

CALCULATED VALUES

INLET DUST CONCENTRATION CORRECTED TO OPERATING TEMPERATURE	3.44	G/M3
FABRIC AND DUST CAKE PROPERTIES CORRECTED FOR GAS VISCOSITY		
SPECIFIC CAKE RESISTANCE, K2	4.94	N-MIN/G-M
EFFECTIVE DRAG, SE	169.	N-MIN/M3
FRACTIONAL AREA CLEANED, AC	0.06	
TIME INCREMENT	0.50	MINUTES
SYSTEM CONSTANT **	0.0	G/M2

TABLE B-2 (continued)

****

RESULTS OF BAGHOUSE ANALYSIS

****

SOUTHWEST PUBLIC SERVICE- LOW LOAD DATA

FOR 28.00 MINUTES OPERATION, CYCLE NUMBER 12

AVERAGE PENETRATION=	3.62E-03
AVERAGE PRESSURE DROP=	423.91 N/M2
AVERAGE SYSTEM FLOW=	0.4510 M/MIN
MAXIMUM PENETRATION=	5.57E-03
MAXIMUM PRESSURE DROP=	464.70 N/M2

FOR 28.00 MINUTES OPERATION, CYCLE NUMBER 13

AVERAGE PENETRATION=	3.62E-03
AVERAGE PRESSURE DROP=	420.13 N/M2
AVERAGE SYSTEM FLOW=	0.4510 M/MIN
MAXIMUM PENETRATION=	5.54E-03
MAXIMUM PRESSURE DROP=	459.94 N/M2

FOR 28.00 MINUTES OPERATION, CYCLE NUMBER 14

AVERAGE PENETRATION=	3.61E-03
AVERAGE PRESSURE DROP=	417.27 N/M2
AVERAGE SYSTEM FLOW=	0.4510 M/MIN
MAXIMUM PENETRATION=	5.51E-03
MAXIMUM PRESSURE DROP=	456.34 N/M2

TABLE B-3. SOUTHWEST PUBLIC SERVICE SIMULATION - HIGH LOAD - S_E = 25 N-min/m^3

****

SUMMARY OF INPUT DATA FOR BAGHOUSE ANALYSIS

****

SOUTHWEST PUBLIC SERVICE - HIGH LOAD DATA

BASIC DESIGN DATA		
NUMBER OF COMPARTMENTS	14	
COMPARTMENT CLEANING TIME (OFF LINE TIME)	1.9	MINUTES
CLEANING CYCLE TIME	28.0	MINUTES
CONTINUOUSLY CLEANED SYSTEM		
REVERSE FLOW VELOCITY	1.5400	M/MIN
OPERATING DATA		
AVERAGE FACE VELOCITY	0.7980	M/MIN
GAS TEMPERATURE	165.	DEGREES CENTIGRADE
INLET DUST CONCENTRATION	2.94	G/M3
MEASURED AT	165.	DEGREES CENTIGRADE
FABRIC AND DUST PROPERTIES		
SPECIFIC RESISTANCE, K2	3.98	N-MIN/G-M
MEASURED AT	165.	DEGREES CENTIGRADE
	0.7980	M/MIN
EFFECTIVE RESIDUAL DRAG, SE	33.	N-MIN/M3
MEASURED AT	165.	DEGREES CENTIGRADE
RESIDUAL LOADING, WR	28.0	G/M2
SPECIAL PROGRAM INSTRUCTIONS		
MAX NUMBER OF CYCLES MODELED	20	
ACCURACY LEVEL	0	
TYPE OF RESULTS REQUESTED	SUMMARY /	
FRACTIONAL AREA CLEANED, AC	0.09	

TABLE B-3 (continued)

CALCULATED VALUES

INLET DUST CONCENTRATION CORRECTED TO OPERATING TEMPERATURE	2.94	G/M3
FABRIC AND DUST CAKE PROPERTIES CORRECTED FOR GAS VISCOSITY		
SPECIFIC CAKE RESISTANCE, K2	3.48	N-MIN/G-M
EFFECTIVE DRAG, SE	130.	N-MIN/M3
FRACTIONAL AREA CLEANED, AC	0.09	
TIME INCREMENT	0.50	MINUTES
SYSTEM CONSTANT W*	0.0	G/M2

TABLE B-3 (continued)

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************************************************************************

RESULTS OF BAGHOUSE ANALYSIS

************************************************************************

SOUTHWEST PUBLIC SERVICE - HIGH LOAD DATA


FOR     28.00 MINUTES OPERATION,  CYCLE NUMBER  10
                                                AVERAGE PENETRATION=            5.95E-03
                                                AVERAGE PRESSURE DROP=           1428.69 N/M2
                                                AVERAGE SYSTEM FLOW=              0.8940 M/MIN
                                                MAXIMUM PENETRATION=            1.04E-02
                                                MAXIMUM PRESSURE DROP=           1561.23 N/M2

FOR     28.00 MINUTES OPERATION,  CYCLE NUMBER  11
                                                AVERAGE PENETRATION=            5.86E-03
                                                AVERAGE PRESSURE DROP=           1405.51 N/M2
                                                AVERAGE SYSTEM FLOW=              0.8940 M/MIN
                                                MAXIMUM PENETRATION=            1.01E-02
                                                MAXIMUM PRESSURE DROP=           1522.97 N/M2

FOR     28.00 MINUTES OPERATION,  CYCLE NUMBER  12
                                                AVERAGE PENETRATION=            5.83E-03
                                                AVERAGE PRESSURE DROP=           1396.48 N/M2
                                                AVERAGE SYSTEM FLOW=              0.8940 M/MIN
                                                MAXIMUM PENETRATION=            1.01E-02
                                                MAXIMUM PRESSURE DROP=           1511.49 N/M2
```

TABLE B-4. SOUTHWEST PUBLIC SERVICE SIMULATION - MEDIUM LOAD - NO VELOCITY EFFECT ON K_2

****

SUMMARY OF INPUT DATA FOR BAGHOUSE ANALYSIS

****

SOUTHWEST PUBLIC SERVICE - MEDIUM LOAD DATA

BASIC DESIGN DATA		
NUMBER OF COMPARTMENTS	14	
COMPARTMENT CLEANING TIME (OFF LINE TIME)	1.9	MINUTES
CLEANING CYCLE TIME	28.0	MINUTES
CONTINUOUSLY CLEANED SYSTEM		
REVERSE FLOW VELOCITY	1.5400	M/MIN
OPERATING DATA		
AVERAGE FACE VELOCITY	0.6870	M/MIN
GAS TEMPERATURE	157.	DEGREES CENTIGRADE
INLET DUST CONCENTRATION	3.58	G/M3
MEASURED AT	157.	DEGREES CENTIGRADE
FABRIC AND DUST PROPERTIES		
SPECIFIC RESISTANCE, K2	3.87	N-MIN/G-M
MEASURED AT	157.	DEGREES CENTIGRADE
	0.6870	M/MIN
EFFECTIVE RESIDUAL DRAG, SE	32.	N-MIN/M3
MEASURED AT	157.	DEGREES CENTIGRADE
RESIDUAL LOADING, WR	28.0	G/M2
SPECIAL PROGRAM INSTRUCTIONS		
MAX NUMBER OF CYCLES MODELED	20	
ACCURACY LEVEL	0	
TYPE OF RESULTS REQUESTED	SUMMARY /	
FRACTIONAL AREA CLEANED, AC	0.12	

TABLE B-4 (continued)

CALCULATED VALUES

INLET DUST CONCENTRATION CORRECTED TO OPERATING TEMPERATURE	3.58	G/M3
FABRIC AND DUST CAKE PROPERTIES CORRECTED FOR GAS VISCOSITY		
SPECIFIC CAKE RESISTANCE, K2	3.87	N-MIN/G-M
EFFECTIVE DRAG, SE	140.	N-MIN/M3
FRACTIONAL AREA CLEANED, AC	0.12	
TIME INCREMENT	0.50	MINUTES
SYSTEM CONSTANT W*	0.0	G/M2

TABLE B-4 (continued)

****

RESULTS OF BAGHOUSE ANALYSIS

****

SOUTHWEST PUBLIC SERVICE - MEDIUM LOAD DATA

```
FOR     28.00 MINUTES OPERATION,  CYCLE NUMBER  10
                                                AVERAGE PENETRATION=            7.38E-03
                                                AVERAGE PRESSURE DROP=             1026.58 N/M2
                                                AVERAGE SYSTEM FLOW=                0.7830 M/MIN
                                                MAXIMUM PENETRATION=            1.03E-02
                                                MAXIMUM PRESSURE DROP=             1090.44 N/M2

FOR     28.00 MINUTES OPERATION,  CYCLE NUMBER  11
                                                AVERAGE PENETRATION=            7.32E-03
                                                AVERAGE PRESSURE DROP=             1018.89 N/M2
                                                AVERAGE SYSTEM FLOW=                0.7830 M/MIN
                                                MAXIMUM PENETRATION=            1.02E-02
                                                MAXIMUM PRESSURE DROP=             1080.88 N/M2

FOR     28.00 MINUTES OPERATION,  CYCLE NUMBER  12
                                                AVERAGE PENETRATION=            7.27E-03
                                                AVERAGE PRESSURE DROP=             1013.28 N/M2
                                                AVERAGE SYSTEM FLOW=                0.7830 M/MIN
                                                MAXIMUM PENETRATION=            1.01E-02
                                                MAXIMUM PRESSURE DROP=             1073.91 N/M2
```

TABLE B-5. SOUTHWEST PUBLIC SERVICE SIMULATION - LOW LOAD - S_E = 300 N-min/m^3

****

SUMMARY OF INPUT DATA FOR BAGHOUSE ANALYSIS

****

SOUTHWEST PUBLIC SERVICE- LOW LOAD DATA

BASIC DESIGN DATA

NUMBER OF COMPARTMENTS	14	
COMPARTMENT CLEANING TIME (OFF LINE TIME)	1.9	MINUTES
CLEANING CYCLE TIME	28.0	MINUTES
CONTINUOUSLY CLEANED SYSTEM		
REVERSE FLOW VELOCITY	1.5400	M/MIN

OPERATING DATA

AVERAGE FACE VELOCITY	0.3550	M/MIN
GAS TEMPERATURE	133.	DEGREES CENTIGRADE
INLET DUST CONCENTRATION	3.44	G/M3
MEASURED AT	133.	DEGREES CENTIGRADE

FABRIC AND DUST PROPERTIES

SPECIFIC RESISTANCE, K2	3.77	N-MIN/G-M
MEASURED AT	133.	DEGREES CENTIGRADE
	0.3550	M/MIN
EFFECTIVE RESIDUAL DRAG, SE	370.	N-MIN/M3
MEASURED AT	133.	DEGREES CENTIGRADE
RESIDUAL LOADING, WR	28.0	G/M2

SPECIAL PROGRAM INSTRUCTIONS

MAX NUMBER OF CYCLES MODELED	20
ACCURACY LEVEL	0
TYPE OF RESULTS REQUESTED	SUMMARY /

FRACTIONAL AREA CLEANED, AC	0.08

TABLE B-5 (continued)

CALCULATED VALUES

INLET DUST CONCENTRATION CORRECTED TO OPERATING TEMPERATURE	3.44	G/M3
FABRIC AND DUST CAKE PROPERTIES CORRECTED FOR GAS VISCOSITY		
SPECIFIC CAKE RESISTANCE, K2	4.94	N-MIN/G-M
EFFECTIVE DRAG, SE	508.	N-MIN/M3
FRACTIONAL AREA CLEANED, AC	0.08	
TIME INCREMENT	0.50	MINUTES
SYSTEM CONSTANT W*	0.0	G/M2

TABLE B-5 (continued)

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**************************************************************************************
RESULTS OF BAGHOUSE ANALYSIS
**************************************************************************************
SOUTHWEST PUBLIC SERVICE- LOW LOAD DATA

FOR     28.00 MINUTES OPERATION,  CYCLE NUMBER  11
                                        AVERAGE PENETRATION=          3.37E-03
                                        AVERAGE PRESSURE DROP=          596.73 N/M2
                                        AVERAGE SYSTEM FLOW=            0.4510 M/MIN
                                        MAXIMUM PENETRATION=          3.90E-03
                                        MAXIMUM PRESSURE DROP=          641.15 N/M2

FOR     28.00 MINUTES OPERATION,  CYCLE NUMBER  12
                                        AVERAGE PENETRATION=          3.37E-03
                                        AVERAGE PRESSURE DROP=          591.18 N/M2
                                        AVERAGE SYSTEM FLOW=            0.4510 M/MIN
                                        MAXIMUM PENETRATION=          3.88E-03
                                        MAXIMUM PRESSURE DROP=          634.24 N/M2

FOR     28.00 MINUTES OPERATION,  CYCLE NUMBER  13
                                        AVERAGE PENETRATION=          3.36E-03
                                        AVERAGE PRESSURE DROP=          587.01 N/M2
                                        AVERAGE SYSTEM FLOW=            0.4510 M/MIN
                                        MAXIMUM PENETRATION=          3.86E-03
                                        MAXIMUM PRESSURE DROP=          629.11 N/M2
```

TABLE B-6. SOUTHWEST PUBLIC SERVICE SIMULATION - MEDIUM LOAD - S_E = 300 N-min/m^3

****

SUMMARY OF INPUT DATA FOR BAGHOUSE ANALYSIS

****

SOUTHWEST PUBLIC SERVICE - MEDIUM LOAD DATA

BASIC DESIGN DATA		
NUMBER OF COMPARTMENTS	14	
COMPARTMENT CLEANING TIME (OFF LINE TIME)	1.9	MINUTES
CLEANING CYCLE TIME	28.0	MINUTES
CONTINUOUSLY CLEANED SYSTEM		
REVERSE FLOW VELOCITY	1.5400	M/MIN
OPERATING DATA		
AVERAGE FACE VELOCITY	0.6870	M/MIN
GAS TEMPERATURE	157.	DEGREES CENTIGRADE
INLET DUST CONCENTRATION	3.58	G/M3
MEASURED AT	157.	DEGREES CENTIGRADE
FABRIC AND DUST PROPERTIES		
SPECIFIC RESISTANCE, K2	3.87	N-MIN/G-M
MEASURED AT	157.	DEGREES CENTIGRADE
	0.6870	M/MIN
EFFECTIVE RESIDUAL DRAG, SE	380.	N-MIN/M3
MEASURED AT	157.	DEGREES CENTIGRADE
RESIDUAL LOADING, WR	28.0	G/M2
SPECIAL PROGRAM INSTRUCTIONS		
MAX NUMBER OF CYCLES MODELED	20	
ACCURACY LEVEL	0	
TYPE OF RESULTS REQUESTED	SUMMARY /	
FRACTIONAL AREA CLEANED, AC	0.16	

TABLE B-6 (continued)

CALCULATED VALUES		
INLET DUST CONCENTRATION CORRECTED TO OPERATING TEMPERATURE	3.58	G/M3
FABRIC AND DUST CAKE PROPERTIES CORRECTED FOR GAS VISCOSITY		
SPECIFIC CAKE RESISTANCE, K2	3.65	N-MIN/G-M
EFFECTIVE DRAG, SE	482.	N-MIN/M3
FRACTIONAL AREA CLEANED, AC	0.16	
TIME INCREMENT	0.50	MINUTES
SYSTEM CONSTANT W*	0.0	G/M2

TABLE B-6 (continued)

****

RESULTS OF BAGHOUSE ANALYSIS

****

SOUTHWEST PUBLIC SERVICE - MEDIUM LOAD DATA

FOR 28.00 MINUTES OPERATION, CYCLE NUMBER 10

AVERAGE PENETRATION= 3.79E-03
AVERAGE PRESSURE DROP= 1088.16 N/M2
AVERAGE SYSTEM FLOW= 0.7830 M/MIN
MAXIMUM PENETRATION= 5.03E-03
MAXIMUM PRESSURE DROP= 1151.75 N/M2

FOR 28.00 MINUTES OPERATION, CYCLE NUMBER 11

AVERAGE PENETRATION= 3.78E-03
AVERAGE PRESSURE DROP= 1084.68 N/M2
AVERAGE SYSTEM FLOW= 0.7830 M/MIN
MAXIMUM PENETRATION= 5.02E-03
MAXIMUM PRESSURE DROP= 1147.00 N/M2

FOR 28.00 MINUTES OPERATION, CYCLE NUMBER 12

AVERAGE PENETRATION= 3.77E-03
AVERAGE PRESSURE DROP= 1082.76 N/M2
AVERAGE SYSTEM FLOW= 0.7830 M/MIN
MAXIMUM PENETRATION= 5.01E-03
MAXIMUM PRESSURE DROP= 1144.31 N/M2

TABLE B-7. SOUTHWEST PUBLIC SERVICE SIMULATION - HIGH LOAD - S_E = 300 N-min/m^3

SUMMARY OF INPUT DATA FOR BAGHOUSE ANALYSIS

SOUTHWEST PUBLIC SERVICE - HIGH LOAD DATA

BASIC DESIGN DATA		
NUMBER OF COMPARTMENTS	14	
COMPARTMENT CLEANING TIME (OFF LINE TIME)	1.9	MINUTES
CLEANING CYCLE TIME	28.0	MINUTES
CONTINUOUSLY CLEANED SYSTEM		
REVERSE FLOW VELOCITY	1.5400	M/MIN
OPERATING DATA		
AVERAGE FACE VELOCITY	0.7980	M/MIN
GAS TEMPERATURE	165.	DEGREES CENTIGRADE
INLET DUST CONCENTRATION	2.94	G/M3
MEASURED AT	165.	DEGREES CENTIGRADE
FABRIC AND DUST PROPERTIES		
SPECIFIC RESISTANCE, K2	3.98	N-MIN/G-M
MEASURED AT	165.	DEGREES CENTIGRADE
	0.7980	M/MIN
EFFECTIVE RESIDUAL DRAG, SE	390.	N-MIN/M3
MEASURED AT	165.	DEGREES CENTIGRADE
RESIDUAL LOADING, WR	28.0	G/M2
SPECIAL PROGRAM INSTRUCTIONS		
MAX NUMBER OF CYCLES MODELED	20	
ACCURACY LEVEL	0	
TYPE OF RESULTS REQUESTED	SUMMARY /	
FRACTIONAL AREA CLEANED, AC	0.11	

TABLE B-7 (continued)

CALCULATED VALUES

INLET DUST CONCENTRATION CORRECTED TO OPERATING TEMPERATURE	2.94	G/M3
FABRIC AND DUST CAKE PROPERTIES CORRECTED FOR GAS VISCOSITY		
SPECIFIC CAKE RESISTANCE, K2	3.48	N-MIN/G-M
EFFECTIVE DRAG, SE	487.	N-MIN/M3
FRACTIONAL AREA CLEANED, AC	0.11	
TIME INCREMENT	0.50	MINUTES
SYSTEM CONSTANT W*	0.0	G/M2

TABLE B-7 (continued)

****

RESULTS OF BAGHOUSE ANALYSIS

****

SOUTHWEST PUBLIC SERVICE - HIGH LOAD DATA

FOR 28.00 MINUTES OPERATION, CYCLE NUMBER 10		
	AVERAGE PENETRATION=	4.35E-03
	AVERAGE PRESSURE DROP=	1631.07 N/M2
	AVERAGE SYSTEM FLOW=	0.8940 M/MIN
	MAXIMUM PENETRATION=	4.86E-03
	MAXIMUM PRESSURE DROP=	1726.53 N/M2
FOR 28.00 MINUTES OPERATION, CYCLE NUMBER 11		
	AVERAGE PENETRATION=	4.32E-03
	AVERAGE PRESSURE DROP=	1619.38 N/M2
	AVERAGE SYSTEM FLOW=	0.8940 M/MIN
	MAXIMUM PENETRATION=	4.82E-03
	MAXIMUM PRESSURE DROP=	1711.78 N/M2
FOR 28.00 MINUTES OPERATION, CYCLE NUMBER 12		
	AVERAGE PENETRATION=	4.29E-03
	AVERAGE PRESSURE DROP=	1610.83 N/M2
	AVERAGE SYSTEM FLOW=	0.8940 M/MIN
	MAXIMUM PENETRATION=	4.79E-03
	MAXIMUM PRESSURE DROP=	1701.34 N/M2

TABLE B-8. KRAMER STATION SIMULATION - TEST S

****

SUMMARY OF INPUT DATA FOR BAGHOUSE ANALYSIS

****

KRAMER - UNIT 2 - TEST - DATE 7/13/79

BASIC DESIGN DATA		
NUMBER OF COMPARTMENTS	10	
COMPARTMENT CLEANING TIME (OFF LINE TIME)	1.4	MINUTES
CLEANING CYCLE TIME	114.2	MINUTES
CONTINUOUSLY CLEANED SYSTEM		
REVERSE FLOW VELOCITY	0.6000	M/MIN
OPERATING DATA		
AVERAGE FACE VELOCITY	0.6000	M/MIN
GAS TEMPERATURE	185.	DEGREES CENTIGRADE
INLET DUST CONCENTRATION	1.37	G/M3
MEASURED AT	185.	DEGREES CENTIGRADE
FABRIC AND DUST PROPERTIES		
SPECIFIC RESISTANCE, K2	3.70	N-MIN/G-M
MEASURED AT	25.	DEGREES CENTIGRADE
	0.6100	M/MIN
EFFECTIVE RESIDUAL DRAG, SE	350.	N-MIN/M3
MEASURED AT	25.	DEGREES CENTIGRADE
RESIDUAL LOADING, WR	56.0	G/M2
SPECIAL PROGRAM INSTRUCTIONS		
MAX NUMBER OF CYCLES MODELED	20	
ACCURACY LEVEL	0	
TYPE OF RESULTS REQUESTED	AVERAGE	
FRACTIONAL AREA CLEANED, AC	0.52	

TABLE B-8 (continued)

CALCULATED VALUES

INLET DUST CONCENTRATION CORRECTED TO OPERATING TEMPERATURE	1.37	G/M3
FABRIC AND DUST CAKE PROPERTIES CORRECTED FOR GAS VISCOSITY		
SPECIFIC CAKE RESISTANCE, K2	5.06	N-MIN/G-M
EFFECTIVE DRAG, SE	763.	N-MIN/M3
FRACTIONAL AREA CLEANED, AC	0.52	
TIME INCREMENT	2.85	MINUTES
SYSTEM CONSTANT W*	0.0	G/M2

TABLE B-8 (continued)

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RESULTS OF BAGHOUSE ANALYSIS

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KRAMER - UNIT 2 - TEST      - DATE 7/13/79


FOR    114.20 MINUTES OPERATION,  CYCLE NUMBER   6
                                       AVERAGE PENETRATION=          6.07E-03
                                       AVERAGE PRESSURE DROP=          746.50 N/M2
                                       AVERAGE SYSTEM FLOW=            0.6075 M/MIN
                                       MAXIMUM PENETRATION=          1.09E-02
                                       MAXIMUM PRESSURE DROP=          893.32 N/M2

FOR    114.20 MINUTES OPERATION,  CYCLE NUMBER   7
                                       AVERAGE PENETRATION=          6.07E-03
                                       AVERAGE PRESSURE DROP=          746.42 N/M2
                                       AVERAGE SYSTEM FLOW=            0.6075 M/MIN
                                       MAXIMUM PENETRATION=          1.09E-02
                                       MAXIMUM PRESSURE DROP=          893.14 N/M2

FOR    114.20 MINUTES OPERATION,  CYCLE NUMBER   8
                                       AVERAGE PENETRATION=          6.07E-03
                                       AVERAGE PRESSURE DROP=          746.41 N/M2
                                       AVERAGE SYSTEM FLOW=            0.6075 M/MIN
                                       MAXIMUM PENETRATION=          1.09E-02
                                       MAXIMUM PRESSURE DROP=          893.11 N/M2
```

TABLE B-9. KRAMER STATION SIMULATION - TEST V

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SUMMARY OF INPUT DATA FOR BAGHOUSE ANALYSIS

****

KRAMER - UNIT 2 - TEST - DATE 1/22/80

BASIC DESIGN DATA		
NUMBER OF COMPARTMENTS	10	
COMPARTMENT CLEANING TIME (OFF LINE TIME)	1.4	MINUTES
CLEANING CYCLE TIME	114.2	MINUTES
CONTINUOUSLY CLEANED SYSTEM	--	
REVERSE FLOW VELOCITY	0.6000	M/MIN
OPERATING DATA		
AVERAGE FACE VELOCITY	0.4100	M/MIN
GAS TEMPERATURE	163.	DEGREES CENTIGRADE
INLET DUST CONCENTRATION	1.37	G/M3
MEASURED AT	163.	DEGREES CENTIGRADE
FABRIC AND DUST PROPERTIES		
SPECIFIC RESISTANCE, K2	3.70	N-MIN/G-M
MEASURED AT	25.	DEGREES CENTIGRADE
	0.6100	M/MIN
EFFECTIVE RESIDUAL DRAG, SE	350.	N-MIN/M3
MEASURED AT	25.	DEGREES CENTIGRADE
RESIDUAL LOADING, WR	56.0	G/M2
SPECIAL PROGRAM INSTRUCTIONS		
MAX NUMBER OF CYCLES MODELED	20	
ACCURACY LEVEL	0	
TYPE OF RESULTS REQUESTED	AVERAGE /	
FRACTIONAL AREA CLEANED, AC	0.21	

TABLE B-9 (continued)

CALCULATED VALUES

INLET DUST CONCENTRATION CORRECTED TO OPERATING TEMPERATURE	1.37	G/M3
FABRIC AND DUST CAKE PROPERTIES CORRECTED FOR GAS VISCOSITY		
SPECIFIC CAKE RESISTANCE, K2	4.89	N-MIN/G-M
EFFECTIVE DRAG, SE	737.	N-MIN/M3
FRACTIONAL AREA CLEANED, AC	0.21	
TIME INCREMENT	2.85	MINUTES
SYSTEM CONSTANT W*	0.0	G/M2

TABLE B-9 (continued)

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RESULTS OF BAGHOUSE ANALYSIS

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KRAMER - UNIT 2 - TEST   -  - DATE 1/22/80


FOR    114.20 MINUTES OPERATION,  CYCLE NUMBER  10
                                                AVERAGE PENETRATION=          3.39E-03
                                                AVERAGE PRESSURE DROP=          572.74 N/M2
                                                AVERAGE SYSTEM FLOW=            0.4175 M/MIN
                                                MAXIMUM PENETRATION=          5.70E-03
                                                MAXIMUM PRESSURE DROP=          705.10 N/M2

FOR    114.20 MINUTES OPERATION,  CYCLE NUMBER  11
                                                AVERAGE PENETRATION=          3.39E-03
                                                AVERAGE PRESSURE DROP=          572.15 N/M2
                                                AVERAGE SYSTEM FLOW=            0.4175 M/MIN
                                                MAXIMUM PENETRATION=          5.69E-03
                                                MAXIMUM PRESSURE DROP=          704.12 N/M2

FOR    114.20 MINUTES OPERATION,  CYCLE NUMBER  12
                                                AVERAGE PENETRATION=          3.39E-03
                                                AVERAGE PRESSURE DROP=          571.85 N/M2
                                                AVERAGE SYSTEM FLOW=            0.4175 M/MIN
                                                MAXIMUM PENETRATION=          5.69E-03
                                                MAXIMUM PRESSURE DROP=          703.64 N/M2
```

TABLE B-10. KRAMER STATION SIMULATION - TEST A

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SUMMARY OF INPUT DATA FOR BAGHOUSE ANALYSIS

****

KRAMER - UNIT 3 - TEST A - DATE 10/77

BASIC DESIGN DATA		
NUMBER OF COMPARTMENTS	10	
COMPARTMENT CLEANING TIME (OFF LINE TIME)	1.4	MINUTES
CLEANING CYCLE TIME	54.2	MINUTES
CONTINUOUSLY CLEANED SYSTEM		
REVERSE FLOW VELOCITY	0.6000	M/MIN
OPERATING DATA		
AVERAGE FACE VELOCITY	0.3800	M/MIN
GAS TEMPERATURE	149.	DEGREES CENTIGRADE
INLET DUST CONCENTRATION	1.29	G/M3
MEASURED AT	149.	DEGREES CENTIGRADE
FABRIC AND DUST PROPERTIES		
SPECIFIC RESISTANCE, K2	3.70	N-MIN/G-M
MEASURED AT	25.	DEGREES CENTIGRADE
	0.6100	M/MIN
EFFECTIVE RESIDUAL DRAG, SE	350.	N-MIN/M3
MEASURED AT	25.	DEGREES CENTIGRADE
RESIDUAL LOADING, WR	56.0	G/M2
SPECIAL PROGRAM INSTRUCTIONS		
MAX NUMBER OF CYCLES MODELED	20	
ACCURACY LEVEL	0	
TYPE OF RESULTS REQUESTED	AVERAGE /	
FRACTIONAL AREA CLEANED, AC	0.07	

TABLE B-10 (continued)

CALCULATED VALUES

INLET DUST CONCENTRATION CORRECTED TO OPERATING TEMPERATURE	1.29	G/M3
FABRIC AND DUST CAKE PROPERTIES CORRECTED FOR GAS VISCOSITY		
SPECIFIC CAKE RESISTANCE, K2	4.78	N-MIN/G-M
EFFECTIVE DRAG, SE	720.	N-MIN/M3
FRACTIONAL AREA CLEANED, AC	0.07	
TIME INCREMENT	1.35	MINUTES
SYSTEM CONSTANT W*	0.0	G/M2

TABLE B-10 (continued)

RESULTS OF BAGHOUSE ANALYSIS

KRAMER - UNIT 3 - TEST A - DATE 10/77

FOR 54.20 MINUTES OPERATION, CYCLE NUMBER 11			
	AVERAGE PENETRATION=	3.91E-03	
	AVERAGE PRESSURE DROP=	525.86	N/M2
	AVERAGE SYSTEM FLOW=	0.4025	M/MIN
	MAXIMUM PENETRATION=	4.68E-03	
	MAXIMUM PRESSURE DROP=	638.01	N/M2
FOR 54.20 MINUTES OPERATION, CYCLE NUMBER 12			
	AVERAGE PENETRATION=	3.89E-03	
	AVERAGE PRESSURE DROP=	521.56	N/M2
	AVERAGE SYSTEM FLOW=	0.4025	M/MIN
	MAXIMUM PENETRATION=	4.66E-03	
	MAXIMUM PRESSURE DROP=	631.91	N/M2
FOR 54.20 MINUTES OPERATION, CYCLE NUMBER 13			
	AVERAGE PENETRATION=	3.88E-03	
	AVERAGE PRESSURE DROP=	518.32	N/M2
	AVERAGE SYSTEM FLOW=	0.4025	M/MIN
	MAXIMUM PENETRATION=	4.63E-03	
	MAXIMUM PRESSURE DROP=	627.34	N/M2

TABLE B-11. KRAMER STATION SIMULATION - TEST 4

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SUMMARY OF INPUT DATA FOR BAGHOUSE ANALYSIS

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KRAMER - UNIT 3   TEST  4  - DATE 5/78

BASIC DESIGN DATA
     NUMBER OF COMPARTMENTS              10
     COMPARTMENT CLEANING TIME            1.4          MINUTES
       (OFF LINE TIME)
     CLEANING CYCLE TIME                 114.2         MINUTES
     CONTINUOUSLY CLEANED SYSTEM
     REVERSE FLOW VELOCITY               0.6000        M/MIN

OPERATING DATA
     AVERAGE FACE VELOCITY               0.3590        M/MIN
     GAS TEMPERATURE                     149.          DEGREES CENTIGRADE
     INLET DUST CONCENTRATION             1.69         G/M3
          MEASURED AT                    149.          DEGREES CENTIGRADE

FABRIC AND DUST PROPERTIES

     SPECIFIC RESISTANCE, K2              3.70         N-MIN/G-M
          MEASURED AT                     25.          DEGREES CENTIGRADE
                                         0.6100        M/MIN
     EFFECTIVE RESIDUAL DRAG, SE         350.          N-MIN/M3
          MEASURED AT                     25.          DEGREES CENTIGRADE
     RESIDUAL LOADING, WR                 56.0         G/M2

SPECIAL PROGRAM INSTRUCTIONS
     MAX NUMBER OF CYCLES MODELED        20
     ACCURACY LEVEL                      0
     TYPE OF RESULTS REQUESTED           AVERAGE /

     FRACTIONAL AREA CLEANED, AC       0.20
```

TABLE B-11 (continued)

CALCULATED VALUES

INLET DUST CONCENTRATION	1.69	G/M3
CORRECTED TO OPERATING TEMPERATURE		
FABRIC AND DUST CAKE PROPERTIES CORRECTED FOR GAS VISCOSITY		
SPECIFIC CAKE RESISTANCE, K2	4.78	N-MIN/G-M
EFFECTIVE DRAG, SE	720.	N-MIN/M3
FRACTIONAL AREA CLEANED, AC	0.20	
TIME INCREMENT	2.85	MINUTES
SYSTEM CONSTANT W*	0.0	G/M2

TABLE B-11 (continued)

****

RESULTS OF BAGHOUSE ANALYSIS

****

KRAMER - UNIT 3 TEST 4 - DATE 5/78

FOR 114.20 MINUTES OPERATION, CYCLE NUMBER 9

AVERAGE PENETRATION=	2.89E-03
AVERAGE PRESSURE DROP=	495.35 N/M2
AVERAGE SYSTEM FLOW=	0.3665 M/MIN
MAXIMUM PENETRATION=	5.29E-03
MAXIMUM PRESSURE DROP=	619.33 N/M2

FOR 114.20 MINUTES OPERATION, CYCLE NUMBER 10

AVERAGE PENETRATION=	2.89E-03
AVERAGE PRESSURE DROP=	494.28 N/M2
AVERAGE SYSTEM FLOW=	0.3665 M/MIN
MAXIMUM PENETRATION=	5.27E-03
MAXIMUM PRESSURE DROP=	617.53 N/M2

FOR 114.20 MINUTES OPERATION, CYCLE NUMBER 11

AVERAGE PENETRATION=	2.89E-03
AVERAGE PRESSURE DROP=	493.78 N/M2
AVERAGE SYSTEM FLOW=	0.3665 M/MIN
MAXIMUM PENETRATION=	5.27E-03
MAXIMUM PRESSURE DROP=	616.71 N/M2

TABLE B-12. KRAMER STATION SIMULATION - TEST 5

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SUMMARY OF INPUT DATA FOR BAGHOUSE ANALYSIS

****

KRAMER - UNIT 3 - TEST 5 - DATE 5/78

BASIC DESIGN DATA		
NUMBER OF COMPARTMENTS	10	
COMPARTMENT CLEANING TIME (OFF LINE TIME)	1.4	MINUTES
CLEANING CYCLE TIME	114.2	MINUTES
CONTINUOUSLY CLEANED SYSTEM		
REVERSE FLOW VELOCITY	0.6000	M/MIN
OPERATING DATA		
AVERAGE FACE VELOCITY	0.4600	M/MIN
GAS TEMPERATURE	149.	DEGREES CENTIGRADE
INLET DUST CONCENTRATION	0.69	G/M3
MEASURED AT	149.	DEGREES CENTIGRADE
FABRIC AND DUST PROPERTIES		
SPECIFIC RESISTANCE, K2	3.70	N-MIN/G-M
MEASURED AT	25.	DEGREES CENTIGRADE
	0.6100	M/MIN
EFFECTIVE RESIDUAL DRAG, SE	350.	N-MIN/M3
MEASURED AT	25.	DEGREES CENTIGRADE
RESIDUAL LOADING, WR	56.0	G/M2
SPECIAL PROGRAM INSTRUCTIONS		
MAX NUMBER OF CYCLES MODELED	20	
ACCURACY LEVEL	0	
TYPE OF RESULTS REQUESTED	AVERAGE /	
FRACTIONAL AREA CLEANED, AC	0.17	

TABLE B-12 (continued)

CALCULATED VALUES

INLET DUST CONCENTRATION CORRECTED TO OPERATING TEMPERATURE	0.69	G/M3
FABRIC AND DUST CAKE PROPERTIES CORRECTED FOR GAS VISCOSITY		
SPECIFIC CAKE RESISTANCE, K2	4.78	N-MIN/G-M
EFFECTIVE DRAG, SE	720.	N-MIN/M3
FRACTIONAL AREA CLEANED, AC	0.17	
TIME INCREMENT	2.85	MINUTES
SYSTEM CONSTANT W*	0.0	G/M2

TABLE B-12 (continued)

****

RESULTS OF BAGHOUSE ANALYSIS

****

KRAMER - UNIT 3 - TEST 5 - DATE 5/78

FOR 114.20 MINUTES OPERATION, CYCLE NUMBER 10

AVERAGE PENETRATION=	5.15E-03
AVERAGE PRESSURE DROP=	549.23 N/M2
AVERAGE SYSTEM FLOW=	0.4675 M/MIN
MAXIMUM PENETRATION=	6.69E-03
MAXIMUM PRESSURE DROP=	668.12 N/M2

FOR 114.20 MINUTES OPERATION, CYCLE NUMBER 11

AVERAGE PENETRATION=	5.14E-03
AVERAGE PRESSURE DROP=	547.59 N/M2
AVERAGE SYSTEM FLOW=	0.4675 M/MIN
MAXIMUM PENETRATION=	6.68E-03
MAXIMUM PRESSURE DROP=	665.60 N/M2

FOR 114.20 MINUTES OPERATION, CYCLE NUMBER 12

AVERAGE PENETRATION=	5.14E-03
AVERAGE PRESSURE DROP=	546.74 N/M2
AVERAGE SYSTEM FLOW=	0.4675 M/MIN
MAXIMUM PENETRATION=	6.67E-03
MAXIMUM PRESSURE DROP=	664.26 N/M2

TABLE B-13. KRAMER STATION SIMULATION - TEST 6

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*************************************************************************************
SUMMARY OF INPUT DATA FOR BAGHOUSE ANALYSIS
*************************************************************************************

KRAMER - UNIT 3 - TEST  6  - DATE 5/78

BASIC DESIGN DATA
     NUMBER OF COMPARTMENTS              10
     COMPARTMENT CLEANING TIME            1.4            MINUTES
       (OFF LINE TIME)
     CLEANING CYCLE TIME                 114.2           MINUTES
     CONTINUOUSLY CLEANED SYSTEM
     REVERSE FLOW VELOCITY               0.6000          M/MIN

OPERATING DATA
     AVERAGE FACE VELOCITY               0.5280          M/MIN
     GAS TEMPERATURE                     166.            DEGREES CENTIGRADE
     INLET DUST CONCENTRATION             2.82           G/M3
          MEASURED AT                    166.            DEGREES CENTIGRADE

FABRIC AND DUST PROPERTIES

     SPECIFIC RESISTANCE, K2              3.70           N-MIN/G-M
          MEASURED AT                     25.            DEGREES CENTIGRADE
                                         0.6100          M/MIN
     EFFECTIVE RESIDUAL DRAG, SE         350.            N-MIN/M3
          MEASURED AT                     25.            DEGREES CENTIGRADE
     RESIDUAL LOADING, WR                 56.0           G/M2

SPECIAL PROGRAM INSTRUCTIONS
     MAX NUMBER OF CYCLES MODELED        20
     ACCURACY LEVEL                      0
     TYPE OF RESULTS REQUESTED           AVERAGE /

     FRACTIONAL AREA CLEANED, AC       0.47
```

TABLE B-13 (continued)

CALCULATED VALUES

INLET DUST CONCENTRATION	2.82	G/M3
~~CORRECTED TO OPERATING TEMPERATURE~~		
FABRIC AND DUST CAKE PROPERTIES CORRECTED FOR GAS VISCOSITY		
SPECIFIC CAKE RESISTANCE, K2	4.92	N-MIN/G-M
EFFECTIVE DRAG, SE	740.	N-MIN/M3
FRACTIONAL AREA CLEANED, AC	0.47	
TIME INCREMENT	2.85	MINUTES
~~SYSTEM CONSTANT W*~~	~~0.0~~	~~G/M2~~

TABLE B-13 (continued)

****

RESULTS OF BAGHOUSE ANALYSIS

****

KRAMER - UNIT 3 - TEST 6 - DATE 5/78

FOR 114.20 MINUTES OPERATION, CYCLE NUMBER 6

AVERAGE PENETRATION=	3.51E-03
AVERAGE PRESSURE DROP=	803.48 N/M2
AVERAGE SYSTEM FLOW=	0.5355 M/MIN
MAXIMUM PENETRATION=	1.07E-02
MAXIMUM PRESSURE DROP=	979.87 N/M2

FOR 114.20 MINUTES OPERATION, CYCLE NUMBER 7

AVERAGE PENETRATION=	3.51E-03
AVERAGE PRESSURE DROP=	803.38 N/M2
AVERAGE SYSTEM FLOW=	0.5355 M/MIN
MAXIMUM PENETRATION=	1.07E-02
MAXIMUM PRESSURE DROP=	979.63 N/M2

FOR 114.20 MINUTES OPERATION, CYCLE NUMBER 8

AVERAGE PENETRATION=	3.51E-03
AVERAGE PRESSURE DROP=	803.36 N/M2
AVERAGE SYSTEM FLOW=	0.5355 M/MIN
MAXIMUM PENETRATION=	1.07E-02
MAXIMUM PRESSURE DROP=	979.58 N/M2

TABLE B-14. KRAMER STATION SIMULATION - TEST U

****

SUMMARY OF INPUT DATA FOR BAGHOUSE ANALYSIS

****

KRAMER - UNIT 4 - TEST - DATE 7/13/79

BASIC DESIGN DATA		
NUMBER OF COMPARTMENTS	16	
COMPARTMENT CLEANING TIME (OFF LINE TIME)	1.4	MINUTES
CLEANING CYCLE TIME	182.7	MINUTES
CONTINUOUSLY CLEANED SYSTEM		
REVERSE FLOW VELOCITY	0.5900	M/MIN
OPERATING DATA		
AVERAGE FACE VELOCITY	0.5600	M/MIN
GAS TEMPERATURE	208.	DEGREES CENTIGRADE
INLET DUST CONCENTRATION	0.92	G/M3
MEASURED AT	208.	DEGREES CENTIGRADE
FABRIC AND DUST PROPERTIES		
SPECIFIC RESISTANCE, K2	3.70	N-MIN/G-M
MEASURED AT	25.	DEGREES CENTIGRADE
	0.6100	M/MIN
EFFECTIVE RESIDUAL DRAG, SE	350.	N-MIN/M3
MEASURED AT	25.	DEGREES CENTIGRADE
RESIDUAL LOADING, WR	56.0	G/M2
SPECIAL PROGRAM INSTRUCTIONS		
MAX NUMBER OF CYCLES MODELED	20	
ACCURACY LEVEL	0	
TYPE OF RESULTS REQUESTED	AVERAGE /	
FRACTIONAL AREA CLEANED, AC	0.49	

TABLE B-14 (continued)

CALCULATED VALUES

INLET DUST CONCENTRATION CORRECTED TO OPERATING TEMPERATURE	0.92	G/M3
FABRIC AND DUST CAKE PROPERTIES CORRECTED FOR GAS VISCOSITY		
SPECIFIC CAKE RESISTANCE, K2	5.24	N-MIN/G-M
EFFECTIVE DRAG, SE	789.	N-MIN/M3
FRACTIONAL AREA CLEANED, AC	0.49	
TIME INCREMENT	2.85	MINUTES
SYSTEM CONSTANT WA	0.0	G/M2

TABLE B-14 (continued)

****

RESULTS OF BAGHOUSE ANALYSIS

****

KRAMER - UNIT 4 - TEST - DATE 7/13/79

FOR 182.70 MINUTES OPERATION, CYCLE NUMBER 6

AVERAGE PENETRATION=	6.04E-03
AVERAGE PRESSURE DROP=	704.77 N/M2
AVERAGE SYSTEM FLOW=	0.5646 M/MIN
MAXIMUM PENETRATION=	8.81E-03
MAXIMUM PRESSURE DROP=	790.71 N/M2

FOR 182.70 MINUTES OPERATION, CYCLE NUMBER 7

AVERAGE PENETRATION=	6.04E-03
AVERAGE PRESSURE DROP=	704.71 N/M2
AVERAGE SYSTEM FLOW=	0.5646 M/MIN
MAXIMUM PENETRATION=	8.81E-03
MAXIMUM PRESSURE DROP=	790.56 N/M2

FOR 182.70 MINUTES OPERATION, CYCLE NUMBER 8

AVERAGE PENETRATION=	6.04E-03
AVERAGE PRESSURE DROP=	704.70 N/M2
AVERAGE SYSTEM FLOW=	0.5646 M/MIN
MAXIMUM PENETRATION=	8.81E-03
MAXIMUM PRESSURE DROP=	790.53 N/M2

TABLE B-15. TEXAS UTILITIES - MONTICELLO STATION SIMULATION

****

SUMMARY OF INPUT DATA FOR BAGHOUSE ANALYSIS

****

TEXAS UTILITIES - MONTICELLO STATION

BASIC DESIGN DATA		
NUMBER OF COMPARTMENTS	18	
COMPARTMENT CLEANING TIME (OFF LINE TIME)	2.5	MINUTES
CLEANING CYCLE TIME	67.5	MINUTES
CONTINUOUSLY CLEANED SYSTEM		
REVERSE FLOW VELOCITY	0.0	M/MIN
OPERATING DATA		
AVERAGE FACE VELOCITY	0.7700	M/MIN
GAS TEMPERATURE	177.	DEGREES CENTIGRADE
INLET DUST CONCENTRATION	15.10	G/M3
MEASURED AT	177.	DEGREES CENTIGRADE
FABRIC AND DUST PROPERTIES		
SPECIFIC RESISTANCE, K2	1.00	N-MIN/G-M
MEASURED AT	25.	DEGREES CENTIGRADE
	0.6500	M/MIN
EFFECTIVE RESIDUAL DRAG, SE	350.	N-MIN/M3
MEASURED AT	25.	DEGREES CENTIGRADE
RESIDUAL LOADING, WR	50.0	G/M2
SPECIAL PROGRAM INSTRUCTIONS		
MAX NUMBER OF CYCLES MODELED	20	
ACCURACY LEVEL	0	
TYPE OF RESULTS REQUESTED	AVERAGE /	
FRACTIONAL AREA CLEANED, AC	0.52	

TABLE B-15 (continued)

[illegible]

INLET DUST CONCENTRATION CORRECTED TO OPERATING TEMPERATURE	15.10	G/M3
FABRIC AND DUST CAKE PROPERTIES CORRECTED FOR GAS VISCOSITY		
SPECIFIC CAKE RESISTANCE, K2	1.31	N-MIN/G-M
EFFECTIVE DRAG, SE	539.	N-MIN/M3
FRACTIONAL AREA CLEANED, AC	0.32	
TIME INCREMENT	0.94	MINUTES
SYSTEM CONSTANT **	0.0	G/M2

TABLE B-15 (continued)

****

RESULTS OF BAGHOUSE ANALYSIS

****

TEXAS UTILITIES - MONTICELLO STATION

FOR 67.50 MINUTES OPERATION, CYCLE NUMBER 6		
	AVERAGE PENETRATION=	2.46E-03
	AVERAGE PRESSURE DROP=	1735.76 N/M2
	AVERAGE SYSTEM FLOW=	0.7700 M/MIN
	MAXIMUM PENETRATION=	8.16E-03
	MAXIMUM PRESSURE DROP=	1845.18 N/M2
FOR 67.50 MINUTES OPERATION, CYCLE NUMBER 7		
	AVERAGE PENETRATION=	2.46E-03
	AVERAGE PRESSURE DROP=	1736.41 N/M2
	AVERAGE SYSTEM FLOW=	0.7700 M/MIN
	MAXIMUM PENETRATION=	8.16E-03
	MAXIMUM PRESSURE DROP=	1845.58 N/M2
FOR 67.50 MINUTES OPERATION, CYCLE NUMBER 8		
	AVERAGE PENETRATION=	2.46E-03
	AVERAGE PRESSURE DROP=	1736.63 N/M2
	AVERAGE SYSTEM FLOW=	0.7700 M/MIN
	MAXIMUM PENETRATION=	8.16E-03
	MAXIMUM PRESSURE DROP=	1845.71 N/M2

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/7-80-157	2.	3. RECIPIENT'S ACCESSION NO. PB 80 214182
4. TITLE AND SUBTITLE Fabric Filtration Analyses for Three Utility Boiler Flyashes		5. REPORT DATE Sept. 1980 Issuing Date.
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) H.A. Klemm, J.A. Dirgo, and Richard Dennis		8. PERFORMING ORGANIZATION REPORT NO. GCA-TR-80-37-G
9. PERFORMING ORGANIZATION NAME AND ADDRESS GCA/Technology Division, 213 Burlington Road, Bedford, Massachusetts 01730		10. PROGRAM ELEMENT NO. EHE624A
		11. CONTRACT/GRANT NO. 68-02-2607, Task 35
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15. SUPPLEMENTARY NOTES Project officer James H. Turner is no longer with the Agency; for technical details, contact Louis Hovis, IERL-RTP, Mail Drop 61, 919/541-2925.

16. ABSTRACT The report gives results of fabric filter analyses of flyash from three utility boilers. A major aim of the program was to augment the present data base for modeling fabric filter systems designed to control inhalable particulate (IP) emissions from coal-fired boilers. Emphasis was placed on the determination of K sub 2, the flyash specific resistance coefficient, and a sub c, a parameter describing fabric cleanability. Fabric filter design, operating, and performance data were analyzed with the assistance of utility personnel from Harrington and Monticello stations in Texas and Kramer station in Nebraska. Supplementary laboratory determinations of K sub 2 were made for flyash produced by the three plants because K sub 2 could not be estimated from field data alone. Based on laboratory tests, it was determined that flyash surface deposits underwent negligible porosity changes for fabric pressure losses <2000 N/sq m. Also, a simple field procedure was developed to measure K sub 2 directly with the aid of heat-resistant membrane filters and a Method 17 in-situ sampling probe. Detailed analyses and modeling trials indicated that K sub 2 and a sub c estimates developed from routine compliance or acceptance tests were too rough for dependable modeling, although providing useful guidelines. Laboratory-estimated K sub 2 was 0.89-3.79 N-min/g-m; a sub c was 0.01-0.52.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group	
Pollution	Analyzing	Pollution Control	13B	14B
Fabrics	Mathematical Models	Stationary Sources	11E	12A
Filtration	Sampling	Fabric Filtration	07D	
Fly Ash	Measurement	Utility Boilers	21B	
Boilers			13A	
Utilities				

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