United States
Environmental Protection
Agency

Industrial Environmental Research
Laboratory
Research Triangle Park NC 27711

EPA-600/7-79-043a
February 1979

EPA

Fabric Filter Model Format Change; Volume I. Detailed Technical Report

Interagency Energy/Environment R&D Program Report

RESEARCH REPORTING SERIES

Research reports of the Office of Research and Development, U.S. Environmental Protection Agency, have been grouped into nine series. These nine broad categories were established to facilitate further development and application of environmental technology. Elimination of traditional grouping was consciously planned to foster technology transfer and a maximum interface in related fields. The nine series are:

1. Environmental Health Effects Research
2. Environmental Protection Technology
3. Ecological Research
4. Environmental Monitoring
5. Socioeconomic Environmental Studies
6. Scientific and Technical Assessment Reports (STAR)
7. Interagency Energy-Environment Research and Development
8. "Special" Reports
9. Miscellaneous Reports

This report has been assigned to the INTERAGENCY ENERGY-ENVIRONMENT RESEARCH AND DEVELOPMENT series. Reports in this series result from the effort funded under the 17-agency Federal Energy/Environment Research and Development Program. These studies relate to EPA's mission to protect the public health and welfare from adverse effects of pollutants associated with energy systems. The goal of the Program is to assure the rapid development of domestic energy supplies in an environmentally-compatible manner by providing the necessary environmental data and control technology. Investigations include analyses of the transport of energy-related pollutants and their health and ecological effects; assessments of, and development of, control technologies for energy systems; and integrated assessments of a wide-range of energy-related environmental issues.

EPA REVIEW NOTICE

This report has been reviewed by the participating Federal Agencies, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Government, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

EPA-600/7-79-043a

February 1979

Fabric Filter Model Format Change; Volume I. Detailed Technical Report

by

Richard Dennis and Hans A. Klemm

GCA Corporation
GCA/Technology Division
Bedford, Massachusetts 01730

Contract No. 68-02-2607
Task No. 8
Program Element No. EHE624

EPA Project Officer: James H. Turner

Industrial Environmental Research Laboratory
Office of Energy, Minerals, and Industry
Research Triangle Park, NC 27711

Prepared for

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Research and Development
Washington, DC 20460

ABSTRACT

A new mathematical model is described for use by control personnel to determine the adequacy of existing or proposed filter systems designed to minimize coal fly ash emissions. Although the basic model design is similar to that discussed in an earlier report, several improvements and many timesaving steps have been introduced so that the immediate needs of agency and other emissions control enforcement groups can be met. To further aid the model user, the study has been presented in two volumes, the first a Detailed Technical Report and the second a User's Guide.

The model is structured so that by using the combustion, operating, and design parameters indicated by power plant and/or manufacturing personnel, the program user can forecast the expected particulate emissions and filter pressure loss.

The program affords the option of providing readily appraised summary performance statistics or highly detailed results if the latter are necessary. Several built in error checks prevent the generation of useless data and avoid unnecessary computer time.

The model takes into account the concentration and specific resistance properties of the dust, air/cloth ratio, sequential compartmentized operation and the method, intensity and frequency of cleaning. The model function depends upon the unique fabric cleaning and dust penetration properties observed with several coal fly ashes (including lignite) and woven glass fabrics. Prior validation of a precursor model showed excellent agreement with measured field performance for the Sunbury, Pennsylvania and Nucla, Colorado fabric filter systems.

CONTENTS

FIGURES

FIGURES (continued)

TABLES

TABLES (continued)

ACKNOWLEDGEMENT

The authors express their most sincere appreciation to Dr. James H. Turner, EPA Project Officer, for his advice, discerning technical reviews and encouragement throughout the present and precursor modeling studies. We also wish to acknowledge the capable support of Mr. William H. Battye in the intricacies of programming and Messrs. Robert R. Hall, Peter H. Anderson and William F. Ostrowski for their appraisal and testing of the model format.

1.0 SUMMARY

A mathematical model is described for use by agency and other personnel to determine the adequacy of proposed filter systems designed to minimize coal fly ash emissions. The operating principles of the model have been discussed at length in an earlier report that includes not only the model development per se but also detailed descriptions of laboratory and field tests performed to provide the necessary data base.[1]

Originally, many supporting calculations and estimating processes were performed outside the computer program to provide more latitude in model validation experiments. Unfortunately, this approach was overly complicated and confusing except to those individuals who were concerned with filtration research. Therefore, the improved model described in this report has been structured so so that emissions enforcement personnel can carry out the same modeling processes discussed earlier but with minimal calculations outside the model. Similarly, the input data (or its absence) determines the most reasonable path for program execution so that the model user is spared many decisions relative to methods of computation, choice of iteration intervals and length of program operation required to depict a steady state operation. Although the present study is concerned mainly with the new model development and, particularly, its practical application, it is emphasized that the engineer should obtain as much background combustion and filter system information as possible before undertaking any predictive modeling.

The basis for the filtration model design is reviewed in Section 3 of this report. The introduction of three new concepts has made it possible to estimate the performance of a multicompartment filter system in much more realistic fashion than previously possible.

The first describes dust separation from woven fabrics as a flaking-off process wherein the application of cleaning energy causes dust separation to occur at the dust layer-fabric interface. Because the cleaning produces uniquely cleaned or uncleaned areas whose drag and dust holdings are definable, subsequent filtration and dust deposition rates as well as drag and penetration characteristics can be estimated for the several surface elements making up the whole filter.

The second concept is based upon a straightforward description of the fabric cleaning process that relates the amount of dust removed to the method of cleaning and the prior dust loading on the fabric surface. Although both collapse with reverse flow and mechanical shaking have been quantitated, the collapse and reverse flow process is expected to see the most use in the present model for fly ash filtration with woven glass fabrics.

The third concept evolves from the unique penetration behavior exhibited by glass fabrics woven from multifilament and bulked yarns. Because of extensive penetration through pinhole leaks ($\sim$100 μm diameter), the estimated size properties of many fly ash aerosols undergo little change in passing through the filter.

Section 4 deals mainly with modifications and additions to the model originating during the current program. For example, it is now possible to compute K_2 entirely within the model by introducing relevant input data that may include temperature and velocity of K_2 measurement, and dust size and density properties. The same applies to the estimation of a_c, the fraction of filter area cleaned by any specified cleaning regimen with respect to the frequency and intensity of energy input. In addition, all input parameters such as effective drag, K_2 and inlet dust concentration that are subject to adjustments for temperature, velocity or size properties are automatically corrected from reference to test conditions by the program. In the absence of certain data, the program will also assign reasonable "default" values so that the program will continue to function.

In Section 5, a step-by-step description of every aspect of the modeling procedure is presented including the specific calculation steps involved in the numerous iterative processes. Here, the role of each major program routine and subroutine is described. Additionally, a complete listing of all variables constituting model data are described with respect to identifying symbols, units of measurement and method and location of entry on program data input cards. Examples are given for the various types of data printout provided by the program. The level of detail in the printout and the level of accuracy required are determined by the model user who introduces the terms DETAILED, SUMMARY or AVERAGE as instructions to the model. In most cases, it is expected that "average" values for pressure drop and dust penetration over a complete cycle (as well as the maximum levels attained by both variables) will suffice to describe system performance. Although ± 1 percent accuracy should satisfy most field applications the model user can select a more stringent level if desired.

In addition to the model per se, guideline tables and graphs (Section 6) have been prepared whose main role it to emphasize the relative importance of the system variables. These data demonstrate how the absolute and relative values of many variables interact in determining overall filter system performance. Used correctly, the above guidelines may help to identify unacceptable or incomplete data prior to carrying out any rigorous modeling.

Several appendices provide additional examples of model uses as well as the key details on program use, routines and card listings required by the programmer.

2.0 INTRODUCTION

2.1 PROGRAM OBJECTIVE

GCA/Technology Division, under contract with the U.S. Environmental Protection Agency,* has developed a mathematical model to describe the performance of woven glass fabric filters used for the collection of coal fly ash.[1,2,3,4] In its original format, certain supporting calculations and estimating processes were performed outside the computer program so that the researcher might have more latitude in his modeling experiments. The above format is not desirable nor necessary, however, if pollution control personnel are required to determine whether an existing or proposed filtration system will meet current particulate emission standards. Aside from requiring decisions best relegated to the filtration expert, the original model also provided a more rigorous analysis of probable filter system performance than that ordinarily demanded to support enforcement personnel in their decision making.

What is required by the pollution control engineer is a relatively uncomplicated procedure whereby he can input specific values for the controlling filtration and process parameters into a predictive model and receive as output a summary of the probable system performance. The present model is directed specifically to fly ash removal from coal-fired boiler effluents where woven glass fabrics constitute the dust collection medium and where the average and

*Contract No. 68-02-1438, Task No. 5, Program Element No. EHE624 maximum particulate concentrations are the primary concern. At the same time, however, the model output should also indicate whether the predicted ranges in fabric pressure loss and the frequency of fabric cleaning are consistent with design specifications. For example, if system operation plans originally postulated intermittent cleaning; e.g., every 2 hours, whereas the model indicates that continuous cleaning will be required, an increase in operating pressure loss and a shortening in fabric service life might be signaled. Both the control agency and the equipment user are thus alerted to potential problems that can be investigated before system construction is undertaken.

The primary objective of this study was to modify the original fabric filtration model developed under prior contract with the U.S. Environmental Protection Agency[1] so that enforcement personnel can use it without extensive training in filtration technology. Although the proposed modifications are intended to provide both diagnostic and design capabilities, it is expected that the former application will see the greatest use.

If it is desired to ascertain whether a filter system scheduled for construction or just about ready to go on-line will meet local, state, or federal emission standards, the engineer making this assessment will use the operating, fabric and dust parameters provided by the user and/or the collector manufacturer. Unless the model indicates that the filter system will not satisfy the emission requirements, time constraints will probably not allow enforcement personnel to determine whether, in fact, the cleaning system is providing optimum performance. The latter effort is the responsibility of the user or manufacturer along with the adoption of any corrective measures needed to bring the system into compliance.

2.2 TECHNICAL APPROACH

As a general approach to simplifying the model so that the user is not required to make decisions nor to perform calculations beyond the realm of a basic understanding of filtration technology, the following steps were considered.

- Certain calculations now performed outside the program, for example, the estimation of the parameter a_c that is used within the program to determine the effect of degree of fabric cleaning on overall emission and resistance characteristics, should be carried out within the program by introducing the appropriate terms to a new subroutine.
- In those cases where the filtration engineer is given the option to use an approximate linear drag versus the nonlinear relationship that more closely describes the actual filtering process, the linear approach is recommended unless the key nonlinear parameters can be accurately defined.
- Selection of a limiting pressure loss at which fabric cleaning will be initiated should be based upon operating conditions where total system flow passes through the on-line compartments only.
- When no data are available to define K_2, K_R, S_E, S_R and W_R, provision should be made to calculate K_2 within the model from measured or estimated values of particle size properties, particle density and nominal bulk density.
- When no direct measurements are available for S_E and W_R for the system under study, the average values derived from previous studies should be used.

- Supplementary graphs or charts indicating model response or sensitivity to numerical changes in input variables should be provided the model user to avoid overly conservative or overly generous estimates of filter system performance.
- The format of the input data should be changed, where appropriate, to enable the user to enter data in a more organized or practical fashion, e.g., Baghouse Design Parameters, Combustion Parameters, Filtration Parameters and Fabric and Dust Parameters.
- Brief instructions should be prepared describing how raw data should be translated to computer input. The rationale for selecting specific model outputs should be pointed out to the model user. Available choices should be designated as:

  Detailed - point by point variations over the entire baghouse with respect to time and fabric location

  Engineering - enough information to describe point-by-point operation with respect to time but averaged over the entire baghouse

  Summary - no point-by-point variations, with average values only for important parameters.

2.3 BACKGROUND INFORMATION

2.3.1 General Appraisal of Filtration Process - Existing System

Field enforcement personnel must be able to determine whether particulate emission levels from a given coal-fired combustion source will comply with pollution regulations. The efficiency of gas cleaning controls for existing systems can ordinarily be established on the basis of standard EPA testing procedures involving extractive stack sampling[5] to determine controlled and uncontrolled particulate emission levels and visual estimates of plume opacity. Preliminary observations of the plume appearance, if detectible, and any periodic or random excursions in opacity from allowable levels will often aid in evaluating the gas cleaning equipment when related to load level changes or tube blowing procedures.

2.3.2 Combustion Process in Compliance with Emission Regulations

If the plant undergoing inspection shows no visible evidence of poor control equipment, has no past history of complaints and all compliance testing has indicated satisfactory performance the task of the enforcement engineer is made simple. However, it is very important that data be gathered describing the plant operating conditions at the time of inspection, including fuel type and load level, and design and operating parameters for the particulate control system. In the latter instances, information should be obtained on air-to-cloth ratios, operating temperatures and controls for the baghouse, method and frequency of fabric cleaning, maintenance protocol, standby equipment and emergency procedures. A file of dust collector performance data coupled with the design and operating parameters associated with equipment use provides a sound basis for future control equipment appraisals. Because of time restrictions, predictive modeling procedures would <u>not</u> be performed, unless some unique operational aspect of a given control system afforded a chance to improve the model structure.

2.3.3 Combustion Process Not in Compliance with Emission Regulations

When a coal-burning power station fails to comply with emission regulations, the extent to which enforcement personnel can hasten the correction of operating difficulties depends upon their knowledge of both combustion and filtration processes along with an awareness of the key problem areas. Prior to resorting to any diagnostic modeling processes, the engineer should compare the original design and operating specifications established by the user and/or the supplier of the filtration equipment with the actual procedures in use at the time of noncompliance with emission regulations. A representative, but not necessarily a complete, listing of several factors that should be considered by enforcement engineers is shown in Table 1.

Although most items listed in Table 1 are self-explanatory, a few comments are in order for certain factors that are often associated with system malfunctions or substandard performance. For example, failure to allow for possible increases in MW load level (Item 1) or increased ash content in the coal (Item 4) will demand increased fabric cleaning (Item 7) if the system is to be operated within the assigned pressure constraints. The result may be decreased bag life accompanied by much higher particle emission rates because of bag damage and greater filtration velocities. An attempt to reduce both space requirements and collector and fabric costs by operating at higher air-to-cloth ratios (Item 6) poses the risk of increased dust penetration and reduces the margin in collector capacity to accommodate to power levels or dust concentrations higher than specified in the original design. The items discussed above represent actions that can be undertaken by the engineer without a rigorous inspection of the malfunctioning filtration facility.

TABLE 1. SUPPORTING DATA FOR EVALUATION OF COMBUSTION AND FILTRATION PROCESSES

Operational or design factor	Expected effects	Special precautions and/or problems
1. Base load or peaking boiler	Variability in flue gas volume, temperature and dust concentration and composition.	Size filter for maximum flow-size compartment and duct heating equipment for minimum flow. Note possible changes in dust properties with flow rate.
2. New system or retrofit	Higher costs with retrofit, deviations from good design because of limited space.	Possible flow distribution and duct or manifold dust settlement problems. Excess dust penetration in high gas flow regions.
3. Fan capacity and response to variable static load	Cleaning frequency varies with fan static capability. Possible variation in gas handling capacity with large changes in filter pressure loss.	Frequent cleaning needed for low bag pressure loss can decrease bag life. Overresponse of draft fans to static pressure changes can cause load level variations
4. Type of coal	Size and composition of uncontrolled effluent depends on ash and sulfur content of fuel.	Design for maximum ash content. Be alert for changes in size properties or H_2SO_4 condensation with high sulfur coals.
5. Design resistance (pressure loss) across fabric filter	Fan power requirements increase with filter pressure loss. High design resistance allows more flexibility in dust concentrations and air-to-cloth ratio.	Design pressure loss limit should be based on highest possible fabric loadings and/or flue gas flow rate.
6. Design air-to-cloth ratio (face velocity)	The higher the face velocity the less fabric area (and cost) required. Conversely, resistance and fan power needs are greater.	High velocity operation requires base load operation with constant ash content. Penetration will be higher although usually not excessive.
7. Cleaning frequency and intensity	Filter pressure loss and fan power vary inversely with frequency and intensity of cleaning. Excursions from mean operating resistance are minimized.	Fabric wear increases with rate and intensity of cleaning. Particulate emissions may be higher due to overcleaning.
8. Materials of construction, damper design, pressure and temperature sensing, and fabric cleaning controls	Good construction and instrumentation practice precludes panel warping, gasket failures, corrosion and condensation in baghouse.	Leakage of cold air into baghouse with condensation and bag plugging. Cooling due to insufficient insulation. Rusting and jamming of compartment dampers. Failure to initiate cleaning at specified pressure level or to activate supplementary heaters.
9. Maintenance and safety features Standby compartment Bypass capability Alarm systems	Standby compartment permits safer and more rapid inspection and maintenance. Bypass capability prevents irreversible damage to fabrics and allows for safe boiler turn down. Excessive pressure drop alarms may prevent bag rupture.	Proper maintenance avoids equipment breakdown. Lack of alarm systems may cause loss of several bags, and also lead to decreased excess air in combustion process.

No decisions or actions should be undertaken to bring a system into compliance, however, until a thorough inspection of the physical plant has been made, preferably by both enforcement and user personnel. Again, a representative but not necessarily complete listing of the more common field problems are summarized in Table 2. Many of the conditions described in Table 2 are the obvious results of a poor operating and maintenance regimen, particularly so the rusting surfaces, missing bags, defective gauges, insulation free surfaces, overflowing dust hopper and heavy dust deposition on bag compartment walls and floor. On the other hand, certain problems relating to torn or apparently plugged bags may arise from improper tensioning or insufficient heating to maintain bag compartments above dew point temperatures. Operation of the system at too high an air-to-cloth ratio or failing to clean the fabric at sufficient intensity or frequency may also be reflected by damaged fabric and/or excessive dust penetration.

Therefore, even if the filter system is put back in order with the bags replaced and other defects corrected, it is possible that initially acceptable emissions will revert to noncompliance levels in a short time unless the basic faults are corrected. In the situation just described, it would aid the enforcement engineer if he could determine by means of a filtration model whether one could ever expect to meet the performance specifications (pressure loss and effluent concentration) with the actual combustion-related and operation parameters. If not, preliminary guidelines for corrective changes would automatically evolve from the model output.

2.4 APPRAISAL OF DESIGN SPECIFICATIONS

In reviewing plans and operating specifications for new systems, the following guidelines may be available to aid enforcement personnel in their

TABLE 2. TYPICAL CAUSES FOR AND INDICATIONS OF EMISSIONS NONCOMPLIANCE FOR FABRIC FILTERS

1. Fabric Bags

   Missing, torn or nonuniformly tensioned bags

2. Clean-Air Side of Bag Compartment

   Gross fabric soiling, dust accumulation on floor

3. Compartment, Duct and Hopper Leakage

   Corroded panels, rust stains, peeling paint, damaged insulation, holes, defective gaskets

4. Missing or Nonfunctioning Gauges

   Temperature, compartment pressure

5. Defective Dampers (Compartment Isolation)

   Incomplete damper closure, minimal compartment cleaning, dust accumulation near dampers, disconnected controls

6. Over-filled Dust Hopper, Screw Conveyor

   Minimal flow to plugged compartment, dust pile up inside bags above tube sheet

7. Defective Temperature Sensing and Compartment Heating

   Moisture and condensation in compartment, rusting and probably damaged bags

8. Defective Cleaning System Controls

   Damper closing incomplete or out of sequence, excessive system pressure loss evaluations. First, the new system may replicate closely in physical design and operating conditions an on-line system for which performance data are available. Second, pilot scale field tests may have been performed for similar boiler designs and fuel properties where the dust permeability of the fly ash can be established even though operating electrical load levels may differ. Third, the filter system supplier has selected a set of average or typical operating parameters that admittedly may be conservative. The supplier then proposes to "tune" the installed system on a trial-and-error basis to an operating regimen that will conform to the required pressure loss and effluent concentration levels.

The probability of success with the preliminary (or trial) parameters depends largely on the experience, intuition and conservatism of the vendor. Here, the application of reliable modeling techniques by the supplier and/or the enforcement engineer should improve the reliability of any estimates of probable system performance. At this point, it should be emphasized that if the enforcement group is the first to use the modeling approach (which for the moment will be assumed to carry enough technical weight to justify design changes in the system) then the equipment supplier may be placed in the unfortunate position of having to make several costly drawing modifications or purchase order changes. Therefore, it would appear logical that fabric filter manufacturers adopt in their design efforts the same modeling procedures that enforcement personnel will use in their assessment of the system capability.

3.0 BASIS FOR EXPERIMENTAL MODEL DESIGN

3.1 WORKING EQUATIONS

The developmental aspects for the filtration model have been discussed in several recent publications.[1-4] It suffices here to point out that the model embraces several well recognized filtration principles that have been reviewed extensively by Billings and Wilder.[6] A listing of the basic equations used to estimate individual filtration parameters and/or to establish their roles within the filtration model is given in Table 3. The indicated relationships include those used in the original experimental model[1] as well as some recent additions from the current program; i.e., Equations 6, 7 and 9. The development and use of the latter equations will be described in the next section. The drag curve in Figure 1 and Equations la, lb, and 5 through 9 in Table 3 typify some of the fundamental relationships used in the model design.

3.2 NEW FILTRATION CONCEPTS

The introduction of three new concepts, however, has made it possible to estimate the performance of a multicompartment filter system in much more realistic fashion than previously possible.

The first describes dust separation from woven fabrics as a flaking-off process wherein the application of cleaning energy causes dust separation to occur at the dust layer-fabric interface. The result is that the first cleaning of a uniformly loaded fabric produces two characteristic regions, the bright, cleaned areas shown in Figure 2 and the adjacent, uncleaned areas from which no dust is dislodged.[1,2] Because there exist characteristic values for the

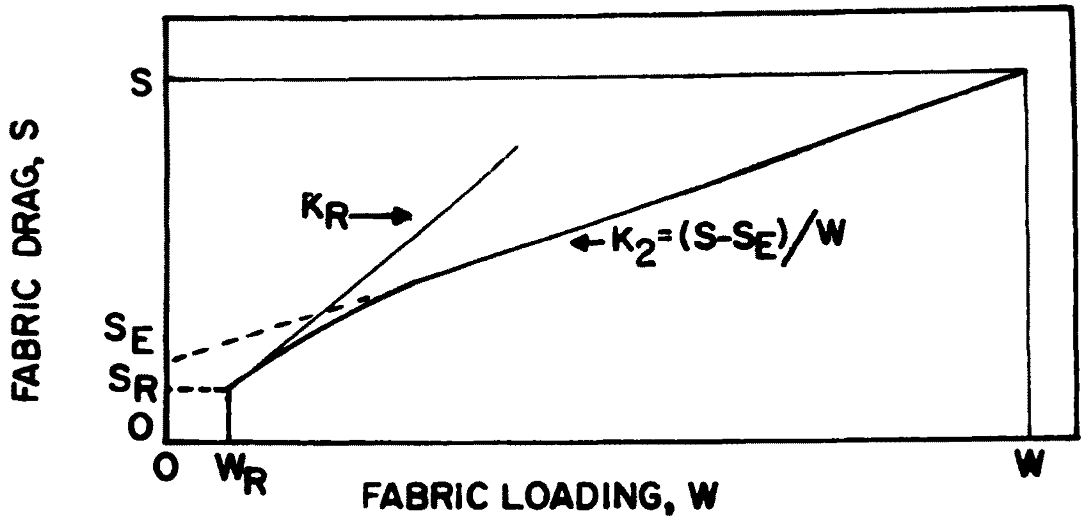

Figure 1. Linear and curvilinear drag versus fabric loading curves

Figure 2. Cleaned (bright) and uncleaned (dark) areas of glass bag with partial fly ash removal. Inside illumination with fluorescent tube

TABLE 3. SUMMARY OF MATHEMATICAL RELATIONSHIPS USED TO MODEL FABRIC FILTER PERFORMANCE

Equation number	Equation	Comments	Terms and units
(1a)	$S = P/V = S_E + K_2 W$	Equations (1a) and (1b), which are used for the linear model, relate filter drag, S, or pressure loss, P, to fabric loading, W. P_L is the limiting pressure loss and W_P the corresponding fabric loading. Cleaning initiated at P_L. S_E is the effective residual drag, W_R the residual fabric loading for the cleaned areas, K_2 the dust specific resistance coefficient and V the face velocity.	$P, P_L = N/m^2$ $S, S_E = \frac{N\text{-}min}{m^3}$ $V = m/min$ $W, W_R = g/m^2$ $K_2 = \frac{N\text{-}min}{g\text{-}m}$ See Figure 1.
(1b)	$P_L = S_E V + K_2 V (W_P - W_R)$		
(2)	$S = S_R + K_2 W' + (K_R - K_2) W^* \left(1 - \exp(-W'/W^*)\right)$ $W' = W - W_R$	Equations (2) and (3), which are used for nonlinear model, describe initial curvature often seen in S versus W curves and also the later approach to linearity. K_R is the initial slope for curvilinear region, S_R the actual residual drag for cleaned area, and W^* a system constant. If W^* is zero, program automatically uses linear model.	$K_R = \frac{N\text{-}m}{g\text{-}m}$ $S_R = \frac{N\text{-}min}{m^3}$ $W^* = g/m^2$ See Figure 2.
(3)	$W^* = (S_E - S_R + K_2 W_R)/K_R - K_2$		
(4)	$S = P/V = \left(\sum_{i=1}^{n} \frac{a_c}{S_c} + \frac{a_{u_1}}{S_{u_1}} + \dots \frac{a_{u_i}}{S_{u_i}}\right)^{-1} A$	Equation (4) describes resultant drag for parallel flow through cleaned and uncleaned regions of fabric surface. The term a_c denotes cleaned fraction of fabric surface with its initial cleaned drag, S_c. "A" refers to total surface fraction and "n" to the total number of fabric elements. Subscript "u" refers to all areas not "just cleaned."	a_c = dimensionless $S_c, S_u = \frac{N\text{-}min}{m^3}$ A = dimensionless = 1.0 See Figures 1 and 2.
(5)	$K_2 = 1.8\ V^{1/2}$	Equation (5) describes effect of face velocity on K_2 with coal fly ash, (MMD = 9 μm and σ_g = 3) and at temperature T = 25 °C	$MMD = cm^{-1}$ σ_g = dimensionless $T = {}^{\circ}C$
(6)	$(K_2)_f = (K_2)_m \left[(S_o)_f \Big/ (S_o)_m \right]^2$	Equation (6) defines K_2 for filtration conditions (f) when the K_2 value is available for the same dust but with different measured (m) specific surface properties, S_o.	$S_{o_f}, S_{o_m} = cm^{-1}$
(7)	$K_2 = \frac{\mu S_o^2}{6 \rho_p C_c} \left[\frac{3 + 2(\beta)^{5/3}}{3 - 4.5(\beta)^{1/3} + 4.5(\beta)^{5/3} - 3(\beta)^2} \right]$	Equation (7) predicts K_2 in terms of gas viscosity, μ, specific surface parameter, S_o, cake bulk density, $\bar{\rho}$, and discrete particle density, ρ_p. Equation (7) used only when no direct K_2 measurements are available. The Cunningham correction, C_c, approaches one for large (fly ash) particles.	μ = poise $\bar{\rho}_p, \rho_p = g/cm^3$ ε = dimensionless C_c = dimensionless
(8)	$1 - \bar{\rho}_p/\rho_p = \varepsilon\ ;\ \bar{\rho}/\rho_p = \beta$		

TABLE 3 (continued)

Equation number	Equation	Comments	Terms and units
(9)	$S_o = 6\left(\frac{10^{1.151 \log^2 \sigma_g}}{MMD}\right)$	Equation (9) computes distribution specific surface parameter, S_o, from cascade impactor data for a logarithmic normal mass distribution.	S_o = cm^{-1}
		<u>Reverse Flow with Bag Collapse</u>	
(10)	$W_P' = \frac{P_L - S_E V}{K_2 V} + W_R + \frac{C_i\ V\ \Sigma t}{2}$	Intermittent, pressure controlled cleaning. Substitution of W_P' from Equation (10) in Equation (11) gives area fraction cleaned, a_c, as function of limiting pressure loss, P_L, and previously cited system parameters. W_P' accounts for the fact that the average W_P' value over the cleaning cycle will exceed the initial values.	a_c = dimensionless
(11)	$a_c = 1.51 \times 10^{-8}\ W_P'^{2.52}$		
(12)	$a_c = (6.00 \times 10^{-3})\ (V\ C_i\ t_c)^{0.715}$ $t_c = \Sigma t + t_f$	Intermittent, time controlled cleaning. Equation (12) applies when total cycle time, t_c, is given. Note that t_c is the sum of time required to clean all compartments, Σt, plus the time between compartment cleaning, t_f. Face velocity, V, and inlet concentration, C_i, must be nearly constant for safe use of time control.	t_c, Σt, t_f = min C_i = g/m^3 V = m/min
(13)	$W_P = 166.4\ (C_i\ V\ \Sigma t)^{0.284}$	Continuously cleaned system. Equation (13), which shows dust loading on compartment ready for cleaning, applies when $W_P \geq 10$ times W_R.	n = number of compartments
(14)	$a_c = (6.00 \times 10^{-3})\ (V\ C_i\ \Sigma t)^{0.715}$	Equation (14) computes a_c for a continuously cleaned system where Σt is the time to clean all compartments.	
		<u>Mechanical Shaking</u>	
(15)	$a_c = 2.23 \times 10^{-12}\ (f^2\ A_s\ W_P')^{2.52}$	Intermittent, pressure controlled cleaning system. Substitution of W_P' from Equation (10) in Equation (15) in conjunction with shaking parameters f and A_s determines a_c. W_P' accounts for the fact that the average W_p value over the cleaning cycle will exceed the initial values.	a_c = dimensionless f = shaking frequency = Hz A_s = shaking frequency = cm
(16)	$a_c = 4.9 \times 10^{-3}\ (f^2\ A_s\ C_i\ V\Sigma t)^{0.715}$	Continuously cleaned system. Equation (16) computes a_c in terms of cleaning parameters f and A_s and the dust accumulation over the time required to clean all compartments ($C_i\ V\Sigma t$).	Σt = time to clean all compartments = min
(17)	$C_o = \left[Pn_s + (0.1 - Pn_s)\ e^{-aW}\right] C_i + C_R$	Equations (17) through (19) are empirical relationships used to compute outlet concentrations, C_o, in terms of incremental increase in fabric loading ($W' = W - W_R$); inlet dust concentration C_i; and local face velocity, V. The term C_R is a constant, low level outlet concentration that is characteristic of the dust fabric combination. Pn_s and a are curve fitting constants for specific systems.	C_i, C_o, C_R = g/m^3 W = g/m^2 V = m/min Pn_s, Pn_t = dimensionless a = m^2/g
(18)	$Pn_s = 1.5 \times 10^{-7} \exp\left[12.7\ (1 - e^{1.03V})\right]$		
(19)	$a = 3.6 \times 10^{-3}\ V^{-4} + 0.094$		
(20)	$Pn_t = \frac{I}{V_t\ IJ} \sum_{i=1}^{I} \sum_{j=1}^{J} Pn_{ij_t}\ V_{ij_t}$	Equation (20) depicts basic iterative structure for defining system penetration at any time, Pn_t as a function of parallel flow through "I" compartments (each subdivided into "J" individual areas) where local face velocities and fabric loadings are variable with respect to time and location.	I = No. compartments J = No. areas per compartment t = time

residual drag, S_R, and residual loading, W_R, for the cleaned regions and because the drag and loading for any uncleaned region are also definable, it becomes possible to compute the resultant fabric drag for the overall filter systems by means of Equation 4, Table 3.

The second concept is based upon a straightforward description of the fabric cleaning process[1,3,4] that relates the amount of dust removed to the method of cleaning and the prior dust loading on the fabric surface. Although both collapse with reverse flow and mechanical shaking have been quantitated, it is expected that the former cleaning method will see the most use in the modeling process for fly ash-glass fabric systems. This opinion is based on the fact that the very brief and low-intensity, supplemental shaking used in some field units does not appear to play a significant role in dust cake removal for filter pressure losses less than 1500 N/m^2 (6 in. H_2O). Equations 10 through 14, Table 3, depict the types of calculations carried out within the program to estimate the fraction of cleaned fabric area, a_c, when reverse flow cleaning is used. If mechanical shaking is used, Equations 10, 15 and 16 are employed to compute the cleaned area fraction.

The third concept evolves from the unique penetration behavior exhibited by fabrics woven from multifilament and bulked yarns. A temporarily or permanently unblocked pore presence (often referred to as pinholes) may contribute to extensive penetration of the upstream aerosol. Furthermore, only minor differences may be detected between the inlet and outlet dust size properties.

Therefore, the model is structured so that it computes the total effluent concentration on a mass basis alone because penetration levels are essentially independent of size. The above situation arises because the aerosol fraction, which sees only minor changes in size properties as it passes through pinholes in the 50 to 200 μm diameter range, represents 95 to 99 percent of the total filter emissions. The potential for extremely high collection by the undisturbed dust cake is seldom realized[1] because of gas flow diversion through the pores. Equations 17 through 19, Table 3, take into account the variable nature of the dust penetration through the filter medium from the time that it is cleaned until a substantial dust deposit has accumulated. The term, C_R, depicts a characteristic, lower limit in effluent concentration (for fly ash-glass fabric systems) that is approached asymptotically as filtration progresses between cleaning intervals. For present purposes, a C_R value of 0.5 mg/m^3 has been selected for the lower threshold based upon laboratory measurements.

4.0 MODIFICATIONS TO FABRIC FILTER MODEL

Major modifications to the Fabric Filter Simulation Program are discussed in this section. As shown in Table 4, the revisions involve reductions in hand calculations and procedural decisions by the model user, reorganization of data inputs, more flexibility in data outputs and a restructuring of program routines.

4.1 SPECIFIC RESISTANCE COEFFICIENT, K_2

Although mathematical procedures for the computation of the specific resistance coefficient, K_2, were described in prior GCA publications,[1,3,4] the calculation process was not included in the computer program. The reason for the omission was that the expected level of accuracy arising from direct calculation appeared to be no better than ±50 percent whereas data obtained from direct field or laboratory measurements were considered much more accurate, ±10 percent. However, if enforcement personnel are compelled to make estimates of filter system performance in the absence of any reliable K_2 measurements, the computation process called for outside the model might be overly time consuming. Therefore, provisions have been made to carry out within the model the necessary calculations to estimate K_2.

Based upon recent studies of dust cake porosity by Rudnick and First,[7] it appears that modifications to the classical Kozeny-Carman (K-C) equation, suggested by the Happel flow field structure[8] afford better estimates of K_2 over

TABLE 4. SUMMARY OF MAJOR MODIFICATIONS TO FABRIC FILTER SIMULATION PROGRAM

A. Reduction in External (Manual) Calculations.

1. Incorporation of calculation of fractional area cleaned, a_c, in the program.

2. Addition of special K_2 calculations.

   a. To correct K_2 from a reference set of size properties to filter system size properties.

   b. To estimate K_2 from dust particle size and density parameters.

3. Calculation of W^* for nonlinear model within the program.

4. Addition of mechanical shaking descriptors (amplitude and frequency) for calculation within the model of cleaning parameter, a_c.

B. Minimizing Procedural Decisions by Model User.

5. Selection of number of time increments to determine iteration period no longer required. Choice restricted to an "accuracy code" factor of 0 or 1 for "accurate" or "very accurate" model computations.

6. Number of repetitive filtration cycles to reach steady conditions determined automatically.

7. Due to the addition of Item 6, the entry "total number of cycles" now indicates the "maximum number of cycles" to be modeled regardless of whether convergence requirements are met.

C. Data Inputs and Outputs.

8. Data inputs have been regrouped as "Design Data," "Operating Data," "Dust and Fabric Properties" and "Special Program Instructions."

9. Data outputs can now be selected at three increasing levels of detail; "Average," "Summary" and "Detailed."

10. Plotted results can be requested if desired.

11. All input parameters subject to adjustments for temperature or other specified properties; e.g., inlet dust concentration, are automatically corrected from the reference to the filtration conditions.

(continued)

TABLE 4 (continued)

D. Programming Changes

12. Two additional subroutines have been added to check the input data for inconsistencies, missing data, and data "out of range" of program processing capabilities. These procedures eliminate some "blow up" conditions and unnecessary runs.

13. The simulation program now consists of three individual Fortran programs: (a) the simulator, (b) a summary table generator, and (c) a plot generator.

a much broader range in cake porosity, up to 90 percent or greater. For porosities ranging from 0.3 to <0.7, the classical K-C relationship

$$K = \frac{36\ k\ \mu\ (1-\varepsilon)}{\rho_p\ d_{vs}^2\ C_c\ \ \varepsilon^3} \qquad (1)$$

and the modification discussed by Rudnick and First[7]

$$K_2 = \frac{18\ \mu\ R}{\rho_p\ d_{vs}^2\ C_c} \qquad (2)$$

agree within better than 20 percent.

The term R has been defined by Happel[8] as

$$R = \frac{3 + 2\ (1-\varepsilon)^{5/3}}{3 - 4.5\ (1-\varepsilon)^{1/3} + 4.5\ (1-\varepsilon)^{5/3} - 3\ (1-\varepsilon)^2} \qquad (3)$$

As used in the Kozeny-Carman relationship, R is defined as $2\ k\ (1-\varepsilon)/\varepsilon^3$ where k is the Kozeny constant usually assumed to be 5.0. Substitution of the latter value in Equation 2 reduces it to the classical K-C form.

Both approaches indicate that dust cake resistance as reflected by K_2 becomes infinitely high as cake porosity decreases. The Happel modification shows that R approaches 1.0 at very high porosities such that the K_2 expression then provides a correct measure of single particle drag. On the other hand, the empirical structure of the K-C function no longer applies at high porosity. For example, at a porosity of 1.0, K_2 becomes zero.

Although the calculations required for the Happel method are more involved than those for the Kozeny-Carman relationship, either approach is readily handled by computer. Hence, Equation (3), with modifications as discussed in the following paragraphs, was selected for use in the revised model.

Equation (1) may also be expressed in the form

$$K_2 = \frac{\mu\ S_o^{\ 2}\ R}{2\ \rho_p\ C_c} \qquad (4)$$

where S_o is the specific surface parameter for the distribution of particle sizes in the fly ash aerosol. Since fly ash sizing data are usually based upon mass distributions determined by cascade impactor measurements, the size parameters, mass median diameter (MMD) and geometric standard deviation (σg) are available from which S_o can be computed for an assumed logarithmic-normal distribution; i.e.,

$$S_o = \frac{6\, d_s^{\,2}}{d_v^{\,3}} = \frac{6}{d_{vs}} = 6\left(10^{\,1.151 \log^2 \sigma_g}\right)/\mathrm{MMD} \qquad (5)$$

where d_s and d_v are the surface and volume mean diameters, respectively.

Since the porosity term, ϵ, appearing in the expression used to define R is best estimated from measurements of the dust cake bulk density ($\bar{\rho}$) and discrete particle density (ρ_p) the term, ε, in Equation (3) is replaced by $(1-\bar{\rho}/\rho_p)$ where $\bar{\rho}/\rho_p$ is the solidity factor. The net result is the development of Equation (6) for use in a model subroutine for estimating K_2 when the terms MMD, σ_g, $\bar{\rho}$ and ρ_s can be defined. Both Equation (6) and its alternate form (Equation 7 of Table 3) include an empirical correction factor of 0.33 that takes into account that the predicted values for K_2 based upon the theoretical relationship, appear to be three times larger than the actual measured values. The preliminary estimate of the correction factor was 0.5 as reflected by a modified Kozeny-Carman constant of 2.5 in an earlier report.[1]

$$K_2 = \frac{6\mu \quad (10^{\,1.151 \log^2 \sigma g})/\mathrm{MMD}^{\;2}}{\rho_p\, C_c} \times \frac{3 + (\bar{\rho}/\rho_s)^{5/3}}{3 - 4.5\,(\bar{\rho}/\rho_s)^{1/3} + 4.5\,(\bar{\rho}/\rho_s)^{5/3} - (\bar{\rho}/\rho_s)^2} \qquad (6)$$

The bulk density, $\bar{\rho}$, can be estimated by determining the volume occupied by a known weight of a bulk sample of the uncontrolled particulate emissions after repeated shaking in a measuring container. Discrete particle density, ρ_p, is estimated by pycnometer measurements or from a priori data for the dust of interest. For most dusts in the fly ash size range; i.e., MMD >5 μ, the

Cunningham-Millikan Correction, C_c, is sufficiently near 1.0 to be ignored. Gas viscosity is automatically computed within the program from the operating temperature data input.

In some cases, K_2 data may be available for dusts having the same chemical and physical properties (including shape factor) but not the same particle size distribution as the dust of interest. According to earlier studies, it appeared that the relationship between the calculated specific surface parameters, S_o, and measured values of K_2 conformed to the $S_o{}^2$ relationship delineated in both the earlier Kozeny-Carman approach and the Happel concept, Equations (4) and (6). Thus, an internal consistency was indicated for the surface to volume relationships even though best estimates of particle and bulk density led to K_2 predictions approximately three times larger than the measured values, (see Figure 3 and Table 5). The solid regression line (Figure 3) is based on data points for the New Hampshire and Colorado fly ashes whereas the dashed line applies to granite dust measurements.

It was decided, therefore, to generate a second and simpler program subroutine to convert the K_2 value determined for one set of particle size parameters to the K_2 corresponding to the size properties of the fly ash entering the baghouse.

$$\left(K_2\right)_2 = \left(K_2\right)_1 \cdot \left(S_{o_2}\right)^2 \Big/ \left(S_{o_1}\right)^2 \qquad (7)$$

The values for $(K_2)_1$ computed either by Equation (6) or (7) represent single point corrections that depict the effective "measured" K input at a specified temperature and at a fixed reference velocity, usually 0.61 m/min, and 25°C.

Equation (4-7) performs the correction for size properties in the same manner used to adjust K_2 to the gas viscosity at baghouse operating conditions. In both cases, a single corrected value applies over the complete filtration

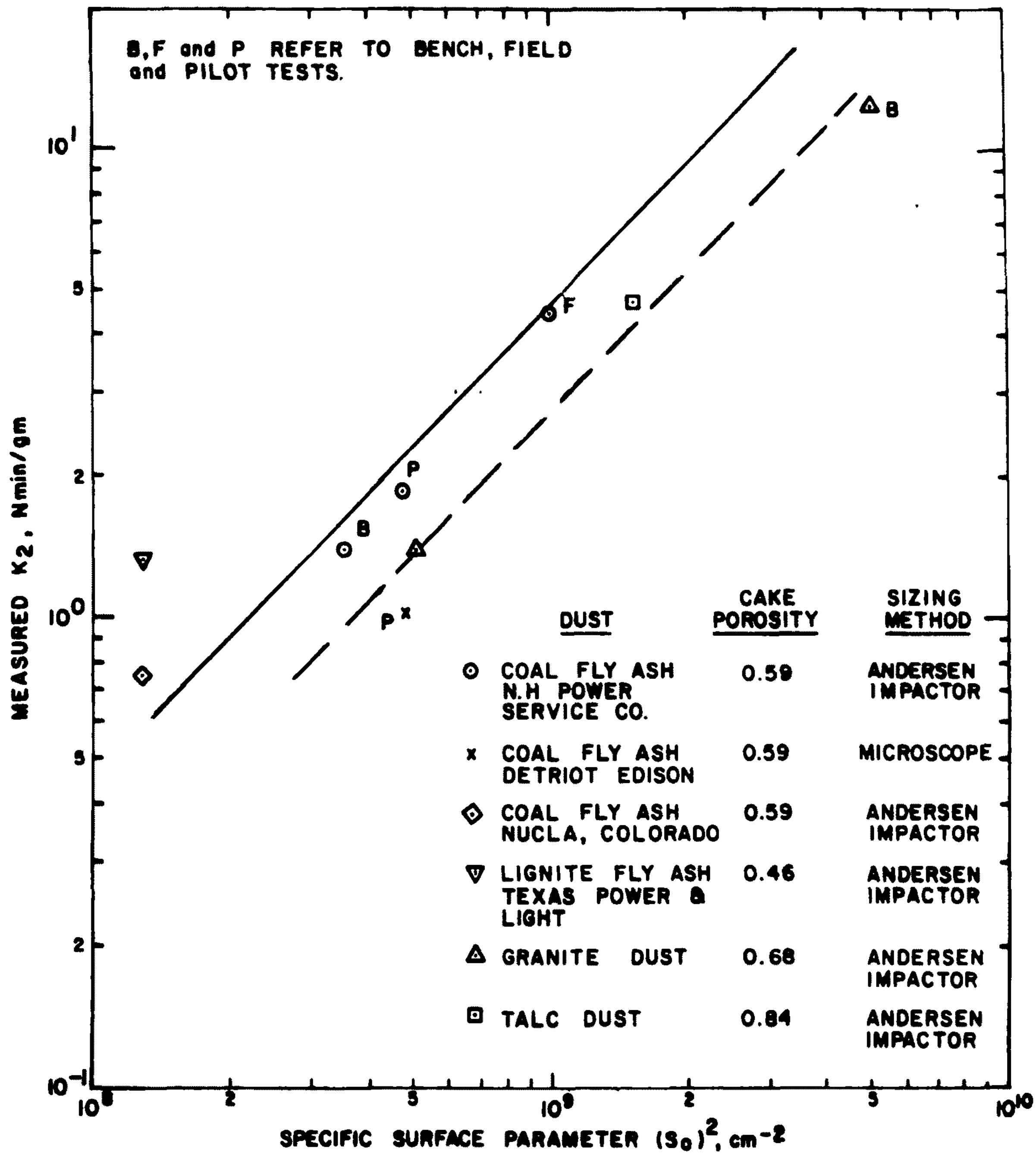

Figure 3. Specific resistance coefficient versus specific surface parameter (S_o^2) for various dusts.[1]

TABLE 5. CALCULATED AND MEASURED VALUES FOR SPECIFIC RESISTANCE COEFFICIENTS FOR COAL FLY ASH[a]

Test dust	Dust parameters: MMD,[b] µm	σ_g	Particle density, g/cm³	S_o^2, cm⁻²	Cake porosity, ε	Filtration parameters: Velocity, m/min	Temp., °C	Filter fabric	Test scale	Measured K_2: Test conditions	Measured K_2: Ambient conditions 21°C 0.605 m/min	Calculated K_2, 21°C	Ratio, calc. K_2 / meas. K_2
Coal fly ash Public Service Co., NH (GCA)	4.17(I)	2.44	2.0	4.73×10^8	0.59	0.915	21	—	Pilot	2.29	1.85	5.72	3.09
	5.0 (M)	2.13	2.0	2.58×10^8	0.59	0.915	21	Napped cotton, sateen weave	Pilot	2.29	1.85	3.74	2.02
	6.38(I)	3.28	2.0	3.55×10^8	0.59	0.605	21	Glass, 3/1 twill	Bench	1.40	1.40	5.14	3.67
Coal fly ash Public Service Co., NH	3.8 (I)	3.28	2.0	9.94×10^8	0.59	0.823	138	Glass, 3/1 twill	Field	6.35	4.45	14.4	3.23
Coal fly ash Nucla, CO	11.3(I)	3.55	2.0	1.28×10^8	0.59	0.851	124	Glass, 3/1 twill	Field	1.05	0.75	1.84	1.98
Lignite fly ash Texas Power and Light	8.85(I)	2.5	2.4	1.06×10^8	0.46	0.605	21	Glass, 3/1 twill	Bench	1.34	1.34	3.67	2.78
	8.85(I)	2.5	2.4	1.06×10^8	0.42	0.605	21	Glass, 3/1 twill	Bench	1.34	1.34	5.16	3.86
	8.85(I)	2.78	2.4	1.30×10^8	0.46	0.605	21	Glass, 3/1 twill	Bench	1.34	1.34	4.49	3.36

[a]Excerpted from Table 38, Reference 1.

[b](I) indicates Anderson impactor measurement.
(M) indicates microscopic measurement (Lightfield 90 × obj).

cycle. On the other hand, the special correction made for the velocity effect on K_2 is a function of the constantly changing face velocities with respect to both fabric location and time.

4.2 CLEANED FABRIC AREA FRACTION, a_c - REVERSE FLOW SYSTEMS

The original fabric filtration model required that the fraction of fabric surface cleaned, a_c, arising from the cleaning process be estimated outside the computer model. The reason for this approach was that it allowed for the use of several alternative methods to compute a_c depending upon the operating constraints placed on the filter system. Although none of the calculating procedures were complicated, it was thought that to include all alternative subroutines in the program might make it unwieldly and confusing to the field users. As a compromise approach for convenient application of the model, two basic operating conditions have been defined.

The first one applies to a proposed or ongoing filter system that is cleaned on an intermittent basis; i.e., the sequential cleaning of all compartments is initiated at a preassigned limiting pressure loss, P_L, followed by an extended period, 1 to 2 hours, when all compartments are filtering and no cleaning takes place. The second condition applies when inlet dust concentrations and constraints on operating pressure loss require continuous cleaning. Thus, for any filtration system in which a compartment is always off line for cleaning, the fraction of total cloth area in use at any time appears as (n-1)/n where n is the number of separate compartments.

4.2.1 Intermittent Cleaning - Defined by Limiting Pressure Loss, P_L

When there are lengthy intervals of filtration between cleaning cycles, average and local fabric loadings for all compartments and bags will approach each other. The limiting filter pressure loss, P_L, at which it is desired to initiate cleaning may be suggested by the filter system user or vendor. It can be defined as shown below

$$P_L = S_E V + K_2 V (W_P - W_R) \quad (8)$$

where S_E and W_R are the characteristic residual drag and fabric loading values, respectively, for the dust/fabric system of interest; V the average face velocity; and K_2 the dust specific resistance coefficient at the indicated face velocity (or air to cloth ratio). The K_2 term may be entered as a measured data input or alternatively it may be computed by a model subroutine based upon Equations (6) or (7). As indicated previously, S_E and W_R are treated as constants for each specific dust/fabric combination analyzed by the filtration model. The model user is provided with estimated values for the above terms unless direct measurements are available.

The term, W_p, represents the average fabric loading corresponding to the limiting or upper pressure limit, P_L, where cleaning is to be initiated. By rearranging Equation (8) followed by substitution for W_P in Equation (9)

$$a_c = 1.51 \times 10^{-8} W_p^{2.52} \quad (9)$$

an equation is derived for use within the filtration model program as a subroutine; i.e.,

$$a_c = 1.51 \times 10^{-8} \left(\frac{P_L - S_E V}{K_2 V} + W_R \right)^{2.52} \quad (10)$$

When a_c is determined by Equation (10), the average system pressure loss will actually increase above the P_L value for brief periods until roughly one-half the compartments have been cleaned. Should there be concern that induced- or forced-draft fan capacity may be reduced excessively by baghouse pressure loss excursions above the P_L limit, a conservative approach can be selected. The latter procedure will take into account the fact that the second compartment to be cleaned in a sequence of n compartments (a) will accumulate additional dust while the first compartment is off-line for cleaning and (b) also see an increased filtration velocity equal to the average value, V, multiplied by n/n-1. Therefore, the system pressure loss just before cleaning the <u>second</u> compartment will have increased to the level, P_{max}; i.e.,

$$P_{max} = P_L + K_2 C_i \left[V \left(n/_{n-1} \right) \right]^{2.5} \Delta t \tag{11}$$

where P_L, K_2, V and n have already been defined. The terms, C_i and Δt refer to average inlet dust loading and the time required to clean one compartment, respectively.

From Equation (11) it may be deduced that if system pressure loss is not to exceed a selected maximum value, P_{max}, the cleaning must be initiated at a lower level, P_L'. By rearrangement of Equation (11)

$$P_L' = P_{max} - K_2 \, C_i \left[Vn/_{n-1} \right]^{2.5} \Delta t \tag{12}$$

the model user may then compute <u>outside</u> the model the revised P_L value, P_L', which becomes a basic data input to the model. In most practical situations, the use of P_L at the start of cleaning, is the recommended approach. In Equation (12), K_2 and C_i must be defined at operating temperatures. The variable impact of velocity on K_2 is reflected by the fractional exponent 2.5.

4.2.2 Intermittent Cleaning-Defined by Length of Cleaning Cycle and Time Interval Between Cleaning Cycles

Rather than specifying a limiting pressure P_L, the filter manufacturer may indicate what cleaning frequency should be used to maintain acceptable performance. When the total time interval for the combined cleaning and filtering cycle and the filtering period alone are to be maintained constant, the system is said to be operating under a time-controlled regimen. Such an approach may be risky unless the gas velocities and particulate loadings are constant. Should either vary appreciably, pressure loss excursions could occur that might reflect adversely on gas flow stability.

To estimate pressure loss and emission characteristics for a time-controlled cleaning system, it is first necessary to establish the total amount of dust, ΔW, deposited on the fabric over the time interval, t_c, representing the summation of the cleaning period, Σt, and the filtering period, t_f; i.e., the interval when all compartments are on-line ($t_c = \Sigma t + t_f$).

$$\Delta W = VC_i \, t_c \tag{13}$$

Since ΔW also represents the amount of dust that must be removed from the fabric over the time period, t_c, once steady state operation has been achieved, the area fraction to be cleaned, a_c, can be expressed as

$$a_c = 1 - \frac{W_P - \Delta W - W_R}{W_P - W_R} \tag{14}$$

and also as

$$a_c = 1 - \frac{W_P - \Delta W}{W_P} = \frac{\Delta W}{W_P} \tag{15}$$

By combining Equations (9), (13) and (15), an expression for calculating the data input, a_c, is obtained.

$$a_c = (0.006)(VC_i\ t_c)^{0.715} \tag{16}$$

Equation (16) appears in the revised model as part of a major subroutine. In practice, absolute uniformity of loading with respect to compartments or individual filter bags is never obtained, even with very lengthy filtration periods without cleaning interruptions. However, past measurements have indicated that after 30 minutes filtration following a cleaning (and filtering) cycle of the same length, the maximum and minimum filtration velocities for a six-compartment system differed by only 10 percent. On the premise that all compartments see the same pressure gradient and assuming that K_2 is nearly constant, these findings indicate that the fabric loadings also differ by about 10 percent from point to point in the system. This means that the W_p values appearing in Equations (9) and (15) actually represent an approximate averaging of the maximum and minimum values. Accordingly, derived a_c values will predict overcleaning or underlceaning depending upon the true fabric loading for a given area location. In view of the computational advantage to operating with a fixed value for a_c, the above approximation (single value) appears as the best approach until further model refinements can be made.

4.2.3 Continuous Cleaning

In certain cases, particularly where retrofit systems are involved, continuous fabric cleaning may have been selected to prevent overall pressure losses from reaching prohibitive levels. Under these conditions, each successive compartment to be cleaned will have the same fabric loading at the initiation of cleaning. At the same time, a decreasing gradation in fabric loadings will be exhibited by the n-1 compartments remaining on-line with the lowest loading appearing on the "just cleaned" compartment. Because the dust loadings are not the same for all compartments when cleaning is actuated, (as assumed for intermittently cleaned systems), the dust loading at the time of compartment cleaning, W_p, no longer defines the system pressure loss at that time. In fact, the average system resistance is lower because of the lesser resistance offered by those compartments operating in parallel with lower fabric loadings.

The fabric loading for the compartment to be cleaned may be expressed as

$$W_p = (6.62 \times 10^7 \; C_i \; V \; \Sigma t)^{0.284} = 166.4 \; (C_i \; V \; \Sigma t)^{0.284} \tag{17}$$

when the average fabric loading is much greater, ~ 10 times, than the fabric residual loading, W_R (which is usually the case). Note that Equation 17 can also be used to calculate W_p for intermittently cleaned systems when t_c is substituted for Σt. Thus, when W_p is redefined in terms of a_c and ΔW, as indicated in Equation (15), a final expression for a_c is developed

$$a_c = (0.006)(VC_i \; \Sigma t)^{0.715} \tag{18}$$

When a_c is computed within the program in conjunction with the other input data, the average and maximum values for both pressure loss and particulate emissions will appear as output.

4.2.4 Cleaned Fabric Area Fractions, a_c - Mechanical Shaking

Based upon prior studies[1,9] it was determined that the degree of cleaning obtained by mechanical shaking could be estimated by the following relationship:

$$a_c = 2.23 \times 10^{-12}(f^2 A_s W_p')^{2.52} \tag{19}$$

for an intermittently cleaned filter systems with pressure loss control. In Equation (19), $\underline{f}$ is the frequency of the shaking action, cycles/sec; A_s is the shaker arm (half stroke) amplitude, cm; and W_p' the fabric loading on the compartment to be cleaned as defined by Equation 10, Table 3.

If the system is cleaned continuously by mechanical shaking, the limiting pressure concept no longer holds because only the compartment due for cleaning will have a fabric loading defined by the limiting pressure, P_L. Thus the cleaning parameter must be computed from the following relationship[1]

$$a_c = 0.00049\ (f^2 A_s C_i V\ \Sigma t)^{0.715} \tag{20}$$

where Σt refers to the time period to clean all compartments.

Equation (20) also applies when the specified frequency of cleaning is intermittent. In this case, the time describing the total dust deposition interval, t_c, is the summation of the cleaning time Σt and the time between cleaning t_f.

4.3 DUST/FABRIC SYSTEM CONSTANT, W^*, FOR NONLINEAR MODEL

To reduce further the number of computations performed outside the model, the calculation of W^* has been incorporated into the program. The magnitude of W^* determines whether the linear ($W^* = 0$) or nonlinear ($W^* > 0$) drag model should be used to describe system drag. If the key data inputs are not available to compute W^* by means of Equation (21); i.e., experimental values for

K_R (the initial slope of the drag versus loading curve) and S_R (the fabric residual drag)

$$W^* = (S_E - S_R + K_2 W_R)/K_R - K_2 \qquad (21)$$

the program now automatically interprets blank entires or zero values for K_R and S_R as an instruction to use the linear model for estimation of system drag. Conversely, when real values for K_R and S_R are specified, the program always chooses the nonlinear model.

4.4 COMPUTER PROGRAMMING MODIFICATIONS

4.4.1 Number and Length of Time Increments

In the original model,[1] the user was required to determine, indirectly, the time increment to be used in the iterative calculations. Because too large a time increment may yield inaccurate results and too small an increment will require excessive computer time, the actual determination of the time increment is now decided automatically by the program. The time increment is determined by dividing the total cleaning cycle time, Σt, by the product of the number of compartments, (n) and a selected "number of increments (n_i) per compartment."

$$\text{Time increment} = \Sigma t/(n \times n_i)\text{(minutes)}$$

The number of increments, (n_i), was varied experimentally over a broad range for both average and extreme operating conditions. The results indicated that, in general, four increments would suffice for most applications. Provisions have been made in the program to increase this value to eight if the need arises. The number of time increments is now determined from the "Accuracy Level" parameter, a new program data input that is entered as a special program instruction. Assignment of a zero (0) value fixes the number of increments at four whereas a value of one (1) will automatically increase the number of increments to eight.

4.4.2 Determining Steady State Filtration (Model) Operation

Depending upon the selected operating parameters, the actual and/or predicted performance characteristics for a filter system will require a finite time interval to reach steady state conditions. From this point, each successive filtration and cleaning cycle will replicate approximately its predecessor provided that all data inputs remain constant.

Prior to the present modification, it was necessary to specify the number of cycles to be simulated to establish a stop point for computer operation. Only by examining the data printout could it be ascertained whether or not steady state conditions had been achieved. It had been observed previously that after 20 repetitive filtration cycles, steady state conditions were closely approximated such that no subsequent changes were discernible in resistance and penetration. On the other hand, it had also been noted that steady state conditions often were reached with 10 or fewer operating cycles. Hence, to continue with 10 additional program cycles would represent a waste of computer time.

The programming process has now been modified so that the computer operates until steady state conditions are achieved before any data printout takes place. Three additional cycles are then modeled accompanied by a tabular printout or graphical plotting so that the constancy of the data output can be verified.

These three cycles describe the operation of the baghouse at steady state. However, to prevent the program from running indefinitely, a practical limit must be set on the number of cycles. Thus, where the number of cycles to be modeled was previously specified as a required input, the "maximum" number of cycles to be modeled now becomes the required data input. Based on prior tests with the model, 20 cycles are generally more than sufficient to achieve equilibrium. If steady state has not been reached within three cycles of the maximum allowed; i.e., 17 cycles, the data for the last 3 cycles, 18 through 20 are printed and/or plotted. The mechanics of how steady state is determined within the program and the rationale for this procedure are discussed in Appendix A. A summary of the approaches examined for estimating steady state conditions is given in the following paragraphs.

Three criteria have been selected to determine the closeness of the most recent or last cycle to steady state operating conditions. The first criterion involves fitting the slope of the curve depicting pressure loss per cycle versus time as it approaches the steady state value of approximately zero by an expotential decay curve. The average pressure, $\overline{P}$, over the indicated time frame, which is determined by integration, is then compared to the average pressure at infinite time predicted by the equation of best fit. When the difference between the local and "infinite" pressure levels is less than 1 percent, the system is considered to be at equilibrium (or at steady state).

The average pressure drop for 4 consecutive cycles is also fit to a least squares regression line with respect to time for the second criterion. If the slope at this time indicates that the average pressure drop is changing at a rate of less than 0.1 percent per cycle, steady state operation is assumed.

The third criterion specifies that in those systems exhibiting oscillations in average pressure drop, the oscillations must converge or remain constant in amplitude but never diverge before the steady state condition is satisfied. The latter state is assumed to have been reached whenever any one of the three convergence criteria are met (which are determined by a sequential analysis at the end of each cycle).

Convergence of average pressure loss was chosen as the indicator of steady state since in all test cases average penetration and total cycle time also converged when average pressure converged.

When an accuracy code of 0 is selected, sufficient operating cycles are generated to satisfy the average pressure loss convergence at the 1 percent level, and the slope convergence at the 0.1 percent level. An accuracy code of 1, which decreases the above convergence limits by a factor of 3, usually requires that a few additional cycles be modeled.

In the case of continuously cleaned or time-controlled systems, the "approach" to steady state is generally determined by the first or second criterion. Certain limiting pressure systems, however, may oscillate in such a way that the first and second criteria fail to signal a near steady state condition whereas the third (oscillation convergence) approach will instruct the program when sufficient cycles have been run.

4.4.3 Data Input and Output Format

Changes in the format for data inputs and outputs are shown in Table 4, Items 8 through 11. These changes allow for a logical ordering of data inputs to the model and better control of the volume of data generated by the program. The above changes will be discussed in more detail in other sections of this report.

4.4.4 Program Structure

The original program for the baghouse model consisted of a single main program and a number of subroutines that performed all the operations from reading the data to plotting the data outputs. To save space and reduce computer time, the program has been broken up into three individual FORTRAN programs. The first program reads in the data, performs the simulation, prints the results of all intermediate calculations (when requested) and generates files of pressure loss, penetration and individual compartment flows versus time. These files are used to generate summary tables (when requested) by the second program (or step). Finally, if a graphical output has been requested, the third program (or step) generates the data plots.

5.0 DESCRIPTION OF THE NEW BAGHOUSE SIMULATION PROGRAM

A complete and updated description of the baghouse simulation program is presented in this section. Several of the modeling and actual computational procedures appearing in an earlier report have been restated here to facilitate model application both for routine and experimental use.

5.1 DESIGNED MODEL CAPABILITY

In the preceding section, the basic filtration equations and the iterative approach for treating multicompartment filtration systems have been reviewed for convenient reference. The following discussion is intended to define the ground rules with respect to how closely the predictive model(s) describes actual fly ash filtration processes for utility applications. The only major constraints are the following: (1) the inlet aerosol should consist of or possess the general physical properties of a coal fly ash; (2) the fabric characteristics should be similar to woven glass media used at the Sunbury and Nucla installations; and (3) the system gas flow should be essentially constant except for flow increases attributable to reverse air flow during the cleaning process. Aside from the above, the model is sufficiently flexible to meet the following operating criteria:

- The model can accommodate to a continuous cleaning regimen; i.e., the immediate repetition of the cleaning cycle following the sequential cleaning of successive individual compartments.

- The model can also describe the situation where lengthy filtration intervals are encountered between the cleaning cycles. In both cases the term cleaning cycle refers to the uninterrupted cleaning of all compartments in the system. No provision is made for the random cleaning of less than all compartments followed by continuous on-line filtration of all compartments.

- The model can be used with a collapse and reverse flow system or a mechanical shaking system but not for combinations of the above. It is not intended for use with pulse jet or high velocity reverse jet cleaning systems.

- The model can be used equally well with pressure or time controlled cleaning cycles.

The actual information generated by the model embraces the following areas:

- The model provides estimates of average and point values of filter drag or resistance for the selected set of operating parameters and dust/fabric specifications.

- The model provides estimates of average and point values for penetration and mass effluent concentration for the selected set of operating parameters and dust/fabric specifications.

- The model alternatively provides an estimate of the necessary frequency of cleaning when the maximum operating resistance P_{max} is cited as an operating specification along with the assigned values of C_i and the selected value for V_i.

In the above instances, it is assumed that the following operating parameters are known: inlet concentration (C_i), average face velocity (V_i), and the cleaning parameters (frequency and amplitude of shaking) if mechanical shaking is employed. In addition, the related parameters, K_2, S_E, W_R, K_R and S_R must also be specified for the given dust/fabric combination when measured values are available.

The system cleaning characteristics are determined by the fraction of fabric area cleaned, a_c, when individual compartments are taken off-line. With respect to bag collapse systems and/or low energy shaking, the dust removal parameter, a_c, is dependent upon the fabric loading, W_T, before cleaning.

5.2 BASIC MODELING PROCESS

The basic model treats each of the "I" compartments of the filter system as a separate element. It is also assumed that the inlet dust concentrations and the filtration velocities are the same for each bag within a given compartment. However, the existence of both concentration and velocity gradients are acknowledged due to the particle size spectrum, bag proximity and air inlet location.

Figure 4 indicates the distribution of volume flow rates for a filter system consisting of "I" separate compartments. Because of the parallel arrangement, the resistance, P, across each compartment is the same just as the voltage drop would be for the analogous electrical circuit. In practice, poor design or cramped quarters may prevent realization of the parallel flow situation for some installations. The volume flow rate, q, and gas velocity, v, through each compartment vary inversely with the individual compartment drag.

The distinguishing feature between the new modeling concept introduced in this study and previously reported efforts[6,10] is that the surface of each bag within a given compartment is subdivided into a number of secondary areas each of which displays its own characteristic fabric loading (W), drag (S), face velocity (V) and dust penetration (Pn). The fact that the contributive role of each of these areas with respect to overall system drag and penetration can be assessed at any time during the cleaning and/or filtering cycles is a unique feature of the new model. Note again that since all bags within a given compartment possess identical performance characteristics, an "I" compartment system could be described equally well as an "I" bag system.

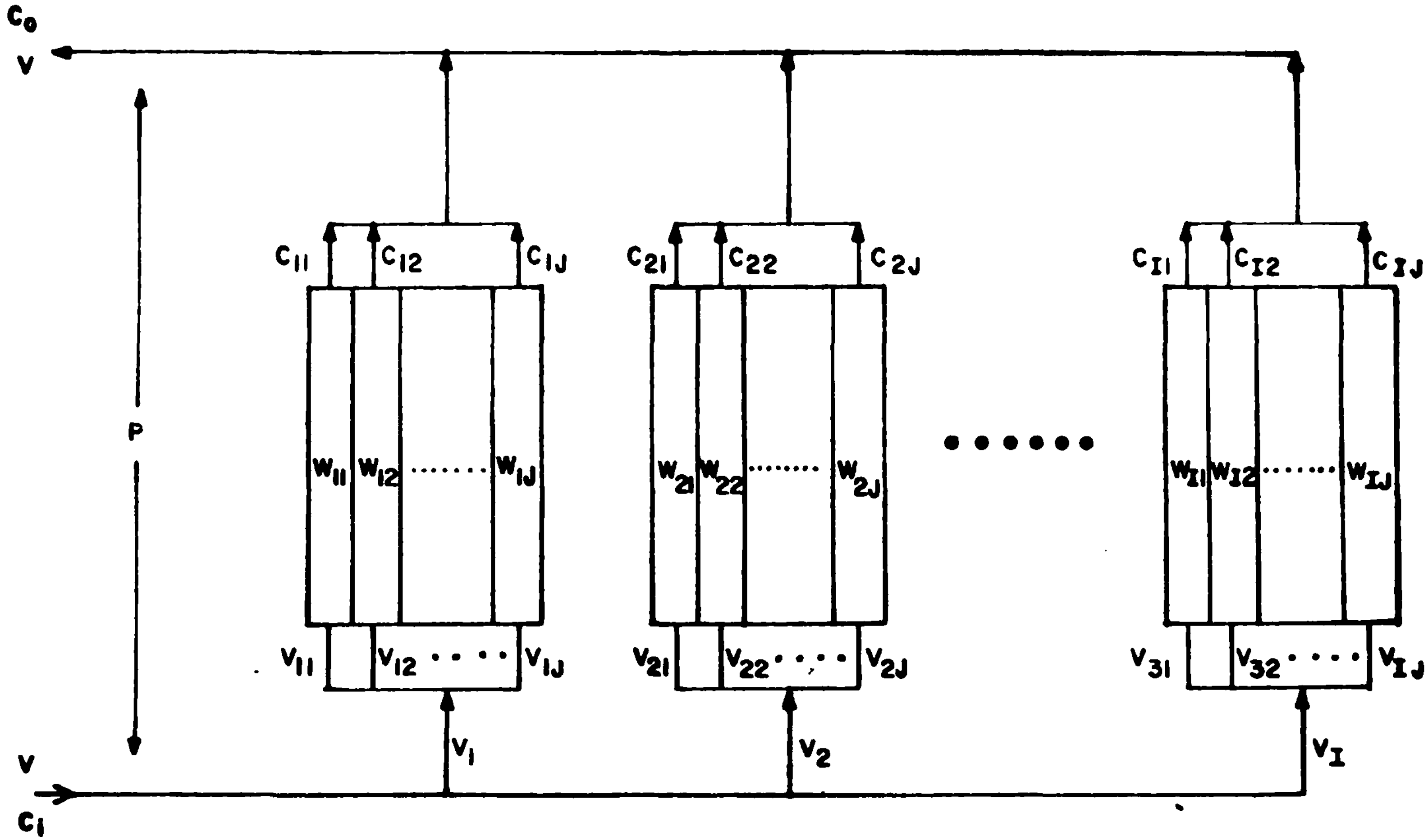

Figure 4. System breakdown for I bags and J areas per bag.

Since it is necessary to deal with several randomly distributed areas of varying areal densities for each bag as well as several compartments, each with its unique variability pattern, the following notational system is introduced to describe the various surface elements. In the multicompartment system, the subscripts i and j, respectively, designate the i^{th} compartment and the j^{th} area subdivision in each compartment. This enables one to identify the specific element of fabric area; e.g., compartment 2, 1st area subdivision for which the local face velocity, surface loading and effluent concentration at a specified time are then defined as V_{21}, W_{21} and C_{21}, respectively, Figure 4.

Although the program is designed to accept as many as 10 separate areas (J=10) per bag, the actual number used in the iteration process (which is automatically selected by the computer program) depends upon value of a_c. Given the restriction that the number of subdivisions or areas must always appear as integer values, the program will always select the number of subareas that comes closest to matching the a_c value. Thus, a value of 3 for J will satisfy exactly the requirement that $a_c = 0.333$ whereas the same J value will also be selected as the nearest approximation to the condition that $a_c = 0.35$. However, if a_c is 0.38, the program will select and operate with 8 areas wherein the cleaning of 3 areas provides a cleaning parameter, a_c, of 0.375.

It was indicated previously that the concentration and size properties of the dust approaching the fabric surface and the aerial density and composition of the dust layer deposited on the filtering surface were assumed to be uniform regardless of the location within the baghouse. Additionally, the impact of successive fabric collapses (which may weaken adhesive bonds but not necessarily lead to immediate dislodgement) has not been included in the modeling operations. It is assumed, that for a specific cleaning method, an equilibrium adhesion level is reached after five to six repetitions of the cleaning process. Beyond this point, no significant increase in dislodgement can be attained without increasing the intensity of the dislodging force. As far as the modeling procedures for the fly ash/woven glass fabric systems are concerned, the simplifying assumptions discussed above reduce significantly the data processing while introducing no obvious penalties in predicting filter system performance.

The equilibrium state attained after five to six repeated cleanings should not be confused with the normal 2 to 3 week period required for the residual fabric dust holding, W_R, to arrive at an approximate steady state level. Similarly, it should also be noted that the residual dust holding and, in particular, the fabric effective or actual residual drags, S_E or S_R, may show a gradual increase, $\sim$100 N/m^2, over the long term, $\sim$2 years.

The general procedure for calculating all the system parameters at any time in a cycle is described below. The calculations proceed by successive iterations with the results from the first iteration constituting the input for the second, and so forth. Individual subareas and compartment (bag) drags are first calculated so that the total (average) system values for drag, pressure drop, and flow rate can be determined. Based on the system pressure drop and individual bag drags, the volume flow is first partitioned among all the compartments followed by a further subdivision among the subareas of each bag. Penetration and outlet concentration are then computed for each subarea, each compartment (bag) and for the total system in the order named. Since the dust deposition rate is determined by a specified flow velocity and inlet concentration, the weight of dust added to any area on any bag can be calculated. Thus, the fabric loadings for all areas can be calculated for the succeeding time increment.

5.2.1 General Procedures

The simulation program is composed of three individual FORTRAN programs (or program steps) as shown in Figure 5. The following operations are performed in the First Program Step: all data inputs are processed, the actual filtration simulation is carried out, intermediate calculated values are printed and the data files which will be printed and/or plotted by the succeeding program steps are generated. All subroutines shown in Figure 5 with the exception of MODEL merely manipulate or adjust the input data in preparation for the simulation, which is carried out by the MODEL subroutine. Each of the subroutines is discussed in detail in the next section. During the course of the simulation carried out in the first program step, files are generated that contain information regarding the variations with time of system pressure drop, penetration and individual compartment gas flows.

The Second Program Step generates a summary table of these data, if requested by the user.

By means of the Third Program Step, the same data can be plotted as a graphical output if requested by the model user. A complete listing of the simulation program is presented in Appendix B.

If errors are detected in the input data, no simulation will be performed within the first program step and error codes will be passed via the data files to program steps two and three so that no summary tables or graphs are produced.

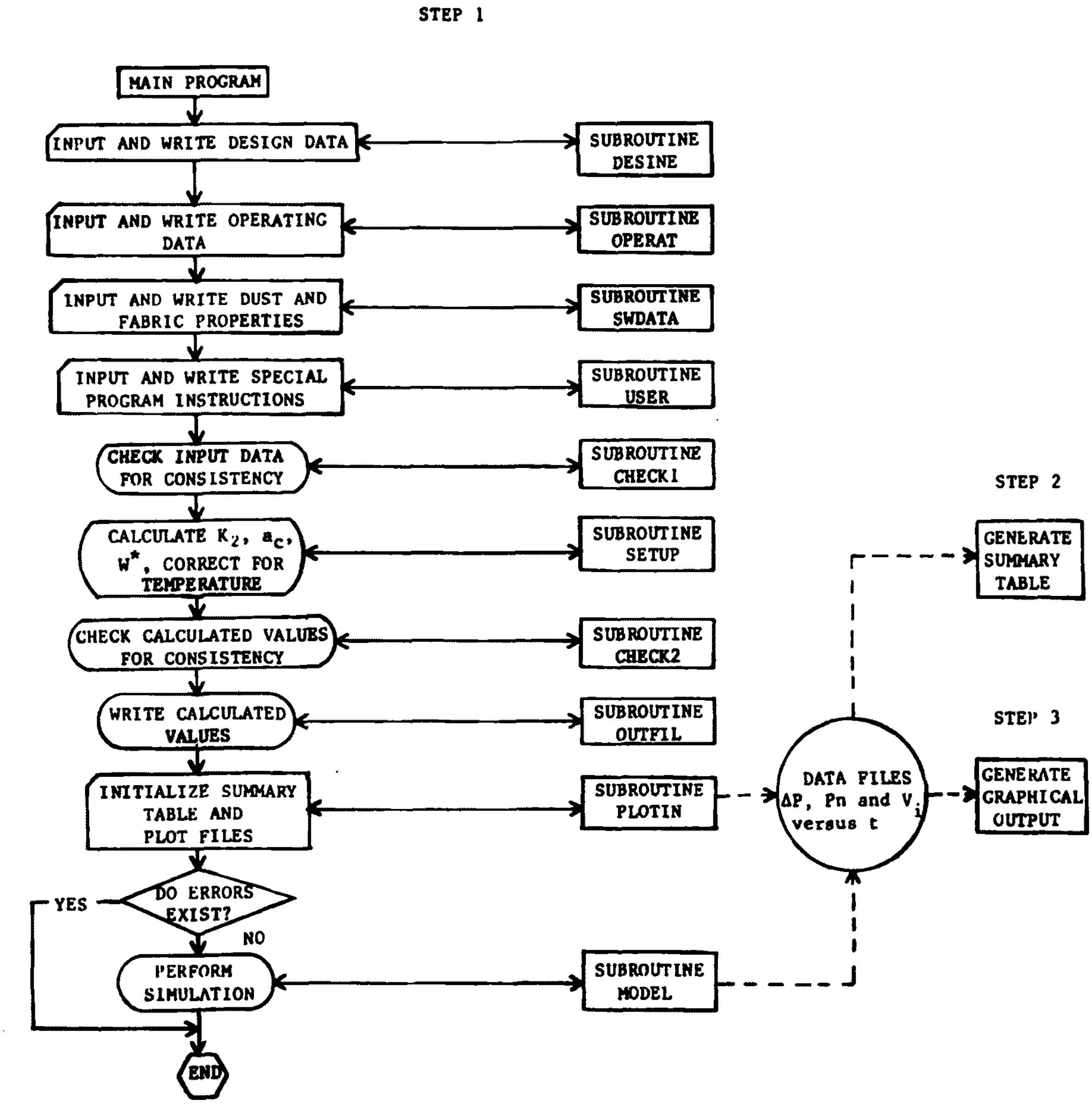

Figure 5. Baghouse simulation program, general flow diagram.

5.3 FUNCTIONS OF THE SUBROUTINES USED IN THE SIMULATION PROGRAM

DESINE Subroutine

The main function of this routine is to read Card 1 (the heading) and Card 2 (basic design data) followed by printing these data as they were entered into the program. Note, however, that blanks in numeric fields (e.g., Card 2) are read as zeroes by the program. The headings for the input data summary are also generated by this routine. The above steps enable the user to confirm that the program will operate upon the correct data inputs.

OPERAT Subroutine

This routine reads data from Card 3 (operating data) and writes the next section of the input data summary. Also, when no value for the measurement temperature of the inlet dust concentration has been entered, a default value of 25°C is automatically assigned. The default temperature and the baghouse gas temperature are converted to absolute temperatures (degrees Kelvin) by OPERAT for use by other routines that perform temperature and viscosity corrections.

SWDATA Subroutine

All dust and fabric properties (Cards 4 and 5) are read by the SWDATA subroutine. After reading the data, the program automatically decides which default values, if any, should be assigned and generates a summary of the input data.

If K_2 must be estimated because no previous or measured value is available for entry, default values will be assigned to S_E and W_R if no measured values for the latter are available. In addition, any temperature or velocity of measurement needed for the computation of K_2, S_E, S_R and K_R will be assigned default values (25°C, 0.61 m/min) if these data are not available for entry.

The output from the SWDATA routine is a summary of the input data with some modifications, for the special circumstances described below:

- If a known (or measured) value for K_2 is entered and no corrections or estimates are required, only K_2 and its temperature and velocity of measurement will be printed.
- If K_2 must be estimated, the inlet dust size descriptors (mass median diameter and geometric standard deviation) discrete particle density and bulk density will be printed.
- If K_2 is to be corrected for size properties, K_2 and the size properties for the reference and inlet dusts will be displayed on the printout.
- When all data required for the non-linear drag model are entered, (S_E, S_R, W_R and K_R) all will be printed. However, if only S_E and W_R are available for entry then they alone will be printed.

USER Subroutine

Special program instructions (Card 6) are entered via the USER routine. A default value for the type of tabular results is assigned automatically if no input level has been entered. At present the default value is the AVERAGE category.

The requests for tabular and graphical results are also checked at this point for consistency. The input data are then returned for display in the input summary.

No printout value for a_c is shown except for the unique situation where it has been provided as a data input.

The time interval required for iterative calculations will be determined by the input accuracy code. A default value of 0 (zero) will automatically be assigned to the accuracy code when the user makes no entry. The accuracy code also determines the boundary conditions for the comparisons made in the stabilization routine (STABLE).

CHECK1 Subroutine

Many of the preliminary input data checks are performed by the CHECK1 subroutine. A complete listing of these checks is presented in Table 5. Those checks performed in CHECK1 are identified by an asterisk (*). If an error is encountered, this subroutine prints an error message and returns an error code to the main program indicating that no modeling should be performed.

However, even when an error is indicated, four additional subroutines are carried out before program execution is stopped. These subroutines are subroutine SETUP, CHECK2, OUTFIL and PLOTIN. Any additional errors will thereby be indicated.

SETUP Subroutine

This subroutine performs the majority of the input data conversions (or corrections) and calculations. If K_2 for the inlet dust has not been specified in the input data, K_2 is then estimated from specified data inputs (size properites, bulk and discrete particle density) or K_2 is corrected for differences in size properties between the reference dust and the filtered dust. The effective residual drag, S_E, is corrected to correspond to a loading equivalent to the residual fabric loading, W_R. Viscosity corrections are made to K_2, S_E, S_R and K_R and the inlet dust concentration, C_i, is corrected to the filtration temperature. An average fabric loading is estimated as a first approximation to the actual loading distribution. The system constant, W^*, is calculated if the non-linear model is to be used. The SETUP routine then calls the subroutine CLEAN whose role is to calculate

TABLE 6. SUMMARY TABLE OF INTERNAL DATA CHECKS

Subroutine indicator	Variable	Range or other constraints
	Valid (acceptable) ranges of variables — (data inputs must fall within constraining range or program will not function)	
*	Number of compartments, N	2 to 30
*	Average face velocity, V	0.3 to 3 m/min
*	Gas temperature, Tg	Greater than $0^{\circ}C$
*	Mass median diameter, MMD	2 to 50 μm
*	Standard deviation, σg	2 to 4
†	Fractional area cleaned, a_c	0 to 1
†	Specific resistance coefficient, K_2 at $25^{\circ}C$	0.25 to 10 N-min/g-m
*	Accuracy code	0 or 1
	Supplementary checks	
*	Compartment cleaning time	≤ Cleaning cycle time
*	Compartment cleaning time	≤ (Cleaning cycle time)/N
*	Bulk density	< Discrete particle density, ρ_p
†	Residual drag, S_R	< Effective drag, S_E
‡	Type of tabular results	Specify as DETAILED, SUMMARY or AVERAGE or leave blank
‡	Type of plotted results	Specify as PLOT or leave blank
	Checks for incomplete or conflicting data	
*	Time or pressure controlled cleaning	Specify one only
*	Shaking frequency and amplitude	Specify both or none at all
*	K_2 value available	Specify reference and filtration size parameters (MMD_1, MMD_2, σg_1 and σg_2) or none at all
*	K_2 value not available	Specify MMD_2, σg_2, ρ_p and $\bar{\rho}$
†	Residual drag S_R and initial slope K_R	Specify both or none at all

*Checked in CHECK1

†Checked in CHECK2

‡Checked in USER

the fractional area cleaned, a_c. The a_c value computed under subroutine CLEAN is then used to calculate the number of elemental subareas into which the compartments (or bags) should be divided and the number of these area that should be cleaned during a cleaning cycle.

CLEAN Subroutine

As stated previously, this routine calculates the fractional area cleaned, a_c.

CHECK2 Subroutine

Calculated and corrected values are checked for consistency and acceptable range in magnitude by this subroutine (see Table 6). The error code from CHECK1 is passed to CHECK2 and finally back to the main program.

OUTFIL Subroutine

This routine prints out all calculated values and those which have been corrected for viscosity and temperature.

PLOTIN Subroutine

The x and y axis lengths of any graphs to be generated are read by PLOTIN. In addition, this routine activates the filing process used to generate the summary tables and plots. The error code from CHECK2 is passed to the PLOTIN subroutine. If errors exist, indicating codes are written into the pressure versus time file. When no errors exist, these codes serve to indicate whether or not a summary table or plot has been requested.

MODEL Subroutine

Subroutine MODEL performs the actual simulation of the filtration process. All preceding program operations merely prepare the data for input to MODEL. Because the MODEL subroutine is the backbone of the entire program, it will be discussed in a separate section.

CAKDRG Subroutine

The drag contribution due to dust cake accumulation on the fabric is calculated by the CAKDRG routine using either the linear or non-linear drag model.

PENET Subroutine

Dust penetration is computed by the PENET subroutine as a function of fabric loading and local face velocity.

STABLE Subroutine

After every complete cycle (filtration plus cleaning interval) STABLE is called by MODEL to determine the proximity to steady state conditions. After four complete cycles, sufficient data have been compiled by STABLE to initiate the three step comparison operation. The first step compares the average pressure value for the indicated number of cycles to the value predicted at infinite time (the latter estimated from an exponential curve fitted via a linear regression to the average pressure drop versus operating time relationship). The second step compares the predicted value of the change in pressure drop from a linear regression of average pressure drop with time to the actual average pressure drop at that time. If the compared values are within predetermined limits, the system is said to be at steady state. The third and last comparison checks the oscillating characteristics of the average pressure drops. If the oscillations are decreasing, the system is said to be at equilibrium. If any of the above criteria are met, a signal is returned to the MODEL subroutine indicating convergence. These three comparisons are discussed in more detail in Appendix A.

The error checking routines have been incorporated into the model to eliminate unnecessary runs caused by, (1) mispunched and "out-of-order" cards; and (2) insufficient or conflicting data. These routines will detect most of the common errors, based upon the present testing and experimentation with the program.

INITAL Subroutine

Variables used in the MODEL and STABLE subroutines are initialized in this section.

RESTRT Subroutine

This subprogram is executed only if a limiting pressure-controlled system was originally specified but the system must, in fact, clean continuously. The system is redefined as a continuously cleaned system and the simulation is restarted. Messages to that effect are printed in the output by RESTRT. This subroutine can be called no more than one time during the simulation.

5.4 FUNCTION OF THE MODEL SUBROUTINE

5.4.1 Overview

The actual simulation is carried out via the MODEL subroutine. When the input data have been entered into the program, corrected for temperature, viscosity or velocity, and have been checked for completeness and consistency, the simulation is performed. A general flow diagram for the MODEL subroutine is shown in Figure 6.

With the exception of the addition of the check for steady state operation (subroutine STABLE), the MODEL subroutine has undergone only minor revisions since its original development.[1] Figure 6 summarizes the major program steps within the MODEL subroutine as it presently stands.

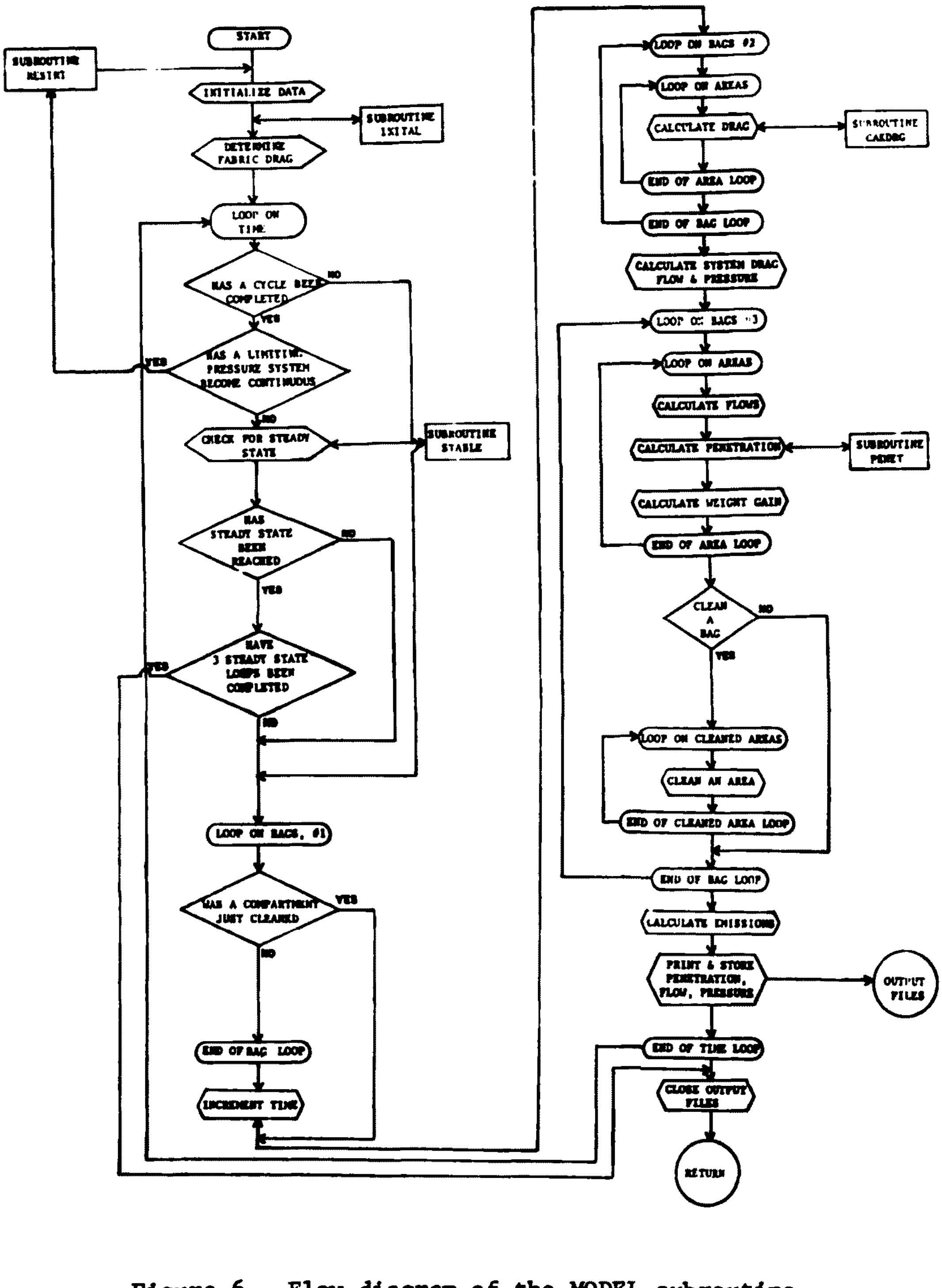

Figure 6. Flow diagram of the MODEL subroutine.

Within the time loop, the first step is to determine whether a complete cleaning and filtering cycle has been performed. If a complete cycle has been performed, the system is checked for continuous cleaning. If after three or more complete cycles, a limiting pressure system is continuously cleaning the simulation is restarted via RESTRT. If the system was originally described as continuously cleaned in the input or if a limiting pressure system operates with a finite, nonzero time between cleaning, then data processing continues through the STABLE subroutine, which after four complete cycles, checks for steady state. Referring again to the first step, if a cycle has not been completed, a check is made to determine whether a compartment was just cleaned (bag loop No. 1). If no compartments were cleaned, time is increased by an additional time increment (determined by the program) and the calculations proceed through the time loop and back again to the beginning of the time loop. However, if a compartment was just cleaned and is scheduled to be brought back into service during the current time loop, then time is not incremented. This step is necessary to properly depict the effect of a cleaned compartment being put back on line nearly instantaneously (within 0.01 minute).

Once steady state is achieved, the program begins to count the number of completed cycles such that only three cycles will be modeled beyond the point at which steady state was achieved. The performance characteristics of these three cycles constitute the results of the program. If steady state is not achieved within three cycles of the "maximum number of cycles," the performance characteristics of these last three cycles along with a non-convergence error message comprise the program results. Throughout the course of the last three cycles, the results of intermediate calculations are printed (if requested) and files containing pressure drop, penetration and individual compartment flows as functions of time are generated. After three steady state cycles have been modeled, control is returned to the main program (Step 1).

5.4.2 Computational Procedures

The computational procedures are based on an iterative calculation method whereby the results of calculations at time = t are used as input to the calculations at a time = t + Δt. Also, since each compartment (or bag) is composed of a specific number of discrete areas, each having its own drag and penetration characteristics, calculations are performed on an area-by-area and bag-by-bag basis.

The following paragraphs provide a description of the procedures and equations used to calculate system performance. A diagram of the basic computations performed is shown in Figure 7. A tabulation of relevant equations with reference to where they are treated in the report is also included in Figure 7.

5.4.3 Drag Computation

Cleaned fabric drag is a predetermined input that is not computed by the program. It is set equal to the effective residual drag, S_E', if the linear drag model is selected and to the residual drag, S_R, if sufficient data for the nonlinear drag model have been entered.

Area drag values are computed by the linear or nonlinear drag models with the subroutine CAKDRG. The choice of subroutines is automatically performed by the program which selects the nonlinear model when W^* has any nonzero value. A zero value for W^* will automatically lead to computer calculations by the linear drag model. Note that W^* is calculated within the SETUP subroutine and that W^* will be nonzero only if values for K_R and S_R are entered.

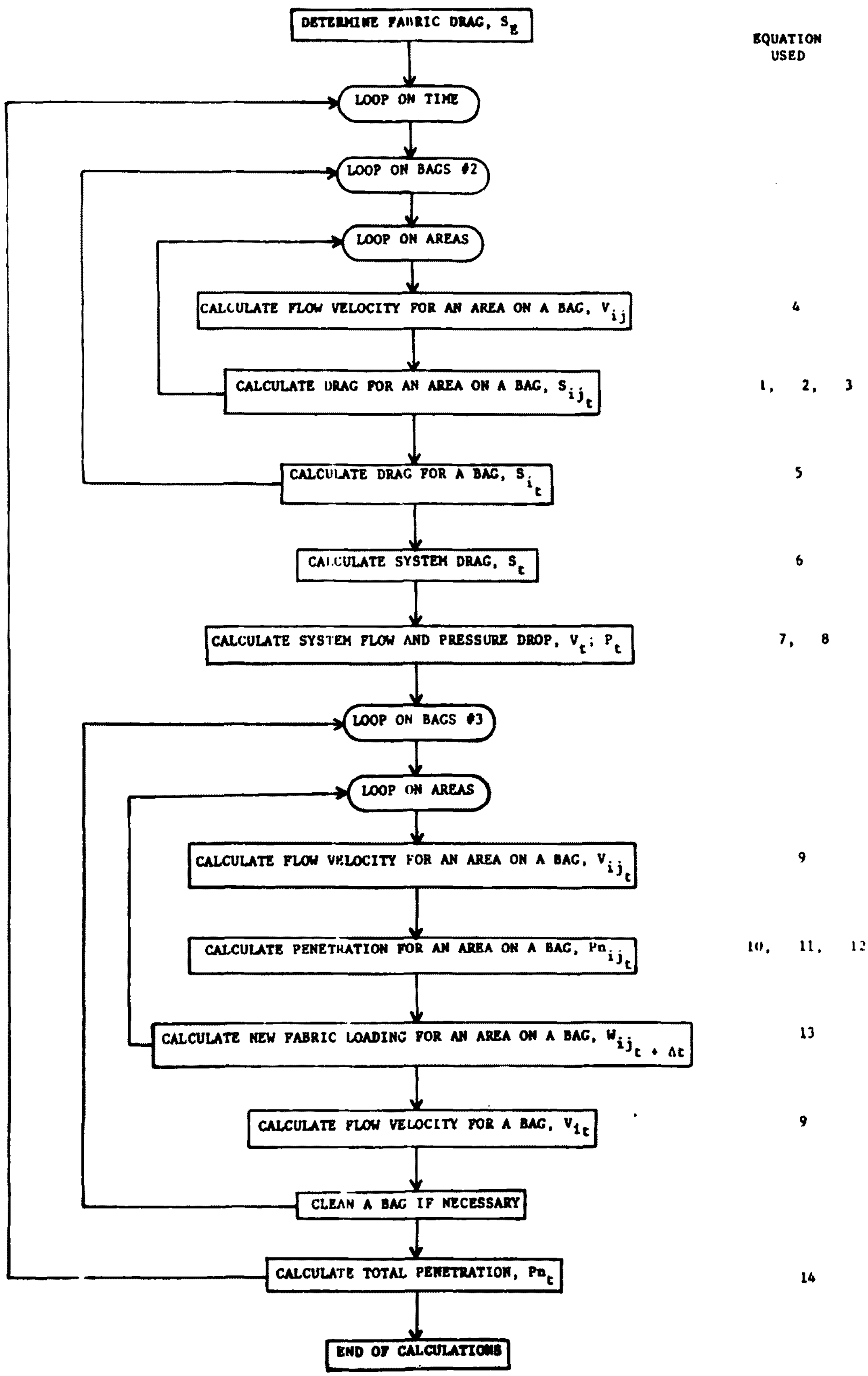

Figure 7. Baghouse model computational procedure.

The area drag equations for the linear model are:

$$S_{ij_t} = S_E' + K_{2_{ij}} \times W'_{ij_t} \qquad (22)$$

and for the nonlinear:

$$S_{ij_t} = S_R + K_{2_{ij}} \times W'_{ij_t} + (K_2 - K_{2_{ij}})W^* (1 - e - W'_{ij_t}/W^*) \qquad (23)$$

where S_{ij_t} = the drag for the j^{th} area on the i^{th} bag at time = t

S_E' = effective residual drag for cleaned fabric

S_R = residual drag for cleaned fabric

$K_{2_{ij_t}}$ = specific cake resistance for the area

W'_{ij_t} = absolute fabric loading less the residual fabric loading

K_R = initial slope of the drag versus loading curve

W^* = constant dependent on fabric and dust properties

t = time

The specific cake resistance (K_2) is a function of velocity:

$$K_{2_{ij_t}} = K_2^\circ \sqrt{V_{ij}/0.61} \qquad (24)$$

where K_2° is the specific resistance at 0.61 m/min and the actual gas temperature. Corrections for gas viscosity and velocity changes are carried out within the program's initiation step (subroutine SETUP).

Since the flow velocity for a specified area is not determined until the system pressure drop and area drag are known, it must be estimated from the previous system pressure drop and the previous drag on the area:

$$V_{ij} = P_{t - \Delta t}/S_{ij_{t - \Delta t}} = V_{ij_{t - \Delta t}} \qquad (25)$$

The total or average drag for a compartment (bag) is calculated for a parallel resistance network of J equal areas as:

$$S_{i_t} = J / \sum_{j=1}^{J} 1/S_{ij_t} \qquad (26)$$

Similarly, total system drag is calculated for I bags as:

$$S_t = I / \sum_{i=1}^{I} 1/S_{i_t} \qquad (27)$$

For convenience in data processing, the drag value for any compartment undergoing cleaning is set equal to 10^{20} in lieu of plus infinity because the compartment velocity is zero. However, since the parameters describing overall system performance are based on total fabric area, the value of I in Equation 27, which designates the total number of system compartments, is not changed. Total baghouse flow can, therefore, be held constant while the average flow velocities for the individual compartments are permitted to vary.

The total or average system pressure drop is calculated from the total system drag and the operating average face velocity. Additionally, when a compartment is being cleaned via reverse flow, the reverse flow air is factored into the computed pressure drop and flow rate.

When reverse flow air is added to the system, the average system gas velocity is calculated by:

$$V_t = V_c + V_R/I \qquad (28)$$

For a constant flow system, the pressure drop is calculated by:

$$P_t = V_c\, S_t + V_R\, S_t/I \qquad (29)$$

where V_c = specified constant system velocity

V_R = reverse flow velocity for a single bag

If no reverse flow is used, V_R is zero in Equations 28 and 29. Once the system pressure drop is known, the calculated flow velocity through an area can be calculated:

$$V_{ij_t} = P_t/S_{ij_t} \qquad (30)$$

5.4.4 Fabric Penetration

Penetration through a specified subarea is calculated by the subroutine PENET from the empirical relationships discussed in Section 3:

$$Pn_{ij_t} = \frac{C_o}{C_i} = Pn_s + (0.1 - Pn_s)e^{-aW_{ij_t}} + C_R/C_i \qquad (31)$$

where Pn_{ij_t} = penetration through the j^{th} area on the i^{th} bag

W_{ij_t} = cloth loading minus residual loading at time = t

C_R = residual concentration, 0.5 mg/m^3, a system constant

C_i = inlet concentration

$$Pn_s = 1.5 \times 10^{-7}\ e^{12.7(1 - e^{-1.03\ V_{ij_t}})} \qquad (32)$$

$$a = 3.6 \times 10^{-3}/(V_{ij_t})^4 + 0.094 \qquad (33)$$

and V_{ij_t} = face velocity of the j^{th} area on the i^{th} compartment (bag) at time = t.

Once the face velocity and penetration have been established for an area, the dust deposition rate can be calculated. The fabric loadings used in the calculations for the succeeding time loop are calculated from:

$$W_{ij_{t+\Delta t}} = V_{ij_t} \times (1-Pn_{ij_t}) \times \Delta t \times C_i + W_{ij_t} \qquad (34)$$

Note that when a compartment (bag) is being cleaned, the velocities on each of its areas are zero and thus no dust is added to the bag. The average flow velocity through a compartment (bag) is calculated in the same manner as that for an area (Equation 30) except that the total compartment drag is used.

After the compartment filtering (or on-line) time has progressed to the point where it is equal to the cleaning cycle time minus the time required to clean one compartment, cleaning is initiated. This entails taking the compartment off line followed by setting its drag equal to 10^{20} to adjust for the zero flow condition.

Total or average system penetration is simply the total mass emitted divided by the total mass input:

$$Pn_t = \frac{1}{V_t IJ} \sum_{i=1}^{I} \sum_{j=1}^{J} Pn_{ij_t} V_{ij_t} \tag{35}$$

After all calculations for time = t have been completed and the fabric loading for the next time loop has been calculated, one proceeds to the next time iteration.

5.5 DATA INPUTS TO THE SIMULATION PROGRAM

The necessary data inputs to the model are presented in Table 7 along with a listing of the symbols used to represent the variables, the units in which each variable must be expressed for entry in the model, the location and format of each variable, and finally the relevant default values. To simplify data entry, a coding form (Figure 8) was developed. On the coding form, all entries not containing an implied decimal point (indicated by a triangle) with the exception of Items 0, 31 and 32 should be right justified. For example, the number 100 would be placed in the three furthest

TABLE 7. FORMAT AND DEFAULT VALUES FOR DATA INPUTS

		Item	Symbol	Units	Card	Starts in column	Format	Default*	Note
	0	Title		-	1	1	8A8		
DESIGN DATA	1	Number of compartments	n	-	2	1	I3		
	2	Compartment cleaning time	Δt	min	2	5	F5.1	$0.5\Sigma t/n$	
	3	Cleaning cycle time	Σt	min	2	11	F5.1		
	4	Time between cleaning cycles	t_f	min	2	17	F5.1		a
	5	Limiting pressure drop	P_L	N/m^2	2	23	F4.0		a
	6	Reverse flow velocity	V_R	m/min	2	28	F6.4	0	b
	7	Shaking frequency	f	cps	2	35	F3.1		b
	8	Shaking amplitude (half stroke)	A	cm	2	39	F4.2		b
OPERATING DATA	9	Average face velocity	V	m/min	3	1	F6.4		
	10	Gas temperature	T	^oC	3	8	F4.0		
	11	Inlet dust concentration	C_i	g/m^3	3	13	F5.2		
	12	measured at temperature of	T	^oC	3	19	F4.0	25	
DUST AND FABRIC PROPERTIES	13	Specific resistance coefficient	K_2	N-min/g-m	4	1	F5.2		c,d
	14	measured at temperature of	T	^oC	4	7	F4.0	25	
	15	measured at velocity of	V	m/min	4	12	F7.4	0.61	
	16	measured at mass median diameter of	MMD_1	μm	4	20	F3.1		d
	17	measured at geometric standard deviation of	σg_1	-	4	24	F3.2		d
	18	Mass median diameter of inlet dust	MMD_2	um	4	28	F3.1		d,e
	19	Geometric standard deviation of inlet dust	σg_2	-	4	32	F3.2		d,e
	20	Discrete particle density of inlet dust	ρ_p	g/cm^3	4	36	F5.3		e
	21	Bulk density of inlet dust	$\bar{\rho}$	g/cm^3	4	42	F5.3		e
	22	Effective residual drag	S_E	$N\text{-}min/m^3$	5	1	F4.0	350^{+}	f,g
	23	measured at temperature of	T	^oC	5	6	F4.0	25	
	24	Residual fabric loading	W_R	g/m^2	5	11	F5.1	50^{+}	f,g
	25	Residual drag	S_R	$N\text{-}min/m^3$	5	17	F4.0		f
	26	measured at temperature of	T	^oC	5	22	F4.0	25	
	27	Initial slope	K_R	n-min/g-m	5	27	F5.2		f
	28	measured at temperature of	T	^oC	5	33	F4.0	25	

(continued)

TABLE 7 (continued)

		Item	Symbol	Units	Card	Starts in Column	Format	Default*	Note
SPECIAL PROGRAM INSTRUCTIONS	29	Maximum number of cycles modeled	nc	-	6	1	I3		h
	30	Accuracy code	0 or 1	-	6	5	I2	0	
	31	Type of tabular results	-	-	6	8	A8	Average	i
	32	Type of plotted results	-	-	6	17	A4		i
	33	Fractional area cleaned	a_c	-	6	22	F3.2		j
	34	x axis length		inches	7	1	F5.2	o	k
	35	y axis length		inches	7	7	F5.2	5	

*these values are used when no entry has been made for the parameter

†used only when K_2 is to be estimated from size properties

Notes: a. Enter item 4 or 5, but not both

b. Enter items 6 or 7 and 8, but not both

c. Enter items 13 through 15 when K_2 measurement is available

d. Enter items 13 through 19 when K_2 measurement must be corrected for size properties

e. Enter items 18 through 21 when K_2 is to be estimated from dust size and density parameters

f. Enter items 22 through 28 for nonlinear drag model

g. Enter items 22 through 24 for linear drag model

h. Generally 20 cycles are sufficient

i. For tabular results specify DETAILED, SUMMARY or AVERAGE, for graphical results specify PLOT or leave blank

j. Enter only in special case when a_c measurement is available

k. Card can be left out if default values are sufficient or if no plotted output is desired

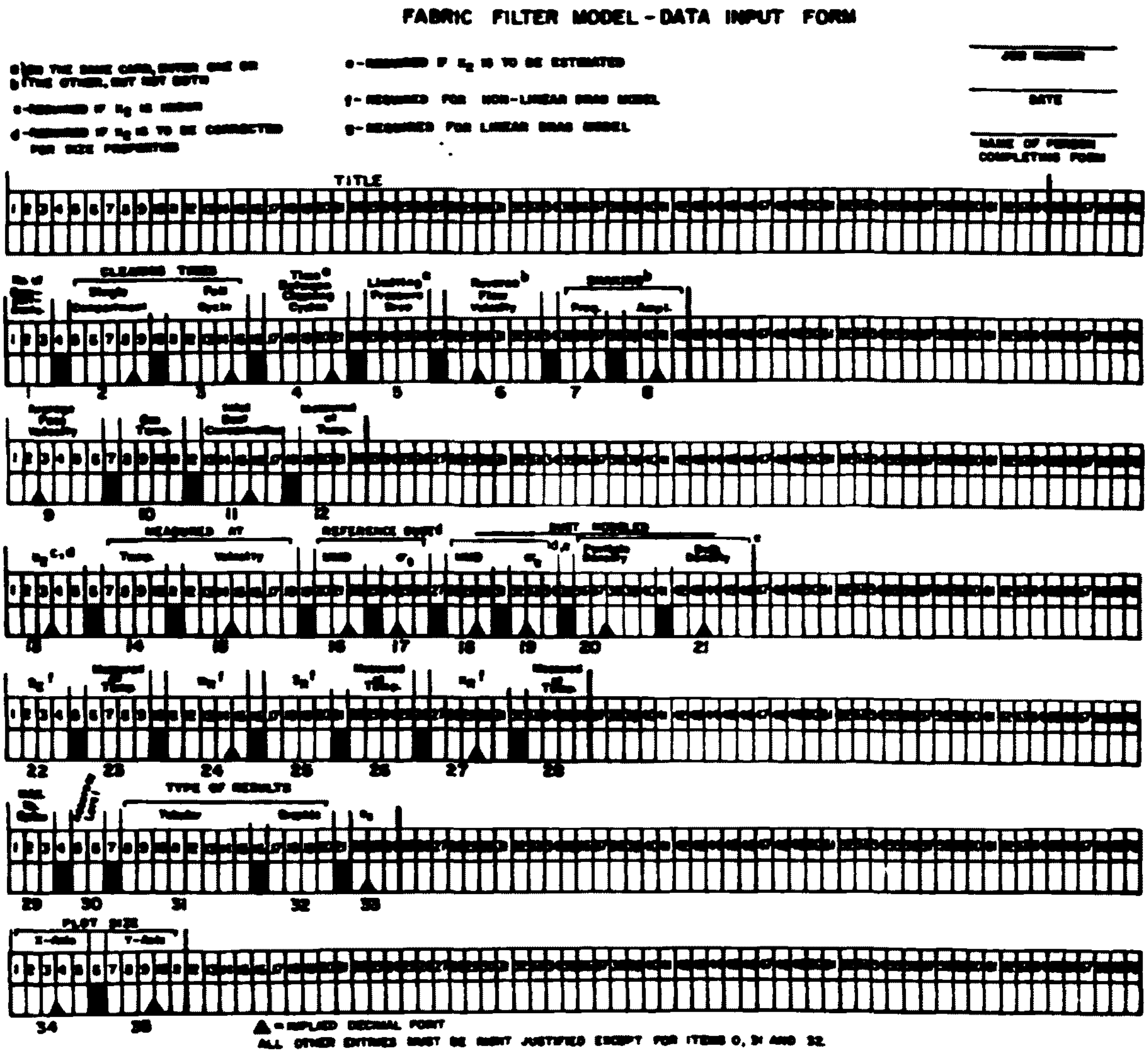

Figure 8. Fabric filter model - data input form.

right blocks in a four block field. The first card (Item 0) is a title or heading card. The information on this card appears as a heading on all printout material along with the input data, summary tables and graphs so that the user can readily identify each simulation. Input data have been grouped into four general categories; i.e., Design Data, Operating Data, Dust and Fabric Properties and Special Program Instructions.

5.5.1 Design Data

Design data are to be entered on the second card. Item 1 refers to the number of parallel compartments each of which is cleaned independently and sequentially. Baghouses operating in parallel but on different cleaning schedules cannot be modeled. The compartment cleaning time (Item 2) is the length of time that any one compartment is off-line for cleaning. The cleaning cycle time (Item 3) is the time required to clean the entire baghouse, including any time during the cleaning cycle when all compartments are on-line. For example, given a 10 compartment system whose cleaning schedule consists of the following steps:

1. all compartments on-line - 1 minute
2. one compartment off-line for cleaning - 3 minutes

The cleaning cycle time is 10 × (3 + 1) or 40 minutes and the compartment cleaning time (Item 2) is 3 minutes.

Items 4 and 5 describe how the cleaning cycle is to be initiated. If, after a cleaning cycle, the baghouse is scheduled to operate without cleaning for a specified amount of time, the time interval between cleaning cycles, (Item 4), must be entered. However, if after a cleaning cycle, the baghouse is allowed to filter until a predetermined pressure loss is reached, the limiting pressure (Item 5) should be entered instead. Finally, if the system is continuously cleaning with no extended filtration time between cleaning cycles, then neither Item 4 or 5 should be entered. If values for both are entered, an error will result and program execution will cease.

The last three items on Card 2 describe the cleaning action itself. Only one type of cleaning method can be specified. If a system uses both reverse air and a shaker-type cleaning action, only the reverse air should be specified. If the cleaning action is entirely shaking, then the shaker amplitude (half stroke) and frequency should both be entered. Since the reverse flow velocity is not used in the determination of the degree of cleaning, it is not a required value for description of cleaning intensity. Its only purpose is to indicate the effect of the additional flow (increased air-to-cloth ratio) on pressure drop and penetration. Reverse flow velocity is defined as the reverse air flow rate divided by the filtration area of one compartment (or the number of compartments cleaned simultaneously).

5.5.2 Operating Data

Item 9, the average face velocity (or air-to-cloth ratio), is the total system air flow at operating conditions divided by the total filtration area. Since the relationship between penetration and velocity was derived from laboratory tests in which the velocity ranged from about 0.3 to 3 m/min, the average face velocity must not exceed this range. The inlet dust concentration (Item 11) can be specified at any reference temperature (Item 12). The program will correct the reference concentration to that corresponding to the inlet gas temperature (Item 10). If the temperature of measurement is not specified, a default value of 25°C is assigned by the program.

5.5.3 Dust and Fabric Properties

Two cards are required to enter the data describing dust and fabric properties. Data pertaining to the specific resistance coefficient, K_2, are entered on Card 4. Three options are available to the user depending upon how many data are available for K_2. If K_2 for the dust in question is known, it should be entered along with the temperature and velocity associated with its measurement (Items 13 through 15). No additional data should be entered on Card 4 if K_2 is known. If measurements are available for a similar dust (i.e., same shape factor, packing density, discrete particle density) but having different size properties, the K_2 corresponding to the dust for which it was measured including the related size properties of the dust and other relevant measurement conditions should be entered as Items 13 through 17. In addition, the size properties of the dust to be filtered must be entered (Items 18 and 19). Finally, if no measured value for K_2 is available, but the size and density properties of the inlet dust are given, Items 18 through 21 alone should be entered. In this last case, an estimate of K_2 will be made by the program. Referring to Items 14 and 15, if no values are entered for the measurement conditions, default values will be assigned. Insufficient or conflicting data on Card 4 will cause the program to return error messages and no modeling will be performed.
The remaining dust and fabric properties are entered on Card 5. When sufficient data are available for the nonlinear drag model, all the parameters on Card 5 must be entered. If, however, the linear drag model is to be used in the calculations, only S_E, W_R and the temperature at which S_E was measured should be entered. If K_2 is to be estimated by the program, and no data are available for S_E and W_R, the card may be left blank and default values will be assigned for S_E and W_R.

5.5.4 Special Program Instructions

Special instructions to the program are entered on Card 6. The first item (Item 29) denotes the maximum number of complete operating cycles to be modeled if convergence is not achieved. Convergence is generally achieved in less than 20 cycles. A value of 20 should therefore be entered unless fewer cycles are desired regardless of convergence. The accuracy code (Item 30) simply modifies the limits of convergence and the length of the time interval, as was discussed in this report under modifications to the model. A value of zero should be entered unless the results of a previous simulation with an accuracy code of zero do not appear to have reached stable values. Three types of tabular results can be requested via Item 31 as described below:

Level of detail requested	Type of Results Printed
DETAILED	Point by point variations in drag, flow and loading for each area of the system versus time and location
SUMMARY	Summary of system pressure drop and penetration versus time.
AVERAGE	Average and maximum pressure and penetration for a complete operating cycle.

If Item 31 is left blank, AVERAGE is assumed. If graphical output is desired "PLOT" should be entered for Item 32. It should otherwise be left blank.

If the level of cleaning, a_c (Item 33), is known it can be entered. In general, a value for a_c will not be available and Item 33 must be left blank. Finally, if plotted output is requested and axis lengths other than defaults are desired, they should be entered in Items 34 and 35 (Card 7). If the default values are acceptable or if no graphs are requested, this card can be omitted from the input deck.

With respect to the data input form (Figure 8), all numbers without decimal points should be right justified. The small triangles in certain fields specify the decimal point location.

Examples of input data forms for a few selected types of simulations and the results of the simulations are presented in Appendix C.

5.6 SIMULATION PROGRAM OUTPUT

As discussed previously, three levels of detail may be requested for the results of the simulation; i.e., DETAILED, SUMMARY or AVERAGE. Examples of each of these plus an example of the input data summary are shown in Tables 8 through 12. Additional examples are presented in Appendix C.

The input data summary (Table 8) consists essentially of most of the data originally entered into the program with few modifications. The title, basic design data and operating data are returned as entered with the exception of the temperature at which the inlet concentration was measured. If no value was entered, the default value of 25°C is printed. Since blanks are treated as if they were zeroes by the program, any blanks in the input (except the title and result requests) will be printed as zeroes. It is emphasized that not all of the fabric and dust property categories are printed. Only those that pertain to (1) the manner in which K_2 is to be treated by the program and (2) the type of drag model to be used are

TABLE 8. EXAMPLE OF INPUT DATA SUMMARY

****

SUMMARY OF INPUT DATA FOR BAGHOUSE ANALYSIS

****

CONTINUOUS/K2 ESTIMATED/AC ENTERED/DETAILED RESULTS/

BASIC DESIGN DATA		
NUMBER OF COMPARTMENTS	12	
COMPARTMENT CLEANING TIME (OFF LINE TIME)	2.0	MINUTES
CLEANING CYCLE TIME	36.0	MINUTES
CONTINUOUSLY CLEANED SYSTEM		
REVERSE FLOW VELOCITY	0.0	M/MIN
OPERATING DATA		
AVERAGE FACE VELOCITY	0.9000	M/MIN
GAS TEMPERATURE	100.	DEGREES CENTIGRADE
INLET DUST CONCENTRATION	5.00	G/M3
MEASURED AT	25.	DEGREES CENTIGRADE
FABRIC AND DUST PROPERTIES		
SPECIFIC RESISTANCE, K2 ESTIMATED FROM		
MASS MEDIAN DIAMETER	9.0	MICRONS
STANDARD DEVIATION	3.00	
PARTICLE DENSITY	2.000	G/CM3
BULK DENSITY	1.000	G/CM3
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	DETAILED /	
FRACTIONAL AREA CLEANED, AC	0.50	

TABLE 9. EXAMPLE OF CALCULATED VALUE PRINTOUT

```
CALCULATED VALUES


INLET DUST CONCENTRATION                  3.99          G/M3
CORRECTED TO OPERATING TEMPERATURE

FABRIC AND DUST CAKE PROPERTIES CORRECTED FOR GAS VISCOSITY

     SPECIFIC CAKE RESISTANCE, K2        1.66          N-MIN/G-M
     EFFECTIVE DRAG, SE                 497.           N-MIN/M3


FRACTIONAL AREA CLEANED, AC             0.50

TIME INCREMENT                           0.75          MINUTES

SYSTEM CONSTANT W*                        0.0          G/M2
```

TABLE 10. EXAMPLE OF POINT-BY-POINT DATA PRINTOUT FOR DETAILED RESULTS SPECIFICATION ONLY

BAG-DRAG=	AREA 1	AREA 2	SBAG
1	9.13E+02	7.10E+02	7.99E+02
2	9.28E+02	7.32E+02	8.19E+02
3	9.42E+02	7.53E+02	8.37E+02
4	9.56E+02	7.73E+02	8.55E+02
5	9.69E+02	7.93E+02	8.72E+02
6	1.00E+20	1.00E+20	1.00E+20
7	5.36E+02	8.17E+02	6.47E+02
8	5.72E+02	8.34E+02	6.79E+02
9	6.05E+02	8.51E+02	7.07E+02
10	6.34E+02	8.67E+02	7.33E+02
11	6.61E+02	8.83E+02	7.56E+02
12	8.99E+02	6.86E+02	7.78E+02
BAG-FLOW=	AREA 1	AREA 2	QBAG
1	8.22E-01	1.06E+00	9.39E-01
2	8.09E-01	1.03E+00	9.17E-01
3	7.97E-01	9.96E-01	8.97E-01
4	7.85E-01	9.71E-01	8.78E-01
5	7.74E-01	9.47E-01	8.61E-01
6	0.0	0.0	7.51E-18
7	1.40E+00	9.19E-01	1.16E+00
8	1.31E+00	9.00E-01	1.11E+00
9	1.24E+00	8.82E-01	1.06E+00
10	1.18E+00	8.65E-01	1.02E+00
11	1.14E+00	8.50E-01	9.93E-01
12	8.35E-01	1.09E+00	9.64E-01

Units: Drag in N-min/m^3

Flow in m/min

Time in min

DELP in N/m^2

Concentration in g/m^3

Fabric loadings in g/m^2

Weight dumped is g/m^2 of area per compartment

T= 270.0 DELP= 750.6 DELQ= .9000 CONCENTRATION= .1091E-01 WEIGHT DUMPED= 127.6

	BAG 1	BAG 2	BAG 3	BAG 4	BAG 5	BAG 6	BAG 7	BAG 8	BAG 9	BAG 10
T=	21.00	24.00	27.00	30.00	33.00	-0.00	3.00	6.00	9.00	12.00
CAKE	2.0646E+02	2.1704E+02	2.2738E+02	2.3750E+02	2.4742E+02	2.5055E+02	1.3599E+02	1.4877E+02	1.6109E+02	1.7296E+02
SBAG	0.7989E+03	0.8185E+03	0.8372E+03	0.8550E+03	0.8721E+03	0.1000E+21	0.6475E+03	0.6788E+03	0.7070E+03	0.7326E+03
QBAG	0.9395E+00	0.9170E+00	0.8966E+00	0.8779E+00	0.8607E+00	0.7506E-17	0.1159E+01	0.1106E+01	0.1062E+01	0.1025E+01

	BAG 11	BAG 12	BAG
T=	15.00	18.00	
CAKE	1.8445E+02	1.9561E+02	
SBAG	0.7562E+03	0.7782E+03	
QBAG	0.9926E+00	0.9645E+00	

TABLE 11. EXAMPLE OF PRINTOUT RESULTS FOR DETAILED OR SUMMARY DATA REQUESTS

SUMMARY TABLE : CONTINUOUS/M2 ESTIMATED/AC ENTERED/DETAILED RESULTS/

TIME (MIN)	PRESSURE DROP (N/M2)	FRACTIONAL PENETRATION	INDIVIDUAL COMPARTMENT FLOWS (M/MIN)				
			COMP.1	COMP.2	COMP.3	COMP.4	COMP.5
0.01	675.	8.493E-03	1.0416	0.9935	0.9539	0.9204	0.8916
0.75	669.	6.034E-03	1.0316	0.9877	0.9512	0.9201	0.8930
1.50	728.	4.931E-03	1.1092	1.0634	1.0250	0.9922	0.9635
2.25	744.	3.653E-03	1.1095	1.0637	1.0254	0.9924	0.9636
3.00	751.	2.731E-03	1.1058	1.0617	1.0246	0.9926	0.9645

TABLE 12. EXAMPLE OF DATA PRINTOUT WHEN DETAILED, SUMMARY OR AVERAGE RESULTS ARE REQUESTED

```
FOR     36.00 MINUTES OPERATION,  CYCLE NUMBER  6
                                                AVERAGE PENETRATION=           5.06E-03
                                                AVERAGE PRESSURE DROP=           713.34 N/M2
                                                AVERAGE SYSTEM FLOW=             0.9000 M/MIN
                                                MAXIMUM PENETRATION=           8.49E-03
                                                MAXIMUM PRESSURE DROP=           750.71 N/M2

FOR     36.00 MINUTES OPERATION,  CYCLE NUMBER  7
                                                AVERAGE PENETRATION=           5.06E-03
                                                AVERAGE PRESSURE DROP=           713.30 N/M2
                                                AVERAGE SYSTEM FLOW=             0.9000 M/MIN
                                                MAXIMUM PENETRATION=           8.49E-03
                                                MAXIMUM PRESSURE DROP=           750.62 N/M2

FOR     36.00 MINUTES OPERATION,  CYCLE NUMBER  8
                                                AVERAGE PENETRATION=           5.06E-03
                                                AVERAGE PRESSURE DROP=           713.29 N/M2
                                                AVERAGE SYSTEM FLOW=             0.9000 M/MIN
                                                MAXIMUM PENETRATION=           8.49E-03
                                                MAXIMUM PRESSURE DROP=           750.60 N/M2
```

returned. In Table 8 only particle size and density properties of the inlet dust are printed since K_2 will be estimated within the program. If K_2 is to be corrected for size properties, the size parameters for both the inlet and reference dusts will be printed along with the temperature and velocity for the reference K_2 measurement. If sufficient data are entered for the nonlinear model, S_R and K_R as well as the temperatures of measurement will also be printed. Under special program instructions, the fractional area cleaned, a_c, is printed only when it is available for entry to the program (as assumed for the example case of Table 8). After all data inputs have been printed, those values which have been calculated within the program and/or corrected for temperature are printed (Table 9).

The input data, actual or calculated, will be printed as shown in Tables 8 and 9 even when errors exist. This enables the model user to compare the results with the original or intended data input when error messages are generated by the program. Examples of the types of error messages that may result from errors in the input data are presented in Appendix C, Table 21.

If no errors exist in the input data, the filtration simulation will be performed and one of three types of tabular results will be printed. When DETAILED results are requested, data similar to that shown in Tables 10, 11 and 12 will be returned to the user. If SUMMARY is specified, data in the formats shown in Tables 11 (less compartment flows) and 12 will be printed. When AVERAGE is selected, only the average and maximum operating conditions shown in Table 12 will be returned to the user.

A complete description of all parameters for each discrete area in each compartment for each time interval is shown in Table 10 as part of the DETAILED output. Results are printed in the order in which they are calculated. The first two blocks of data are the drag values and face velocities corresponding to the two areas (in this case $a_c = 0.50$) on each bag (or compartment), respectively. The units for each parameter are also shown in Table 10. Note that compartment 6 is currently off-line as indicated by a very high drag (10^{20}) and zero flows.

The next line of information is the simulation time (T), the total system pressure loss (DELP), total system flow velocity (DELQ), system outlet concentration and, finally, the amount of dust removed from a compartment during cleaning. This weight is expressed as grams of dust removed per unit of cloth area in a single compartment. For example, for the case shown, if the total filtration area for a compartment were 100 m^2 then 100 m^2 × 127.69/m^2 or 12,760 grams of dust would have been removed from the bags in a single compartment.

The average values for fabric loading, drag and flow (velocity) through each compartment are summarized in the last block of data.

Total system pressure loss and penetration are presented as functions of time in the summary table (Table 11). Individual compartment flows for up to five compartments also appear in the summary table. These data correspond exactly to those which will be plotted if a graphical output is requested. Since more than five curves on the individual flow versus time graph would produce a very crowded figure, data for only five or less compartments are plotted.

In Table 12 is shown an example of the format by which system pressure loss, penetration and flow averaged over an entire filtering and cleaning cycle are printed. The maximum penetration and pressure loss experienced during a cycle are also output. The time specifications preceding the cycle number is the total cleaning and filtering cycle time.

6.0 GUIDELINE SENSITIVITY TESTS

Several guideline tables and graphs have been prepared so that the model user can make preliminary approximations of filter system performance based upon estimates of the principal design and operating parameters. The above approach allows the model user to determine the relative importance and the range of credible values for the major system variables before carrying out any extensive computer modeling. For example, given the situation that the fly ash concentration and size properties may vary appreciably for a specific combustion process, or the size properties have not been determined at a high level of accuracy, it is advantageous to define the impact of this variability on filter system performance by means of the guideline tables and graphs. This preliminary step will usually indicate when the data inputs are inconsistent with normal filter function or incompatible with the modeling process.

Tests were performed to determine the effect of either variability or errors in the assigned operating parameters on system performance and to identify those operating parameters that have little or no effect on the filtration process. Based upon preliminary tests, average face velocity (V), fractional area cleaned (a_c), limiting pressure (P_L), inlet concentration (C_i) and the specific resistance coefficient (K_2) were found to produce the greatest impact on performance. Performance was defined by the three indices, average pressure loss, average penetration and cleaning frequency. Those parameters that play minor roles in determining system performance are the number of compartments, compartment cleaning time and the reverse flow velocity during cleaning. The above variables and five additional parameters were assigned constant values (see Table 13) so that the effects of changes in the major variables could be ascertained. The numerical values shown in Table 13 (with the exception of reverse flow velocity) are typical or average values associated with the filtration of coal fly ash. Although K_2 was not varied for the bulk of the testing, the effect of K_2 variations on pressure drop closely paralleled the effect of changes in inlet dust concentration. This effect is not unexpected since dust cake resistance is linearly related to both K_2 and C_1.

A summary sampling of sensitivity tests showing the interrelationships among the more important variables involved in the filter system operation are indicated in Table 14. For example, the first two data groupings (1 and 2) indicate how average pressure drop, penetration and time between cleaning might vary due to differences or errors in estimating the fractional area cleaned, a_c, for two different systems. As a result of variations in velocity and cleaning frequency, the test range for a_c (0.1 to 1.0) has a decidedly different impact on both average pressure drop and penetration.

Further reference to the tabulated data confirms the observation that the absolute effect of changing one variable depends strongly upon the magnitude of the other system variables. In some cases, one might conclude that variations in any one data input have little effect on system performance based upon resistance and emission criteria. However, when the time between cleaning increases from 6.6 to 672 minutes for a test velocity range of 0.3 to 0.91 m/min, data group 6, the frequency of fabric cleaning is increased nearly 20 times.

TABLE 13. SYSTEM OPERATING PARAMETERS HELD CONSTANT FOR SENSITIVITY ANALYSIS

Parameter	Constant value
Number of compartments	10
Cleaning cycle time	30 min
Compartment cleaning time	3 min
Reverse flow velocity	0 m/min
Gas temperature	150°C
Effective drag, S_E	
at 25°C	400 N-min/m^3
at 150°C	528 N-min/m^3
Specific resistance coefficient, K_2	
at 25°C, 0.61 m/min	1.0 N-min/g-m
at 150°C, 0.61 m/min	1.32 N-min/g-m
Residual fabric loading, W_R	50 g/m^2

TABLE 14. DATA SAMPLING FROM SENSITIVITY TESTS

Data group	Constant parameters*				Variable parameter*	Average pressure drop (N/m^2)	Average penetration (percent)	Time between cleanings (min)
1	$K_2 = 1.0$	$V = 1.22$	Continuous	$C_i = 6.87$	$a_c = 0.1$	4171	0.78	0.
					$a_c = 0.4$	1690	0.57	0.
					$a_c = 1.0$	1209	0.70	0.
2	$K_2 = 1.0$	$V = 0.61$	$P_L = 1000$	$C_i = 6.87$	$a_c = 0.1$	1130	0.13	8.0
					$a_c = 0.4$	860	0.13	80.0
					$a_c = 1.0$	713	0.14	170.
3	$K_2 = 1.0$	$V = 1.22$	Continuous	$a_c = 0.4$	$c_i = 2.29$	1159	0.78	0.
					$c_i = 6.87$	1690	0.57	0.
					$c_i = 22.9$	3517	0.77	0.
4	$K_2 = 1.0$	$V = 0.61$	$P_L = 1000$	$a_c = 0.4$	$c_i = 2.29$	810	0.029	270.
					$c_i = 6.87$	860	0.13	80.
					$c_i = 22.9$	1050	0.17	10.
5	$K_2 = 1.0$	$c_i = 6.87$	$a_c = 0.4$	Continuous	$V = 0.61$	560	0.36	0.
					$V = 0.8$	865	0.32	0.
					$V = 1.22$	1690	0.57	0.
6	$K_2 = 1.0$	$c_i = 6.87$	$a_c = 0.4$	$P_L = 1000$	$V = 0.3$	726	0.037	672.
					$V = 0.61$	860	0.13	80.
					$V = 0.91$	1097	0.30	6.6
7	$V = 0.61$	$P_L = 2000$	$C_i = 2.29$	$a_c - 0.4$	$K_2 = 1$	1445	0.08	759.
					$K_2 = 3$	1520	0.19	240.
8	$V = 0.61$	Continuous	$C_i = 2.29$	$a_c = 0.4$	$K_2 = 1$	460	0.98	0.
					$K_2 = 3$	650	0.98	0.
9	$V = 0.61$	$K_2 = 3$	$C_i = 2.29$ $a_c = 0.4$	$P_L = 2000$	Linear	1520	0.17	230.
					Nonlinear	1440	0.19	240.
10	$V = 0.61$	$P_L = 2000$	$a_c = 0.4$		$K_2 = 1$, $C_i = 6.87$	1480	0.08	236.
					$K_2 = 3$, $C_i = 2.29$	1520	0.17	230.
11	$V = 0.61$	Continuous	$a_c = 0.4$		$K_2 = 1$, $C_i = 6.87$	560	0.36	0.
					$K_2 = 3$, $C_i = 2.29$	650	0.98	0.

*a_c = dimensionless, $C_i = g/m^3$, $P_L = N/m^2$, K_2 = N-min/g-m, V = m/min
Continuous indicates a continuously-cleaned system

The impact of errors (or variation) in K_2 on filter performance is demonstrated in data groups 7 and 8. A factor of 3 increase in K_2 produces only minor changes in average pressure loss for limiting pressure systems (group 7) but results in a significant change in penetration. On the other hand, the effects are reversed for continuously cleaned systems (group 8).

The effect of K_2 on pressure loss may be approximated in some cases by examining the effect of inlet concentration. Data groups 10 and 11 show the results of tests in which K_2 and C_i were varied simultaneously, but with their product held constant. Test data indicate that changes or errors in K_2 will produce changes in pressure loss roughly the same as those which would be experienced if C_i were changed in proportion to the change in K_2.

Figure 9 shows the effect of variations in face velocity, V, and limiting pressure, P_L, on the average system pressure loss, $\overline{P}$, when all other system variables are held constant. The lowest curve shown describes the resistance path for a continuously cleaned system. Once an average velocity is selected, the average resistance can never be lower than that corresponding to the velocity intercept with that curve; i.e., no pressure-velocity coordinate can exist in the shaded region. Thus, if one selects a limiting pressure loss of 1000 N/m^2 as the point where cleaning is to be initiated and concurrently selects a face velocity of 1.5 m/min, the system automatically reverts to a continuously cleaned system with an average operating pressure drop of 2500 N/m^2, far exceeding the limiting pressure. On the other hand, given a face velocity of 1.0 m/min and a limiting pressure of 2000 N/m^2, the velocity-pressure intersection occurring above the shaded zone indicates that the system will operate according to the selected V and P_L values and on an intermittently cleaned basis.

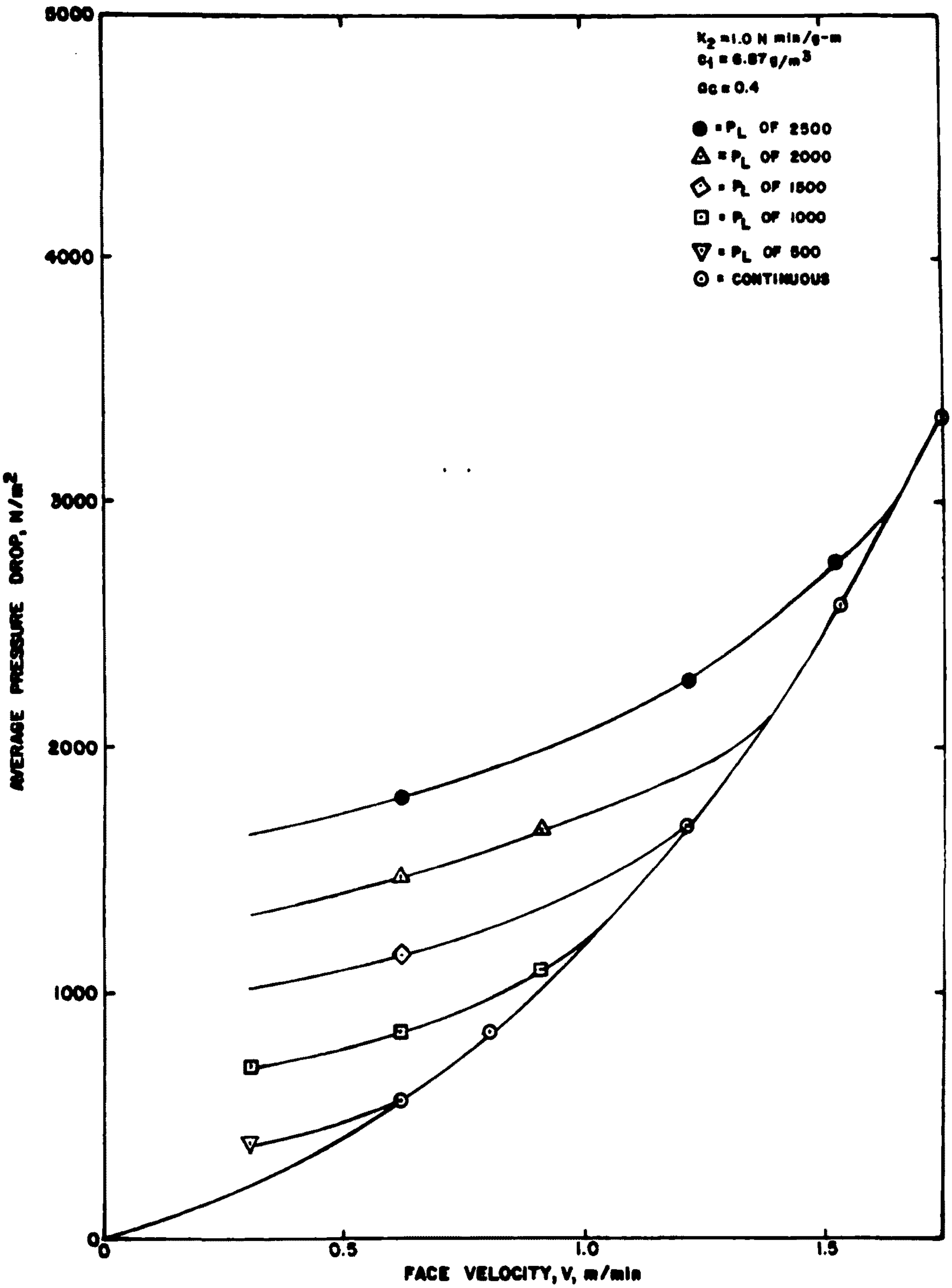

Figure 9. Effect of face velocity (V) and limiting pressure loss (P_L) on average pressure loss ($\overline{P}$).

The curves shown in Figure 9 represent the average pressure levels for systems in which the fractional area cleaned, a_c, is 0.4. However, a_c is a function not only of fabric loading but other factors as well such that the loading distributions will differ for various combinations of velocity and limiting pressure. Depending on the type and intensity of cleaning, some systems may never achieve a cleaning level of 40 percent while others may exceed this value. Refer to Equations 18 and 20.

Numerous plots of average pressure loss, penetration and time between cleanings have been prepared for different combinations of inlet concentration and cleaned area fraction. Due to the large number of plots generated from the sensitivity testing, only a few summary results are given in this report. Complete tabulations, however, are provided in a related report in which sensitivity tests were the main object of study. Reference 11 also furnishes a detailed interpretation of the sensitivity tests and their applications.

The cleaning frequency (defined by the time between cleaning) and the dust penetration associated with the systems described in Figure 9 are presented in Figures 10 and 11, respectively.

The time between cleanings, which increases as the limiting pressure drop is allowed to increase and decreases as the face velocity increases is consistent with expected filter system behavior, Figure 10. Similarly, Figure 11 shows that dust penetration increases rapidly with increasing face velocity, regardless of the assigned limiting pressure with one very important exception. During continuous cleaning, the effect of increased face velocity is first to provide additional surface cover within the time frame of the cleaning cycle. This effect overrides the reentrainment effect of increased filtration velocity until, for the systems described by Figure 11, the adverse velocity effect dictates a rise in penetration.

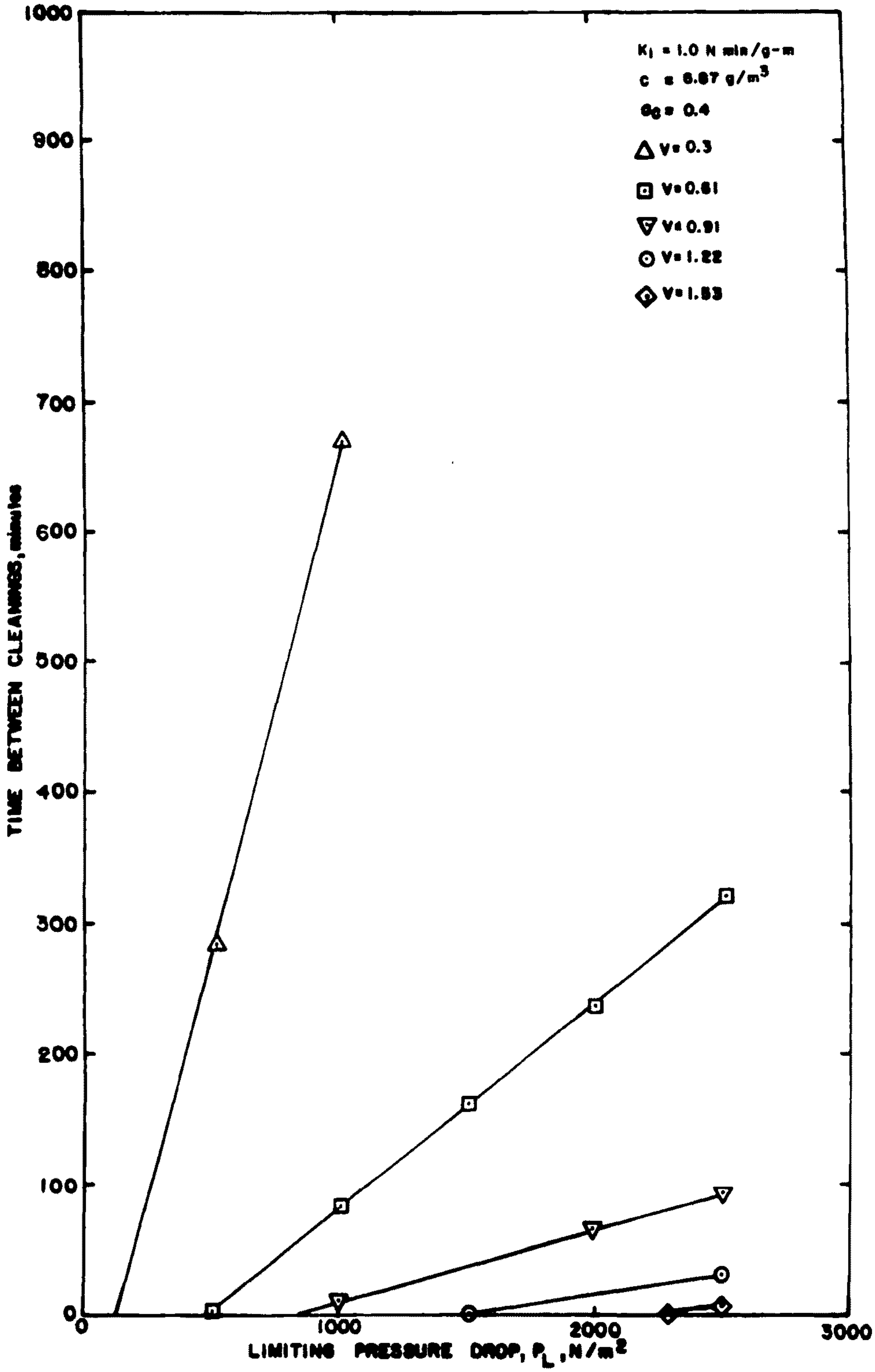

Figure 10. Relationship between time between cleanings, limiting pressure loss and face velocity.

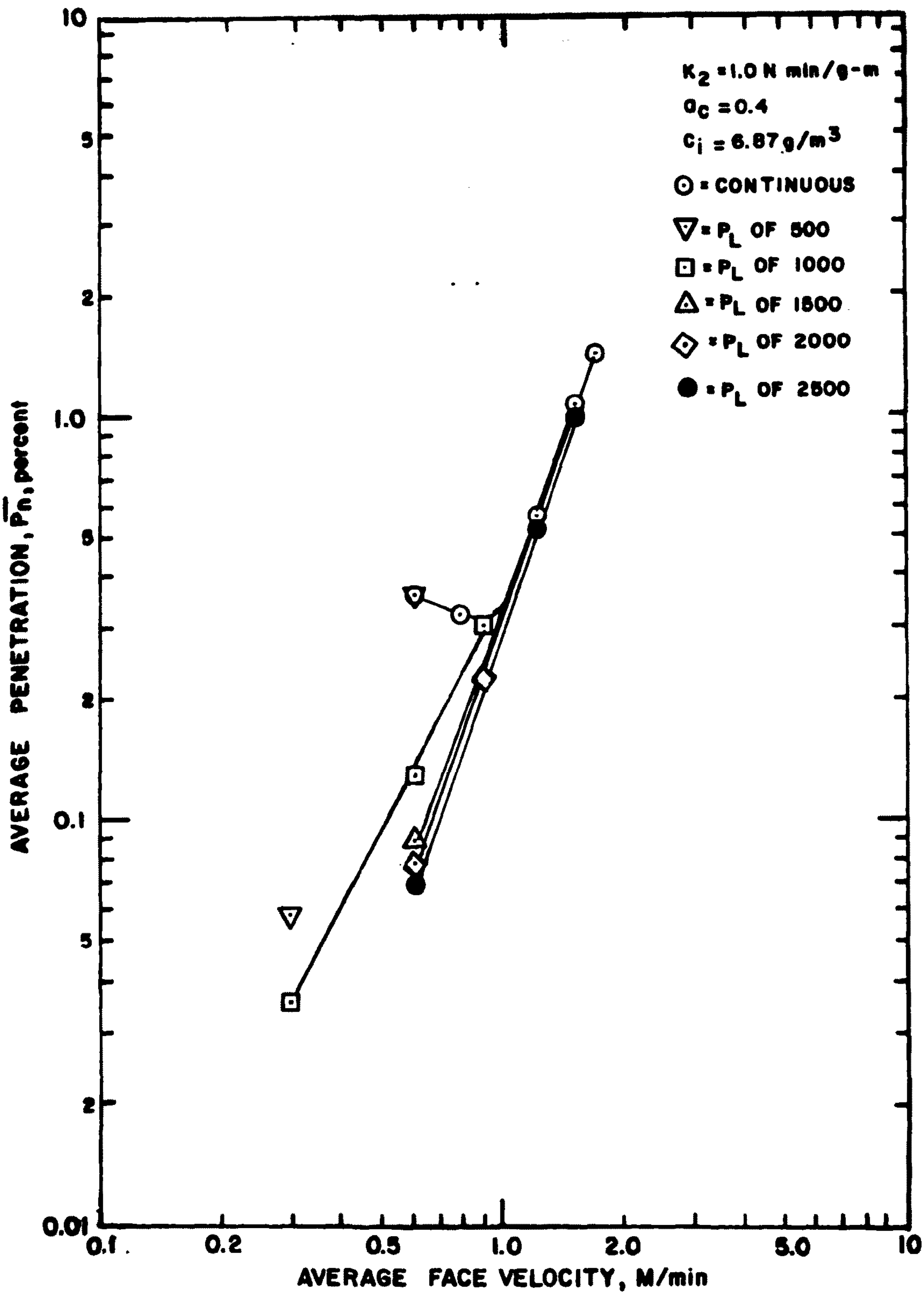

Figure 11. Effect of face velocity and limiting pressure drop on average penetration.

REFERENCES

1. Dennis, R., et. al. Filtration Model for Coal Fly Ash with Glass Fabrics. U.S. Environmental Protection Agency, Industrial Environmental Research Laboratory, Research Triangle Park, North Carolina. EPA-600/7-77-084. August 1977.

2. Dennis, R., R. W. Cass, and R. R. Hall. Dust Dislodgement From Woven Fabrics Versus Filter Performance. J Air Pollut Control Assoc. 48 No. 1. 47:32, 1978.

3. Dennis, R. and H. A. Klemm. Modeling Coal Fly Ash Filtration With Glass Fabrics. Third Symposium on Fabric Filters for Particulate Collection. Report No. EPA-600/7-78-087. June 1978. p. 13-40.

4. Dennis, R. and H. A. Kelmm. A Model for Coal Fly Ash Filtration (Presented at the 71st Annual Meeting of the Air Pollution Control Association. Houston, Texas. June 2-30, 1978.)

5. 40 CFR 60, Appendix A Methods 1 through 5 and 9

6. Billings, C. E. and J. E. Wilder. Handbook of Fabric Filter Technology. Volume I, Fabric Filter Systems Study. Environmental Protection Agency. Publication Number APTD-0690 (NTIS No. PB-200-648). December 1970. 649 p.

7. Rudnick, S. N. and M. W. First. Specific Resistance (K_2) of Filter Dust Cakes: Comparison of Theory and Experiments. Third Symposium on Fabric Filters for Particulate Collection. Report No. EPA-600/7-78-087. June 1978. p. 251-288.

8. Happel, J. Viscous Flow in Multiparticle Systems: Slow Motion of Fluids Relative to Beds of Spherical Particles. AIChE J. 4:197-201, 1958.

9. Dennis, R., and J. E. Wilder. Fabric Filter Cleaning Studies. U.S. Environmental Protection Agency, Control Systems Laboratory, Research Triangle Park, North Carolina. EPA-650/2-75-009 (NTIS No. PB-240-372/3G1). January 1975.

10. Robinson, J. W., R. E. Harrington, and P. W. Spaite, "A New Method for Analysis of Multicompartment Fabric Filtration, "Atmos Environ. 1:499-508, (1967).

11. Dennis, R. and H. A. Klemm. Fabric Filter Model Sensitivity Analysis . U.S. Environmental Protection Agency, Industrial Environmental Research Laboratory, Research Triangle Park, North Carolina. EPA-600--- In Press. (1979)

APPENDIX A

SUBROUTINE STABLE — DETERMINATION OF STEADY STATE

A description of the three criteria used to determine when the simulation has reached a given level of convergence is presented below. Average pressure loss is the test variable which is traced throughout the simulation. In the course of evaluating the convergence tests discussed here, it was noted that average penetration and filtration cycle time (time between cleaning) also converged when average pressure loss converged.

Check #1

Check #1 involves the determination of a least squares fit for the regression line through the points indicated in Figure 12, i.e., natural logarithm of the slope of the $\overline{P}$ versus T curve, versus average time, t. Here, average time refers to the average of the absolute times bracketing the time interval over which the slope is measured. Thus, the slope can be represented as:

$$m = \frac{dP}{dT} = e^{A+Bt} \tag{36}$$

where m = slope of P versus T

A = intercept of the regression line of Figure 12

B = slope of the regression line of Figure 12

The actual average pressure drop at infinite time, P_∞, can be found by integrating Equation 36 with respect to absolute test time, T:

$$P = \int \frac{dP}{dT}\, dt = \int e^{A+Bt}\, dt$$

Since t = T + constant

$$dt = dT$$

$$\text{and } P = \int e^{A=Bt}\, dt = \frac{1}{B}\, e^{A+Bt} \Big|_{t_1}^{t_2} \tag{37}$$

By integrating between the limits $t_1 = 0$ and $t_2 = t_{avg}$, the following general equation results:

$$P = \frac{1}{B}\,(e^{A+Bt_{avg}} - e^{A}) \tag{38}$$

which reduces to $P_\infty = \frac{1}{B}\,(-e^{A})$ when t_{avg} approaches infinity.

An estimate of how close the actual value of average pressure drop, $\overline{P}$, is to the predicted final value, P_∞; i.e., the fractional error can be computed from Equation 39:

$$E = \left| \frac{P(t_{avg}) - P_\infty}{P_\infty} \right| = \left| -e^{Bt_{avg}} \right| \tag{39}$$

The current convergence criterion used in the Subroutine STABLE for this check is 0.01. This limit is decreased to a value of 0.00333 when an accuracy code of 1 is selected in place of the less stringent code of 0.

Check #2

Again referring to Figure 13, a second check involves a linear regression for the last four data points; i.e., the results of the most recent four operating cycles. The slope of the regression line is an indication of how average pressure drop is changing with time. An estimate of the change in pressure from cycle to cycle is:

$$E = \left| \frac{m \cdot \Delta T}{P} \right| \tag{40}$$

where E = ratio of the estimated change in pressue drop over a cycle to the actual pressure drop

m = slope of the regression line of Figure 13

ΔT = complete cycle time

$\overline{P}$ = average pressure drop of the most recent complete cycle

When E is computed to be less than some predetermined limit (currently 0.005) the system is considered to be at equilibrium.

Check #3

If the average pressure drop oscillates about the steady state value as shown in Figure 14, and convergence is not indicated by either Checks #1 or #2 the system may actually be at or very close to equilibrium. Check #3 determines whether or not the magnitude of the oscillations is decreasing with time. Successive changes in average pressure drop are compared without regard to sign once oscillation has begun. If the absolute difference between P_8 and P_7 is less than that between the preceding values P_7 and P_6, Figure 14, the system is considered to be at steady state.

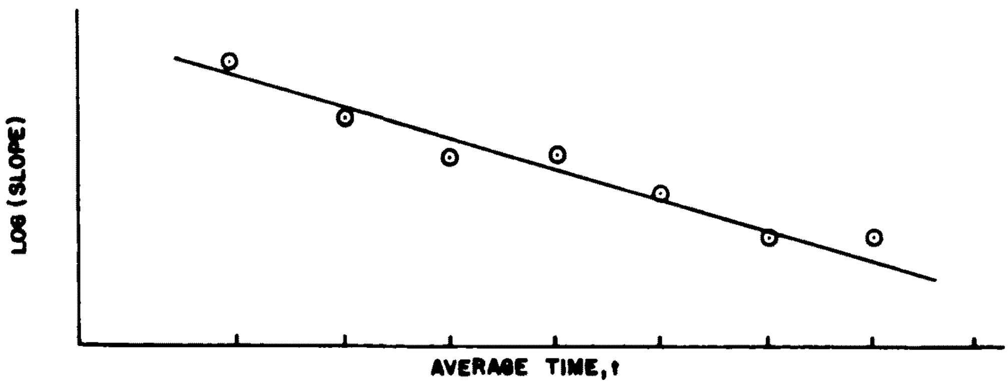

Figure 12. Method of fitting data to exponential curve for Check #1.

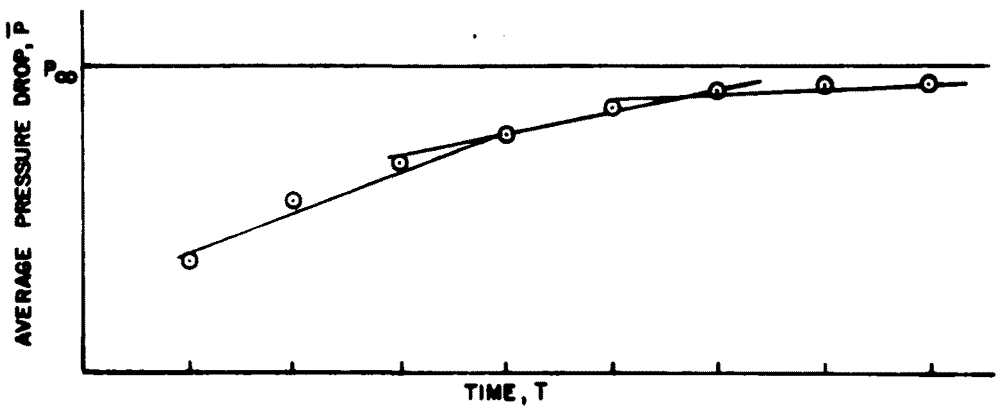

Figure 13. Example of linear regression lines used in Check #2.

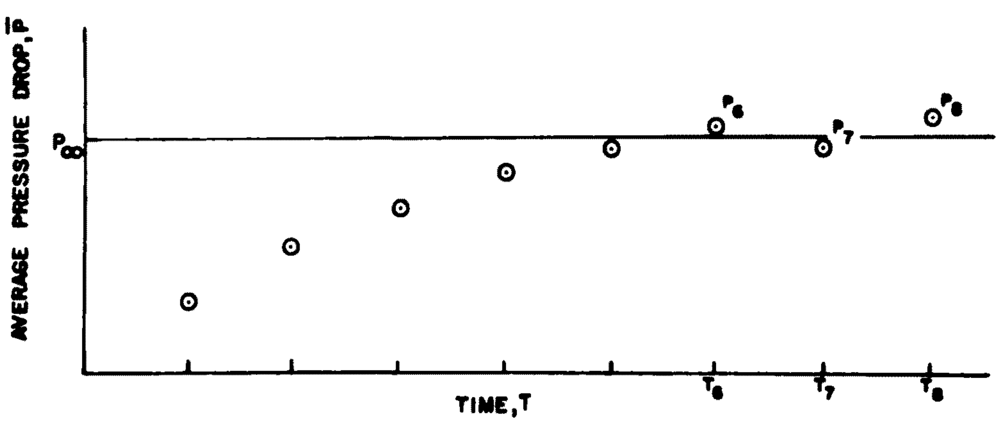

Figure 14. Example of oscillating pressure drop used in Check #3.

APPENDIX B

BAGHOUSE SIMULATION PROGRAM LISTING

A listing of the baghouse simulation program card deck is presented in Table 15. The listing includes all the Job Control Language required to run the program on an IBM 370 under OS/VS2 using the FORTRAN G1 V2.0 Compiler. Plotting routines are compatible with the CalComp Basic Software Package for Pen Plotters and General Subroutines Package. A list of all the variables and arrays used in the program is presented in Tables 16 and 17.

TABLE 15. PROGRAM LISTING

```
//HK161418 JOB (0170,072,DESK),'KLEMM',CLASS=F,TIME=6
//*  BAGHOUSE PROGRAM  IBM 370 WITH CALCOMP PLOTTER
//*  1976 GCA TECHNOLOGY    ROGER STERN - DOUG COOPER
//*   BAGHOUSE SIMULATION PROGRAM- IBM 370- ZETA PLOTTER
//*   1977 GCA TECHNOLOGY DIVISION  HANS KLEMM- RICHARD DENNIS
//*   REVISED OCT. 78 - GCA/TECHNOLOGY DIVISION - HANS KLEMM/ RICHARD DENNIS
//SIMULA EXEC FORTG1CG,ACCT=COST,PARM.GO='SIZE=68K'
//FORT.SYSIN DD *


C***********************************************************************
C
C     STEP = SIMULA     BAGHOUSE MODEL STEP # 1
C     MAIN PROGRAM FOR BAGHOUSE SIMULATION PROGRAM
C     IF ERRORS EXIST IN THE INPUT DATA I=1
C
C***********************************************************************
      CALL DESINE
      CALL OPERAT
      CALL SWDATA
      CALL USER(I)
      CALL CHECK1(I)
      CALL SETUP
      CALL CHECK2(I)
      CALL OUTFIL
      CALL PLOTIN(I)
      IF(I.EQ.1) GO TO 20
      CALL MODEL
   20 DO 10 N=10,15
      END FILE N
   10 REWIND N
      END FILE 6
      REWIND 6
      CALL EXIT
      END
```

(continued)

TABLE 15 (continued)

```
      SUBROUTINE CAKDRG(WDEL,VEL,CDRAG)
C***********************************************************************
C
C          SUBROUTINE OF BAGHOUSE  4/77/HAK-RD GCA TECHNOLOGY  DIVISION
C      SUBROUTINE OF BAGHOUSE  10/78 HAK/RD GCA/TECH DIV
C-CALCULATES CAKE DRAG
C-ZK2=SPECIFIC CAKE RESISTANCE OF CAKE AT 0.61 M/MIN, N-MIN/G-M
C-WDEL=TOTAL FABRIC LOADING ON AN AREA OF FABRIC, G/M2
C-WR=RESIDUAL FABRIC LOADING ON AN AREA OF FABRIC, G/M2
C-WSTAR= CONSTANT CHARACTERISTIC OF DUST AND FABRIC, G/M2
C-ZKZERO= INITIAL SLOPE OF DRAG VS. LOADING CURVE, N-MIN/G-M
C-VEL=VELOCITY,M/MIN
C-CDRAG=CAKE DRAG,S,  N-MIN/M3
C
C***********************************************************************
      COMMON/FABDUS/ZK2,SE,WR,SR,ZKR,WSTAR
      ZK2V=ZK2*SQRT(VEL*3.281/2.)
      IF(WSTAR.GT.1.E-20) GO TO 10
C-LINEAR MODEL
      CDRAG=ZK2V*(WDEL-WR)
      GO TO 20
   10 WPRIME=WDEL-WR
      EXPO=-WPRIME/WSTAR
      IF(EXPO.LT.-30.) EXPO=-30.
C-NON-LINEAR MODEL
      CDRAG=ZK2V*WPRIME+(ZKR-ZK2V)*WSTAR*(1.-EXP(EXPO))
   20 RETURN
      END
```

```
      SUBROUTINE PENET(CZERO,WEIGHT,VEL,WR,PEN)
C***********************************************************************
C
C          SUBROUTINE OF BAGHOUSE  4/77/HAK-RD GCA TECHNOLOGY  DIVISION
C-CALCULATES TOTAL PENETRATION
C-CZERO=INLET CONCENTRATION, G/M3
C-WEIGHT=TOTAL FABRIC LOADING ON AN AREA OF FABRIC, G/M2
C-VEL=VELOCITY, M/MIN
C-WR=RESIDUAL FABRIC LOADING ON AN AREA OF FABRIC, G/M2
C-PEN=PENETRATION
C
C***********************************************************************
      CS=0.0005
      A=400.
      IF(VEL.GT.1.E-9) A=0.416/(VEL*3.281)**4+0.094
      IF(VEL.LT.1.E-9) VEL=0.0
      XF=1.5E-7
      IF(VEL.GT.1.E-9) XF=1.5E-7*EXP(12.7*(1.-EXP(-VEL/3.2*3.281)))
      EXPO=(WEIGHT-WR)*A
      PEN=0.0
      IF(EXPO.LT.40.) PEN=(0.1-XF)*EXP(-EXPO)
      PEN=PEN+XF+CS/CZERO
      RETURN
      END
```

(continued)

TABLE 15 (continued)

```
      SUBROUTINE MODEL
C***************************************************************************
C
C          SUBROUTINE OF BAGHOUSE 12/1/RWS-DC GCA TECHNOLOGY  DIVISION
C          SUBROUTINE OF BAGHOUSE  4/77/HAK-RD GCA TECHNOLOGY  DIVISION
C          SUBROUTINE OF BAGHOUSE  10/78 HAK/RD  GCA/TECH DIV
C-MAIN DRIVER SUBPROGRAM
C-ALL T'S ARE TIMES,MIN
C-ALL W'S ARE CAKE LOADINGS,G/M2
C-ALL S'S ARE DRAGS,N-MIN/M3
C-ALL P'S ARE PENETRATIONS
C-ALL C'S ARE CONCENTRATIONS
C-A BAG IS A COMPARTMENT
C-ZK2=SPECIFIC CAKE RESISTANCE OF CAKE AT 0.61 M/MIN, N-MIN/G-M
C-WR=RESIDUAL FABRIC LOADING ON AN AREA OF FABRIC, G/M2
C-WSTAR= CONSTANT CHARACTERISTIC OF DUST AND FABRIC, G/M2
C-ZKR= INITIALSLOPE OF THE DRAG VERSUS LOADING CURVE
C-SZERO=RESIDUAL DRAG, N-MIN/M3
C-TEMPK=GAS TEMPERATURE,DEGRESS KELVIN
C-ACAKE=CAKED AREA,THAT PORTION OF A BAG WHICH IS NOT CLEANED
C-ZK2MU=VISCOSITY CORRECTION FOR SPECIFIC CAKE RESISTANCE
C-N=NUMBER OF COMPARTMENTS OR BAGS
C-T=CLEANING CYCLE TIME,MIN
C-NT=TOTAL NUMBER OF CYCLES TO BE MODELED
C-M=NUMBER OF TIME INCREMENTS PER BAG
C-SMALQ=AVERAGE SYSTEM VELOCITY,IF OPERATING AT CONSTANT TOTAL FLOW, M/M
C-CZERO=INLET CONCENTRATION,G/M3
C-LDIAG=PRINT DIAGNOSTICS
C-TLAG=TIME PERIOD FOR WHICH ALL BAGS ARE ON LINE AFTER  ENTIRE CLEANING
C-CYCLE
C-DPSTOP=PRESSURE DROP AT WHICH CLEANING IS INITIATED, N/M2
C-WSTART=INITIAL LOADING ON ALL BAGS AT TIME = ZERO
C-VRFLO=REVERSE AIR VELOCITY FOR ONE BAG, M/MIN
C-SE=EFFECTIVE CAKE DRAG, N-MIN/M3
C
C***************************************************************************
      COMMON/DESIGN/N,T,TCLEAN,TLAG,VRFLO,DPSTOP,FREQ,AMPLIT
      COMMON/OPDATA/SMALQ,TEMPK,CZERO,TCZERO
      COMMON/FABDUS/ZK2,SE,WR,SR,ZKR,WSTAR
      COMMON/EXTERN/NT,M,WSTART,ACLEAN
      COMMON/DIAG/LDIAG,PRDIAG,PLDIAG
      COMMON/CALC/DELT,NAREA,IAREA
      COMMON/ACURAC/JCODE
      COMMON/TITLE/HEAD
      COMMON/MODELD/PAVR,TCONT,DTLAST,PENTOT,PAVTOT,DPAVG,QAVG,TLAST,
     *  TDSUM,PNMAX,DELP,DPMAX,TREF,IFBAG,NFLAG,JFLAG,LUPCNT
      COMMON/DEVICE/INPUT,OUTPUT
      INTEGER OUTPUT
      LOGICAL LDIAG,PLDIAG,PRDIAG
      REAL*8 HEAD(8)
```

(continued)

TABLE 15 (continued)

```
      DIMENSION IDUM(10),PDP(3),PDU(3),PT(3),PPS(3),PQ(3,5)
      DIMENSION TIME(30),OLDTIM(30),CAKE(30),SBAG(30),QBAG(30)
      DIMENSION WD(10,30),S(10,30),QAREA(10),P(10)
      LOGICAL LCONP,LDIAG
      DATA DRAG,BAG1,BAG2/'AREA','SBAG','QBAG'/
      WRITE(OUTPUT,220) HEAD
  220 FORMAT(1H1//T20,80('*')//
     *  T20,'RESULTS OF BAGHOUSE ANALYSIS'//T20,80('*')//T20,8A8///)
      GO TO 3
    2 CZERO=CZEROE
      CALL RESTRT
C-INITIALIZE DATA
    3 CALL INITAL
      AREA=1./IAREA
      IREPT=FLOAT(N)/10.+0.95
      DO 5 I=1,IAREA
      QAREA(I)=SMALQ
      DO 5 IBAG=1,N
      OLDTIM(IBAG)=-2
      TIME(IBAG)=-1
    5 WD(I,IBAG)=WSTART
      CZEROE=CZERO
      TCORR=0.0
      TLAG=IFIX(TLAG/DELT+0.5)*DELT
      IF(TLAG.LT.0.01) TLAG=0.0
      TMOD=TLAG+T
      IF(DPSTOP.GT.0.)TMOD=1.E+20
      K3=0
      MAXJ=NT*(M*N+IFIX(TLAG/T*M*N+0.9999))+1+5
C  DETERMINE DRAG THROUGH FABRIC
      SFAB=SR
      IF(WSTAR.LT.1.E-20) SFAB=SE
      JLOOP=0
C  LOOP ON TIME
    1 JLOOP=JLOOP+1
      DELT=T/M/N
      TTEST=AMOD(TCONT+0.01,TMOD)-0.01
      IF(TTEST.LT.0.005) TTEST=0.0
      IF(TTEST.GT.(T-0.005).AND.TTEST.LT.(T+0.005)) TTEST=T
      IF(TCONT.LT.1.E-9.OR.TTEST.LE.-0.01.OR.TTEST.GE.0.01) GO TO 12
      LOPCNT=LOPCNT+1
      TDIF=TCONT-TLAST
      QAVGN=(QAVG-QSYSTM*DTLAST)/2./TDSUM
      PAVNOW=(PAVTOT-PENTOT*DTLAST)/2./TDSUM
      DPAVGN=(DPAVG-DELP*DTLAST)/2./TDSUM
      TDSUM=0.0
      TLAST=TCONT
      QAVG=QSYSTM*DTLAST
      PAVTOT=PENTOT*DTLAST
      DPAVG=DELP*DTLAST
```

(continued)

```
C  CHECK FOR A LIMITING PRESSURE SYSTEM FOR FORCED CONTINUOUS OPERATION
C  CHECK FOR TIME BETWEEN CLEANING CYCLES EQUAL TO ZERO
      CONTST=TDIF-T
      IF(DPSTOP.GT.0.5.AND.LOPCNT.GT.3.AND.
     *  CONTST.GT.-T/M/N.AND.CONTST.LE.(T/M/N+0.01)) GO TO 2
C-WRITE AVERAGE PRESSURE DROP,FLOW AND PENETRATION UP TO TIME=TCONT
      IF(NFLAG.GT.0) WRITE(OUTPUT,230) TDIF,LOPCNT,PAVNOW,DPAVGN,QAVGN,
     *  PNMAX,DPMAX
      IF(JFLAG.EQ.0) CALL STABLE(DPAVGN,TCONT,JCODE,JFLAG)
      LOPTST=NT-LOPCNT
      IF(LOPTST.LE.3.AND.JFLAG.EQ.0) JFLAG=20
      IF(JFLAG.NE.0) NFLAG=NFLAG+1
      IF(NFLAG.EQ.4) GO TO 310
      IF(NFLAG.EQ.1) TREF=TCONT
      IF(JFLAG.EQ.20.AND.NFLAG.EQ.1) WRITE(OUTPUT,231) LOPCNT
  231 FORMAT(' ***CONVERGENCE TO STEADY STATE NOT REACHED AFTER',5X,
     *  I3,5X,'CYCLES ***'///)
      PNMAX=0.0
      DPMAX=0.0
   12 CONTINUE
      IF(TTEST.GT.T) GO TO 11
C  EXTRA PASS FOR CLEANED BAG
C-BAG LOOP        1
      DO 13 IBAG=1,N
      IF(OLDTIM(IBAG).LE.TIME(IBAG)) GO TO 13
      IFBAG=IBAG
      TCONT=TCONT+.01
      GO TO 14
   13 CONTINUE
C-END OF BAG LOOP     1
   11 IFBAG=0
      DELT=T/M/N
      JTIME=JLOOP-1
C-DETERMINE TIME
      TCONT=JTIME*DELT+TCORR*IFIX((TCONT+DELT)/(T+TLAG))
   14 TTEST=AMOD(TCONT+0.01,TMOD)-0.01
      IF(TTEST.LT.0.005) TTEST=0.0
      IF(TTEST.GT.(T-0.005).AND.TTEST.LT.(T+0.005))TTEST=T
      IF(TTEST.GT.T.AND.TTEST.GE.(T+TLAG-DELT)) DELT=DELT+TCORR
      SSYSTM=0.0
      DELTT=DELT
      VRFLOW=0.0
      IF(LDIAG.AND.NFLAG.GT.0) WRITE(OUTPUT,16) (DRAG,I,I=1,IAREA),BAG1
   16 FORMAT(1X,'BAG-DRAG=',1X,11(3X,A4,1X,I2))
C-BAG LOOP    2
      DO 20 IBAG=1,N
      SBAG(IBAG)=0.0
C-AREA LOOP       1
      DO 6 I=1,IAREA
C  IF A BAG WAS JUST CLEANED , ESTIMATE FLOW VELOCITY
```

(continued)

TABLE 15 (continued)

```
      IF(S(IAREA,IBAG).LT.1.E+19) GO TO 17
      CALL CAKDRG(WD(I,IBAG),SMALQ,S(I,IBAG))
      S(I,IBAG)=S(I,IBAG)+SFAB
   17 CONTINUE
      IF(TCONT.GT.1.E-9)QAREA(I)=DELP/S(I,IBAG)
C-DETERMINE DRAG ON EACH AREA
      CALL CAKDRG(WD(I,IBAG),QAREA(I),S(I,IBAG))
      S(I,IBAG)=S(I,IBAG)+SFAB
    6 SBAG(IBAG)=SBAG(IBAG)+AREA/S(I,IBAG)
C-END OF AREA LOOP      1
      SBAG(IBAG)=1./SBAG(IBAG)
C  DETERMINE TIME IN CYCLE
      IF(TTEST.GT.(T+0.005)) GO TO 21
      OLDTIM(IBAG)=TIME(IBAG)
      TIME(IBAG)=AMOD(TTEST+0.01+IBAG*T/N,T)-0.01
   21 IF(TTEST.GT.T) GO TO 19
C-TEST FOR AN OFF LINE BAG
      IF(TCONT.LT.1.E-9.AND.TIME(IBAG).LT.(T-TCLEAN-.001)) GO TO 19
      IF(TIME(IBAG).LT.(T-TCLEAN-.001).AND.TIME(IBAG).GT.0.005) GO TO 19
      IF(TIME(IBAG).LT.(T-TCLEAN-.001).AND.TTEST.LE.0.01.AND.TLAG.GT.1.E
     *-9) GO TO 19
      DO 22 I=1,IAREA
   22 S(I,IBAG)=1.E+20
      SBAG(IBAG)=1.E+20
      VRFLOW=VRFLO
C-OUTPUT INTERMEDIATE RESULTS
   19 IF(LDIAG.AND.NFLAG.GT.0) WRITE(OUTPUT,15) IBAG,(S(I,IBAG),I=1,
     *  IAREA),SBAG(IBAG)
   15 FORMAT(1X,I3,7X,11(1X,1PE9.2))
      SSYSTM=SSYSTM+1./SBAG(IBAG)
      IF(OLDTIM(IBAG).GT.TIME(IBAG).AND.TTEST.LT.(T+0.005)) DELTT=0.01
   20 CONTINUE
C-END OF BAG LOOP 2
C-CALCULATE SYSTEM DRAG,PRESSURE DROP AND FLOW VELOCITY
      SSYSTM=1./SSYSTM
      DELP=SMALQ*SSYSTM*N+VRFLOW*SSYSTM
      QSYSTM=SMALQ+VRFLOW/N
C-CORRECT INLET CONCENTRATION FOR REVERSE FLOW AIR
      CZERO=CZEROE*(QSYSTM-VRFLOW/N)/QSYSTM
      IF(LDIAG.AND.NFLAG.GT.0) WRITE(OUTPUT,30) (DRAG,I,I=1,IAREA),BAG2
   30 FORMAT(1X,'BAG-FLOW=',1X,11(3X,A4,1X,I2))
      PENTOT=0.0
      WDUMP=0.0
C-BAG LOOP    3
      DO 60 IBAG=1,N
      IF(TTEST.GT.T) GO TO 26
      DELT=DELTT
      IF((TIME(IBAG)+T/M/N).GT.(T-TCLEAN))DELT=T-TCLEAN-TIME(IBAG)
   26 WCOMP=0.0
      CAKE(IBAG)=0.0
```

(continued)

TABLE 15 (continued)

```
C-AREA LOOP   2
      DO 28 I=1,IAREA
      QAREA(I)=DELP/S(I,IBAG)
C-DETERMINE PENETRATION
      CALL PENET(CZERO,WD(I,IBAG),QAREA(I),WR,P(I))
      WAREA=QAREA(I)*(1.-P(I))*DELT*CZERO
      CAKE(IBAG)=CAKE(IBAG)+WD(I,IBAG)*AREA
   27 PENTOT=PENTOT+P(I)*AREA*QAREA(I)/QSYSTM/N
   28 WD(I,IBAG)=WD(I,IBAG)+WAREA
C-END OF AREA LOOP   2
      QBAG(IBAG)=DELP/SBAG(IBAG)
C-OUTPUT INTERMEDIATE RESULTS
      IF(LDIAG.AND.NFLAG.GT.0) WRITE(OUTPUT,15) IBAG,(QAREA(I),I=1,
     *  IAREA),QBAG(IBAG)
      IF(TTEST.GT.T) GO TO 60
      IF(OLDTIM(IBAG).LE.TIME(IBAG))GO TO 60
C-CLEAN  NAREA AREAS ON A BAG IF NECESSARY
      WDUMP=0.0
      DO 36 II=1,NAREA
      WCOMP=0.0
C-AREA LOOP        3
      DO 35 I=1,IAREA
      IF(WD(I,IBAG).LT.WCOMP) GO TO 35
      WCOMP=WD(I,IBAG)
      IFAREA=I
   35 CONTINUE
C-END OF AREA LOOP      3
      WDUMP=WDUMP+(WD(IFAREA,IBAG)-WR)*AREA
   36 WD(IFAREA,IBAG)=WR
   60 CONTINUE
C-END OF BAG LOOP          3
      DELT=DELTT
      DPAVG=DPAVG+(DTLAST+DELT)*DELP
      QAVG=QAVG+(DTLAST+DELT)*QSYSTM
      PAVTOT=PAVTOT+PENTOT*(DELT+DTLAST)
      PAVR=PAVR+PENTOT*(DELT+DTLAST)
      TDSUM=TDSUM+DTLAST
      DTLAST=DELT
      CONTOT=PENTOT*CZERO
      IF(PENTOT.GT.PNMAX) PNMAX=PENTOT
      IF(DELP.GT.DPMAX) DPMAX=DELP
      IF(NFLAG.EQ.0) GO TO 120
      IF(.NOT.PLDIAG.AND..NOT.PRDIAG) GO TO 120
      K3=K3+1
      PT(K3)=TCUNT-TREF
      PDP(K3)=DELP
      PDQ(K3)=QSYSTM
      PPS(K3)=PENTOT
      LMAX=MINO(5,N)
      DO 100 L=1,LMAX
```

(continued)

TABLE 15 (continued)

```
  100 PQ(K3,L)=QBAG(L)
      IF(K3.LT.3) GO TO 120
      K3=0
C
C  PUNCH PLOT
C
  110 FORMAT(6G10.5)
      WRITE(8,110)  ((PT(K),PDP(K)),K=1,3)
      DO 115 L=1,LMAX
      IUNIT=L+9
  115 WRITE(IUNIT,110) ((PT(K),PQ(K,L)),K=1,3)
      WRITE(15,110)(PT(K),PPS(K),K=1,3)
  120 IF(.NOT.LDIAG) GO TO 290
      IF(NFLAG.EQ.0) GO TO 290
C
C  PRINT DIAGNOSTICS
C
      WRITE(OUTPUT,130) TCONT,DELP,QSYSTM,CONTOT,WDUMP
  130 FORMAT(1X/' T=',G10.4,10X,'DELP=',G10.4,10X,'DELQ=',G10.4,
     &          10X,'CONCENTRATION=',G10.4,10X,'WEIGHT DUMPED=',G10.4)
      IDUM(10)=0
      DO 250 L=1,IREPT
  140 DO 150 K=1,10
      MAXK=MINO(K,(N-10*(L-1)))
  150 IDUM(K)=IDUM(10)+K
      WRITE(OUTPUT,160) (IDUM(K),K=1,MAXK)
  160 FORMAT(5X,10(6X,'BAG ',I2))
      WRITE(OUTPUT,170) (TIME(IDUM(I)),I=1,MAXK)
  170 FORMAT(' T=',T6,10(F9.2,3X))
      WRITE(OUTPUT,180) (CAKE(IDUM(I)),I=1,MAXK)
  180 FORMAT(' CAKE=',T6,1PE12.4,9E12.4)
      WRITE(OUTPUT,190) (SBAG(IDUM(I)),I=1,MAXK)
  190 FORMAT(' SBAG',T6,10E12.4)
      WRITE(OUTPUT,200) (QBAG(IDUM(I)),I=1,MAXK)
  200 FORMAT(' QBAG',T6,10E12.4,0PF2.0)
  250 CONTINUE
      IF(TTEST.GT.T) GO TO 270
      IF(OLDTIM(N).LT.TIME(N)) GO TO 270
      PAVR=(PAVTOT-PENTOT*DTLAST)/2./TDSUM
      WRITE(OUTPUT,260) PAVR
  260 FORMAT(//' AVERAGE PENETRATION DURING CLEANING CYCLE',5X,
     *  1PG10.3//)
      PAVR=0.0
  270 CONTINUE
      WRITE(OUTPUT,500)
  500 FORMAT(///)
  290 IF(IFBAG.NE.0) GO TO 11
      IF(DPSTOP.LT.1.E-9) GO TO 300
      IF(TMOD.LT.1.E+19.AND.TTEST.GT.(T+T/M/N)) TMOD=TCONT-T-T/M/N
      IF(TTEST.LE.T.OR.DELP.LT.DPSTOP) GO TO 300
```

(continued)

TABLE 15 (continued)

```
      TMOD=TCONT
      TCORR=0.0
  300 GO TO 1
C     *END OF TIME LOOP
C
C FINISH PUNCHING
C
  310 CONTINUE
      IF(.NOT.PLDIAG.AND..NOT.PRDIAG) GO TO 430
      WRITE(8,400) PT(3),POP(3)
      IUNIT=9+LMAX
      WRITE(IUNIT,400) PT(3),PQ(3,LMAX)
  400 FORMAT(2G10.5,T75,'NEW')
      IF(LMAX.EQ.1) GO TO 425
      LMAX=LMAX-1
      DO 410 L=1,LMAX
      IUNIT=L+9
  410 WRITE(IUNIT,420) PT(3),PQ(3,L)
  420 FORMAT(2G10.5,T75,'SAME')
  425 WRITE(15,400)PT(3),PPS(3)
  430 CONTINUE
  230 FORMAT(/1X,'FOR',F10.2,' MINUTES OPERATION,',
     *  '  CYCLE NUMBER ',I3/
     *T50,'AVERAGE PENETRATION=',T80,1PE9.2/
     *T50,'AVERAGE PRESSURE DROP=',T80,0PF10.2,' N/M2'/
     *T50,'AVERAGE SYSTEM FLOW=',T80,0PF10.4,' M/MIN'/
     *T50,'MAXIMUM PENETRATION=',T80,1PE9.2/
     *T50,'MAXIMUM PRESSURE DROP=',T80,0PF10.2,' N/M2'/
     *   )
       RETURN
       END
```

(continued)

TABLE 15 (continued)

```
      SUBROUTINE PLOTIN(IERROR)
C************************************************************************
C
C     SUBROUTINE TO INITIALIZE PLOTTER    11/11/75/RWS-DC
C          SUBROUTINE OF BAGHOUSE  4/77/HAK-RD GCA TECHNOLOGY  DIVISION
C     SUBROUTINE OF BAGHOUSE  10/78 HAK/RD GCA/TECH DIV
C
C************************************************************************
      COMMON/DESIGN/N,T,TCLEAN,TLAG,VRFLO,DPSTOP,FREQ,AMPLIT
      COMMON/DIAG/ALDIAG,PRDIAG,PLDIAG
      COMMON/TITLE/HEAD
      COMMON/DEVICE/INPUT,OUTPUT
      INTEGER OUTPUT
      LOGICAL PRDIAG,PLDIAG,ALDIAG
      REAL*8 HEAD(8)
      DATA AMP/'&'/
      DATA XLENTH,YLENTH/2*0./
      IMAX=MINO(N,5)
      LDIAG=0
      IF(PRDIAG)LDIAG=10
      IF(ALDIAG) LDIAG=LDIAG+10
      IF(PLDIAG)LDIAG=LDIAG+1
      IF(IERROR.EQ.1) LDIAG=0
      WRITE(8,15)LDIAG,IMAX
   15 FORMAT(I2,I1)
      READ(INPUT,200,END=26) XLENTH,YLENTH
  200 FORMAT(F5.2,1X,F5.2)
C-DEFAULT VALUES FOR X&Y AXIS LENGTHS
   26 CONTINUE
      IF(XLENTH.LT.6.0) XLENTH=6.0
      IF(YLENTH.LT.5.0) YLENTH=5.0
      IF(XLENTH.GT.24.) XLENTH=24.
      IF(YLENTH.GT.12.) YLENTH=12.
      CHIT1=FLOAT(IFIX(XLENTH/0.64/7.)*7)/100.
      IF(CHIT1.LT.0.14) CHIT1=0.14
      CHIT2=CHIT1-0.07
      YPOS1=YLENTH+5.*CHIT2+CHIT1+0.24
      YPOS2=YPOS1-0.04-CHIT1
      YPOS3=YPOS2-0.04-CHIT2
C-PRESSURE DROP VS TIME
      DO 20 IUNIT=8,10,2
   20 WRITE(IUNIT,25) HEAD,YPOS1,CHIT1,AMP
   25 FORMAT(8A8,5X,2F5.2,A1)
      WRITE(8,30) YPOS2,CHIT1,XLENTH,YLENTH
   30 FORMAT(
     &'PRESSURE VS TIME GRAPH',T70,2F5.2,'&'//
     &T28,'TIME (MINUTES)'/
     &T23,'PRESSURE (N/M2)'/
     &'SEMISEMI',T55,F6.2,T65,F6.2,T80,'1')
C-INDIVIDUAL FLOW VS TIME
      WRITE(10,50) YPOS2,CHIT1,YPOS3,CHIT2,XLENTH,YLENTH
   50 FORMAT(
     &'INDIVIDUAL FLOW RATE GRAPH',T70,2F5.2,'&'/
     &'COMPARTMENT # 1',T70,2F5.2/
     &T28,'TIME (MINUTES)'/
     &T23,'FLOW RATE (M/MIN)'/
     &'SEMISEMI',T55,F6.2,T65,F6.2,T80,'1')
```

(continued)

TABLE 15 (continued)

```
      IMAX=MIN0(N,5)
      IF(IMAX.EQ.1) GO TO 75
      DO 60 I=2,IMAX
      IUNIT=I+9
      YPOSI=YPOS3-(I-1)*(0.04+CHIT2)
   60 WRITE(IUNIT,70) I,YPOSI,CHIT2
   70 FORMAT('COMPARTMENT # ',I1,T70,2F5.2)
   75 WRITE(15,25) HEAD,YPOS1,CHIT1,AMP
C-PENETRATION VS TIME
      WRITE(15,80) YPOS2,CHIT1,XLENTH,YLENTH
   80 FORMAT(
     &'PENETRATION VS TIME GRAPH',T70,2F5.2,'&'/
     &/
     &T28,'TIME (MINUTES)'/
     &T23,'PENETRATION',T70,'1.E-5  1.0'/
     &'LOG-SEMI',T55,F6.2,T65,F6.2,T80,'1')
      DO 100 IUNIT=8,10,2
  100 WRITE(IUNIT,110)
      WRITE(15,110)
  110 FORMAT(T8,'0.0',T18,'0.0')
  120 RETURN
      END
```

(continued)

TABLE 15 (continued)

```
      SUBROUTINE DESINE
C***********************************************************************
C
C     SUBROUTINE OF BAGHOUSE  10/78 HAK/RD GCA/TECH DIV
C     READ AND PRINT HEADINGS AND DESIGN DATA
C
C***********************************************************************
      REAL*8 HEAD(8)
      INTEGER OUTPUT
      COMMON/DESIGN/N,T,TCLEAN,TLAG,VRFLO,DPSTOP,FREQ,AMPLIT
      COMMON/DEVICE/INPUT,OUTPUT
      COMMON/TITLE/HEAD
      OUTPUT=6
      INPUT=5
      READ(INPUT,500) HEAD
      READ(INPUT,510) N,TCLEAN,T,TLAG,DPSTOP,VRFLO,FREQ,AMPLIT
C-DEFAULT FOR COMPARTMENT CLEANING ( OFF LINE ) TIME
C- 50% OF CLEANING CYCLE TIME/NUMBER OF COMPARTMENTS
      IF(TCLEAN.LT.0.05) TCLEAN=T/N*0.5
      WRITE(OUTPUT,600) HEAD
      WRITE(OUTPUT,610) N,TCLEAN,T
      IF(TLAG.GT.0.05) WRITE(OUTPUT,620) TLAG
      IF(DPSTOP.GT.0.05) WRITE(OUTPUT,630) DPSTOP
      IF(TLAG.LT.0.05.AND.DPSTOP.LT.0.05) WRITE(OUTPUT,640)
      WRITE(OUTPUT,650) VRFLO
      IF(FREQ.GT.0.05) WRITE(OUTPUT,660) FREQ
      IF(AMPLIT.GT.1.E-5) WRITE(OUTPUT,670) AMPLIT
      WRITE(OUTPUT,680)
  500 FORMAT(8A8)
  510 FORMAT(I3,1X,F5.1,1X,F5.1,1X,F5.1,1X,F4.0,1X,F6.4,1X,F3.1,1X,F4.2)
  600 FORMAT(1H1,T20,80('*')//T20,'SUMMARY OF INPUT DATA FOR ',
     1  'BAGHOUSE ANALYSIS'//T20,80('*')//T20,8A8)
  610 FORMAT(//T20,'BASIC DESIGN DATA'/
     1  T25,'NUMBER OF COMPARTMENTS',T55,I3/
     3  T25,'COMPARTMENT CLEANING TIME',T55,F6.1,T70,'MINUTES'/
     4  T27,'(OFF LINE TIME)'/
     2  T25,'CLEANING CYCLE TIME',T55,F6.1,T70,'MINUTES'
     5  )
  620 FORMAT(T25,'TIME BETWEEN CLEANING CYCLES',T55,F6.1,T70,'MINUTES')
  630 FORMAT(T25,'LIMITING PRESSURE DROP',T55,F5.0,T70,'N/M2')
  640 FORMAT(T25,'CONTINUOUSLY CLEANED SYSTEM')
  650 FORMAT(T25,'REVERSE FLOW VELOCITY',T55,F7.4,T70,'M/MIN')
  660 FORMAT(T25,'SHAKING FREQUENCY',T55,F4.1,T70,'CYCLES/SEC')
  670 FORMAT(T25,'SHAKING AMPLITUDE',T55,F5.2,T70,'CM')
  680 FORMAT(1X)
      RETURN
      END
```

(continued)

TABLE 15 (continued)

```
      SUBROUTINE OPERAT
C***********************************************************************
C
C     SUBROUTINE OF BAGHOUSE  10/78 HAK/RD GCA/TECH DIV
C     READ AND PRINT OPERATING DATA AND CORRECT TEMPERATURES TO
C     DEGREES KELVIN
C
C***********************************************************************
      INTEGER OUTPUT
      COMMON/OPDATA/SMALQ,TEMPK,CZERO,TCZERO
      COMMON/DEVICE/INPUT,OUTPUT
      READ(INPUT,500) SMALQ,TEMPK,CZERO,TCZERO
      IF(TCZERO.LT.1.E-5) TCZERO=25.01
      WRITE(OUTPUT,600) SMALQ,TEMPK,CZERO,TCZERO
      TEMPK=TEMPK+273.
      TCZERO=TCZERO+273.
  500 FORMAT(F6.4,1X,F4.0,1X,F5.2,1X,F4.0)
  600 FORMAT(T20,'OPERATING DATA'/
     1  T25,'AVERAGE FACE VELOCITY',T55,F7.4,T70,'M/MIN'/
     3  T25,'GAS TEMPERATURE',T55,F5.0,T70,'DEGREES CENTIGRADE'/
     4  T25,'INLET DUST CONCENTRATION',T55,F6.2,T70,'G/M3'/
     5  T30,'MEASURED AT',T55,F5.0,170,'DEGREES CENTIGRADE'/
     5  )
      RETURN
      END
```

(continued)

TABLE 15 (continued)

```
      SUBROUTINE SWDATA
C***********************************************************************
C
C     SUBROUTINE OF BAGHOUSE  10/78 MAK/RD GCA/TECH DIV
C     READ AND PRINT DUST AND FABRIC PROPERTIES AND CORRECT TEMPERATURES
C     TO DEGREES KELVIN
C
C***********************************************************************
      INTEGER OUTPUT
      REAL MMD1,MMD2
      COMMON/FABDUS/ZK2,SE,WR,SR,ZKR,WSTAR
      COMMON/DEVICE/INPUT,OUTPUT
      COMMON/K2EST/TZK2,VZK2,MMD1,SG1,MMD2,SG2,RHOP,RHOBLK
      COMMON/MUCORR/TSE,TSR,TZKR
      WRITE(OUTPUT,600)
  600 FORMAT(T20,'FABRIC AND DUST PROPERTIES'/)
      READ(INPUT,500)  ZK2,TZK2,VZK2,MMD1,SG1,MMD2,SG2,RHOP,RHOBLK
      READ(INPUT,510) SE,TSE,WR,SR,TSR,ZKR,TZKR,WSTAR
  500 FORMAT(F5.2,1X,F4.0,1X,F7.4,1X,F3.1,1X,F3.2,1X,F3.1,1X,F3.2,1X,
     1  F5.3,1X,F5.3)
  510 FORMAT(F4.0,1X,F4.0,1X,F5.1,1X,F4.0,1X,F4.0,1X,F5.2,1X,F4.0,1X,
     *  F5.1)
C IF K2 WAS NOT ENTERED ASSUME IT IS TO BE CALCULATED
      IF(ZK2.GT.1.E-5) GO TO 20
      IF(SE.LT.1.E-5) SE=350.
      IF(WR.LT.1.E-5) WR=50.
      IF(TSE.LT.1.E-5) TSE=25.01
      WRITE(OUTPUT,620) MMD2,SG2,RHOP,RHOBLK
  620 FORMAT(T25,'SPECIFIC RESISTANCE, K2 ESTIMATED FROM'/
     1  T30,'MASS MEDIAN DIAMETER',T55,F4.1,T70,'MICRONS'/
     2  T30,'STANDARD DEVIATION',T55,F4.2,/
     3  T30,'PARTICLE DENSITY',T55,F6.3,T70,'G/CM3'/
     4  T30,'BULK DENSITY',T55,F6.3,T70,'G/CM3'/
     5 )
      TZK2=25.01
      VZK2=0.61
      GO TO 30
C K2 WAS ENTERED
   20 IF(TZK2.LT.1.) TZK2=25.01
      IF(VZK2.LT.1.E-5) VZK2=0.61
      WRITE(OUTPUT,610) ZK2,TZK2,VZK2
  610 FORMAT(T25,'SPECIFIC RESISTANCE, K2',T55,F6.2,T70,'N-MIN/G-M'/
     1 T30,'MEASURED AT',
     2 T55,F5.0,T70,'DEGREES CENTIGRADE'/
     3 T55,F7.4,T70,'M/MIN'
     4 )
C IF NO SIZE PROPERTIES FOR INLET DUST WERE ENTERED ASSUME NO
C   CORRECTIONS ARE TO BE MADE
      IF(MMD2.LT.1.E-5) GO TO 30
      WRITE(OUTPUT,630) MMD1,SG1,MMD2,SG2
```

(continued)

TABLE 15 (continued)

```
  630 FORMAT(T45,'MMD1',T55,F4.1,T70,'MICRONS',T85,'-STANDARD DEVIATION
     *',T105,F4.2/
     * T30,'CORRECTED TO ',
     * T45,'MMD2',T55,F4.1,T70,'MICRONS',T85,'-STANDARD DEVIATION',T105
     *,F4.2/
     * )
   30 CONTINUE
      IF(TSE.LT.1.E-5) TSE=25.01
      IF(TSR.LT.1.E-5) TSR=25.01
      IF(TZKR.LT.1.E-5) TZKR=25.01
      WRITE(OUTPUT,640) SE,TSE,WR
  640 FORMAT(T25,'EFFECTIVE RESIDUAL DRAG, SE',T55,F5.0,T70,'N-MIN/M3'/
     1  T30,'MEASURED AT',T55,F5.0,T70,'DEGREES CENTIGRADE'/
     2 T25,'RESIDUAL LOADING, WR',T55,F6.1,T70,'G/M2'
     3 )
C IF SR AND KR WERE NOT ENTERED ASSUME LINEAR DRAG MODEL
      IF(SR.LT.1.E-5.AND.ZKR.LT.1.E-5) GO TO 40
      WRITE(OUTPUT,650) SR,TSR,ZKR,TZKR
  650 FORMAT(T25,'RESIDUAL DRAG, SR',T55,F5.0,T70,'N-MIN/M3'/
     1 T30,'MEASURED AT',T55,F5.0,T70,'DEGREES CENTIGRADE'/
     2T25,'INITIAL SLOPE, KR',T55,F6.2,T70,'N-MIN/G-M'/
     3 T30,'MEASURED AT',T55,F5.0,T70,'DEGREES CENTIGRADE')
   40 WRITE(OUTPUT,660)
  660 FORMAT(/)
      TSE=TSE+273.
      TZKR=TZKR+273.
      TZK2=TZK2+273.
      TSR=TSR+273.
      RETURN
      END
```

(continued)

TABLE 15 (continued)

```
      SUBROUTINE USER(IERROR)
C***********************************************************************
C
C     SUBROUTINE OF BAGHOUSE  10/78 HAK/RD GCA/TECH DIV
C     READ SPECIAL PROGRAM INSTRUCTIONS
C**ALDIAG IS T/F FOR ALL RESULTS
C**PRDIAG IS T/F FOR SUMMARY TABLE RESULTS ONLY
C**PLDIAG IS FOR PLOTTING
C
C***********************************************************************
      INTEGER OUTPUT
      LOGICAL ALDIAG,PLDIAG,PRDIAG
      REAL*8 DETAIL,SUM1,SUM2,BLANK8,AVG1,AVG2,DATYPE
      COMMON/ACURAC/JCODE
      COMMON/DEVICE/INPUT,OUTPUT
      COMMON/DIAG/ALDIAG,PRDIAG,PLDIAG
      COMMON/EXTERN/NT,M,WSTART,ACLEAN
      DATA AVG1,AVG2/' AVERAGE','AVERAGE '/
      DATA DETAIL,SUM1,SUM2,PLOTER,BLANK4,BLANK8/
     * 'DETAILED',' SUMMARY','SUMMARY ','PLOT','    ','        '/
      READ(INPUT,500) NT,JCODE,DATYPE,PLTYPE,ACLEAN
      WRITE(OUTPUT,600) NT,JCODE,DATYPE,PLTYPE
  600 FORMAT(T20,'SPECIAL PROGRAM INSTRUCTIONS'/
     1  T25,'MAX NUMBER OF CYCLES MODELED',T55,I3/
     1 T25,'ACCURACY LEVEL',T55,I2/
     2  T25,'TYPE OF RESULTS REQUESTED',T55,A8,' / ',A4/
     3  )
      IF(ACLEAN.GT.1.E-5) WRITE(OUTPUT,610) ACLEAN
  610 FORMAT(T25,'FRACTIONAL AREA CLEANED, AC',T55,F4.2)
      IERROR=0
  500 FORMAT(I3,1X,I2,1X,A8,1X,A4,1X,F3.2)
C SET FLAGS FOR LEVEL OF DETAIL ON OUTPUT AND CHECK INPUT FOR ERRORS
      ALDIAG=.FALSE.
      PLDIAG=.FALSE.
      PRDIAG=.FALSE.
C     CHECK INPUT DATA FOR ERRORS
      IF(DATYPE.EQ.BLANK8) GO TO 10
      IF(DATYPE.EQ.DETAIL) GO TO 20
      IF(DATYPE.EQ.SUM1.OR.DATYPE.EQ.SUM2) GO TO 30
      IF(DATYPE.NE.AVG1.AND.DATYPE.NE.AVG2) IERROR=1
      GO TO 10
   20 ALDIAG=.TRUE.
   30 PRDIAG=.TRUE.
   10 IF(PLTYPE.EQ.BLANK4) GO TO 40
      IF(PLTYPE.EQ.PLOTER) PLDIAG=.TRUE.
      IF(.NOT.PLDIAG) IERROR=1
C  DETERMINE NUMBER OF INCREMENTS
   40 M=42
      IF(JCODE-1) 50,60,70
   50 JCODE=1

      M=4
      RETURN
   60 JCODE=3
      M=8
   70 RETURN
      END
```

(continued)

TABLE 15 (continued)

```
      SUBROUTINE CHECK1(I)
C***********************************************************************
C
C     SUBROUTINE OF BAGHOUSE  10/78 HAK/RD GCA/TECH DIV
C
C***********************************************************************
      REAL MMD1,MMD2
      COMMON/K2EST/TZK2,VZK2,MMD1,SG1,MMD2,SG2,RHOP,RHOBLK
      COMMON/DESIGN/N,T,TCLEAN,TLAG,VRFLO,DPSTOP,FREQ,AMPLIT
      COMMON/DEVICE/INPUT,J
      COMMON/OPDATA/SMALQ,TEMPK,CZERO,TCZERO
      COMMON/FABDUS/ZK2,SE,WR,SR,ZKR,WSTAR
      COMMON/EXTERN/NT,M,WSTART,ACLEAN
      WRITE(J,500)
      IF(I.EQ.1) WRITE(J,600)
  600 FORMAT(/T20,'ILLEGAL REQUEST FOR TYPE OF RESULTS')
      IF(N.LE.30.AND.N.GT.0) GO TO 10
      WRITE(J,510)
      I=1
   10 IF((N*TCLEAN).LE.T)GO TO 20
      WRITE(J,520)
      I=1
   20 IF(TCLEAN.LT.T)GO TO 30
      WRITE(J,530)
      I=1
   30 IF(T/N/M.GT.0.01) GO TO 35
      WRITE(J,560)
      I=1
   35 IF(SMALQ.GE.0.3.AND.SMALQ.LE.3.0) GO TO 40
      I=1
      WRITE(J,590)
  590 FORMAT(/T20,'AVERAGE FACE VELOCITY OUT OF RANGE, 0.3 TO 3.0')
   40 IF(TEMPK.GT.273.5) GO TO 50
      WRITE(J,540)
      I=1
   50 IF(FREQ.GT.1.E-5.AND.AMPLIT.GT.1.E-5) GO TO 60
      IF(FREQ.LT.1.E-5.AND.AMPLIT.LT.1.E-5) GO TO 60
      WRITE(J,570)
      I=1
   60 IF(M.NE.42) GO TO 70
      I=1
      WRITE(J,580)
   70 IF(TLAG.GT.1.E-5.AND.DPSTOP.GT.1.E-5) GO TO 75
      GO TO 100
   75 WRITE(J,610)
      I=1
  100 IF(ZK2.LT.1.E-5) GO TO 130
      IF(MMD1.GT.1.E-5.AND.SG1.GT.1.E-5.AND.MMD2.GT.1.E-5.AND.SG2.GT.
     * 1.E-5) GO TO 110
      IF(MMD1.LT.1.E-5.AND.SG1.LT.1.E-5.AND.MMD2.LT.1.E-5.AND.SG2.LT.
```

(continued)

TABLE 15 (continued)

```
     * 1.E-5) GO TO 180
       I=1
       WRITE(J,630)
   630 FORMAT(/T20,'PARTICLE SIZE DATA FOR K2 ARE INCOMPLETE')
   110 IF(MMD1.GE.2..AND.MMD1.LE.50.) GO TO 120
       I=1
       WRITE(J,640)
   640 FORMAT(/T20,'MASS MEDIAN DIAMETER OF MEASUREMENT OUT OF RANGE',
     * ' 2 TO 50 MICRONS')
   120 IF(SG1.GE.2..AND.SG1.LE.4.) GO TO 130
       I=1
       WRITE(J,650)
   650 FORMAT(/T20,'STANDARD DEVIATION OF MEASUREMENT OUT OF RANGE',
     * ' 2 TO 4')
   130 IF(MMD2.GE.2..AND.MMD2.LE.50.) GO TO 140
       I=1
       WRITE(J,660)
   660 FORMAT(/T20,'MASS MEDIAN DIAMETER OF DUST OUT OF RANGE',
     * ' 2 TO 50 MICRONS')
   140 IF(SG2.GE.2..AND.SG2.LE.4.) GO TO 150
       I=1
       WRITE(J,670)
   670 FORMAT(/T20,'STANDARD DEVIATION OF DUST OUT OF RANGE',
     * ' 2 TO 4')
   150 IF(MMD1.GT.1.E-5.AND.MMD2.GT.1.E-5.AND.SG1.GT.1.E-5.AND.SG2.GT.
     * 1.E-5) GO TO 180
       IF(RHOBLK.LT.RHOP) GO TO 160
       I=1
       WRITE(J,680)
   680 FORMAT(/T20,'BULK DENSITY CANNOT EXCEED DISCRETE PARTICLE DENSITY
     * ')
   160 IF(RHOBLK.GT.1.E-5.AND.RHOP.GT.1.E-5) GO TO 180
       I=1
       WRITE(J,690)
   690 FORMAT(/T20,'BULK OR DISCRETE DENSITY MISSING')
   180 CONTINUE
   610 FORMAT(/T20,'BOTH TIMED AND PRESSURE CONTROLLED CLEANINGS ',
     * 'SPECIFIED - ONLY ONE IS VALID')
   500 FORMAT('1',T20,'DIAGNOSTIC MESSAGES')
   510 FORMAT(//T20,'THE NUMBER OF COMPARTMENTS MUST NOT EXCEED 30')
   520 FORMAT(/T20,'THE NUMBER OF COMPARTMENTS TIMES THE COMPART',
     1 'MENT CLEANING TIME MUST BE LESS THAN THE CLEANING CYCLE TIME')
   530 FORMAT(/T20,'THE COMPARTMENT CLEANING TIME MUST BE LESS',1X,
     1 'THAN THE TOTAL CYCLE TIME')
   540 FORMAT(/T20,'A GAS TEMPERATURE HAS NOT BEEN ENTERED')
   560 FORMAT(/T20,'TIME INCREMENT TOO SMALL, IE. < 0.01 MINUTES')
   570 FORMAT(/T20,'INVALID FREQUENCY OR AMPLITUDE FOR SHAKER')
   580 FORMAT(/T20,'INVALID ACCURACY CODE')
       RETURN
       END
```

(continued)

```
      SUBROUTINE SETUP
C***********************************************************************
C
C     SUBROUTINE OF BAGHOUSE  10/78 HAK/RD GCA/TECH DIV
C     CORRECT FOR TEMPERATURE AND VISCOSITY
C     CALCULATE AND CORRECT K2 FOR SIZE PROPERTIES
C     CALCULATE SYSTEM CONSTANT W*
C     DETERMINE NUMBER OF AREAS THAT A BAG IS TO BE BROKEN UP INTO
C  IF I=1 AN ERROR EXISTS
C
C***********************************************************************
      REAL MMD1,MMD2
      COMMON/K2EST/TZK2,VZK2,MMD1,SG1,MMD2,SG2,RHOP,RHOBLK
      COMMON/MUCORR/TSE,TSR,TZKR
      COMMON/OPDATA/SMALQ,TEMPK,CZERO,TCZERO
      COMMON/CALC/DELT,NAREA,IAREA
      COMMON/FABDUS/ZK2,SE,WR,SR,ZKR,WSTAR
      COMMON/EXTERN/NT,M,WSTART,ACLEAN
      COMMON/DESIGN/N,T,TCLEAN,TLAG,VRFLO,DPSTOP,FREQ,AMPLIT
C- VISCOSITY CORRECTIONS
      VISC(TEMP)=1.46E-3*TEMP**1.5/(TEMP+110.)
C- DELT
      DELT=T/M/N
      TTEST1=N*TCLEAN+N*TCLEAN*1.E-4
      TTEST2=N*TCLEAN-N*TCLEAN*1.E-4
      IF(T.GE.TTEST2.AND.T.LE.TTEST1) TCLEAN=TCLEAN-0.0015
      ISKIP=0
      IF(ACLEAN.GT.1.E-5) ISKIP=1
C  CALCULATE K2 IF NECESSARY
C        IF K2=0 CALCULATE IT
C     IF K2>0 AND MMD2=0 DO NOT CALCULATE
C     IF K2>0 AND MMD2>0 CORRECT IT FOR MMD&SIGMAG
      IF(ZK2.GT.1.E-5.AND.MMD2.LT.1.E-5) GO TO 30
      IF(ZK2.GT.1.E-5.AND.MMD2.GT.1.E-5) GO TO 20
C  CALCULATE K2
      SOLID=RHOBLK/RHOP
      R=(3.+2.*SOLID**(5./3.))/(3.-4.5*SOLID**(1./3.)+4.5*SOLID**(5./3.
     *  )-3.*SOLID**2)
      SO2=36.*10.**(2.304*(ALOG10(SG2))**2)/MMD2**2
C  PARTICLE SIZE IN MICRONS,DENSITY IN G/CC, VISCOSITY IN CENTIPOISE
      ZK2=16.64*0.018*R*SO2/6./RHOP
      GO TO 30
C  CORRECT FOR MMD AND SIGMAG
   20 SOB2=36.*10.**(2.304*(ALOG10(SG1))**2)/MMD1**2
      SOF2=36.*10.**(2.304*(ALOG10(SG2))**2)/MMD2**2
      ZK2=ZK2*SOF2/SOB2
C  CORRECT TO VELOCITY OF 0.61 M/MIN
   30 ZK2=ZK2*SQRT(0.61/VZK2)
C  CORRECT  FOR TEMPETURE
      ZK2=ZK2*VISC(TEMPK)/VISC(TZK2)
```

(continued)

TABLE 15 (continued)

```
      SE=SE*VISC(TEMPK)/VISC(TSE)
      SR=SR*VISC(TEMPK)/VISC(TSR)
      ZKR=ZKR*VISC(TEMPK)/VISC(TZKR)
      CZERO=CZERO*TCZERO/TEMPK
C  CORRECT SE TO WR
      SE=SE+WR*ZK2
C  CALCULATE WSTART
C INITIAL LOADING ON EACH COMPARTMENT AT TIME ZERO
      IF(DPSTOP.LT.1.) GO TO 40
      WSTART=(DPSTOP-SE*SMALQ)/(ZK2*SQRT(SMALQ/0.61))/SMALQ+WR
      GO TO 50
      ENTRY RECALC
   40 WSTART=166.*(CZERO*SMALQ*(T+TLAG))**0.284-CZERO*SMALQ*T*N
     *  /(N-1)/2.+WR
   50 IF(WSTART.LT.WR) WSTART=WR
C  CALCULATE SYSTEM CONSTANT WSTAR ( W* )
      WSTAR=0.0
      IF(ZKR.GT.1.E-5.AND.SR.GT.1.E-5) WSTAR=(SE-SR)/(ZKR-ZK2)
      IF(ISKIP.NE.1) CALL CLEAN(0.0,DUMMY)
C- TOTAL NUMBER OF AREAS ON A BAG (IAREA) AND
C- NUMBER TO BE CLEANED (NAREA)
      ERR=0.01
    7 I=1./ACLEAN+0.3+0.2
      J=1
      IF(ERR.GT.0.06)GO TO 9
      DO 8 I=1,10
      DO 8 J=1,I
      ATEST=FLOAT(J)/FLOAT(I)
      IF (ATEST.LE.(ACLEAN+ERR).AND.ATEST.GE.(ACLEAN-ERR))GO TO 9
    8 CONTINUE
      ERR=ERR+0.01
      GO TO 7
    9 NAREA=J
      IAREA=I
      RETURN
      END
```

(continued)

TABLE 15 (continued)

```
      SUBROUTINE CHECK2(I)
C*******************************************************************************
C
C     SUBROUTINE OF BAGHOUSE  10/78 MAK/RD GCA/TECH DIV
C     CHECK CALCULATED VALUES FOR ERRORS AND PROPER RANGE
C
C*******************************************************************************
      COMMON/DEVICE/INPUT,OUTPUT
      COMMON/FABDUS/ZK2,SE,WR,SR,ZKR,WSTAR
      COMMON/EXTERN/NT,M,WSTART,ACLEAN
      COMMON/OPDATA/SMALQ,TEMPK,CZERO,TCZERO
      INTEGER OUTPUT
      IF(WSTAR.LT.1.E-5) GO TO 45
      IF(SE.GE.SR) GO TO 46
      I=1
      WRITE(OUTPUT,200)
  200 FORMAT(/T20,'EFFECTIVE DRAG, SE , IS LESS THAN RESIDUAL, SR')
   45 IF(ZKR.LT.1.E-5.AND.SR.LT.1.E-5) GO TO 50
      I=1
      WRITE(OUTPUT,620)
  620 FORMAT(/T20,'INCOMPLETE DATA FOR NON-LINEAR DRAG MODEL')
   46 IF(SR.GT.1.E-5) GO TO 47
      I=1
      WRITE(OUTPUT,630)
  630 FORMAT(/T20,'RESIDUAL DRAG SR , IS MISSING')
   47 IF(ZKR.GT.1.E-5) GO TO 50
      I=1
      WRITE(OUTPUT,640)
  640 FORMAT(/T20,'INITIAL SLOPE , KR , IS MISSING')
   50 IF(ACLEAN.GT.1.E-5.AND.ACLEAN.LE.1.) GO TO 60
      I=1
      WRITE(OUTPUT,600)
  600 FORMAT(/T20,'FRACTIONAL AREA CLEANED OUT OF RANGE,0 TO 1')
   60 TESTK2=ZK2*298**1.5/408.*(TEMPK+110)/TEMPK**1.5
      IF(TESTK2.GE.0.25.AND.TESTK2.LE.10.) GO TO 75
      WRITE(OUTPUT,610)
  610 FORMAT(/T20,'K2 IS OUT OF RANGE,0.25 TO 10')
      I=1
   75 IF(I.EQ.0) GO TO 80
      WRITE(OUTPUT,210)
      RETURN
   80 WRITE(OUTPUT,220)
  210 FORMAT(///,T20,'THE PROGRAM HAS BEEN TERMINATED BECAUSE OF '
     1 ,'ERRORS IN THE INPUT DATA')
  220 FORMAT(///,T20,'THERE ARE NO ERRORS IN THE INPUT DATA')
      RETURN
      END
```

(continued)

```
      SUBROUTINE OUTFIL
C***********************************************************************
C
C     SUBROUTINE OF BAGHOUSE  10/78 HAK/RD GCA/TECH DIV
C     PRINT CALCULATED AND CORRECTED VALUES
C
C***********************************************************************
      COMMON/EXTERN/NT,M,WSTART,ACLEAN
      COMMON/OPDATA/SMALQ,TEMPK,CZERO,TCZERO
      COMMON/DEVICE/INPUT,J
      COMMON/CALC/DELT,NAREA,IAREA
      COMMON/FABDUS/ZK2,SE,WR,SR,ZKR,WSTAR
      WRITE(J,100) CZERO,ZK2,SE
      IF(ZKR.GT.1.E-5) WRITE(J,610) ZKR
      IF(SR.GT.1.E-5) WRITE(J,620) SR
      WRITE(J,630)
      WRITE(J,600) ACLEAN,DELT,WSTAR
  100 FORMAT('1',T20,'CALCULATED VALUES',////,
     1 T20,'INLET DUST CONCENTRATION',T55,F6.2,T70,'G/M3',5X/
     * T20,'CORRECTED TO OPERATING TEMPERATURE'//
     2   T20,'FABRIC AND DUST CAKE PROPERTIES CORRECTED FOR GAS '
     3   ,'VISCOSITY',//,
     4  T25,'SPECIFIC CAKE RESISTANCE, K2',T55,F6.2,T70,'N-MIN/G-M'/
     6  T25,'EFFECTIVE DRAG, SE',T55,F5.0,T70,'N-MIN/M3')
  600 FORMAT(T20,'FRACTIONAL AREA CLEANED, AC',T55,F4.2//
     9  T20,'TIME INCREMENT',T55,F5.2,T70,'MINUTES'//
     *  T20,'SYSTEM CONSTANT W*',T55,F5.1,T70,'G/M2'//
     *  )
  610 FORMAT(T25,'INITIAL SLOPE, KR',T55,F6.2,T70,'N-MIN/G-M')
  620 FORMAT(T25,'RESIDUAL DRAG, SR',T55,F5.0,T70,'N-MIN/M3')
  630 FORMAT(/)
      RETURN
      END

      SUBROUTINE CLEAN(WTOTAL,ACLN)
C***********************************************************************
C
C     SUBROUTINE OF BAGHOUSE  10/78 HAK/RD GCA/TECH DIV
C     CALCULATES FRACTIONAL AREA CLEANED, AC , FOR SHAKER AND COLLAPSE
C     SYSTEMS
C          NOTE : WTOTAL AND ACLN ARE NOT USED BY THE PROGRAM
C
C***********************************************************************
      COMMON/OPDATA/SMALQ,TEMPK,CZERO,TCZERO
      COMMON/FABDUS/ZK2,SE,WR,SR,ZKR,WSTAR
      COMMON/DESIGN/N,T,TCLEAN,TLAG,VRFLO,DPSTOP,FREQ,AMPLIT
      COMMON/EXTERN/NT,M,WSTART,ACLEAN
      IF(WTOTAL.GT.1.) GO TO 30
      IF(DPSTOP.LT.1.) GO TO 20
      WP=(DPSTOP-SE*SMALQ)/(ZK2*SQRT(SMALQ/0.61))/SMALQ+WR
      WPRIME=WP+T*CZERO*SMALQ/2.
      ACLEAN=1.51E-8*WPRIME**2.52
      IF(FREQ.GT.1.E-5) ACLEAN=2.23E-12*(FREQ**2*AMPLIT*WPRIME)**2.52
      GO TO 25
   20 ACLEAN=0.006*(CZERO*SMALQ*(T+TLAG))**0.716
      IF(FREQ.GT.1.E-5) ACLEAN=4.9E-4*(FREQ**2*AMPLIT*CZERO*SMALQ*
     *    (T+TLAG))**0.716
   25 IF(ACLEAN.GT.1.) ACLEAN=1.
      IF(ACLEAN.LT.0.1) ACLEAN=0.1
      RETURN
   30 ACLN=1.51E-8*WTOTAL**2.52
      IF(FREQ.GT.1.E-5)   ACLN=2.23E-12*(FREQ**2*AMPLIT*WTOTAL)**2.52
      IF(ACLN.GT.1.) ACLN=1.
      IF(ACLN.LT.0.1) ACLN=0.1
      RETURN
      END
```

(continued)

```
      SUBROUTINE STABLE(DROP,TIME,JCODE,LCODE)
C***********************************************************************
C
C     SUBROUTINE OF BAGHOUSE  10/78 HAK/RD GCA/TECH DIV
C     CHECKS FOR CONVERGENCE TO STEADY STATE
C
C***********************************************************************
      COMMON/STABLD/T1,T2,T001,T002,DP1,DP2,P01,P02,SIGN1,I,N,NL,NCHG
      DIMENSION T(50),DP(50),DPDP(20)
      REAL NCHK3
      REAL LIM1,LIM2
      LCODE=0
      I=I+1
      T(I)=TIME
      DP(I)=DROP
      T1=T1+TIME
      T2=T1+TIME*TIME
      DP1=DP1+DROP
      DP2=DP2+DROP*TIME
      N=N+1
      IF(I.NE.1)GO TO 45
C SET LIMITS OF CONVERGENCE
      LIM1=0.01
      LIM2=0.001
      LIM1=LIM1/FLOAT(JCODE)
      LIM2=LIM2/FLOAT(JCODE)
   35 GO TO 40
   45 TAVG=(T(I)+T(I-1))/2.
      DELDP=(DP(I)-DP(I-1))/(T(I)-T(I-1))
      IF(I.LT.5)GO TO 10
      N=N-1
      T1=T1-T(I-4)
      T2=T2-T(I-4)*T(I-4)
      DP1=DP1-DP(I-4)
      DP2=DP2-T(I-4)*DP(I-4)
   10 ADELDP=ABS(DELDP)
      IF(ADELDP.LT.1.E-20) GO TO 15
      T001=T001+TAVG
      T002=T002+TAVG*TAVG
      P01=P01+ALOG(ADELDP)
      P02=P02+ALOG(ADELDP)*TAVG
      NL=NL+1
      IF(NL.LE.3)GO TO 25
      B1=(NL*P02-T001*P01)/(NL*T002-T001*T001)
C CHECK # 1
      CHK1=EXP(B1*TAVG)
      IF(CHK1.LE.LIM1) GO TO 50
   15 IF(I.LT.5)GO TO 25
      B1=(N*DP2-T1*DP1)/(N*T2-T1*T1)
C CHECK # 2
      CHK2=B1/(DROP/(T(I)-T(I-1)))
      ACHK2=ABS(CHK2)
      IF(ACHK2.LE.LIM2) GO TO 50
   25 GO TO 55
   50 LCODE=1
      GO TO 70
   55 IF((SIGN1*DELDP).GE.0..AND.DELDP.NE.0.)GO TO 20
      NCHG=NCHG+1
      DPDP(NCHG)=DROP
   20 SIGN1=DELDP
      IF(NCHG.LT.3)GO TO 40
C CHECK # 3
      NCHK3=ABS(DPDP(NCHG)-DPDP(NCHG-1))-ABS(DPDP(NCHG-1)-DPDP(NCHG-2))
      IF(NCHK3.LE.0.0) GO TO 50
   40 LCODE=0
   65 CONTINUE
   70 CONTINUE
      RETURN
      END
```

(continued)

TABLE 15 (continued)

```
      SUBROUTINE INITAL
C*****************************************************************************
C
C     SUBROUTINE OF BAGHOUSE  10/78 HAK/RD GCA/TECH DIV
C     THIS ROUTINE INITIALIZES VARIABLES USED BY MODEL AND STABLE
C
C*****************************************************************************
      COMMON/MODELD/PAVR,TCONT,DTLAST,PENTOT,PAVTOT,DPAVG,QAVG,TLAST,
     *  TDSUM,PNMAX,DELP,DPMAX,TREF,IFBAG,NFLAG,JFLAG,LOPCNT
      COMMON/STABLD/T1,T2,T001,T002,DP1,DP2,P01,P02,SIGN1,I,N,NL,NCHG
      DIMENSION ZERUM(13),ZEROS(9),IZEROM(4),IZEROS(4)
      EQUIVALENCE (PAVR,ZERUM(1)),(IFBAG,IZEROM(1)),
     *  (T1,ZEROS(1)),(I,IZEROS(1))
      DO 10 J=1,4
      IZEROS(J)=0
   10 IZEROM(J)=0
      DO 20 J=1,9
   20 ZEROS(J)=0.0
      DO 30 J=1,13
   30 ZERUM(J)=0.0
      RETURN
      END

      SUBROUTINE RESTRT
C*****************************************************************************
C
C     SUBROUTINE OF BAGHOUSE  10/78 HAK/RD GCA/TECH DIV
C     SUBROUTINE TO RESTART THE SIMULATION IF A PRESSURE
C     CONTROLLED SYSTEM BECOMES CONTINUOUSLY CLEANED
C
C*****************************************************************************
      COMMON/EXTERN/NT,M,WSTART,ACLEAN
      COMMON/DESIGN/N,T,TCLEAN,TLAG,VRFLO,DPSTOP,FREQ,AMPLIT
      COMMON/DEVICE/INPUT,OUTPUT
      INTEGER OUTPUT
      DPSTOP=0.0
      CALL RECALC
      WRITE(OUTPUT,600) ACLEAN
  600 FORMAT(T20,80('-')//T20,
     1  'LIMITING PRESSURE SYSTEM HAS BECOME CONTINUOUS'/
     2  T20,'SIMULATION HAS BEEN RESTARTED'/
     3  T20,'CALCULATIONS NOW BASED ON CONTINUOUSLY CLEANED SYSTEM'///
     4  T20,'REVISED FRACTIONAL AREA CLEANED, AC = ',F4.2//
     5  T20,80('-'))
      RETURN
      END
```

(continued)

TABLE 15 (continued)

```
//GO.FT08F001 DD UNIT=SYSDA,DISP=(NEW,PASS),DSN=&&BAG1,
//     DCB=(RECFM=FB,LRECL=80,BLKSIZE=400),SPACE=(CYL,(5,1),RLSE)
//GO.FT10F001 DD UNIT=SYSDA,DISP=(NEW,PASS),DSN=&&BAG3,
//     DCB=(RECFM=FB,LRECL=80,BLKSIZE=400),SPACE=(CYL,(5,1),RLSE)
//GO.FT11F001 DD UNIT=SYSDA,DISP=(NEW,PASS),DSN=&&BAG4,
//     DCB=(RECFM=FB,LRECL=80,BLKSIZE=400),SPACE=(CYL,(5,1),RLSE)
//GO.FT12F001 DD UNIT=SYSDA,DISP=(NEW,PASS),DSN=&&BAG5,
//     DCB=(RECFM=FB,LRECL=80,BLKSIZE=400),SPACE=(CYL,(5,1),RLSE)
//GO.FT13F001 DD UNIT=SYSDA,DISP=(NEW,PASS),DSN=&&BAG6,
//     DCB=(RECFM=FB,LRECL=80,BLKSIZE=400),SPACE=(CYL,(5,1),RLSE)
//GO.FT14F001 DD UNIT=SYSDA,DISP=(NEW,PASS),DSN=&&BAG7,
//     DCB=(RECFM=FB,LRECL=80,BLKSIZE=400),SPACE=(CYL,(5,1),RLSE)
//GO.FT15F001 DD UNIT=SYSDA,DISP=(NEW,PASS),DSN=&&BAG8,
//     DCB=(RECFM=FB,LRECL=80,BLKSIZE=400),SPACE=(CYL,(5,1),RLSE)
//GO.SYSIN DD *
//*  INSERT INPUT DATA CARDS BEFORE THIS CARD
//SUMTBL EXEC FORTG1CG,ACCT=CUST,PARM.GO='SIZE=66K'
//FORT.SYSIN DD *
```

(continued)

```
C*********************************************************************
C
C      STEP= SUMTBL BAGHOUSE STEP # 2
C      SUMMARY TABLE GENERATOR FOR BAGHOUSE MODEL
C      UNIT 8 = PRESSURE VS TIME , N/M2 VS MIN
C      UNIT 15 = FRACTIONAL PENETRATION VS TIME
C     UNIT 10-14 = INDIVIDUAL COMPARTMENT FLOWS FOR COMP. 1-5 VS TIME
C      FIRST RECORD OF FILE #8 CONTAINS PRINT FLAG,PLOT FLAG,MAX # OF
C      COMPARTMENTS FOR WHICH FLOWS ARE PRINTED
C      0=NO PRINT/PLOT AND 1= YES  FOR PRINT AND PLOT FLAGS
C      2 IN THE PRINT LOCATION INDICATES DETAILED OUTPUT
C      FIRST 8 OR 80 RECORDS ARE SET UP BY PLOTIN ( HEADINGS AND SCALE
C      FACTORS, ETC. )
C      DATA ARRANGED AS 3 DATA POINTS PER RECORD
C
C*********************************************************************
      DIMENSION TIME(3),PRESSR(3),SYSFLO(3)
      REAL INDFLO(5,3),PENET(3)
      REAL*8 HEAD(8),COMP
      DATA COMP/'COMP.'/
      LINES=60
      IPR=6
      READ(8,500)IPRINT,IMAX
      IF(IPRINT.NE.1.AND.IPRINT.NE.2) GO TO 1000
      READ(8,505) HEAD
      BACKSPACE 8
      DO 10 IN=8,10,2
      DO 10 J=1,7
   10 READ(IN,510)DUMMY
      DO 20 J=1,7
   20 READ(15,510)DUMMY
      JMAX=9+IMAX
      IF(IMAX.EQ.1)GO TO 40
      DO 30 IN=11,JMAX
   30 READ(IN,510)DUMMY
   40 CONTINUE
C- READY TO READ IN DATA
      IPAGE=0
   50 READ(8,520)(TIME(I),PRESSR(I),I=1,3)
      IF(IPRINT.EQ.1) GO TO 65
      DO 60 IN=10,JMAX
   60 READ(IN,530) (INDFLO(IN-9,I),I=1,3)
   65 CONTINUE
      READ(15,530)(PENET(I),I=1,3)
C- DATA HAS BEEN READ IN
      IF(TIME(2).LT.1.E-5.AND.TIME(3).LT.1.E-5)GO TO 1000
      IF(LINES.LT.56)GO TO 70
      IPAGE=IPAGE+1
      LINES=6
      IF(IPRINT.EQ.2) WRITE(IPR,600) HEAD,IPAGE,(COMP,I,I=1,IMAX)
```

(continued)

```
      IF(IPRINT.EQ.1) WRITE(IPR,620) HEAD,IPAGE
   70 CONTINUE
      DO 80 I=1,3
      IF(IPRINT.EQ.2) WRITE(IPR,610) TIME(I),PRESSR(I),PENET(I),
     *  (INDFLO(J,I),J=1,IMAX)
      IF(IPRINT.EQ.1) WRITE(IPR,610) TIME(I),PRESSR(I),PENET(I)
   80 CONTINUE
      LINES=LINES+3
      GO TO 50
 1000 DO 1010 I=8,15
 1010 REWIND I
  500 FORMAT(I1,1X,I1)
  505 FORMAT(8A8)
  510 FORMAT(A1)
  520 FORMAT(6G10.5)
  530 FORMAT(3(10X,G10.5))
  600 FORMAT(  '1SUMMARY TABLE 1',2X,8A8,5X,'PAGE',2X,I2//
     1  T22,'PRESSURE',T34,'FRACTIONAL'/
     2  T9,'TIME',T24,'DROP',T34,'PENETRATION',T64,
     3  'INDIVIDUAL COMPARTMENT FLOWS (M/MIN)'/
     4  T9,'(MIN)',T23,'(N/M2)',T52,A5,I1,T67,A5,I1,T82,
     5  A5,I1,T97,A5,I1,T112,A5,I1/)
  610 FORMAT(3X,F10.2,5X,F10.0,5X,1PE9.3,5X,0PF10.4,4(5X,F10.4))
  620 FORMAT(  '1SUMMARY TABLE 1',2X,8A8,5X,'PAGE',2X,I2//
     1  T22,'PRESSURE',T34,'FRACTIONAL'/
     2  T9,'TIME',T24,'DROP',T34,'PENETRATION'/
     4  T9,'(MIN)',T23,'(N/M2)'/)
      END

//GO.FT08F001 DD UNIT=SYSDA,DISP=(OLD,PASS),DSN=*.SIMULA.GO.FT08F001
//GO.FT10F001 DD UNIT=SYSDA,DISP=(OLD,PASS),DSN=*.SIMULA.GO.FT10F001
//GO.FT11F001 DD UNIT=SYSDA,DISP=(OLD,PASS),DSN=*.SIMULA.GO.FT11F001
//GO.FT12F001 DD UNIT=SYSDA,DISP=(OLD,PASS),DSN=*.SIMULA.GO.FT12F001
//GO.FT13F001 DD UNIT=SYSDA,DISP=(OLD,PASS),DSN=*.SIMULA.GO.FT13F001
//GO.FT14F001 DD UNIT=SYSDA,DISP=(OLD,PASS),DSN=*.SIMULA.GO.FT14F001
//GO.FT15F001 DD UNIT=SYSDA,DISP=(OLD,PASS),DSN=*.SIMULA.GO.FT15F001
//SCRIBE EXEC FORTGICG,ACCT=COST,PARM.GO='SIZE=175K'
//FORT.SYSIN DD *
```

(continued)

TABLE 15 (continued)

```
C GRAPH LIBRARY  7/16/75/RWS  GCA TECHNOLOGY
C  VERSION 8/1/76
C CARDS-
C TITLE(1-64)       OPTIONS: XPOS(65-69) YPOS(70-74) HEIGHT(75-79)  &(80)
C XAXIS LABEL(1-64)OPTIONS: BEGIN(69-74) UNITS OR LOGS/INCH(75-80)
C YAXIS (SAME)
C TYPE (YAXIS-XAXIS)(SEMI,LOG-,PROB,BAR-)(1-8)
C       OPTIONS: LOG-(9-12) FOR A LOGRITHMIC BAR GRAPH
C                NEW GRAPH DIST(35-40) DEFAULT=6
C                X-AXIS HEIGHT(45-50)  DEFAULT=2
C                X AXIS LENGTH(55-60)  DEFAULT=6
C                Y-AXIS LENGTH(65-70)  DEFAULT=5
C                DOUBLE AXIS(74)  1 FOR X, 2 FOR Y, 3 FOR BOTH
C                SYMBOL(75-80)  POINTS BETWEEN PLOT SYMBOLS
C                               NEGATIVE FOR SYMBOLS BUT NO LINES
C DATA  X(1-10) Y(11-20)
C       OPTION: X(21-30) Y(31-40)  X(41-50) Y(51-60)
C OPTION (END,NEW,SAME)(75-78) (NEW MAKES NEW GRAPH-REPEAT ALL CARDS)
C                               (SAME PLOTS ON OLD GRAPH-NO X-Y AXIS)
C                      (79-80) (CHANGE 'SYMBOL' FOR NEXT PLOT)
      DIMENSION IBUF(4000),XAR(1002),YAR(1002),PRN(50),PRB(100)
      DIMENSION XPLAB(26),YPLAB(26),XPROB(38),YPLAS(26)
      REAL LOG,NEW,NEXT,NEX
      REAL*8 TAB(8),XLAB(8),YLAB(8),SPLAB(12),SPLAT(12)
      DATA XPLAB/.00,.30,.48,.65,.91,1.10,1.32,1.65,1.95,2.30,2.56,2.78,
     &3.00,3.22,3.44,3.70,4.05,4.35,4.68,4.90,5.09,5.35,5.52,6.00,0.,1./
      DATA YPLAB/25*0.0,1./
      DATA YPLAS/24*5.0,.0,1./
      DATA SPLAB/'.01 .05 ','.1,2  .5',' 1  2   ',' 5   10 ','  20  30',
     2          ' 40 50 6','0 70  80','   90   ','95   98 ','99 99.5 ',
     3          ' 99.9  9','9.99    '/
      DATA SPLAT/' 99.99 9','9.9  99.','5 99 98 ','  95  90','   80  7',
     2          '0 60 50 ',' 40 30  ','20   10 ',' 5    2 ',' 1  .5  ',
     3          '.2 .1   ','.01     '/
      DATA XPROB/.0,.16,.45,.65,.91,1.10,1.42,1.68,1.94,2.17,2.43,2.82,
     &3.04,3.33,3.63,3.88,4.24,4.53,4.92,5.21,5.57,5.89,6.28,6.63,
     &7.06,7.51,7.90,8.32,8.84,9.29,9.81,10.36,10.91,11.55,12.27,
     &13.09,13.95,15.00/
      DATA BLA,SEMI,LOG,PROB,BAR/'    ','SEMI','LOG-','PROB','BAR-'/
      DATA SAME,NEW,ENDD/'SAME','NEW ','END '/
      READ(3,600) IPLOT
  600 FORMAT(1X,I1)
      IF(IPLOT.NE.1) GO TO 1020
      CALL PLOTS(IBUF,4000)
      INUNIT=3
      IOUTUN=4
      NEXT=NEW
   10 ISYM=0
      CALL PLOT(0.,-36.,-3)
      CALL PLOT(0.0,2.,-3)
```

(continued)

```
      IPOS=0
      BARX=0.
      BARY=0.
      PROBX=0.
      LTYP=0
   20 ISYM=ISYM+1
      NEX=NEXT
      IF(NEXT.NE.SAME) GO TO 30
      XBEG=XAR(IMAX+1)
      XINC=XAR(IMAX+2)
      YBEG=YAR(IMAX+1)
      YINC=YAR(IMAX+2)
C   TITLE
   30 READ(INUNIT,40,END=1000) TAR,XPOS,YPOS,CHIT,CONT
   40 FORMAT(8A8,3G5.2,A1)
      IF(ABS(XPOS).LT.1.E-20) XPOS=.5
      IF(ABS(YPOS).LT.1.E-20) YPOS=8.0-(.25*IPOS)
      IF(CHIT.LT.1.E-20.AND.ISYM.EQ.1.AND.CONT.NE.BLA) CHIT=.21
      IF(CHIT.LT.1.E-20.AND.CONT.EQ.BLA) CHIT=.14
      WRITE(IOUTUN,41) TAR,XPOS,YPOS,CHIT,CONT
   41 FORMAT(1X,8A8,3X,'XPOS=',F7.3,3X,'YPOS=',F7.3,3X,'HEIGHT=',F7.3,
     &        3X,'CONT=',A1)
      IF(CONT.NE.BLA.OR.IPOS.EQ.0) GO TO 45
      XPOS=XPOS+.2
      DO 42 I=1,7
      IF(TAR(8).EQ.TAR(I)) GO TO 42
      CALL SYMBOL(XPOS-.1,YPOS,CHIT,ISYM,0.,-1)
      GO TO 45
   42 CONTINUE
   45 CALL SYMBOL(XPOS,YPOS,CHIT,TAR,0.,64)
      IPOS=IPOS+1
      IF(CONT.NE.BLA) GO TO 30
C LABELS
      IF(ISYM.GT.1.AND.NEXT.EQ.SAME) GO TO 70
      READ(INUNIT,50) XLAB,XBEG,XINC
   50 FORMAT(8A8,T69,2G6.2)
      WRITE(IOUTUN,55) XLAB,XBEG,XINC
   55 FORMAT(1X,8A8,3X,'XBEG=',G10.3,3X,'XINC=',G10.3)
      READ(INUNIT,50) YLAB,YBEG,YINC
      WRITE(IOUTUN,58) YLAB,YBEG,YINC
   58 FORMAT(1X,8A8,3X,'YBEG=',G10.3,3X,'YINC=',G10.3)
C TYPE
      READ(INUNIT,60) YTYP,XTYP,ZTYP,XOVER,YUP,XAXL,YAXL,IDOUB,LTYP
   60 FORMAT(3A4,T31,4(4X,G6.2),T74,I1,I6)
      IF(XTYP.EQ.BLA) XTYP=SEMI
      IF(YTYP.EQ.BLA) YTYP=SEMI
      IF(YUP.LT.1.E-5) YUP=2.
      YUP=YUP-2.
      CALL PLOT(0.,YUP,-3)
      IF(XAXL.LT..5) XAXL=6.
```

(continued)

TABLE 15 (continued)

```
      IF(ABS(XOVER).LT.1.E-20) XOVER=6.
      PMOVE=XAXL+XOVER
      IF(YAXL.LT..5) YAXL=5.
      WRITE(IOUTUN,65) YTYP,XTYP,ZTYP,XOVER,YUP,XAXL,YAXL,IDOUB,LTYP
   65 FORMAT(1X,3A4,5X,'XOVER=',F6.2,3X,
     2       'XAXIS HT=',F6.2,5X,'XAXIS L=',F6.2,5X,
     3       'YAXIS L=',F6.2,5X,
     4              '#AXIS=',I1,10X,'POINTS PER TICK=',I6)
      IF(ZTYP.EQ.BLA) ZTYP=SEMI
C DATA
   70 J=1
      WRITE(IOUTUN,75)
   75 FORMAT(T40,'DATA'/
     &       T5,'X1',T15,'Y1',T25,'X2',T35,'Y2',T45,'X3',T55,'Y3',T72,
     &       'NEXT GRAPH TYPE     NEW SYMBOL'/)
      DO 100 I=1,1000
      K=J+2
      READ(INUNIT,80,END=90)  ((XAR(M),YAR(M)),M=J,K),NEXT,NEWSYM
   80 FORMAT(6G10.5,T75,A4,I2)
      WRITE(IOUTUN,85)        ((XAR(M),YAR(M)),M=J,K),NEXT,NEWSYM
   85 FORMAT(1X,6(1PE10.3),T74,A4,T93,I3)
      IF(XAR(J+1).LT.1.E-20.AND.YAR(J+1).LT.1.E-20.AND.XAR(K).LT.1.E-20
     &.AND.YAR(K).LT.1.E-20) J=J-1
      IF(XAR(K).LT.1.E-20.AND.YAR(K).LT.1.E-20) J=J-1
      J=J+3
      IF(J.GT.1000) GO TO 90
      IF(NEXT.EQ.BLA) GO TO 100
      IF(XAR(J-1).LT.1.E-20.AND.YAR(J-1).LT.1.E-20) J=J-1
      IF(NEWSYM.NE.0) LTYP=NEWSYM
   90 IMAX=J-1
      IF(NEXT.EQ.BLA) NEXT=ENDD
      GO TO 102
  100 CONTINUE
C SCALES AND AXIS
  102 XAR(IMAX+1)=XBEG
      XAR(IMAX+2)=XINC
      YAR(IMAX+1)=YBEG
      YAR(IMAX+2)=YINC
C  CUT OFF VALUES OUT OF RANGE
      IF(ABS(XINC).LT.1.E-20) GO TO 106
      IF(XTYP.EQ.PROB) GO TO 106
      XBYG=XBEG+XINC*XAXL
      IF(XTYP.EQ.LOG) XBYG=XBEG*10**(XINC*XAXL)
      DO 104 IMLOOP=1,IMAX
      IF(XBYG.GT.XBEG.AND.XAR(IMLOOP).GT.XBYG) XAR(IMLOOP)=XBYG
      IF(XBYG.GT.XBEG.AND.XAR(IMLOOP).LT.XBEG) XAR(IMLOOP)=XBEG
      IF(XBYG.LT.XBEG.AND.XAR(IMLOOP).LT.XBYG) XAR(IMLOOP)=XBYG
      IF(XBYG.LT.XBEG.AND.XAR(IMLOOP).GT.XBEG) XAR(IMLOOP)=XBEG
  104 CONTINUE
  106 IF(ABS(YINC).LT.1.E-20) GO TO 110
```

(continued)

TABLE 15 (continued)

```
      YBYG=YBEG+YINC*YAXL
      IF(YTYP.EQ.LOG) YBYG=YBEG*10**(YINC*YAXL)
      DO 108 IMLOOP=1,IMAX
      IF(YBYG.GT.YBEG.AND.YAR(IMLOOP).GT.YBYG) YAR(IMLOOP)=YBYG
      IF(YBYG.GT.YBEG.AND.YAR(IMLOOP).LT.YBEG) YAR(IMLOOP)=YBEG
      IF(YBYG.LT.YBEG.AND.YAR(IMLOOP).LT.YBYG) YAR(IMLOOP)=YBYG
      IF(YBYG.LT.YBEG.AND.YAR(IMLOOP).GT.YBEG) YAR(IMLOOP)=YBEG
  108 CONTINUE
C  CUT OFF LOW VALUES
  110 XBYG=1.E-20
      YBYG=1.E-20
      IF(XTYP.NE.LOG) GO TO 113
      DO 112 IMLOOP=1,IMAX
      IF(XAR(IMLOOP).LT.XBYG) XAR(IMLOOP)=XBYG
  112 CONTINUE
  113 IF(YTYP.NE.LOG) GO TO 115
      DO 114 IMLOOP=1,IMAX
      IF(YAR(IMLOOP).LT.YBYG) YAR(IMLOOP)=YBYG
  114 CONTINUE
  115 IF(NEX.EQ.SAME) GO TO 147
      IF(XTYP.EQ.BAR.OR.YTYP.EQ.BAR) GO TO 200
      IF(XTYP.NE.SEMI) GO TO 120
      IF(XINC.LT.1.E-20) CALL SCALE(XAR,XAXL,IMAX,1)
  116 CALL AXIS(0.0,0.0,XLAB,-64,XAXL,0.0,XAR(IMAX+1),XAR(IMAX+2))
      IF(IDOUB.EQ.1.OR.IDOUB.EQ.3)
     &CALL AXIS(0.0,YAXL,XLAB,+64,XAXL,0.0,XAR(IMAX+1),XAR(IMAX+2))
  120 IF(YTYP.NE.SEMI) GO TO 130
      IF(YINC.LT.1.E-20) CALL SCALE(YAR,YAXL,IMAX,1)
  126 CALL AXIS(0.0,0.0,YLAB,64,YAXL,90.0,YAR(IMAX+1),YAR(IMAX+2))
      IF(IDOUB.GE.2)
     &CALL AXIS(XAXL,0.0,YLAB,-64,YAXL,90.0,YAR(IMAX+1),YAR(IMAX+2))
  130 IF(XTYP.NE.LOG) GO TO 140
      IF(XINC.LT.1.E-20) GO TO 135
      IF(XBEG.GT.1.E-20) GO TO 133
      XBEG=1.
      XAR(IMAX+1)=1.
  133 CONTINUE
      GO TO 136
  135 CALL SCALG(XAR,XAXL,IMAX,1)
  136 CALL LGAXS(0.0,0.0,XLAB,-64,XAXL,0.0,XAR(IMAX+1),XAR(IMAX+2))
      IF(IDOUB.EQ.1.OR.IDOUB.EQ.3)
     &CALL LGAXS(0.0,5.0,XLAB,64,XAXL,0.0,XAR(IMAX+1),XAR(IMAX+2))
  140 IF(YTYP.NE.LOG) GO TO 147
      IF(YINC.LT.1.E-20) GO TO 145
      IF(YBEG.GT.1.E-20) GO TO 143
      YBEG=1.
      YAR(IMAX+1)=1.
  143 CONTINUE
      GO TO 146
  145 CALL SCALG(YAR,YAXL,IMAX,1)
```

(continued)

TABLE 15 (continued)

```
  146 CALL LGAXS(0.0,0.0,YLAB,64,YAXL,90.0,YAR(IMAX+1),YAR(IMAX+2))
      IF(IDOUB.GE.2)
     &CALL LGAXS(6.0,0.0,YLAB,-64,YAXL,90.0,YAR(IMAX+1),YAR(IMAX+2))
  147 IF(XTYP.NE.SEMI.OR.YTYP.NE.SEMI) GO TO 150
      CALL LINE(XAR,YAR,IMAX,1,LTYP,ISYM)
      GO TO 500
  150 IF(XTYP.NE.SEMI.OR.YTYP.NE.LOG) GO TO 160
      LOGT=1
      GO TO 180
  160 IF(XTYP.NE.LOG.OR.YTYP.NE.SEMI) GO TO 170
      LOGT=-1
      GO TO 180
  170 IF(XTYP.NE.LOG.OR.YTYP.NE.LOG) GO TO 200
      LOGT=0
  180 CALL LGLIN(XAR,YAR,IMAX,1,LTYP,ISYM,LOGT)
      GO TO 500
C  BAR GRAPH
  200 IF(XTYP.NE.BAR) GO TO 220
      YAR(IMAX+1)=YAR(IMAX)
      DO 210 I=1,IMAX
      J=IMAX-I+1
      XAR(3*J+1)=XAR(J)
      XAR(3*J)=XAR(J)
      XAR(3*J-1)=XAR(J)
      YAR(3*J+1)=YAR(J+1)
      YAR(3*J)=YBEG
      YAR(3*J-1)=YAR(J)
  210 CONTINUE
      XAR(1)=XBEG
      IMAX=3*IMAX+1
      XAR(IMAX+1)=XBEG
      XAR(IMAX+2)=XINC
      YAR(IMAX+1)=YBEG
      YAR(IMAX+2)=YINC
      BARX=1.
      XTYP=ZTYP
      GO TO 110
  220 IF(YTYP.NE.BAR) GO TO 250
      XAR(IMAX+1)=XAR(IMAX)
      DO 230 I=1,IMAX
      J=IMAX-I+1
      YAR(2*J)=YAR(J)
      YAR(2*J-1)=YAR(J)
      XAR(2*J)=XAR(J+1)
  230 XAR(2*J-1)=XAR(J)
      IMAX=2*IMAX
      BARY=1.
      YTYP=ZTYP
      XAR(IMAX+1)=XBEG
      XAR(IMAX+2)=XINC
```

(continued)

TABLE 15 (continued)

```
      YAR(IMAX+1)=YBEG
      YAR(IMAX+2)=YINC
      GO TO 110
C PROB GRAPH
  250 IF(XTYP.NE.PROB) GO TO 300
      IF(NEX.EQ.SAME) GO TO 255
      XPLAB(26)=6.0/XAXL
      CALL LINE(XPLAB,YPLAB,24,1,1,13)
      CHXP=XAXL/6.*.0681
      PSYMS=-CHXP
      PSYT=-.17*(XAXL/6.)
      CALL SYMBOL(PSYMS,PSYT,CHXP,SPLAB,0.,96)
      CALL SYMBOL(0.,-.35,.14,XLAB,0.,69)
      IF(IDOUB.NE.1.AND.IDOUB.NE.3) GO TO 255
      DO 251 IDUMII=1,24
  251 YPLAS(IDUMII)=YAXL
      CALL LINE(XPLAB,YPLAS,24,1,1,13)
      PSYMS=2.*(-CHXP)
      PSYT=YAXL-PSYT
      CALL SYMBUL(PSYMS,PSYT,CHXP,SPLAT,0.,96)
      CALL SYMBOL(0.,5.35,.14,XLAB,0.,69)
  255 DO 270 I=1,IMAX
      LEFT=1
      IF(XAR(I).LT..01) XAR(I)=.01
      IF(XAR(I).LT.50.) GO TO 260
      LEFT=0
      IF(XAR(I).GT.99.99) XAR(I)=99.99
      XAR(I)=100.-XAR(I)
  260 RLP=ALOG10(XAR(I)*100.)*10.+1.
      IF(RLP.LT.1.) RLP=1.
      IF(RLP.GT.38.) RLP=38.
      LP=IFIX(RLP)
      XAR(I)=(XPROB(LP)+(RLP-LP)*(XPROB(LP+1)-XPROB(LP)))/5.
      IF(LEFT.EQ.0) XAR(I)=6.-XAR(I)
  270 CONTINUE
      XAR(IMAX+1)=0.
      XAR(IMAX+2)=XAXL/6.
      PROBX=1.
      XTYP=SEMI
      GO TO 1?7
  300 IF(YTYP.NE.PROB) GO TO 450
  450 WRITE(6,460) XTYP,YTYP
  460 FORMAT(' NO SUCH GRAPH TYPE AS ',2A4)
      GO TO 1000
C AGAIN
  500 CONTINUE
      IF(BARX.GT..5) XTYP=BAR
      IF(BARY.GT..5) YTYP=BAR
      IF(PROBX.GT..5) XTYP=PROB
      IF(NEXT.NE.NEW) GO TO 510
```

(continued)

TABLE 15 (continued)

```
      CALL PLOT(PMOVE,0.,-3)
      GO TO 10
  510 IF(NEXT.EQ.SAME) GO TO 20
 1000 WRITE(IOUTUN,1010) NEXT
 1010 FORMAT(' END    NEXT= ',A4)
      CALL PLOT(PMOVE,0.,999)
 1020 CALL EXIT
      END


//GO.SYSLIB DD DISP=SHR
// DD DSN=SYS1.PLOTTER,DISP=SHR
//GO.PLOTTAPE DD DSN=PLOT3656,
// DISP=(,KEEP),UNIT=(TAPE7,,DEFER),
// LABEL=(,BLP),VOL=SER=PLXXXX
//GO.FT03F001 DD UNIT=SYSDA,DISP=(OLD,PASS),DSN=*.SUMTBL.GO.FT08F001
//            DD UNIT=SYSDA,DISP=(OLD,PASS),DSN=*.SUMTBL.GO.FT10F001
//            DD UNIT=SYSDA,DISP=(OLD,PASS),DSN=*.SUMTBL.GO.FT11F001
//            DD UNIT=SYSDA,DISP=(OLD,PASS),DSN=*.SUMTBL.GO.FT12F001
//            DD UNIT=SYSDA,DISP=(OLD,PASS),DSN=*.SUMTBL.GO.FT13F001
//            DD UNIT=SYSDA,DISP=(OLD,PASS),DSN=*.SUMTBL.GO.FT14F001
//            DD UNIT=SYSDA,DISP=(OLD,PASS),DSN=*.SUMTBL.GO.FT15F001
//GO.FT04F001 DD DUMMY
```

(continued)

TABLE 16. VARIABLES AND ARRAYS USED IN BAGHOUSE SIMULATION PROGRAM, STEP 1

VARIABLES		
ACHK2	-	Absolute value of CHK2.
ACLEAN	-	Fractional area cleaned, calculated or input.
ACLN	-	Fractional area cleaned, a_c, calculated in CLEAN if WTOTAL is nonzero.
ADELDP	-	Absolute value of slope of average pressure drop, $\overline{P}$, versus time curve $N/m^2/min$.
AMPLIT	-	Shaking amplitude, half-stroke, cm.
AREA	-	Fractional area on a bag. The product of AREA and the number of areas cleaned gives the fractional area cleaned.
ATEST	-	Intermediate calculation in determining AREA.
BAG1	-	Heading, 'SBAG'.
BAG2	-	Heading, 'QBAG'.
BLANK	-	Four blank characters.
BLANK8	-	Eight blank characters.
B1	-	Slope of least squares fit to either log (slope) of $\overline{P}$ versus time or $\overline{P}$ versus time, min^{-1}.
CHK1	-	Estimated fractional error for Check No. 1 in STABLE.
CHK2	-	Estimated fractional error for Check No. 2 in STABLE.
CLAREA	-	Fractional area cleaned on a bag, calculated.
CONTOT	-	Total outlet concentration from the system, g/m^3.
CZERO	-	Inlet concentration, calculated, g/m^3.
CZEROE	-	Inlet concentration, input, g/m^3.
DATYPE	-	Type of printed data requested, input.
DELDP	-	Slope of $\overline{P}$ versus time, $N/m^2/min$.
DELP	-	System pressure drop, N/m^2.
DELT	-	Time increment, min.
DELTT	-	Intermediate in determining time increment, min.
DETAIL	-	Used to check for 'DETAILED' results request.
DPAVG	-	Intermediate in calculating average pressure drop, N/m^2.
DPAVGN	-	Average pressure drop at the end of a cycle, N/m^2.
DPMAX	-	Maximum pressure drop during a cycle.
DPSTOP	-	Maximum system pressure, if exceeded cleaning begins, N/m^2.

(continued)

TABLE 16 (continued)

DP1	-	Sum of average pressure drops, $\bar{P}$, N/m^2.
DP2	-	Sum of the product of average pressure drop and time, N-min/m^2.
DRAG	-	Heading, 'AREA'.
DROP	-	Average pressure drop passed to STABLE, N/m^2.
DTLAST	-	Time increment of last loop, min.
ERR	-	Error used in determining cleaned area.
FREQ	-	Shaking frequency, cycles/sec.
I	-	Index. Error code.
IAREA	-	Number of areas on a bag.
IBAG	-	Bag index.
IERROR	-	Error code.
IFAREA	-	Number of the area to be cleaned.
IFBAG	-	Number of the bag just cleaned.
II	-	Index.
INPUT	-	Input device, initialized in subroutine DESINE to a value of 5. All cards are read from INPUT.
IREPT	-	Line counter for output of intermediate calculations.
IUNIT	-	Output file number.
J	-	Index.
JCODE	-	Accuracy code, input. This is subsequently changed from input (0 or 1) to (1 or 3) to alter the limits (LIM1, LIM2) in STABLE.
IFLAG	-	Flag from STABLE to signal convergence.
JLOOP	-	Index in time loop.
JTIME	-	JLOOP-1.
K	-	Index.
K3	-	Index in determining when to write on a file, data points for graphs are written three at a time.
L	-	Index.
LCODE	-	Flag in STABLE signaling convergence.
LDIAG	-	Detailed print diagnostics; if true, intermediate calculations are output.

(continued)

TABLE 16 (continued)

LIM1	-	Limit for Check #1 in STABLE.
LIM2	-	Limit for Check #2 in STABLE.
LMAX	-	Maximum number of individual flow rate graphs, limit = 5.
LOPCNT	-	Number of cycles modeled at any time in the simulation.
LOPTST	-	Difference between NT and LOPCNT.
M	-	Number of increments per bag, input.
MAXJ	-	Total number of increments used in time loop.
MAXK	-	Maximum number of bags for which calculations are output per line.
MMD1	-	Mass median diameter of reference dust, μm, input.
MMD2	-	Mass median diameter of inlet dust, μm, input.
N	-	Number of bags (compartments), input.
NAREA	-	Number of areas to be cleaned.
NCHG	-	Number of times the slope of DPAVG versus time curve has changed sign.
NCHK3	-	Difference between the changes in average pressure drop for two successive cycles where the slope of the DPAVG versus time curve is changing sign.
NFLAG	-	Number of cycles completed after convergence.
NL	-	Number of cycles completed - one for use in Check #1, STABLE.
NT	-	Maximum allowable number of cycles modeled, input.
OUTPUT	-	Output device for printed data. Initialized in DESINE to a value of 6. All printed output is written to OUTPUT.
PAVNOW	-	Average penetration at the end of a cycle.
PAVR	-	Average penetration at the end of a cleaning cycle.
PAVTOT	-	Intermediate in calculating average penetration.
PENTOT	-	Total system penetration at any time.
PLOTER	-	'PLOT'.
PLTYPE	-	Type of plotted data requested.
PNMAX	-	Maximum penetration (fractional) during a cycle.
PØ1	-	Sum of natural logarithms of slope of DPAVG versus T curve.

(continued)

TABLE 16 (continued)

PØ2	-	Sum of product of natural logarithms of slope of $\overline{P}$ versus and T.
QAVG	-	Intermediate in calculating average system flow, m/min.
QAVGN	-	Average system flow at the end of a cycle, m/min.
QSYSTM	-	Total system flow, m/min.
R	-	Porosity function in Happel theory for K_2.
RHOBLK	-	Bulk density of cake, g/cm^3.
RHOP	-	Discrete dust particle density, g/cm^3.
SE	-	Effective drag, input, $N\text{-}min/m^3$.
SFAB	-	Fabric drag, $N\text{-}min/m^3$.
SG1	-	Geometric standard deviation of size distribution of reference (measured) dust.
SG2	-	Geometric standard deviation of size distribution of inlet dust.
SIGN1	-	Slope of ΔP_{avg} versus time curve for last cycle modeled, $N\text{-}min/m^2$.
SMALQ	-	Specified constant total flow, input, m/min.
SOLID	-	Solidity, 1 - e (porosity).
SR	-	Residual drag, $N\text{-}min/m^3$, input.
SSYSTM	-	Total system drag, $N\text{-}min/m^3$.
SUM1	-	"SUMMARY".
SUM2	-	"SUMMARY".
SØB2	-	Square of specific surface of reference dust, μm^{-2}.
SØF2	-	Square of specific surface of inlet dust, μm^{-2}.
SØ2	-	Specific surface of inlet dust, μm^{-2}.
T	-	Cleaning cycle time, input, min.
TAVG	-	Average of previous and current continuous simulation times at which cycles end, min.
TCLEAN	-	Single bag cleaning time, input, min.
TCONT	-	Continuous simulation time, min.
TCORR	-	Correction for time interval splitting at the end of a cycle, min. Currently this is always set to zero.
TCZERO	-	Temperature at which inlet dust concentration was measured, ^{o}C, input.

(continued)

TABLE 16 (continued)

TDIF	-	Total cycle time, min.
TDSUM	-	Sum of all time increments constituting a full cycle, min.
TEMPK	-	Gas temperature, input, °K.
TIME	-	Dummy variable in STABLE through which the continuous simulation time is passed at the end of a cycle.
TLAG	-	Time between cleaning cycles, min, input.
TLAST	-	Continuous simulation time at the end of the previous cycle, min.
TMOD	-	Total cycle time = T + TLAG, reference time for cleaning cycle, min. If pressure controlled (i.e., TLAG unknown) TMOD is set to the continuous time, TCONT, at the end of the previous cycle.
TREF	-	Continuous simulation time at which point convergence was reached, min.
TSE	-	Temperature at which the effective residual drag, S_E, was measured, °C, input.
TSR	-	Temperature at which the residual drag, S_R, was measured, °C, input.
TTEST	-	TCONT in a modulo TMOD system; it is the time since the current or last cleaning cycle started, min.
TTEST1	-	1.0001 × N × TCLEAN, min.
TTEST2	-	0.9999 × N × TCLEAN, min.
TZKR	-	Temperature at which the initial drag versus loading slope, K_R, was measured, °C, input.
TZK2	-	Temperature at which the specific resistance coefficient, K_2, was measured, °C, input.
TØØ1	-	Sum of all TAVG, min.
TØØ2	-	Sum of all squares of TAVG, min^2.
T1	-	Sum of all TIME, min.
T2	-	Sum of all squares of TIME, min^2.
VRFLO	-	Reverse flow velocity based on a single compartment, input, m/min.
VRFLOW	-	Reverse flow used in calculations; set to zero if not cleaning, VRFLO if cleaning, m/min.
VZK2	-	Velocity at which specific resistance coefficient, K_2, was measured, m/min, input.

(continued)

TABLE 16 (continued)

WAREA	-	Weight per unit area added to an area in one time increment, g/m^2.
WCOMP	-	Intermediate in determining areas of highest loading, g/m^2.
WPRIME	-	Total minus residual fabric loading, g/m^2.
WR	-	Residual fabric loading, input, g/m^2, input.
WSTAR	-	Constant for nonlinear drag model, g/m^2.
WSTART	-	Absolute fabric loading at time zero, g/m^2.
WTOTAL	-	Dummy variable through which a loading can be passed to CLEAN for calculation of ACLN, g/m^2.
ZK2	-	Specific cake resistance, K_2, input, N-min/g-m.

ARRAYS

CAKE(IBAG)	-	Average fabric loading on bag # IBAG, g/m^2.
DP(I)	-	Average pressure drop at the end of cycle # I.
DPDP(NCMC)	-	Average pressure drop at the end of cycle # I.
IDUM(I)	-	Variable array index for output of intermediate results.
IZEROM(J)	-	Array in subroutine INITIAL used to initialize integer variables in MODEL.
IZEROS(J)	-	Array in subroutine INITIAL used to initialize integer variables in STABLE.
OLDTIM(IBAG)	-	Previous time for bag # IBAG, min.
P(IAREA)	-	Penetration for area # IAREA.
PDP(K3)*	-	System pressure drop, N/m^2.
PDQ(K3)*	-	System flow, m/min.
PPS(K3)*	-	System penetration.
PQ(K3,LMAX)*	-	Individual compartment flow, m/min.
PT(K3)*	-	Simulated time, min.
QAREA(IAREA)	-	Face velocity on area # IAREA, m/min.
QBAG(IBAG)	-	Average face velocity for bag # IBAG, m/min.
S(IAREA,IBAG)	-	drag of area # IAREA on bag # IBAG.
SBAG(IBAG)	-	Total drag of bag # IBAG.

(continued)

TABLE 16 (continued)

T(I)	-	Total cycle time at the end of cycle # I.
TIME(IBAG)	-	Time after cleaning for bag # IBAG.
WD(IAREA, IBAG)	-	Dust cake loading on area # IAREA on bag # IBAG.
ZEROM(J)	-	Array in subroutine INITAL used to initialize real variables in MODEL.
ZEROS(J)	-	Array in subroutine INITAL used to initialize real variables in STABLE

*These arrays contain only three entries. When data is output for subsequent processing by the plot routine SCRIBE, they are output in groups of three.

TABLE 17. VARIABLES AND ARRAYS USED IN BAGHOUSE SIMULATION PROGRAM — SUMMARY TABLE GENERATOR, STEP2

COMP	-	Used to generate table headings for compartment identification = 'COMP'.
DUMMY	-	Dummy variable
I	-	Index of DO loop.
IMAX	-	Maximum number of compartments for which individual flow velocities will be printed, no more than five.
IN	-	Input device for reading compartment flow velocities, logical units 10 to 14.
IPAGE	-	Page counter.
IPR	-	Output device. Currently has a value of 6.
IPRINT	-	Print flag. If IPRINT = 0, no summary table is generated. If IPRINT = 1, a table is generated. Location is the first byte of the first record on unit #8, the pressure versus time file.
J	-	Index of DO loop.
JMAX	-	IMAX + 9, value of the logical unit number for the last individual flow file to be printed.
LINES	-	Counter for number of lines printed.
HEAD(8)	-	REAL*8 variable containing the title.
INDFLO(IBAG,J)*	-	Flow velocity through compartment # IBAG, data point # J on any particular record.
PENET(J)*	-	Average system penetration at time = TIME(J), data point # J on a record.
PRESSR(J)*	-	Average system pressure loss at time = TIME(J), data point # J on a record.
TIME(J)*	-	Time at data point # J on a record.

*The data on the files are arranged in groups of three.

APPENDIX C

EXAMPLES OF DATA INPUT FORMS, METHODS OF DATA ENTRY AND DATA PRINTOUTS FOR VARIOUS FILTRATION SIMULATIONS

Figures 15 through 21 and Tables 18 through 33 have been prepared to demonstrate how the filtration model input data are handled from the point where the necessary information is entered in a standard format on the input forms shown in Figures 15, 16, 20 and 21 to the ultimate data printouts for selected model applications. Sample printouts are shown in Tables 18 through 33 for input data reiterations, error messages, calculations performed within the program, and excerpted tabulations of data printouts for sample data inputs.

The blank spaces appearing on the data input forms may indicate the following situations:

- No data entry is available or no data entry is required for the indicated variables. For example, no limiting pressure loss, P_L should be specified for a system to be operated with continuous cleaning (Figure 15).
- The variable of interest may actually possess a true zero value, e.g., the time between cleaning for which the model user may enter a zero or leave blank. In the latter case, the model assumes a default value of zero minutes which is consistent with continuous cleaning provided that P_L is not specified (Figure 15).
- A zero or blank value of K_2 indicates that no value is available. Hence, entries for dust size and density parameters are required so that K_2 can be computed within the program (Figure 15).
- Zero or blank values for dust size and density properties indicate that these data are not needed because K_2 (along with the temperature and velocity associated with its measurement condition) are available (Figure 16). If the measuring

conditions were 25°C and 0.61 m/min, K_2 alone is sufficient for entry because these specific reference conditions are automatically processed by the program (Figure 21).

- If a value for K_2 is not entered, a zero or blank value for S_E or W_R indicates that no data are available and that the program will automatically assign default values representing best estimates for these terms.

Figure 15 shows a completed data input form for a continuously cleaned filter system for which K_2 is to be estimated within the model program and for the rare occasion where the cleaning parameter, a_c, has been defined beforehand.

Table 18 shows a summary printout of the input data previously entered on the input form with appropriate units so that the model user can be assured that the simulation model will operate upon the correct data and present it in the desired form. Note that assumed or default values contained within the program will also be printed with the input data summary when actual values are not available for items such as S_E and W_R or a blank value has been indicated for reverse flow velocity, V_r.

However, those terms requiring calculation within the program or not required as data inputs for the specific modeling conditions are not shown in Table 18. In lieu of printing out a zero value "time between cleaning cycles," the equivalent expression CONTINUOUS CLEANING is printed.

The printout shown in Table 19, Diagnostic Messages, indicates that there are no errors in the input data with respect to the permissible numerical ranges for input data, redundancies or data emissions which would automatically stop any further program operations.

Table 20 lists the numerical values for those filtration parameters actually computed within the program so that model user can appraise their

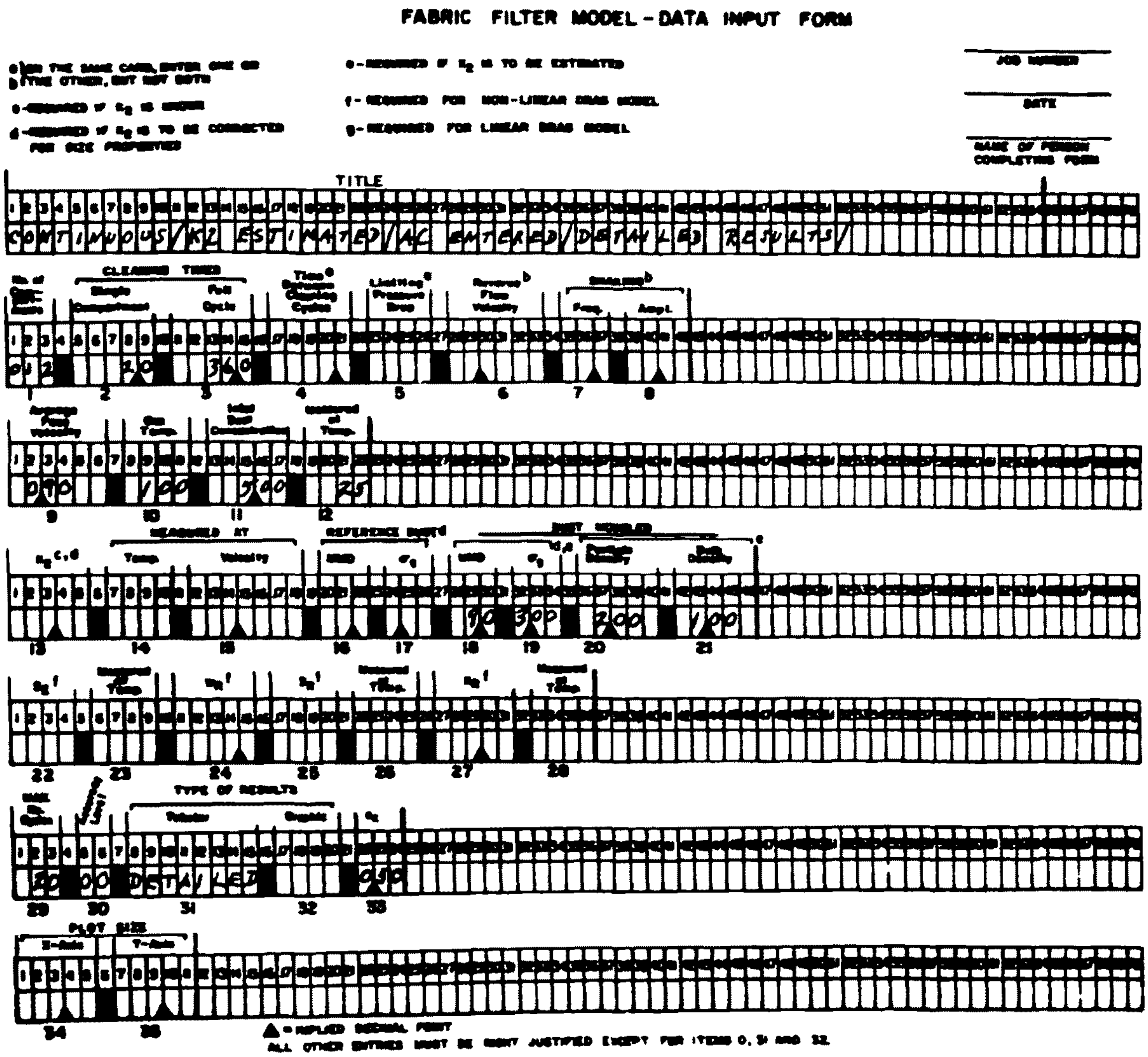

Figure 15. Fabric filter model - data input form for Example 1.

TABLE 18. SUMMARY OF INPUT DATA FOR BAGHOUSE ANALYSIS (REFERENCE FIGURE 15)

```
*******************************************************************************

SUMMARY OF INPUT DATA FOR BAGHOUSE ANALYSIS

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

CONTINUOUS/K2 ESTIMATED/AC ENTERED/DETAILED RESULTS/


BASIC DESIGN DATA
     NUMBER OF COMPARTMENTS           12
     COMPARTMENT CLEANING TIME         2.0          MINUTES
       (OFF LINE TIME)
     CLEANING CYCLE TIME              36.0          MINUTES
     CONTINUOUSLY CLEANED SYSTEM
     REVERSE FLOW VELOCITY            0.0           M/MIN

OPERATING DATA
     AVERAGE FACE VELOCITY            0.9000        M/MIN
     GAS TEMPERATURE                  100.          DEGREES CENTIGRADE
     INLET DUST CONCENTRATION          5.00         G/M3
          MEASURED AT                  25.          DEGREES CENTIGRADE

FABRIC AND DUST PROPERTIES

     SPECIFIC RESISTANCE, K2 ESTIMATED FROM
          MASS MEDIAN DIAMETER        9.0           MICRONS
          STANDARD DEVIATION         3.00
          PARTICLE DENSITY            2.000         G/CM3
          BULK DENSITY                1.000         G/CM3

     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      DETAILED /

     FRACTIONAL AREA CLEANED, AC    0.50
```

TABLE 19. DIAGNOSTIC MESSAGES (REFERENCE FIGURE 15)

```
DIAGNOSTIC MESSAGES


THERE ARE NO ERRORS IN THE INPUT DATA
```

TABLE 20. INPUT VARIABLES CALCULATED BY PROGRAM (REFERENCE FIGURE 15)

```
CALCULATED VALUES


INLET DUST CONCENTRATION                  3.99          G/M3
CORRECTED TO OPERATING TEMPERATURE

FABRIC AND DUST CAKE PROPERTIES CORRECTED FOR GAS VISCOSITY

     SPECIFIC CAKE RESISTANCE, K2         1.66          N-MIN/G-M
     EFFECTIVE DRAG, SE                  497.           N-MIN/M3

FRACTIONAL AREA CLEANED, AC             0.50

TIME INCREMENT                           0.75          MINUTES

SYSTEM CONSTANT W*                        0.0           G/M2
```

TABLE 21. AVERAGE AND MAXIMUM PENETRATION AND PRESSURE DROP VALUES FOR FIGURE 15 DATA INPUTS

FOR 36.00 MINUTES OPERATION,	CYCLE NUMBER 6		
		AVERAGE PENETRATION=	5.06E-03
		AVERAGE PRESSURE DROP=	713.34 N/M2
		AVERAGE SYSTEM FLOW=	0.9000 M/MIN
		MAXIMUM PENETRATION=	8.49E-03
		MAXIMUM PRESSURE DROP=	750.71 N/M2
FOR 36.00 MINUTES OPERATION,	CYCLE NUMBER 7		
		AVERAGE PENETRATION=	5.06E-03
		AVERAGE PRESSURE DROP=	713.30 N/M2
		AVERAGE SYSTEM FLOW=	0.9000 M/MIN
		MAXIMUM PENETRATION=	8.49E-03
		MAXIMUM PRESSURE DROP=	750.62 N/M2
FOR 36.00 MINUTES OPERATION,	CYCLE NUMBER 8		
		AVERAGE PENETRATION=	5.06E-03
		AVERAGE PRESSURE DROP=	713.29 N/M2
		AVERAGE SYSTEM FLOW=	0.9000 M/MIN
		MAXIMUM PENETRATION=	8.49E-03
		MAXIMUM PRESSURE DROP=	750.60 N/M2

TABLE 22. EXCERPTED DATA FOR SYSTEM DETAILED PERFORMANCE CHARACTERISTICS AFTER 180 MINUTES OF SIMULATED FILTRATION (REFERENCE FIGURE 15)

****

RESULTS OF BAGHOUSE ANALYSIS

****

CONTINUOUS/K2 ESTIMATED/AC ENTERED/DETAILED RESULTS/

BAG-DRAG=	AREA 1	AREA 2	SBAG
1	8.17E+02	5.36E+02	6.48E+02
2	8.35E+02	5.72E+02	6.79E+02
3	8.52E+02	6.04E+02	7.07E+02
4	8.68E+02	6.34E+02	7.33E+02
5	8.84E+02	6.61E+02	7.57E+02
6	9.00E+02	6.86E+02	7.79E+02
7	9.15E+02	7.10E+02	7.99E+02
8	9.29E+02	7.32E+02	8.19E+02
9	9.44E+02	7.54E+02	8.38E+02
10	9.57E+02	7.74E+02	8.56E+02
11	9.71E+02	7.93E+02	8.73E+02
12	8.00E+02	4.97E+02	6.13E+02
BAG-FLOW=	AREA 1	AREA 2	QBAG
1	8.25E-01	1.26E+00	1.04E+00
2	8.08E-01	1.18E+00	9.93E-01
3	7.92E-01	1.12E+00	9.54E-01
4	7.77E-01	1.06E+00	9.20E-01
5	7.63E-01	1.02E+00	8.92E-01
6	7.50E-01	9.83E-01	8.66E-01
7	7.37E-01	9.50E-01	8.44E-01
8	7.26E-01	9.21E-01	8.23E-01
9	7.15E-01	8.95E-01	8.05E-01
10	7.05E-01	8.72E-01	7.88E-01
11	6.95E-01	8.51E-01	7.73E-01
12	8.43E-01	1.36E+00	1.10E+00

T= 180.0 DELP= 674.6 DELQ= .9000 CONCENTRATION= .3393E-01 WEIGHT DUMPED= .0

	BAG 1	BAG 2	BAG 3	BAG 4	BAG 5	BAG 6	BAG 7	BAG 8	BAG 9	BAG 10
T=	3.01	6.01	9.01	12.01	15.01	18.01	21.01	24.01	27.01	30.01
CAKE	1.3607E+02	1.4885E+02	1.6118E+02	1.7306E+02	1.8456E+02	1.9572E+02	2.0659E+02	2.1719E+02	2.2755E+02	2.3769E+02
SBAG	0.6476E+03	0.6790E+03	0.7072E+03	0.7328E+03	0.7566E+03	0.7787E+03	0.7995E+03	0.8192E+03	0.8379E+03	0.8559E+03
QBAG	0.1042E+01	0.9935E+00	0.9539E+00	0.9205E+00	0.8916E+00	0.8663E+00	0.8437E+00	0.8234E+00	0.8050E+00	0.7881E+00

	BAG 11	BAG 12	BAG
T=	33.01	0.01	
CAKE	2.4763E+02	1.2302E+02	
SBAG	0.8731E+03	0.6133E+03	
QBAG	0.7726E+00	0.1100E+01	

TABLE 23. SYSTEM PRESSURE DROP, SYSTEM PENETRATION AND COMPARTMENT FLOW DISTRIBUTION VERSUS TIME (REFERENCE FIGURE 15)

SUMMARY TABLE : CONTINUOUS/K2 ESTIMATED/AC ENTERED/DETAILED RESULTS/ PAGE 1

TIME (MIN)	PRESSURE DROP (N/M2)	FRACTIONAL PENETRATION	INDIVIDUAL COMPARTMENT FLOWS (M/MIN) COMP.1	COMP.2	COMP.3	COMP.4	COMP.5
0.01	675.	8.493E-03	1.0416	0.9935	0.9539	0.9204	0.8916
0.75	669.	6.034E-03	1.0316	0.9877	0.9512	0.9201	0.8930
1.50	728.	4.931E-03	1.1092	1.0634	1.0250	0.9922	0.9635
2.25	744.	3.653E-03	1.1095	1.0637	1.0254	0.9924	0.9636
3.00	751.	2.731E-03	1.1058	1.0617	1.0246	0.9926	0.9645
3.01	675.	8.492E-03	0.9935	0.9539	0.9204	0.8916	0.8663
3.75	669.	6.033E-03	0.9877	0.9511	0.9201	0.8930	0.8692
4.50	728.	4.931E-03	1.0634	1.0250	0.9922	0.9635	0.9380
5.25	744.	3.653E-03	1.0637	1.0254	0.9924	0.9636	0.9380
6.00	751.	2.731E-03	1.0617	1.0246	0.9926	0.9645	0.9395
6.01	675.	8.492E-03	0.9539	0.9204	0.8916	0.8663	0.8437
6.75	669.	6.033E-03	0.9511	0.9201	0.8930	0.8692	0.8478
7.50	728.	4.931E-03	1.0250	0.9922	0.9635	0.9380	0.9152
8.25	744.	3.653E-03	1.0254	0.9924	0.9636	0.9380	0.9150
9.00	751.	2.731E-03	1.0246	0.9926	0.9645	0.9395	0.9170
9.01	675.	8.492E-03	0.9204	0.8916	0.8663	0.8437	0.8235
9.75	669.	6.033E-03	0.9200	0.8930	0.8692	0.8478	0.8285
10.50	728.	4.931E-03	0.9922	0.9635	0.9380	0.9152	0.8946
11.25	744.	3.653E-03	0.9924	0.9636	0.9380	0.9150	0.8942
12.00	751.	2.731E-03	0.9926	0.9645	0.9395	0.9170	0.8966
12.01	675.	8.492E-03	0.8916	0.8663	0.8438	0.8235	0.8050
12.75	669.	6.033E-03	0.8930	0.8692	0.8478	0.8285	0.8109
13.50	728.	4.931E-03	0.9635	0.9380	0.9152	0.8946	0.8757
14.25	744.	3.653E-03	0.9636	0.9380	0.9150	0.8942	0.8752
15.00	751.	2.731E-03	0.9645	0.9395	0.9170	0.8966	0.8779
15.01	674.	8.492E-03	0.8663	0.8438	0.8235	0.8051	0.7882
15.75	669.	6.033E-03	0.8692	0.8478	0.8285	0.8109	0.7948
16.50	728.	4.931E-03	0.9380	0.9152	0.8946	0.8757	0.8583
17.25	744.	3.653E-03	0.9380	0.9150	0.8942	0.8752	0.8577
18.00	751.	2.731E-03	0.9395	0.9170	0.8966	0.8779	0.8607
18.01	674.	8.492E-03	0.8438	0.8235	0.8051	0.7882	0.7727
18.75	669.	6.033E-03	0.8478	0.8285	0.8109	0.7948	0.7799
19.50	728.	4.931E-03	0.9152	0.8946	0.8757	0.8583	0.0000
20.25	744.	3.653E-03	0.9150	0.8942	0.8752	0.8577	0.0000
21.00	751.	2.731E-03	0.9170	0.8966	0.8779	0.8607	0.0000
21.01	674.	8.492E-03	0.8235	0.8051	0.7882	0.7727	1.0997
21.75	669.	6.033E-03	0.8285	0.8109	0.7948	0.7799	1.0854
22.50	728.	4.931E-03	0.8946	0.8757	0.8583	0.0000	1.1649
23.25	744.	3.653E-03	0.8942	0.8752	0.8577	0.0000	1.1653
24.00	751.	2.731E-03	0.8966	0.8779	0.8607	0.0000	1.1593
24.01	674.	8.492E-03	0.8051	0.7882	0.7727	1.0997	1.0415
24.75	669.	6.033E-03	0.8110	0.7948	0.7799	1.0854	1.0316
25.50	728.	4.931E-03	0.8757	0.8583	0.0000	1.1649	1.1091
26.25	744.	3.653E-03	0.8752	0.8577	0.0000	1.1653	1.1095
27.00	751.	2.731E-03	0.8779	0.8607	0.0000	1.1593	1.1057
27.01	674.	8.492E-03	0.7882	0.7727	1.0997	1.0415	0.9934
27.75	669.	6.033E-03	0.7948	0.7799	1.0854	1.0316	0.9876
28.50	728.	4.931E-03	0.8583	0.0000	1.1649	1.1091	1.0633
29.25	744.	3.653E-03	0.8577	0.0000	1.1653	1.1094	1.0637
30.00	751.	2.731E-03	0.8607	0.0000	1.1593	1.1057	1.0617
30.01	674.	8.492E-03	0.7727	1.0997	1.0415	0.9934	0.9538

TABLE 23 (continued)

SUMMARY TABLE : CONTINUOUS/N2 ESTIMATED/AC ENTERED/DETAILED RESULTS/ PAGE 2

TIME (MIN)	PRESSURE DROP (N/M2)	FRACTIONAL PENETRATION	INDIVIDUAL COMPARTMENT FLOWS (M/MIN) COMP.1	COMP.2	COMP.3	COMP.4	COMP.5
30.75	669.	6.033E-03	0.7799	1.0854	1.0316	0.9876	0.9511
31.50	728.	4.931E-03	0.0000	1.1649	1.1091	1.0633	1.0250
32.25	744.	3.653E-03	0.0000	1.1653	1.1094	1.0637	1.0253
33.00	751.	2.731E-03	0.0000	1.1593	1.1057	1.0617	1.0246
33.01	674.	8.492E-03	1.0997	1.0415	0.9934	0.9538	0.9204
33.75	669.	6.033E-03	1.0854	1.0316	0.9876	0.9511	0.9200
34.50	728.	4.931E-03	1.1649	1.1091	1.0633	1.0250	0.9922
35.25	744.	3.653E-03	1.1653	1.1094	1.0637	1.0253	0.9924
36.00	751.	2.731E-03	1.1593	1.1057	1.0617	1.0246	0.9926
36.01	674.	8.492E-03	1.0415	0.9934	0.9538	0.9204	0.8916
36.75	669.	6.033E-03	1.0316	0.9876	0.9511	0.9200	0.8930
37.50	728.	4.931E-03	1.1091	1.0633	1.0250	0.9922	0.9635
38.25	744.	3.653E-03	1.1094	1.0637	1.0253	0.9924	0.9636
39.00	751.	2.731E-03	1.1057	1.0617	1.0246	0.9926	0.9645
39.01	674.	8.492E-03	0.9934	0.9538	0.9204	0.8916	0.8663
39.75	669.	6.033E-03	0.9876	0.9511	0.9200	0.8930	0.8692
40.50	728.	4.931E-03	1.0633	1.0250	0.9922	0.9635	0.9381
41.25	744.	3.653E-03	1.0637	1.0253	0.9924	0.9636	0.9380
42.00	751.	2.731E-03	1.0617	1.0246	0.9926	0.9645	0.9395
42.01	674.	8.492E-03	0.9538	0.9204	0.8916	0.8663	0.8438
42.75	669.	6.033E-03	0.9511	0.9200	0.8930	0.8692	0.8478
43.50	728.	4.931E-03	1.0250	0.9922	0.9635	0.9381	0.9153
44.25	744.	3.653E-03	1.0253	0.9924	0.9636	0.9380	0.9151
45.00	751.	2.731E-03	1.0246	0.9926	0.9645	0.9395	0.9170
45.01	674.	8.492E-03	0.9204	0.8916	0.8663	0.8438	0.8235
45.75	669.	6.033E-03	0.9200	0.8930	0.8692	0.8478	0.8285
46.50	728.	4.931E-03	0.9922	0.9635	0.9381	0.9153	0.8946
47.25	744.	3.653E-03	0.9924	0.9636	0.9380	0.9151	0.8942
48.00	751.	2.731E-03	0.9926	0.9645	0.9395	0.9170	0.8966
48.01	674.	8.492E-03	0.8916	0.8663	0.8438	0.8235	0.8051
48.75	669.	6.033E-03	0.8930	0.8692	0.8478	0.8285	0.8110
49.50	728.	4.931E-03	0.9635	0.9381	0.9153	0.8946	0.8757
50.25	744.	3.653E-03	0.9636	0.9380	0.9151	0.8942	0.8752
51.00	751.	2.731E-03	0.9645	0.9395	0.9170	0.8966	0.8779
51.01	674.	8.492E-03	0.8663	0.8438	0.8235	0.8051	0.7882
51.75	669.	6.033E-03	0.8692	0.8478	0.8285	0.8110	0.7948
52.50	728.	4.931E-03	0.9381	0.9153	0.8946	0.8757	0.8584
53.25	744.	3.653E-03	0.9380	0.9151	0.8942	0.8752	0.8578
54.00	751.	2.731E-03	0.9395	0.9170	0.8966	0.8779	0.8607
54.01	674.	8.492E-03	0.8438	0.8235	0.8051	0.7882	0.7727
54.75	669.	6.033E-03	0.8478	0.8285	0.8110	0.7948	0.7799
55.50	728.	4.931E-03	0.9153	0.8946	0.8757	0.8584	0.0000
56.25	744.	3.653E-03	0.9151	0.8942	0.8752	0.8578	0.0000
57.00	751.	2.731E-03	0.9170	0.8966	0.8779	0.8607	0.0000
57.01	674.	8.492E-03	0.8235	0.8051	0.7882	0.7727	1.0997
57.75	669.	6.033E-03	0.8285	0.8110	0.7948	0.7799	1.0854
58.50	728.	4.931E-03	0.8946	0.8757	0.8584	0.0000	1.1649
59.25	744.	3.653E-03	0.8942	0.8752	0.8578	0.0000	1.1653
60.00	751.	2.731E-03	0.8966	0.8779	0.8607	0.0000	1.1593
60.01	674.	8.492E-03	0.8051	0.7882	0.7727	1.0997	1.0415
60.75	669.	6.033E-03	0.8110	0.7948	0.7800	1.0854	1.0315

TABLE 23 (continued)

SUMMARY TABLE 1 CONTINUOUS/K2 ESTIMATED/AC ENTERED/DETAILED RESULTS/ PAGE 3

TIME (MIN)	PRESSURE DROP (N/M2)	FRACTIONAL PENETRATION	INDIVIDUAL COMPARTMENT FLOWS (M/MIN) COMP.1	COMP.2	COMP.3	COMP.4	COMP.5
61.50	728.	4.931E-03	0.8757	0.8584	0.0000	1.1649	1.1091
62.25	744.	3.653E-03	0.8752	0.8578	0.0000	1.1653	1.1094
63.00	751.	2.731E-03	0.8779	0.8607	0.0000	1.1593	1.1057
63.01	674.	8.492E-03	0.7882	0.7727	1.0997	1.0415	0.9934
63.75	669.	6.033E-03	0.7948	0.7800	1.0854	1.0315	0.9876
64.50	728.	4.931E-03	0.8584	0.0000	1.1649	1.1091	1.0633
65.25	744.	3.653E-03	0.8578	0.0000	1.1653	1.1094	1.0637
66.00	751.	2.731E-03	0.8607	0.0000	1.1593	1.1057	1.0617
66.01	674.	8.492E-03	0.7727	1.0997	1.0415	0.9934	0.9538
66.75	669.	6.033E-03	0.7800	1.0854	1.0315	0.9876	0.9511
67.50	728.	4.931E-03	0.0000	1.1649	1.1091	1.0633	1.0250
68.25	744.	3.653E-03	0.0000	1.1653	1.1094	1.0637	1.0253
69.00	751.	2.731E-03	0.0000	1.1593	1.1057	1.0617	1.0246
69.01	674.	8.492E-03	1.0997	1.0415	0.9934	0.9538	0.9204
69.75	669.	6.033E-03	1.0854	1.0315	0.9876	0.9511	0.9200
70.50	728.	4.931E-03	1.1649	1.1091	1.0633	1.0250	0.9922
71.25	744.	3.653E-03	1.1653	1.1094	1.0637	1.0253	0.9924
72.00	751.	2.731E-03	1.1593	1.1057	1.0617	1.0246	0.9926
72.01	674.	8.492E-03	1.0415	0.9934	0.9538	0.9204	0.8916
72.75	669.	6.033E-03	1.0315	0.9876	0.9511	0.9200	0.8930
73.50	728.	4.931E-03	1.1091	1.0633	1.0250	0.9922	0.9635
74.25	744.	3.653E-03	1.1094	1.0637	1.0253	0.9924	0.9636
75.00	751.	2.731E-03	1.1057	1.0617	1.0246	0.9926	0.9645
75.01	674.	8.492E-03	0.9934	0.9538	0.9204	0.8916	0.8663
75.75	669.	6.033E-03	0.9876	0.9511	0.9200	0.8930	0.8692
76.50	728.	4.931E-03	1.0633	1.0250	0.9922	0.9635	0.9381
77.25	744.	3.653E-03	1.0637	1.0253	0.9924	0.9636	0.9380
78.00	751.	2.731E-03	1.0617	1.0246	0.9926	0.9645	0.9395
78.01	674.	8.492E-03	0.9538	0.9204	0.8916	0.8663	0.8438
78.75	669.	6.033E-03	0.9511	0.9200	0.8930	0.8692	0.8478
79.50	728.	4.931E-03	1.0250	0.9922	0.9635	0.9381	0.9153
80.25	744.	3.653E-03	1.0253	0.9924	0.9636	0.9380	0.9151
81.00	751.	2.731E-03	1.0246	0.9926	0.9645	0.9395	0.9170
81.01	674.	8.492E-03	0.9204	0.8916	0.8663	0.8438	0.8235
81.75	669.	6.033E-03	0.9200	0.8930	0.8692	0.8478	0.8285
82.50	728.	4.931E-03	0.9922	0.9635	0.9381	0.9153	0.8946
83.25	744.	3.653E-03	0.9924	0.9636	0.9380	0.9151	0.8942
84.00	751.	2.731E-03	0.9926	0.9645	0.9395	0.9170	0.8966
84.01	674.	8.492E-03	0.8916	0.8663	0.8438	0.8235	0.8051
84.75	669.	6.033E-03	0.8930	0.8692	0.8478	0.8285	0.8110
85.50	728.	4.931E-03	0.9635	0.9381	0.9153	0.8946	0.8757
86.25	744.	3.653E-03	0.9636	0.9380	0.9151	0.8942	0.8752
87.00	751.	2.731E-03	0.9645	0.9395	0.9170	0.8966	0.8779
87.01	674.	8.492E-03	0.8663	0.8438	0.8235	0.8051	0.7882
87.75	669.	6.033E-03	0.8692	0.8478	0.8285	0.8110	0.7948
88.50	728.	4.931E-03	0.9381	0.9153	0.8946	0.8757	0.8584
89.25	744.	3.653E-03	0.9380	0.9151	0.8942	0.8752	0.8578
90.00	751.	2.731E-03	0.9395	0.9170	0.8966	0.8779	0.8607
90.01	674.	8.492E-03	0.8438	0.8235	0.8051	0.7882	0.7727
90.75	669.	6.033E-03	0.8478	0.8285	0.8110	0.7948	0.7800
91.50	728.	4.931E-03	0.9153	0.8946	0.8757	0.8584	0.0000

TABLE 23 (continued)

SUMMARY TABLE : CONTINUOUS/M2 ESTIMATED/AC ENTERED/DETAILED RESULTS/ PAGE 4

TIME (MIN)	PRESSURE DROP (N/M2)	FRACTIONAL PENETRATION	INDIVIDUAL COMPARTMENT FLOWS (M/MIN) COMP.1	COMP.2	COMP.3	COMP.4	COMP.5
92.25	744.	3.653E-03	0.9151	0.8942	0.8752	0.8578	0.0000
93.00	751.	2.731E-03	0.9170	0.8966	0.8779	0.8607	0.0000
93.01	674.	8.492E-03	0.8235	0.8051	0.7882	0.7727	1.0997
93.75	669.	6.033E-03	0.8285	0.8110	0.7948	0.7800	1.0854
94.50	728.	4.931E-03	0.8946	0.8757	0.8584	0.0000	1.1649
95.25	744.	3.653E-03	0.8942	0.8752	0.8578	0.0000	1.1653
96.00	751.	2.731E-03	0.8966	0.8779	0.8607	0.0000	1.1593
96.01	674.	8.492E-03	0.8051	0.7882	0.7727	1.0997	1.0415
96.75	669.	6.033E-03	0.8110	0.7948	0.7800	1.0854	1.0315
97.50	728.	4.931E-03	0.8757	0.8584	0.0000	1.1649	1.1091
98.25	744.	3.653E-03	0.8752	0.8578	0.0000	1.1653	1.1094
99.00	751.	2.731E-03	0.8779	0.8607	0.0000	1.1593	1.1057
99.01	674.	8.492E-03	0.7882	0.7727	1.0997	1.0415	0.9934
99.75	669.	6.033E-03	0.7948	0.7800	1.0854	1.0315	0.9876
100.50	728.	4.931E-03	0.8584	0.0000	1.1649	1.1091	1.0633
101.25	744.	3.653E-03	0.8578	0.0000	1.1653	1.1094	1.0637
102.00	751.	2.731E-03	0.8607	0.0000	1.1593	1.1057	1.0617
102.01	674.	8.492E-03	0.7727	1.0997	1.0415	0.9934	0.9538
102.75	669.	6.033E-03	0.7800	1.0854	1.0315	0.9876	0.9511
103.50	728.	4.931E-03	0.0000	1.1649	1.1091	1.0633	1.0250
104.25	744.	3.653E-03	0.0000	1.1653	1.1094	1.0637	1.0253
105.00	751.	2.731E-03	0.0000	1.1593	1.1057	1.0617	1.0246
105.01	674.	8.492E-03	1.0997	1.0415	0.9934	0.9538	0.9204
105.75	669.	6.033E-03	1.0854	1.0315	0.9876	0.9511	0.9200
106.50	728.	4.931E-03	1.1649	1.1091	1.0633	1.0250	0.9922
107.25	744.	3.653E-03	1.1653	1.1094	1.0637	1.0253	0.9924
108.00	751.	2.731E-03	1.1593	1.1057	1.0617	1.0246	0.9926

reasonableness. The only exception is the printout for a_c which will always appear regardless of whether computed within the program or an original data input.

Tables 21 through 23 indicate the tabular printouts received when DETAILED results are requested.

Table 21 provides a printout of average and maximum values over cycles 6 through 8 for dust penetration and filter pressure drop as well as showing the average system flow (or air-to-cloth) ratio. According to checks performed within the simulation model, approximate steady state operations have been reached during cycles 6 through 8, thus eliminating the need for further cycling.

Table 22 represents a detailed summary of filter system performance parameters after 180 minutes of simulated filtration. The instantaneous gas flow and drag values for both the individual bag regions (areas 1 and 2) and the entire bag (or compartment) are indicated for each of the 12 compartments making up the filter systems. Also shown are the times that each compartment (bag) has filtered after 180 minutes of system operation along with the corresponding fabric dust holding.

Over the 180 minutes required to execute filtration cycles 6 through 8 (Table 21) and the corresponding time interval 0.01 through 180 minutes indicated in Table 23, a total of 144 separate tabulations similar to Table 22 would be printed for each 0.75 minute time increment. It is emphasized that this capability, which has been designed within the model for research purposes only, is not called upon for routine model applications.

Table 23 provides a point by point tabulation of overall filter system pressure loss and dust penetration for the 144 iteration periods cited previously. In addition, gas flow distributance for 5 of the 12 compartments are indicated for each of the iteration periods. It should be noted that the gas flow distribution data are only printed when a DETAILED printout is requested for research purposes.

For those cases requiring a less rigorous data reporting, the specification of SUMMARY printout will provide only the first three columns of Table C-6.

Figure 16 shows data inputs for a filter system to be cleaned on the basis of pressure control as indicated by the data input of 1000 N/m^2 for P_L. In this case, a zero or blank entry for "time between cleaning" merely indicates that the true value is unknown and will be determined subsequently from the final program outputs. Only six operating cycles were chosen so that the printout could be demonstrated for the nonsteady state or nonconvergence condition.

Table 25 shows a printout of the calculated and/or corrected values for key input variables used in the modeling process for the Figure 16 data.

Tables 26 and 27, and Figures 17 through 19 represent the model output received when SUMMARY PLOT is entered (Figure 16). Note that the message "convergence to steady state not reached after 3 cycles" appears on Table 26. Therefore, there might be some risk in accepting the average and maximum values for pressure drop and dust penetration shown for the six cycle data summary and the Table 27 tabulation of overall system pressure drop and fractional penetration versus time over the 40.5 minute period starting at the end of the third filtration cycle.

In Figure 17, average system pressure loss is indicated for three consecutive filter cycles for a five compartment system. The pressure spikes (positive and negative) depict the system pressure loss immediately before and after the cleaning of each compartment. The smooth concave downward regions

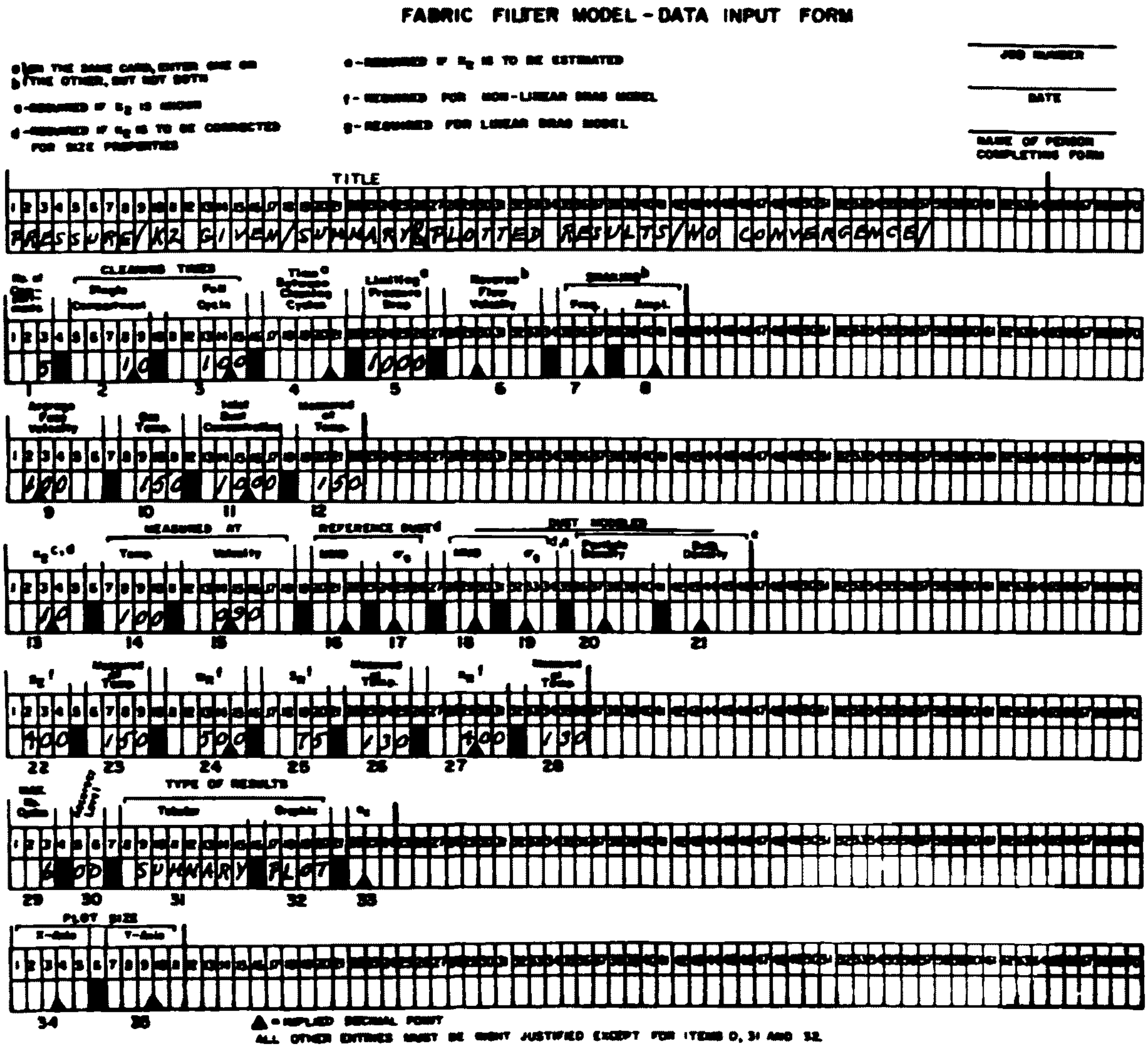

Figure 16. Fabric filter model - data input form for Example 2.

TABLE 24. SUMMARY OF INPUT DATA FOR BAGHOUSE ANALYSIS (REFERENCE FIGURE 16)

```
*****************************************************************************

SUMMARY OF INPUT DATA FOR BAGHOUSE ANALYSIS

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

PRESSURE/K2 GIVEN/SUMMARY&PLOTTED RESULTS/NO CONVERGENCE/

BASIC DESIGN DATA
     NUMBER OF COMPARTMENTS              5
     COMPARTMENT CLEANING TIME            1.0          MINUTES
       (OFF LINE TIME)
     CLEANING CYCLE TIME                 10.0          MINUTES
     LIMITING PRESSURE DROP            1000.           N/M2
     REVERSE FLOW VELOCITY               0.0           M/MIN

OPERATING DATA
     AVERAGE FACE VELOCITY              1.0000         M/MIN
     GAS TEMPERATURE                    150.           DEGREES CENTIGRADE
     INLET DUST CONCENTRATION           10.00          G/M3
          MEASURED AT                   150.           DEGREES CENTIGRADE

FABRIC AND DUST PROPERTIES

     SPECIFIC RESISTANCE, K2             1.00          N-MIN/G-M
          MEASURED AT                   100.           DEGREES CENTIGRADE
                                        0.9000         M/MIN
     EFFECTIVE RESIDUAL DRAG, SE        400.           N-MIN/M3
          MEASURED AT                   150.           DEGREES CENTIGRADE
     RESIDUAL LOADING, WR                50.0          G/M2
     RESIDUAL DRAG, SR                   75.           N-MIN/M3
          MEASURED AT                   130.           DEGREES CENTIGRADE
     INITIAL SLOPE, KR                   4.00          N-MIN/G-M
          MEASURED AT                   130.           DEGREES CENTIGRADE


SPECIAL PROGRAM INSTRUCTIONS
     MAX NUMBER OF CYCLES MODELED        6
     ACCURACY LEVEL                     0
     TYPE OF RESULTS REQUESTED          SUMMARY / PLOT
```

TABLE 25. INPUT VARIABLES CALCULATED BY PROGRAM (Reference Figure 16)

CALCULATED VALUES

INLET DUST CONCENTRATION CORRECTED TO OPERATING TEMPERATURE	10.00	G/M3
FABRIC AND DUST CAKE PROPERTIES CORRECTED FOR GAS VISCOSITY		
SPECIFIC CAKE RESISTANCE, K2	0.90	N-MIN/G-M
INITIAL SLOPE, KR	0.14	N-MIN/G-M
EFFECTIVE DRAG, SE	445.	N-MIN/M3
RESIDUAL DRAG, SR	78.	N-MIN/M3
FRACTIONAL AREA CLEANED, AC	0.14	
TIME INCREMENT	0.50	MINUTES
SYSTEM CONSTANT KA	113.4	G/M2

TABLE 26. RESULTS OF BAGHOUSE ANALYSIS (REFERENCE FIGURE 16)

```
****************************************************************************

RESULTS OF BAGHOUSE ANALYSIS

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

PRESSURE/K2 GIVEN/SUMMARY&PLOTTED RESULTS/NO CONVERGENCE/


**CONVERGENCE TO STEADY STATE NOT REACHED AFTER       3     CYCLES ***


OR      13.50 MINUTES OPERATION,  CYCLE NUMBER    4
                                            AVERAGE PENETRATION=          6.73E-03
                                            AVERAGE PRESSURE DROP=          1064.60 N/M2
                                            AVERAGE SYSTEM FLOW=            1.0000 M/MIN
                                            MAXIMUM PENETRATION=          3.00E-02
                                            MAXIMUM PRESSURE DROP=          1389.92 N/M2

OR      13.50 MINUTES OPERATION,  CYCLE NUMBER    5
                                            AVERAGE PENETRATION=          6.72E-03
                                            AVERAGE PRESSURE DROP=          1062.97 N/M2
                                            AVERAGE SYSTEM FLOW=            1.0000 M/MIN
                                            MAXIMUM PENETRATION=          3.00E-02
                                            MAXIMUM PRESSURE DROP=          1391.00 N/M2

FOR     14.00 MINUTES OPERATION,  CYCLE NUMBER    6
                                            AVERAGE PENETRATION=          6.49E-03
                                            AVERAGE PRESSURE DROP=          1054.00 N/M2
                                            AVERAGE SYSTEM FLOW=            1.0000 M/MIN
                                            MAXIMUM PENETRATION=          2.99E-02
                                            MAXIMUM PRESSURE DROP=          1383.77 N/M2
```

TABLE 27. PRESSURE DROP AND FRACTIONAL PENETRATION VERSUS TIME (REFERENCE FIGURE 16)

SUMMARY TABLE 1 PRESSURE/K2 GIVEN/SUMMARY&PLOTTED RESULTS/NO CONVERGENCE/

TIME (MIN)	PRESSURE DROP (N/M2)	FRACTIONAL PENETRATION
0.01	1020.	1.759E-03
0.50	1032.	1.640E-03
1.00	1289.	3.673E-03
1.50	1373.	3.710E-03
2.00	1390.	3.484E-03
2.01	808.	3.003E-02
2.50	918.	4.158E-03
3.00	1208.	6.383E-03
3.50	1298.	5.594E-03
4.00	1329.	4.884E-03
4.01	787.	2.954E-02
4.50	896.	4.503E-03
5.00	1172.	7.007E-03
5.50	1259.	6.150E-03
6.00	1292.	5.349E-03
6.01	774.	2.918E-02
6.50	881.	4.661E-03
7.00	1147.	7.170E-03
7.50	1232.	6.313E-03
8.00	1265.	5.500E-03
8.01	764.	2.884E-02
8.50	869.	4.681E-03
9.00	1127.	7.180E-03
9.50	1209.	6.328E-03
10.00	1242.	5.524E-03
10.01	756.	2.854E-02
10.50	860.	4.673E-03
11.00	923.	4.046E-03
11.50	945.	3.191E-03
12.00	965.	2.708E-03
12.50	981.	2.365E-03
13.00	996.	2.116E-03
13.50	1010.	1.928E-03
13.51	1022.	1.780E-03
14.00	1034.	1.660E-03
14.50	1290.	3.713E-03
15.00	1374.	3.749E-03
15.50	1391.	3.524E-03
15.51	808.	3.004E-02
16.00	919.	4.170E-03
16.50	1208.	6.398E-03
17.00	1298.	5.610E-03
17.50	1328.	4.903E-03
17.51	787.	2.957E-02
18.00	895.	4.507E-03
18.50	1170.	7.004E-03
19.00	1258.	6.146E-03
19.50	1290.	5.349E-03
19.51	773.	2.913E-02
20.00	879.	4.656E-03
20.50	1144.	7.151E-03

TABLE 27 (continued)

SUMMARY TABLE : PRESSURE/K2 GIVEN/SUMMARY&PLOTTED RESULTS/NO CONVERGENCE/

TIME (MIN)	PRESSURE DROP (N/M2)	FRACTIONAL PENETRATION
21.00	1229.	6.292E-03
21.50	1262.	5.483E-03
21.51	762.	2.877E-02
22.00	867.	4.668E-03
22.50	1124.	7.145E-03
23.00	1205.	6.292E-03
23.50	1238.	5.491E-03
23.51	753.	2.845E-02
24.00	857.	4.653E-03
24.50	919.	4.016E-03
25.00	941.	3.166E-03
25.50	961.	2.685E-03
26.00	977.	2.344E-03
26.50	992.	2.098E-03
27.00	1005.	1.911E-03
27.01	1018.	1.764E-03
27.50	1030.	1.647E-03
28.00	1284.	3.681E-03
28.50	1367.	3.714E-03
29.00	1384.	3.493E-03
29.01	805.	2.992E-02
29.50	915.	4.152E-03
30.00	1201.	6.347E-03
30.50	1290.	5.556E-03
31.00	1320.	4.853E-03
31.01	783.	2.943E-02
31.50	890.	4.538E-03
32.00	1163.	6.934E-03
32.50	1249.	6.075E-03
33.00	1281.	5.282E-03
33.01	769.	2.897E-02
33.50	874.	4.620E-03
34.00	1136.	7.066E-03
34.50	1219.	6.207E-03
35.00	1252.	5.402E-03
35.01	758.	2.859E-02
35.50	861.	4.625E-03
36.00	1114.	7.048E-03
36.50	1195.	6.195E-03
37.00	1227.	5.349E-03
37.01	748.	2.825E-02
37.50	850.	4.604E-03
38.00	911.	3.949E-03
38.50	933.	3.106E-03
39.00	952.	2.629E-03
39.50	968.	2.293E-03
40.00	983.	2.051E-03
40.50	996.	1.867E-03

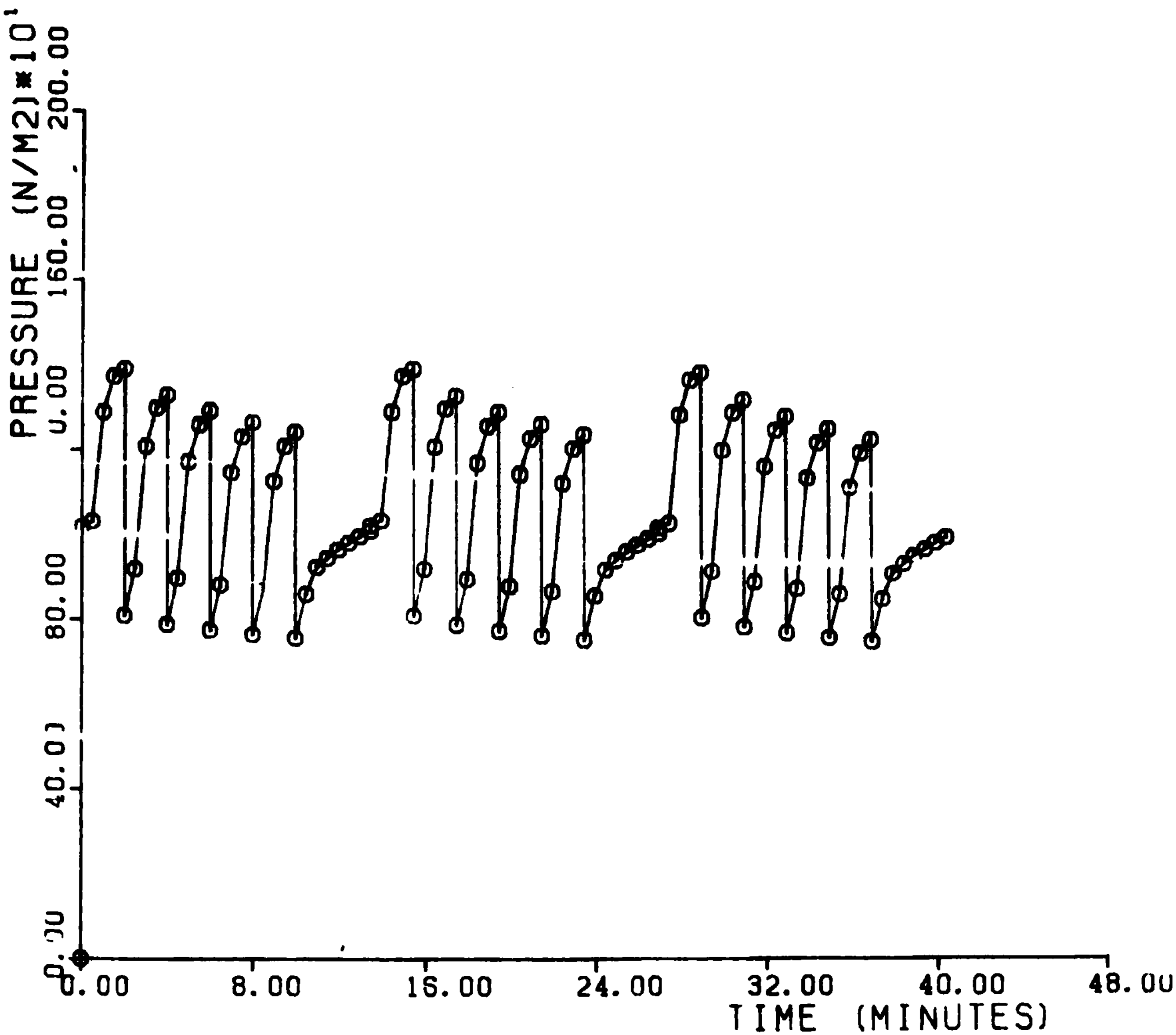

Figure 17. Pressure versus time plot for Example 2
(Reference Figure 16).

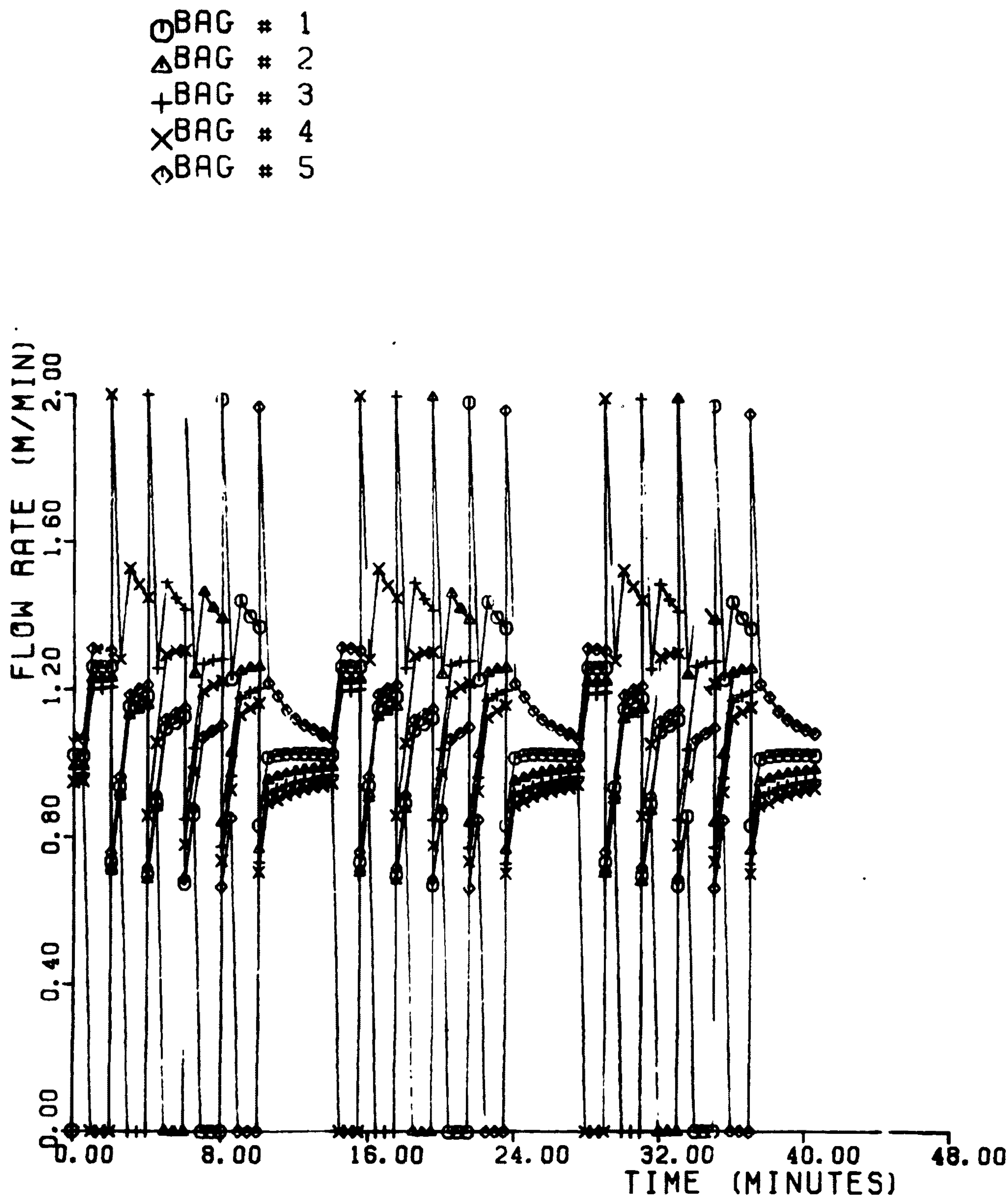

Figure 18. Individual compartment flow versus time plot for Example 2 (Reference Figure 16).

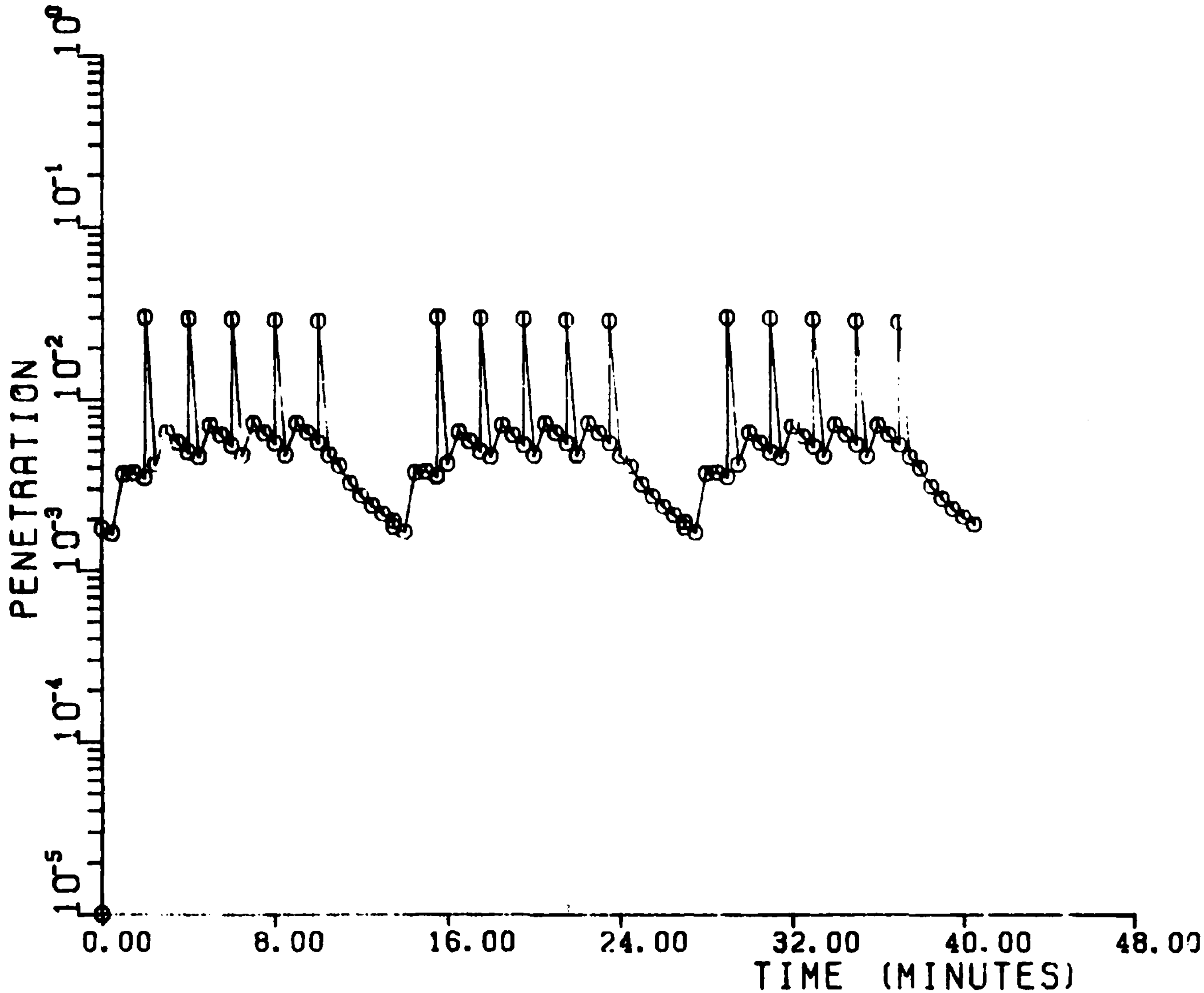

Figure 19. Penetration versus time plot for Example 2 (Reference Figure 16).

of the curves represent that portion of the system operation when all compartments are on line. Figure 18 shows special traces called out by a SUMMARY request that indicate the concurrent velocity-time distributions for each of the five compartments. Ordinarily, the above data would be used for research purposes.

The concurrent variations in dust penetration with time are shown for Example 2 in Figure 19. Note that the maximum penetration values coincide with the minimum pressure loss levels indicated on Figure 17. During those time intervals when all compartments are on line, the penetration varies inversely with pressure loss as should be expected.

Figure 20 data inputs reflect a time cycle operation in which the filter user or designer has set the constraint that there be a specific, i.e., 11 minute, time interval between successive compartment cleanings. In this example, it is assumed that a K_2 value is available for the dust of interest but for a different size spectrum and with measurement at a temperature and velocity differing from that of the filter system. The input data summary generated by the program for the Figure 20 input form appears in Table 28. Calculated and/or corrected values for C_i, K_2, and S_E are given in Table 29. It should also be noted that since AVERAGE data were requested, the average pressure drop and penetration statistics alone are printed, Table 30.

An example of an incorrectly prepared data input card is shown in Figure 21 so that the program response via diagnostic printout could be demonstrated. The types of errors depict illegal values, redundancies, contractions and omissions. Table 31 shows the input data summary that by itself may alert the model user to the numerous input errors and Table 32 indicates calculated and/or corrected values for relevant data inputs.

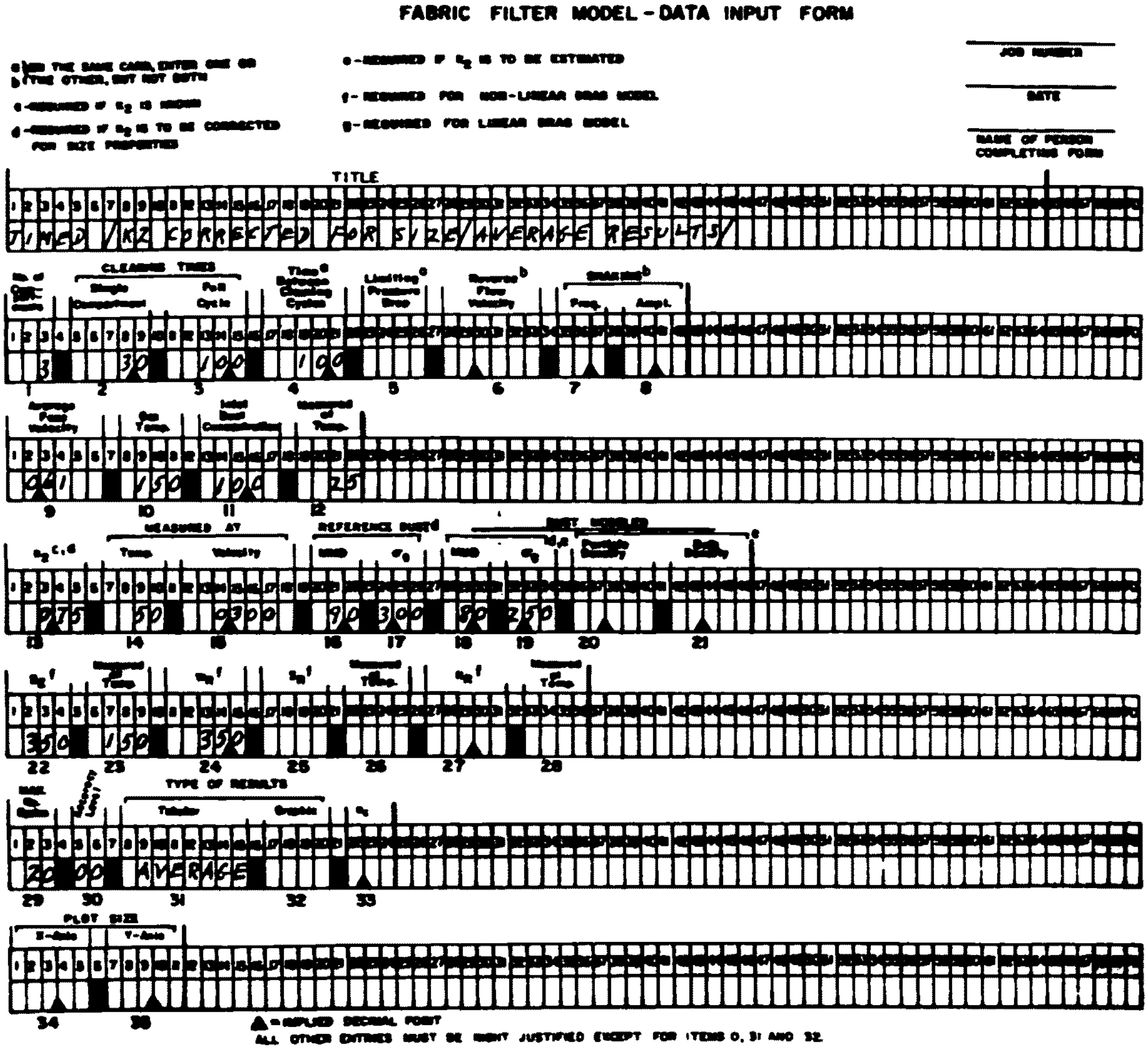

Figure 20. Fabric filter model - data input form for Example 3.

TABLE 28. SUMMARY OF INPUT DATA FOR BAGHOUSE ANALYSIS (REFERENCE FIGURE 20)

****

SUMMARY OF INPUT DATA FOR BAGHOUSE ANALYSIS

****

TIMED/K2 CORRECTED FOR SIZE/AVERAGE RESULTS/

BASIC DESIGN DATA			
NUMBER OF COMPARTMENTS	3		
COMPARTMENT CLEANING TIME (OFF LINE TIME)	3.0	MINUTES	
CLEANING CYCLE TIME	10.0	MINUTES	
TIME BETWEEN CLEANING CYCLES	11.0	MINUTES	
REVERSE FLOW VELOCITY	0.0	M/MIN	
OPERATING DATA			
AVERAGE FACE VELOCITY	0.6100	M/MIN	
GAS TEMPERATURE	150.	DEGREES CENTIGRADE	
INLET DUST CONCENTRATION	10.00	G/M3	
MEASURED AT	25.	DEGREES CENTIGRADE	
FABRIC AND DUST PROPERTIES			
SPECIFIC RESISTANCE, K2	0.75	N-MIN/G-M	
MEASURED AT	50.	DEGREES CENTIGRADE	
	0.3000	M/MIN	
MMD1	9.0	MICRONS	-STANDARD DEVIATION 3.00
CORRECTED TO MMD2	8.0	MICRONS	-STANDARD DEVIATION 2.50
EFFECTIVE RESIDUAL DRAG, SE	350.	N-MIN/M3	
MEASURED AT	150.	DEGREES CENTIGRADE	
RESIDUAL LOADING, WR	35.0	G/M2	
SPECIAL PROGRAM INSTRUCTIONS			
MAX NUMBER OF CYCLES MODELED	20		
ACCURACY LEVEL	0		
TYPE OF RESULTS REQUESTED	AVERAGE /		

TABLE 29. INPUT VARIABLES CALCULATED BY PROGRAM (REFERENCE FIGURE 20)

CALCULATED VALUES		
INLET DUST CONCENTRATION CORRECTED TO OPERATING TEMPERATURE	7.04	G/M3
FABRIC AND DUST CAKE PROPERTIES CORRECTED FOR GAS VISCOSITY		
SPECIFIC CAKE RESISTANCE, K2	1.14	N-MIN/G-M
EFFECTIVE DRAG, SE	390.	N-MIN/M3
FRACTIONAL AREA CLEANED, AC	0.15	
TIME INCREMENT	0.83	MINUTES
SYSTEM CONSTANT W*	0.0	G/M2

TABLE 30. RESULTS OF BAGHOUSE ANALYSIS (REFERENCE FIGURE 20)

```
**********************************************************************************
RESULTS OF BAGHOUSE ANALYSIS
**********************************************************************************
TIMED/K2 CORRECTED FOR SIZE/AVERAGE RESULTS/


FOR     20.83 MINUTES OPERATION,   CYCLE NUMBER  10
                                                 AVERAGE PENETRATION=          2.41E-03
                                                 AVERAGE PRESSURE DROP=          564.40 N/M2
                                                 AVERAGE SYSTEM FLOW=            0.6100 M/MIN
                                                 MAXIMUM PENETRATION=          1.02E-02
                                                 MAXIMUM PRESSURE DROP=          797.98 N/M2

FOR     20.83 MINUTES OPERATION,   CYCLE NUMBER  11
                                                 AVERAGE PENETRATION=          2.40E-03
                                                 AVERAGE PRESSURE DROP=          562.87 N/M2
                                                 AVERAGE SYSTEM FLOW=            0.6100 M/MIN
                                                 MAXIMUM PENETRATION=          1.02E-02
                                                 MAXIMUM PRESSURE DROP=          795.02 N/M2

FOR     20.83 MINUTES OPERATION,   CYCLE NUMBER  12
                                                 AVERAGE PENETRATION=          2.40E-03
                                                 AVERAGE PRESSURE DROP=          561.88 N/M2
                                                 AVERAGE SYSTEM FLOW=            0.6100 M/MIN
                                                 MAXIMUM PENETRATION=          1.02E-02
                                                 MAXIMUM PRESSURE DROP=          793.08 N/M2
```

The numerous errors in preparing the inlet format card, Figure 21, are called out in the diagnostic messages of Table 33. The reader should recognize that the likelihood of the indicated error count (hopefully) is extremely remote. However, the summary of diagnostic messages provides some indication of the model's capability to recognize poor programming.

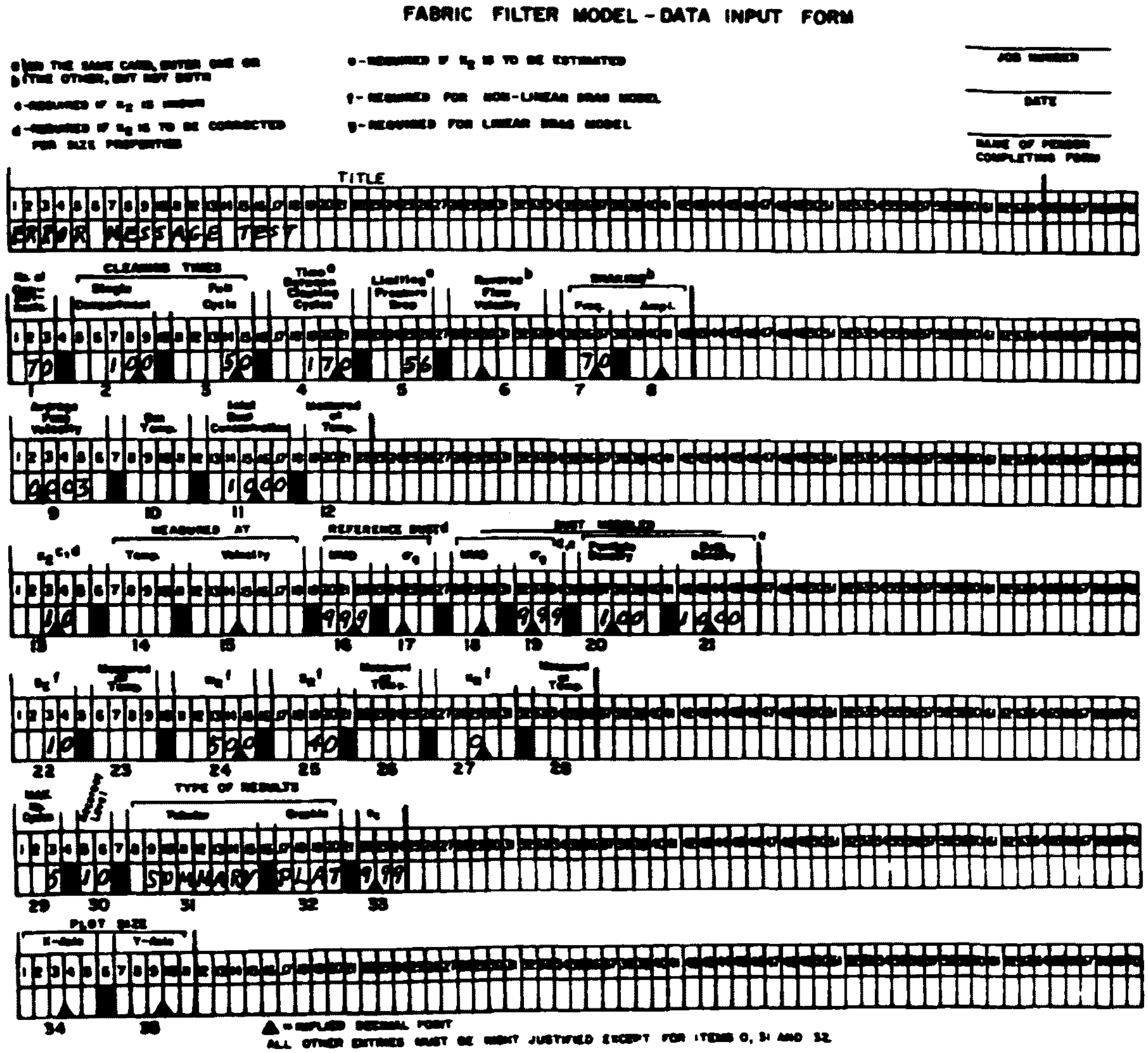

Figure 21. Fabric filter model - data input form for Example 4.

TABLE 31. SUMMARY OF INPUT DATA FOR BAGHOUSE ANALYSIS (REFERENCE FIGURE 21)

```
*******************************************************************************

SUMMARY OF INPUT DATA FOR BAGHOUSE ANALYSIS

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

ERROR MESSAGE TEST


BASIC DESIGN DATA
     NUMBER OF COMPARTMENTS              70
     COMPARTMENT CLEANING TIME            10.0          MINUTES
       (OFF LINE TIME)
     CLEANING CYCLE TIME                   5.0          MINUTES
     TIME BETWEEN CLEANING CYCLES         17.0          MINUTES
     LIMITING PRESSURE DROP               56.           N/M2
     REVERSE FLOW VELOCITY               0.0            M/MIN
     SHAKING FREQUENCY                   7.0            CYCLES/SEC

OPERATING DATA
     AVERAGE FACE VELOCITY               0.0030         M/MIN
     GAS TEMPERATURE                      0.            DEGREES CENTIGRADE
     INLET DUST CONCENTRATION            10.00          G/M3
          MEASURED AT                     25.           DEGREES CENTIGRADE

FABRIC AND DUST PROPERTIES

     SPECIFIC RESISTANCE, K2              1.00          N-MIN/G-M
          MEASURED AT                     25.           DEGREES CENTIGRADE
                                         0.6100         M/MIN
     EFFECTIVE RESIDUAL DRAG, SE          10.           N-MIN/M3
          MEASURED AT                     25.           DEGREES CENTIGRADE
     RESIDUAL LOADING, WR                 50.0          G/M2
     RESIDUAL DRAG, SR                    40.           N-MIN/M3
          MEASURED AT                     25.           DEGREES CENTIGRADE
     INITIAL SLOPE, KR                    0.0           N-MIN/G-M
          MEASURED AT                     25.           DEGREES CENTIGRADE


SPECIAL PROGRAM INSTRUCTIONS
     MAX NUMBER OF CYCLES MODELED          5
     ACCURACY LEVEL                      10
     TYPE OF RESULTS REQUESTED            SUMMARY / PLAT

     FRACTIONAL AREA CLEANED, AC        9.99
```

TABLE 32. INPUT VARIABLES CALCULATED BY PROGRAM (REFERENCE FIGURE 21)

CALCULATED VALUES

INLET DUST CONCENTRATION CORRECTED TO OPERATING TEMPERATURE	10.92	G/M3
FABRIC AND DUST CAKE PROPERTIES CORRECTED FOR GAS VISCOSITY		
SPECIFIC CAKE RESISTANCE, K2	0.93	N-MIN/G-M
EFFECTIVE DRAG, SE	56.	N-MIN/M3
RESIDUAL DRAG, SR	37.	N-MIN/M3
FRACTIONAL AREA CLEANED, AC	9.99	
TIME INCREMENT	0.00	MINUTES
SYSTEM CONSTANT W*	0.0	G/M2

TABLE 33. DIAGNOSTIC MESSAGES (REFERENCE FIGURE 21)

DIAGNOSTIC MESSAGES

ILLEGAL REQUEST FOR TYPE OF RESULTS

THE NUMBER OF COMPARTMENTS MUST NOT EXCEED 30

THE NUMBER OF COMPARTMENTS TIMES THE COMPARTMENT CLEANING TIME MUST BE LESS THAN THE CLEANING CYCLE TIME

THE COMPARTMENT CLEANING TIME MUST BE LESS THAN THE TOTAL CYCLE TIME

TIME INCREMENT TOC SMALL, IE. < 0.01 MINUTES

AVERAGE FACE VELOCITY OUT OF RANGE, 0.3 TO 3.0

A GAS TEMPERATURE HAS NOT BEEN ENTERED

INVALID FREUUENCY OR AMPLITUDE FOR SHAKER

INVALID ACCURACY CODE

BOTH TIMED AND PRESSURE CONTROLLED CLEANINGS SPECIFIED - ONLY ONE IS VALID

PARTICLE SIZE DATA FOR K2 ARE INCOMPLETE

MASS MEDIAN DIAMETER OF MEASUREMENT OUT OF RANGE 2 TO 50 MICRONS

STANDARD DEVIATION OF MEASUREMENT OUT OF RANGE 2 TO 4

MASS MEDIAN DIAMETER OF DUST OUT OF RANGE 2 TO 50 MICRONS

STANDARD DEVIATION OF DUST OUT OF RANGE 2 TO 4

BULK DENSITY CANNOT EXCEED DISCRETE PARTICLE DENSITY

INCOMPLETE DATA FOR NON-LINEAR DRAG MODEL

INITIAL SLOPE , KR , IS MISSING

FRACTIONAL AREA CLEANED OUT OF RANGE,0 TO 1

THE PROGRAM HAS BEEN TERMINATED BECAUSE OF ERRORS IN THE INPUT DATA

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

1. REPORT NO. EPA-600/7-79-043a	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE Fabric Filter Model Format Change; Volume I. Detailed Technical Report		5. REPORT DATE February 1979
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Richard Dennis and Hans A. Klemm		8. PERFORMING ORGANIZATION REPORT NO. GCA-TR-78-51-G(2)
9. PERFORMING ORGANIZATION NAME AND ADDRESS GCA Corporation GCA/Technology Division Bedford, Massachusetts 01730		10. PROGRAM ELEMENT NO. EHE624
		11. CONTRACT/GRANT NO. 68-02-2607, Task 8
12. SPONSORING AGENCY NAME AND ADDRESS EPA, Office of Research and Development Industrial Environmental Research Laboratory Research Triangle Park, NC 27711		13. TYPE OF REPORT AND PERIOD COVERED Task Final; 11/77 -12/78
		14. SPONSORING AGENCY CODE EPA/600/13

15. SUPPLEMENTARY NOTES IERL-RTP project officer is James H. Turner, MD-61, 919/541-2925.

16. ABSTRACT The report describes an improved mathematical model for use by control personnel to determine the adequacy of existing or proposed filter systems designed to minimize coal fly ash emissions. Several time-saving steps have been introduced to facilitate model application by Agency and other groups. To further aid the model user, the study is in two volumes: a detailed technical report and a user's guide. By using selected combustion, operating, and design parameters, the model user can forecast the expected emissions and filter pressure loss. The program affords the option of providing readily appraised summary performance statistics or highly detailed results. Several built-in error checks prevent the generation of useless data and avoid unnecessary computer time. The model takes into account the concentration and physical properties of the dust, air/cloth ratio, sequential compartmentized operation, and the method, intensity, and frquency of cleaning. The model function depends on the unique fabric cleaning and dust penetration properties observed with several coal fly ashes (including lignite) and woven glass fabrics.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group	
Air Pollution	Glass Fibers	Air Pollution Control	13B	11B
Mathematical Models	Aerosols	Stationary Sources	12A	
Filtration	Dust	Fabric Filters	07D	11G
Fly Ash	Utilities	Particulate	21B	
Coal	Boilers		21D	13A
Woven Fabrics			11E	

18. DISTRIBUTION STATEMENT Unlimited	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 179
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE

EPA Form 2220-1 (9-73)