FINAL REPORT. VOLUME IV. FABRIC FILTER SYSTEMS STUDY

GCA Corporation
Bedford, Massachusetts

December 1970

GCA-TR-70-17-G

FINAL REPORT

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Prepared by

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NATIONAL AIR POLLUTION CONTROL ADMINISTRATION
U.S. DEPARTMENT OF HEALTH, EDUCATION AND WELFARE
Public Health Service
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FOREWORD

This document is submitted to the Department of Health, Education and Welfare, National Air Pollution Control Administration, in partial fulfillment of the requirements under Contract CPA 22-69-38. The principal technical objectives under the contract were: (1) to evaluate the status of engineering technology currently available to the researcher, manufacturer and user of fabric filter systems; (2) investigate the current practices in the application of fabric filtration; (3) investigate major air pollution control areas which could be amenable to control by fabric filtration; (4) make a critical review and engineering evaluation of the major types of fabric filter devices currently available in order to assess the strength and weakness of each type of device; (5) prepare a comprehensive report containing the information collected in the task areas cited above; and (6) develop five-year research and development programs specifying the research and development efforts required to fill the stated technical gaps. The results of the contract efforts are presented in the following four volumes:

Volume I - Handbook of Fabric Filter Technology
Volume II - Appendices to Handbook of Fabric Filter Technology
Volume III - Bibliography, Fabric Filter Systems Study
Volume IV - Final Report, Fabric Filter Systems Study

The following professional staff members of the GCA Technology Division contributed to the study and preparation of this report: Dr. Charles E. Billings, Mr. Richard Dennis, Dr. Leonard M. Seale, and Dr. John Wilder. The results of the contract efforts, partially presented in this document, covered the period from January 1969 to January 1971.

Mr. Dale Harmon of the Process Control Engineering Division, National Air Pollution Control Administration, served as the Contract Project Officer.

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FABRIC FILTER SYSTEM STUDY

ABSTRACT

This report describes a study directed to the definition of two alternative five-year research and development programs based on different levels of funding for fabric filter systems used in air pollution control applications. These plans provide specific performance, to improve economics of usage, and to promote extension of fabric filtration to control of a greater number of applications present and future. Specific tasks undertaken include: A survey of engineering technology available as data or analytical design and operation equations; the identification and investigation of current practices, limitations, and problems of fabric filter systems in present usage and in possible future applications; and a review of the major types of fabric filter equipment available. Results of the above efforts have been presented in a comprehensive analytical handbook, and in an indexed bibliography of fabric filtration literature.

CHAPTER 1

INTRODUCTION

1.1 SUMMARY

In early 1968, the Division of Process Control Engineering (DPCE) of the Air Pollution Control Office (APCO), Environmental Protection Agency (EPA)*, decided to undertake a comprehensive study of particulate air pollution control equipment. Technical and administrative preparations were made to fund three major programs:

- Systems Study of Fabric Filters
- Systems Study of Electrostatic Precipitators
- Systems Study of Scrubbers

In response to Request-for-Proposal No. PH22-68-Neg.10, GCA Technology Division submitted the successful proposal for the Fabric Filter Systems Study. Following the contract award in late 1968, Dr. Charles E. Billings was appointed as the GCA Program Director, and Mr. Dale L. Harmon as the APCO Program Monitor.

The objectives of the program were to:

1. identify and evaluate the status of current engineering technology
2. define current practices in the application of fabric filters for air pollution control
3. identify potential areas for new applications of fabric filters for air pollution control
4. investigate existing fabric filter systems, and
5. define research and development recommendations to extend future applications and improve performance of existing fabric filter systems.

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* Formerly National Air Pollution Control Administration (NAPCA) U. S. Department of Health Education and Welfare (HEW).

The program included three major data acquisition activities:

1. a survey of current applications from filter users;
2. a survey of design and application experience obtained from fabric filter manufacturers and component suppliers; and
3. a review of fabric filtration literature.

The results of this study are presented in four volumes as described below:

Volume 1 - " Handbook of Fabric Filter Technology", a synthesis of current engineering technology as applied to the present utilization of fabric filter systems for air pollution control.

Volume 2 - "Handbook Appendices for Volume 1".

Volume 3 - "Bibliography", an indexed bibliography of pertinent literature plus a data storage and retrieval system for the program bibliography.

Volume 4 - "Final Report", a description of the development of and recommendations for research and development programs submitted for consideration by APCO.

The Handbook of Fabric Filter Technology, which represents a major output of this program, is intended to function as a guide in the design, development, application and operation of fabric filter systems. The Chapter contents are summarized in the following listing:

Chapter	Title
1	Introduction
2	Fabric Filtration Technology
3	Types of Fabric Filters
4	Fabric Selection
5	Engineering Design of Fabric Filter System
6	Fabric Filter Performance
7	Economics
8	Operation and Maintenance

The handbook is aimed primarily at those engineering and scientific personnel who must deal with air pollution control problems for which fabric filtration affords a satisfactory solution. The handbook coverage is broad, ranging from the underlying theoretical aspects to the practical design and economic consideration encountered in selecting and operating field installations.

The handbook examines several types of individual applications and points out the range and importance of the major operating parameters.

1.2 CONCLUSIONS

General conclusions arising from this study are presented in the following section:

1. The estimated yearly sales for fabric filter dust collectors range from $35 to $50 million for approximately 7500 individual units. Although there are about 50 manufacturers of fabric filter collectors in the U.S.A., nearly 80 percent of dollar sales are attributable to ten manufacturers. Sales have increased historically at a rate of 7 percent annually until recently wherein the rate appears to have nearly doubled.
2. An additional $25 million yearly are represented by the sales of fabric media for either new equipment or for replacement in existing units.
3. There are 10^5 to 10^6 fabric filter collectors in use in the U. S. at the present time. These range in size from 10 to 10^6 sq. ft. of fabric filter area, with a current average purchased size of approximately 3000 sq. ft.
4. Due to variations in design, equipment costs per unit size vary by as much as a factor of ten. A typical purchase cost for the collector alone is $0.80 per CFM filtered or $2.40 per CFM installed with all necessary accessories. The cost of owning and using the equipment, including

replacement fabric, electric power, labor, and other expenses, is approximately $1. per CFM per year, again with considerable variation from one installation to another.

5. An industrial plant may use from one to several hundred fabric filter collectors for a broad variety of applications. The selection of fabric filter equipment is usually based upon its high, 99 percent or greater, particulate removal characteristics. In some circumstances, however, the choice may be solely one of economics relative to other dust collection systems, e.g., electrical precipitation or wet scrubbing. Fabric filter collectors can be used for most dust and fumes, provided that gas temperatures are maintained above the dew point and that the upper working temperature of the fabrics is not exceeded.

6. More than 25 percent of all maintenance costs for fabric filter systems were associated with fabric repair or replacement. Mainly, these costs resulted from dust-fabric interactions such as blinding or fabric wear, accentuated by the intense cleaning necessary to overcome particle-fabric adhesion. Other significant maintenance costs appeared to arise from the selection of under-designed and less expensive equipment as a means of cost control.

7. Variations in design of fabric collectors, chiefly in the method of cleaning the fabric, and variations in fabric material and weave provide considerable latitude in the selection of a filter system. Presently, the selection process depends mainly on experience with similar systems because the theoretical factors relating fabrics, particles, and gases in filtration and cleaning are not well established. As a result of the study, a number of areas for research and development have been identified. The results of these future studies are expected to improve greatly the overall performance (both cost and efficiency) of existing systems and to suggest new applications for fabric filter equipment.

CHAPTER 2

DATA COLLECTION METHODS

Most fabric filter designs are basically unchanged from those conceived approximately 120 years ago. Only within the last 20 years have any new types or novel designs appeared. Over this period, a tremendous amount of practical design and usage experience has evolved which, unfortunately, has never been summarized systematically. The literature reports fragments of this experience, but because fabric filtration is still as much an art as a science, the best information sources are the people directly involved with the equipment. Thus, in addition to a literature review, the present study required a systematic survey of fabric filtration equipment users, equipment manufacturers, control agencies, consultants, and laboratories having interests in fabric filtration.

2.1 EQUIPMENT USERS

The initial approach in the user survey was to establish several broad industrial categories and to estimate the aggregate effluent source strengths in each of these. Specific processes and operations significant in particulate air pollution were surveyed for description of their characteristic gas and particulate parameters. The process effluents were then combined as shown in Table 1 for ten industry classes. This first-order analysis was instrumental in establishing priorities for the survey effort.

Reference to Column (A), Table 1 provides an estimate of the total amount of particulate released to the atmosphere for the various industrial categories assuming that no control measures are exercised. These data, however, do not take into account other key factors that may influence the emission ratio. If the potential effluent has sufficient value to warrant recovery, Column (B), it becomes highly illogical to vent it to the atmosphere. On the other hand, any properties of the gas stream, Column (C), or the particulate matter, Column (D), which present cleaning difficulties tend to increase its pollution potential. The indices 1 or 2 designating either a favorable or adverse effect, respectively, have been combined with the

TABLE 1

GROSS POLLUTION AND POTENTIAL CONTROL

Category	Industry	Total Annual Product Tons/Year x10^{-6}	(A) Total[a] Particulate Emissions Tons/Year x10^{-6}	(B) Valuable Recoverable Product		(C) Gas and Particulate Handling Capability[b] Gas		(D) Particulate		(E) Relative[c] Polluting Potential
				No	Yes	Easy	Difficult	Easy	Difficult	
				(2)	(1)	(1)	(2)	(1)	(2)	RP
1	Combustion									
	Coal	375	37	X			X	X		296
	Oil	30	0.06	X			X		X	0.5
	Incineration	200[d]	10	X			X		X	80
2	Food & Feed	300	3		X	X		X		3
3	Pulp & Paper	40	6.4		X		X	X		12.8
4	Inorganic Chemical	100	10		X		X	X		20
5	Organic Chemical	--	--		X		X	X		--
6	Petroleum Refining									
	Combustion	700	1.4	X			X		X	11.2
	Catalyst	3500	3.5		X	X		X		3.5
7	Non-Metallic Minerals									
	Cement	500	10	X			X	X		40
	Fertilizer	30	1.5	X			X		X	9
8	Iron & Steel, Foundries	200	10	X			X		X	80
9	Non-Ferrous Metals	10	1		X		X		X	4
10	Miscellaneous	(Includes highly toxic materials, e.g. radioactivity or beryllium and reactive materials e.g. pyrophoric metals. Emissions usually controlled for reasons of health and safety.)								

a) No credit for particulate controls.

b) Indices (1) and (2) indicate favorable or adverse gas cleaning conditions.

c) RP indicates relative pollution potential

RP = A x B x C x D

d) Based upon an estimated 1 ton/year per person in U.S.A.

yearly particulate emission rate to establish a descriptor of relative pollution potential, Column (E). Despite this qualitative approach, the relative magnitude of these descriptions appear to align well with the observed pollution levels noted for many major industries.

As a second step in structuring the filter usage survey, a list-in-breadth was made of all processes for which fabric filters have been used or might conceivably be used, see Appendix 1, "List of Particulate Sources and Indications of FF Use Potential". This tabulation represents a condensation of nearly 300 dusts compiled from several sources and including some sources too small to warrant further attention in this study, e.g., powdered corn cob; pollens.

Table 1 and Appendix 1 form the basis for estimating the potential market for FF equipment, i.e., the quantity of emissions and the possibilities of using fabric filters. Also available are data on reported sales of equipment for the years 1966 and 1967, representing in effect the actual market for FF equipment. After comparing the latter statistics with the data of Table 1, a sample listing of fabric filter users was structured as shown in Table 2.

A comprehensive questionnaire was prepared to obtain complete descriptive, operating, and performance data from fabric filter system users. This questionnaire (Appendix 2) was approved by the Bureau of Budget as an instrument of the contract. Meanwhile, preliminary visits were made to several local users of FF equipment to test the questionnaire prior to developing the final format. The questionnaire consisted of seven pages:

Page 1. User company, address, key FF personnel
Page 2. Process capacity and emission level
Page 3. FF manufacturer, dimensions, fabric type
Page 4. FF pressure data, economics
Page 5. FF cleaning cycle, dust description
Page 6. Equipment needs, suggestions for future research
Page 7. Miscellaneous fabric and gas properties.

TABLE 2

FABRIC FILTER SURVEY SAMPLE STRUCTURE, VISITS PLANNED AND ACCOMPLISHED

I. User Category	No. Planned	No. Visited	No. Questionnaires Completed
1. Combustion	3	5	3
2. Food & Feed	2	1	1
3. Pulp & Paper	1	1	0
4. Inorganic Chemical	3	3	2
5. Organic Chemical	5	5	5
6. Petroleum Refining	1	0	0
7. Non-Metallic Minerals	11	15	11
8. Iron & Steel Foundries	14	15	13
9. Non-Ferrous Metals	8	5	5
10. Miscellaneous	2	2	1
Subtotal	50	52	41
II. Filter Manufacturers	7	9	
III. Fabric Manufacturers	3	4	
IV. Agencies, etc.	--	6	
Total	60	71	

The questionnaire was designed to cover all major aspects of the design and performance of the equipment and, especially, to obtain the user's opinions as to how the equipment might be improved. Since the questionnaire asked over 100 questions, individuals using only a small filter collector often were not prepared to answer a large percentage of the questions. In these instances, cooperation was obtained by having the interviewer personally solicit and record the answers to the appropriate questions after having submitted the questionnaire previously to the subject. The above interview could be handled adequately in a one to two hour period.

Arrangements for plant visits involved several telephone calls and written communications to guarantee access to the plants and, most important, to establish which persons were most familiar with the filtration equipment. Frequently, several individuals representing management, plant engineering and maintenance categories were contacted in order to obtain complete coverage.

During many visits, an informal discussion yielded more information and engendered more thinking than the formal page-by-page completion of the questionnaire. Inspection of plant facilities sometimes revealed additional features about a system which had not been discussed previously. Follow-up telephone calls were frequently made to clarify or amplify information gained during a plant visit.

It was frequently noted that even the most important system variables (e.g., temperature, flow rate, dust loading, pressure drops) were not known because the system had no appropriate instrumentation. In the smaller systems, these variables sometimes had never been measured. Although a thermometer and anemometer were usually carried on the tour, suitable measuring points were usually not available. Thus, it became apparent that (a) the data would be limited both in quality and quantity, and (b) that future surveys should also include a field measurement activity.

Most of the survey was performed in several two and three day trips to Ohio, Pennsylvania and New York State. In addition to a few Greater

Boston firms, scattered visits were also made to Maine, California, West Virginia, Ontario, Kentucky and Michigan.

The number of individual plants or companies visited, classified according to process, is shown in Table 3. In that some 10^5 to 10^6 fabric filter operations are estimated to be in use at the present time, the number of installations visited represents a very small sampling. Despite this fact, the discussions and responses to questionnaires resulting from the survey are believed to represent a good cross-section of the information available from the field. Had the program permitted a more extensive survey, several additional process categories and plants might have been included (Suggested Survey Extensions, Table 3).

The types of fabric and the manufacturers of fabric filter equipment described in the user survey are listed in Table 4. In view of the small sampling and the non-random structuring of the survey, the indicated frequencies should not be extrapolated.

2.2 EQUIPMENT MANUFACTURERS

The most recent survey of fabric filter equipment manufacturers, 1960, served as a starting point for the present survey. A review of industrial indices and periodicals produced a list of about 200 companies either known to manufacture or considered to have a possible interest in the manufacture of FF equipment. In March, 1969, a letter was sent to each, asking for an expression of interest and willingness to cooperate in this study. About 40 positive replies were received offering various degrees of cooperation.

A second mailing was made to 75 manufacturers from the same group in which they were requested to correct and up-date a condensed listing and description (prepared by GCA) of their product line. From this survey and a subsequent follow-up, a tabulation of some 50 manufacturers was prepared that embraced more than 100 different collector models and a wide range of air flows. A condensed version of these data is shown in Appendix 3. The complete listing appears in the "Handbook Appendices for Volume 1", Volume 2, "Fabric Filter Manufacturers and Equipment Summary". New manufacturers appear to enter the market at a rate of about two per year.

TABLE 3

FABRIC FILTER USER SURVEY

Category	Industry	Result*	Suggested** Survey Extensions
1	Combustion		
	1 Oil-fired Boiler	D	Municipal Incinerator, NYC
	2 Coal-fired Boiler	D	
	3 Coal-fired Boiler	Q	
	4 Municipal Incinerator	Q	
	5 Municipal Incinerator	Q	
2	Food & Feed		
	1 Grain/Flour Mill	Q	Powdered Mixes
3	Pulp & Paper		
	1 Kraft Mill	D	
4	Inorganic Chemicals		
	1 Lime	Q	Fertilizer
	2 Indust. Chem.	Q	
	3 Lime, Gypsum	D	
5	Organic Chemicals		
	1 Carbon Black	Q	Pharmaceuticals
	2 Carbon Black	Q	Soap & Detergent
	3 Plastics/Resins	Q	
	4 Polyvinyl Alcohol	Q	
	5 Alum	Q	
6	Petroleum Refining		Catalytic Cracking
	None		
7	Non-Metallic Minerals		
	1 Cement Plant	Q	Mining

TABLE 3 (Continued)

Category		Industry	Result*	Suggested** Survey Extensions
7(Cont.)	2	Cement Plant	Q	Ceramics
	3	Cement Terminal	Q	Clay Plant
	4	Cement Plant	Q	Lime Plant
	5	Cement Plant	D	Asphalt Batching, Chicago
	6	Cement Plant	D	Asbestos, Quebec
	7	Cement Plant	D	Coal Cleaning
	8	Lime Plant	Q	
	9	Stone Crushing	Q	
	10	Gypsum Plant	Q,Q	
	11	Abrasives	D	
	12	Abrasives	Q	
	13	Glass Mfgr.	Q	
	14	Glass Mfgr.	D	
	15	Mineral Wool	(Q)	
8		<u>Iron and Steel</u>		
	1	Electric Furnace	Q	Coke Oven
	2	Electric Furnace	Q	
	3	Electric Furnace	Q	Sintering
	4	Electric Furnace	Q	
	5	Elec. Furnace Room	Q	
	6	Cupola Furnace	Q	Basic Oxygen Furnace
	7	Cupola Furnace	Q	
	8	Foundry	Q	
	9	Foundry	Q	
	10	Foundry	Q	
	11	BOF Reladling	Q	
	12	Sinter Line Dropoff	Q	

TABLE 3 (Continued)

Category	Industry	Result*	Suggested** Survey Extensions
8 (Cont.)	13 Motor Room	Q	
	14 Miscellaneous	D	
9	Non-Ferrous Metals		
	1 Copper	Q,Q	Zinc
	2 Lead	Q	
	3 Aluminum	D	Zinc Galvanizing
	4 Brass Refining	Q	Aluminum
	5 NFM Machining	Q	Lead Smelting
10	Miscellaneous		
	1 Product Fabrication	Q	Wood Products Ultrafiltration

*Result: Q, Questionnaire completed

D, General discussion, no questionnaire

**Plants or operations not included in present survey

TABLE 4

SUMMARY OF FABRIC TYPES AND COLLECTOR MANUFACTURERS DESCRIBED IN USER SURVEY

Fabric*	Frequency	Percent Frequency
Cotton	12	36.4
Dacron[R]	5	15.1
Dynel[R]	1	3.0
Glass	9	27.3
Nomex[R]	1	3.0
Orlon[R]	2	6.1
Polypropylene (felt)	1	3.0
Wool	2	6.1
	33	100.0

*Working temperatures - 16 systems $\geq 200^{o}F$, 17 systems $< 200^{o}F$

Collector Manufacturers	Frequency
American Air Filter Company, Inc.	4
Carter-Day Company	3
Dustex Division, American Precision Industries, Inc.	1
Flex-Kleen Corporation, Research Cottrell, Inc.	2
Hydromation Engineering Company	1
G.A. Kleissler Company	1
Northern Blower Division, Buell Engineering Co., Inc.	3
Own Design	4
Pangborn Division, The Carborundum Company	5
W.W. Sly Manufacturing Company	3
The Wheelabrator Corporation	6

R: Registered trademark

During July, 1969, a similar letter survey with a reply card was directed to more than 80 companies engaged in the manufacture of fiber and fabrics of the types used in fabric filtration. Although an effort was made to include all known suppliers of filter bags and envelopes, there are literally hundreds of sources of textile fiber. Thus, the tabulation, "1969 Suppliers List: Filter Fabrics and Related Materials" Handbook Appendices Volume 2 forms the basis for a more detailed future survey of fiber and fabric sources, finishes, weaves and other fabric properties.

Most manufacturers of fabric filter collectors were not in favor of participating in this survey. In April, 1969, GCA representatives met with members of the Fabric Collectors Division of the Industrial Gas Cleaning Institute (IGCI) in an attempt to develop some basis for cooperation. Group membership in IGCI represents approximately 80 percent of sales in the industrial gas cleaning market. IGCI spokesmen stated that the highly proprietary aspects of their products would prevent any free exchange of information. The concept of cooperative efforts in basic research and development were considered reasonable, but no approaches were found acceptable to IGCI. Therefore, IGCI took no official position, recommending that member companies establish their own policies.

Replies from individual IGCI member firms reflected for the most part the IGCI stance, although some suggested that companies asked to supply information might be compensated for the time and effort involved. This approach was acceptable to GCA, provided that the data fulfilled the needs of this study. Although no provision for such effort was included in the present program budget, it appeared that this avenue might be explored in future programs.

Despite the official position taken by many companies, it is emphasized that several did furnish a substantial amount of information and nearly all furnished their product brochures.

Nine equipment manufacturers were visited, representing a wide range in sales volume, equipment types, and sizes. Four fabric and fiber manufacturers were visited as well as two laboratories engaged in fabric research. Both samples, which encompass a much larger percentage of the manufacturing population than the equipment user survey sample, are believed to be representative. In retrospect, however, more fabric information would be desirable in view of the emphasis now placed on fabric performance.

Some manufacturers were reluctant to suggest installations of their equipment that might be visited, although most were willing to discuss installations that had already been visited by GCA. Most manufacturers were glad to discuss the types of R & D they considered necessary, although the expressed opinion of many was that there was not much to be done to improve the equipment now available.

2.3 LITERATURE SURVEY

A substantial quantity of both domestic and foreign information directly or indirectly relatable to fabric filtration has been published. Some unpublished literature such as experimental results, internal reports, and guidelines to operation of fabric filter equipment, are also available. This survey consisted of locating useful information; obtaining copies of pertinent documents; indexing, coding, and storing the information, and preparing a bibliographic summary which is published as Volume 3 of this program.

2.3.1 Indexing and Coding System

Faced with the need for organizing a large amount of information, a system of descriptors was chosen for classifying and relocating documents on fabric filtration. The descriptors were structured in several general categories relating to dust source, dust type, gases, fabric, etc., as described in Volume 3. While some investment of time was required to review and code each document, the descriptor method proved to be very useful and efficient during the subsequent data analysis phase. The number of descriptors was limited to approximately 100. In retrospect, however, it now appears that some of the descriptors might be combined or eliminated, and others added, especially in the area of system design.

The item index selected was simply a consecutive numbering of documents in order of their review. Thus, more documents can be added at any future time without resorting or renumbering. Numbers used ran from 0010 through 0509. Documents were also cross-indexed by author and by descriptor, using card sorting methods. It was originally planned to cross-index all information by computer. When, however, the total number of documents appeared to be only about 500, this approach was dropped.

2.3.2 Literature Search

The literature reviewed in this survey was obtained from many sources. Four libraries* were especially useful: APTIC, Bay Area, APCO, and GCATD; and provided an estimated 60 percent of the 500 items gathered in this survey. The remaining 40 percent were acquired through various abstracting services, the bibliographies of papers previously reviewed, personnel communications, and assorted periodicals. Table 5 lists these sources along with the approximate coverages furnished by each**.

Copies of many documents were ordered from the John Crerar Library in Chicago, while others were obtained from the Massachusetts Institute of Technology Library. Once given an accession number, documents were reviewed at which time up to 25 appropriate descriptors were selected from the master listing. These descriptors, plus bibliographic information were punched on IBM cards. These cards filed in numerical sequence constitute the bibliography cited previously.

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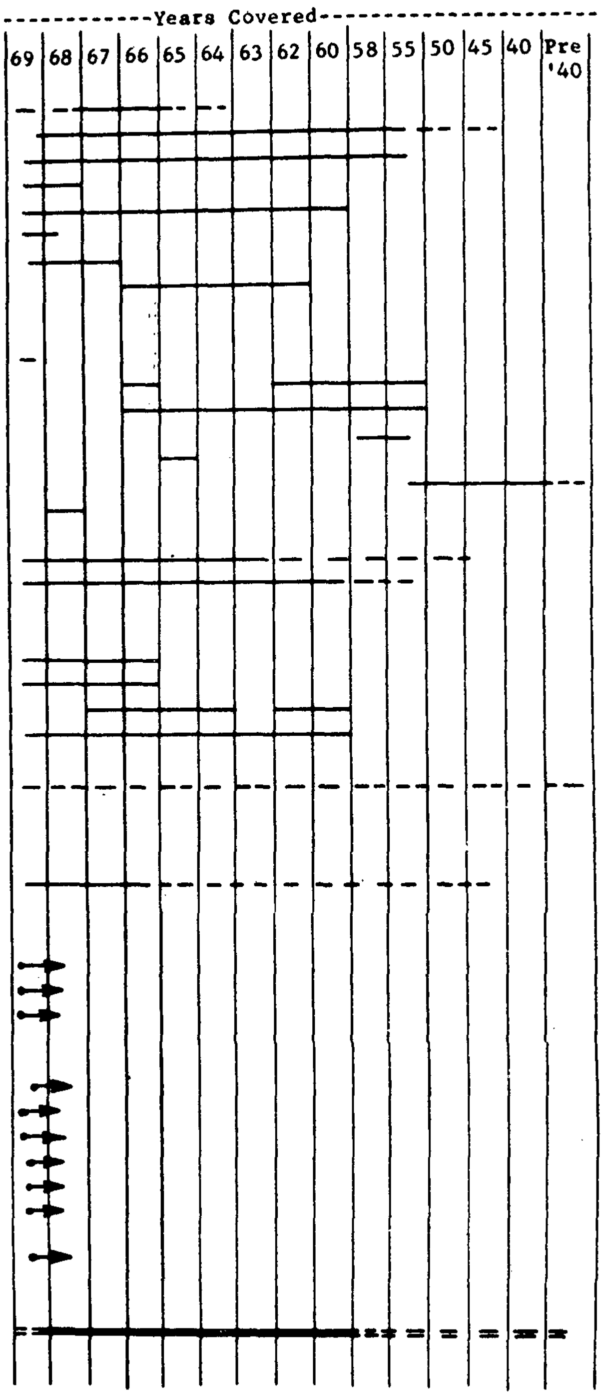
* APTIC: Air Pollution Technical Information Center, APCO, Raleigh, North Carolina. Bay Area: San Francisco Bay Area Pollution Control District; several copies of this data bank exist, including one at APTIC. APCO: Process Control Engineering Division, Development Engineering Branch, Equipment Development Section, Technical Library. GCATD: GCA Technology Division, Bedford, Massachusetts.

** This list is not in the order of search. A different search sequence would ascribe slightly different relative importance to these sources.

TABLE 5. LIST OF SOURCES SEARCHED DURING FABRIC FILTER SYSTEM STUDY

SOURCES SEARCHED	Approx. Yield
Main abstracts:	
APTIC	25%
Bay Area	15
APCA Abstracts	5
Brit. AP Abstracts	5
App. Sci. and Tech. Index	10
MEDLARS	0
Fuel Abstracts	1
Chemical Abstracts	0
Misc. Abstracts	
AP Translations	-
Guide to Res in AP	-
AP Publicns - Sel. Bib.	2
The AP Bibliography	1
AP Titles	-
AP - A Bibliography	5
Subj. Indx to Lit,A&W Cons.	0
Files at GCA	10
Tech. Lit. File, NAPCA	10
Periodicals - Indices searched:	
Filtration & Separation	1
Air Engineering	1
Rock Products	1
Textile Res Jnl	0
Periodicals - sources, but not searched completely	
Secondary Bibliographies	5
Companies and Consultants	
Approx 30 FF Users	1
Approx 15 FF Fabric Mfgrs.	1
Approx 10 FF Consultants	1
Organizations:	
IGCI	0
Filtration Society	0
Textile Res. Institute	0
Am Foundrymen's Soc.	0
Am Petroleum Inst.	0
Mfg. Chemists Soc.	0
Est. 30 other trade organizations	0
Total	**100%, or 500 items**



Despite advances in library science through automation, considerable duplication as well as omissions in technical area and time were encountered during the literature search. Lack of standard terminology relating to the subject matter also complicated the search process and many libraries were unable to define the limits of their subject area coverage.

Although the above difficulties created some delays, it is believed that the end result covered most of the pertinent and recent literature on fabric filter technology and that at least 90 percent of the useful U. S. publications were located. While the literature search was considered to be essentially of optimum size for the present program, it could be up-dated and made more complete in any of the following ways:

1. Up-date from mid-1969, using the principal sources listed in Table 5.
2. Back search the periods before and up to the early 1950's. The early literature was not searched systematically in this study, because: (a) there were already some bibliographies of air pollution technology extending back into the 1800's, and (b) fabric filtration technology prior to the 1950's was very limited in types of fabric and methods of cleaning.
3. Intensify search of the areas already reviewed. Some obscure journals were noted, but not located in the present search. In addition, manufacturers may have some experimental data for release, and sales brochures can be re-examined from several viewpoints.
4. Broaden the search to related areas such as liquid filtration, textile finishing, instrumentation, aerosol science, economics of sheet metal manufacturing or powder physics. About 100 abstracts in these peripheral areas were obtained at APTIC which have not been further processed.

5. Search foreign literature and domestic and foreign patents. Although patent searches had originally been considered in the present program, it was later decided that they would be more relevant to future equipment development programs.

2.4 OTHER DATA SOURCES

Nearly all the data used in this study came from equipment users, manufacturers and manufacturers' brochures, or from the open literature. City and county air pollution control groups in a few instances provided leads to installations of interest in their geographical areas. Similarly, a few trade organizations assisted in identifying people or plants that later contributed to the study. Although more than a dozen trade organizations were contacted, none were able to contribute any new data, with the exception of IGCI. Discussions with academic and industrial consultants yielded qualitative data that aided in shaping the opinions formed during the study. Personnel involved in past and current laboratory studies made at APCO and at the Harvard School of Public Health were especially helpful. A large amount of unpublished material was contributed to the study by APCO.

CHAPTER 3

ANALYSIS OF DATA

In this section, the methods of data analysis and the forms of data presentation selected for this study are discussed. Generally, data could be grouped in three main classifications:

- Applications and equipment markets
- Performance, engineering and economic
- Design and improvement of equipment

3.1 APPLICATIONS OF FILTER SYSTEMS

3.1.1 Status and Trends in the Filter Industry

A complete national inventory, listing all particulate sources and those presently controlled by fabric filters, accompanied by technical and economic data necessary to provide reliable aggregate estimates of the present market structure for filters, would be most useful. It would identify potential R&D requirements as well as providing a valuable document for national air pollution control policy planning. No such complete documentation exists. A few air pollution control agencies had source inventories in various stages of preparation, but access to these data was generally not permitted.

In the absence of any national inventory of particulate sources, an attempt was made in this survey to develop some reasonable estimate. The approach involved a soliciting of sales and use data from a sampling of individual manufacturers, and by surveying specific industrial sources to determine the distribution of fabric filter equipment among the different industries. The quality and extent of the data thus obtained, however, was limited to order of magnitude accuracy.

When filter applications in process industries are included, the estimate of total yearly sales rises to more than 10^4 collectors. Based upon the rate of growth in the number of filter manufacturers, (10 and 30, respectively in 1950 and 1960), the gross number of collectors sold over the 20 year period, 1950 to 1970, is estimated at 2×10^5

collectors. The same information sources suggest a historical growth rate in the fabric filter industry of about 7% and within the last few years, an approximate doubling of this rate. Refining of the above statistics beyond the levels cited here is beyond the scope of the present program.

3.1.2 Distribution of Equipment

In contrast to other types of particulate control equipment, notably, electrostatic precipitators, fabric filters can be operated economically in all sizes including units with as little as 10 ft^2 cloth area. This fact, plus the broad capabilities of fabric filter equipment, explains the 10^5 to 10^6 units of equipment that are in use. These applications might be categorized by effluent volume rate, particle size distribution, gas temperature, gas or particle corrosivity, industry, product or plant operations. It is unfortunately very difficult to analyze the distribution of the equipment because of the lack of national inventory data noted above.

An important portion of this study was the identification of needs in specific areas of application, together with a measure of the magnitude of each need, in order to justify possible subsequent R&D attention. The survey data have been collected across ten industrial categories, and in these same categories, the equipment distribution was examined using what manufacturers data were available. Distribution of sales for two recent years is summarized in Table 6.

Most of these major categories embrace several industries, e.g. non-ferrous metals includes primary copper, secondary copper, zinc galvanizing, and aluminum. Only in the non-metallic mineral category was a systematic survey of air pollution control equipment found. (See Appendix 1, Volume 2). The manufacturers' data in general did not specify the industrial process on which the filtration equipment was used. Thus, within the allocated program effort the distribution of filtration equipment among industries and industrial processes could not be determined quantitatively.

However, numerous APCO and other reports summarizing air pollution control activities in various industries enabled a listing of about

TABLE 6

DISTRIBUTION OF IGCI FABRIC FILTER SALES FOR AIR POLLUTION CONTROL*

Category	Percent Sales, 1966-67 Averages	
	Count Percent	Dollar Percent
Combustion	0.4	1.6
Food and Feed	5.8	5.4
Pulp and Paper	1.2	0.9
Inorganic Chemicals	2.5	3.6
Organic Chemicals	13.0	18.7
Petroleum Refining	0.6	1.2
Non-metallic Minerals	6.4	18.4
Iron and Steel	12.0	29.1
Non-Ferrous Metals	2.1	5.2
Miscellaneous	56.2	16.2

*Reported in greater detail in Tables 1.4 and 1.5, Volume I.

300 processes generating dusts and fumes. A condensation of this list, showing present and potential applications for fabric filters appears in Appendix 1. Usually the data source did not give details as to the extent of use of fabric filter equipment in these areas, nor were the needs for fabric filtration R&D usually given. Discussions with users, manufacturers, and review of the literature contributed to a subjective appreciation of the relative importance of various applications and needs.

Table 7 indicates the order-of-magnitude potential for fabric filtration equipment in a variety of industrial applications. To the present time, use of filtration equipment has been non-existent or at least very limited in these areas. The specific applications were selected from a larger list (see Appendix 1) either because they appear to have high potential or because they represent a general class of operations that might be controlled by filtration equipment. Examples of the latter are sulphuric acid plants and kraft pulp digesters which typify high moisture content and odor producing operations, respectively. Successful research and development of fabric filtration equipment for control of these areas would have far-reaching applications in other industries.

Three parameters are given in Table 7, each of which is basic to the economics of the indicated applications. These parameters relate to the probability that such applications might be considered seriously in the near future by equipment manufacturers or purchasers without government assistance. The parameters also indicate the probable effect of government or other third party assistance.

The first parameter, the sales volume of equipment that may be expected over the next ten year period (Column 1), is a measure of the interest that equipment manufacturers should have in these areas and their willingness to personally undertake the necessary R&D work. These figures are based on a) the present numbers and sizes of plants and the degree of control presently exercised, b) the likelihood of enforcement of plant control, c) the rate of growth of plant numbers and sizes, and d) the replacement rate of present control equipment. It is assumed that

TABLE 7

ESTIMATED POTENTIAL OF FABRIC FILTER APPLICATIONS IN SELECTED PROCESSES

Application	(1) Estimated[a)] Filter sales (10 yr.) $\$ \times 10^{-6}$	(2) Particulate[b)] Yield TPY x 10^{-6}	(3) Estimated R&D Needs $	(4) Incentive Indices[c)] Filter Sales/ Part. Yield	(5) Part. Yield/ R&D Dollars
High Yield					
1. Coal fired utility, low sulphur fuel	900	40	10^5	20	400
Moderate Yield					
2. Basic oxygen furnace	40	0.7	3×10^5	60	2
3. Kraft pulping,					
Kiln	20	0.4	10^5	50	4
Recovery furnace	10	0.2	2×10^5	50	1
4. SO_2 acid plant, catalytic	10	0.4[d)]	10^5	30	4
5. Oil fired utility	100	0.2	3×10^4	500	7
6. Municipal Incineration	50	0.1	3×10^4	500	3
Low Yield					
7. Calcium carbide plant	0.2	0.03	10^5	7	0.3
8. Cupola, iron foundry	30	0.02	2×10^5	1500	0.1
9. Kraft digester, odor control	2	0.02[d)]	2×10^5	100	0.1
10. Secondary zinc processing	(small)	0.01	10^5	--	0.1
11. Coke ovens, pushing process	20	.007	10^5	3000	0.07

a) Replacement and substitution in existing plants and installation in new plants over the next ten years.

b) Additional particulate emissions controlled at end of tenth year in tons per year.

c) Incentive indices

Column 4 = ratio of columns 1 and 2

Column 5 = ratio of columns 2 and 3

d) Potential control of gaseous emissions (tonnage not included) by modified fabric filter equipment.

filtration equipment will be developed to the point of being more attractive than equipment presently used. The indicated sales figures also reflect present costs of filtration equipment, modified in accordance with the problems expected for a proposed application.

The second parameter listed in Table 7 is the particulate yield, that is, the amount of particulate pollutant that would be controlled by these filter applications over and above the present degree of control. For example, if filtration equipment were to be used on 100 plants, only 50 of which now have control equipment that is 80 percent effective, then the filtration equipment is credited in Table 7 with a yield equal to the emission of 60 uncontrolled plants. However, particulate material larger than about 10 microns is excluded from the estimates, since it will probably be controlled more economically by other gas cleaning methods. In addition, the larger size fractions usually present much less of a health hazard. Any gases that may be controlled are not included in the yield figures.

The ratio of sales volume and particulate yield is given in Column 4. The smaller this index number, the more likely the equipment would be purchased by the indicated industry in the absence of any additional incentive (assuming that pollution enforcement regulations apply equally to all industries). For example, calcium carbide plants would much more readily purchase the needed equipment than the iron foundries and coke oven operators. In these latter cases, even if no R&D studies were required, the equipment might still not be purchased without further incentive.

The third basic parameter is the estimated cost of R&D programs to establish the necessary filtration technology. These estimates are of course especially difficult to make in a preliminary survey. In making these estimates, the amount of industry experience with fabric filtration equipment, as well as the unique problems associated with each application have been taken into consideration.

The ratio of particulate yield and R&D cost is given in Column 5 of Table 7. The larger the number, the more attractive is the expenditure from the APCO point of view, e.g., the coal fired utility application is especially attractive. In this instance, however, it would appear reasonable that equipment manufacturers undertake responsibility for R&D needs because of the potential market. This would permit APCO to support other needed control applications not offering the same sales incentives.

3.1.3 Outlook for New Applications

Present usage of fabric filters is already widespread with respect to both the number of units in service and the diversity in applications. It is believed, however, that there are several operations for which the substitution of fabric filter equipment might now afford engineering and economic advantages. Additionally, collector design improvements, stricter control requirements and changes in process economics may lead to many future applications that previously had not been considered feasible. The development of new processing techniques, e.g., the spray process for making steel and new industries, and catalyst manufacture, also point to fabric filtration as a prospective control method.

Thus, although it is difficult to predict the future size of the fabric filter market, there is no doubt that the number and diversity of applications will increase significantly.

The enactment of air pollution control legislation, which is probably an important factor in recent increased usage of fabric filters, will continue to play a large role for the next five years. Since the most offensive emission sources have already come under scrutiny and are being put under control, the following sources are likely subjects of future attention:

- small volume systems
- remote (isolated) locations
- nuisance emissions
- unique operations

Whereas many industrial processes were uncontrolled 15 years ago, most new plants now have some degree of control. Within another ten years, practically all older plants still in operation will use air pollution control systems if their emissions are in any way offensive.

The trend toward automation and continuous operation as opposed to batch processing is common to most industries. For continuous flow of material, a large and increasing number of solids are now being handled and processed in granular, powdered or pelletized form rather than in bulk form such as ingot or sheet. Since fabric filters are the most popular means of dust control for dry powders handling operations, this particular application may be expected to increase, for both pollution control and process convenience. In the latter case, the recovery of valuable fines is an economically attractive practice that does not require legislative enforcement. The development of improved filter equipment for air pollution control purposes, however, will also lead to still wider process applications.

The largest users of fabric filter equipment are the metal industries, e.g., iron and steel, aluminum, copper, zinc and lead. These industries share the common problems associated with high temperatures and very small particles that make emission control difficult with present equipment. However, fabrics and hardware materials able to better withstand high temperatures are under continuing development. It may be anticipated that improved fabrics and materials will increase filter usage in these areas. Several other industries who share these same problems will also profit by these technical advances.

Operating a filter near the dew point presents a problem common to many applications. Development of a filter system that can be continuously operated while damp or wet would result in much wider usage. The above R&D needs and many others are discussed in Section 3.6.

Combustion processes probably provide the largest current source of uncontrolled particulate emissions. Special fabric filter designs are now undergoing prototype evaluation on coal and oil-fired power plants and on municipal incinerators. Although electrostatic precipitators and scrubbers have traditionally been used here (and will continue to be used in some cases) the indications are that new developments in filtration technology will greatly expand the use of filters in these areas. One reason is that filters are also amenable to the control of sulphur dioxide, other gaseous emissions, and possibly odors by using absorbing additives. Control of emissions from institutional and domestic incinerators, from residential and industrial heating plants, and from automobiles and other vehicles suggest a large market for filtration equipment of some kind, if and when such control is demanded and the equipment is made available.

In terms of numbers, far more small fabric filters are sold than large filters. For every single 100,000 ft^2 installation, between 100 and 1000 units of order 100 ft^2 capacity are sold. In addition to the new emission regulation now being extended to the smaller sources, public awareness and concern about their inhalation of small particles are increasing. For the above reasons, the number of small fabric filters, sold per year during the next few years is expected to increase sharply.

Industrial applications, however, will predominate in the fabric filter market. Certain processes, notably fossil fuel combustion and waste incineration, are judged to offer high potential for particulate control by fabric filtration. These and other processes have been listed in Appendix 1.

3.2 PERFORMANCE ANALYSES

The main reason for using a fabric filter system is to prevent the release of particulate matter to the plant or outside environment, whether it be for product recovery or anti-pollution purposes. Therefore, the principal descriptor of performance is the collection efficiency of the system.

The collection efficiency for filter installations, on a weight basis, is remarkably high, almost always over 90%, frequently greater than 99%, and sometimes 99.9% or better. Other aspects of performance more difficult to evaluate include the reliability of the equipment in terms of the percent time it operates properly (usually 95% or better), and the simplicity of operating and maintenance procedures.

The best efficiency data are probably that reported in the literature (Appendix 6.4, Volume 2), because the authors reporting efficiency have either made or had access to actual tests and were willing to document the results. In contrast, most of the surveyed users of filter equipment did not know how the efficiency, believing it to be so high that tests had not been considered necessary. There were exceptions, of course, particularly among users requested to conform to certain emission standards. Manufacturers seldom warrant the collection efficiency of their equipment because the efficiency depends largely on the fabric, the dust particles, and on the maintenance by the equipment user.

In defense of those users and manufacturers who did not state the collection efficiency of their equipment, it is emphasized that efficiency is a variable quantity over both the span of each cleaning cycle and over the service of the fabric. Since in certain installations the collection efficiency of the equipment appears marginal with respect to present and future emission requirements, a study of efficiency is considered to be one R&D requirement (Chapter 4).

As for the reliability of fabric filter equipment, both the literature and the user survey provided good qualitative data in the form of problem commentary and suggestions for improvements (Chapter 8, Volume 1).

3.3 COST ANALYSES

In the previous section, collector performance was examined in terms of system efficiency, dependability, and ease of operation and maintenance. From a very practical standpoint, these attributes must be measured against the cost to achieve the desired performance. Given a required efficiency target, or a not-to-be-exceeded daily or hourly emission rate, it is essential that cost optimization procedures be conducted to minimize the overall cost of fabric filtration. A detailed presentation of cost data is given in Volume I, Chapter 7, of the Handbook.

Purchase costs for equipment and fabric media were obtained from manufacturers, users and the literature whereas maintenance labor requirements were derived chiefly from the user survey.

Data analyses were limited to development of tabular arrays and averaging methods without attempting to infer quantitative relationships between costs and the many contributing factors. In view of the relatively small sample size, a more detailed analysis was not considered justifiable at this time. The first step was to attempt to reduce cost categories to some common bases as shown in the following tabulation:

1. Installed Cost

   F.O.B. Fabric Filter
   Freight
   Fan and Motor
   Ducting
   Disposal Equipment
   Instrumentation
   Planning and Design
   Foundation and Installation Labor
   Start-up

2. Annual Cost

   Electric Power
   Cloth Purchases
   Labor
   Plant Overhead

3. Total Cost of Operation

   Annual Cost
   Amortization of the Installed Cost
   Interest on the Unamortized Amount of Installed Cost

Material costs were further adjusted to reflect 1969 price levels, using the Marshall and Stevens index. Despite these adjustments, however, ambiguity remained in some statements of cost, for example, literature reports stating that "The equipment cost $16,000 including the set of bags" might be construed to mean the cost of the dust collector as shipped, the collector alone installed, or installed plus one or more ancillary cost items. Income tax rebate for costs of replacement parts such as fabric may or may not have been included. Certain overhead items may be charged against the filter system or may remain hidden to the engineer-author making the report. Furthermore, it was not always possible to clarify these points during interviews with equipment users, although the user data are probably more reliable than the literature data in these respects.

Equipment manufacturers and others have objected to reporting cost averages on the grounds that they vary so much, that the averages will confuse the inexperienced. In order to avoid misleading statements, our cost averages are qualified by a statement that certain costs may vary by as much as a factor of ten from one installation to another. Additionally, specific costs for a number of representative installations have been tabulated in detail in Appendices to Chapter 7, Volume 1, in an effort to avoid misunderstandings.

3.4 ENGINEERING DESIGN ANALYSES

3.4.1 Collector Design

Over 100 different filter models are sold by the approximately 50 manufacturers of fabric filters. The word model is used herein to distinguish between collectors having variations in the design parameters listed below. Most models are available in either several discrete sizes or in a virtually unlimited range of sizes:

Collector Design Parameters Analyzed

- Type of Filter Element
  - Bag, Tube or Envelope
  - Flow Directions
    - Upward or Downward
    - Inward or Outward

Length, Diameter, and Spacings of Filter Elements
Type of Element Fastenings

Cleaning Method
Automatic Shaking, Vibration, Rapping
Reverse Flow, with or without Flexure
Pulse, Reverse or Forward
Reverse Jet
Sonic
Manual Shaking

Housing
Materials of Construction
Methods of Joining
Inlet and Outlet Valves

Most manufacturers furnished complete sets of their collector product brochures thus providing an excellent data base for available equipment.

The information given in Appendix 3 constitutes a useful guide in system planning or for equipment purchase since it provides data in the following areas:

Manufacturer's Name, Address
Model Name
Configuration
Envelope of Cylindrical Filter Element
Upward of Downward Flow
Inside or Outside Filtering
Method of Cleaning the Filter Fabric
Sizes Available as Standard Items
Types of Service Provided by the Equipment

It is emphasized that no information on cost or performance appears in Appendix 3. As noted previously, the results of the literature and user surveys did not provide sufficient data to generate detailed cost and performance analyses. Yet, the choice of design parameters given in Appendix 3 has a far reaching effect upon several factors relating to cost and engineering performance. The best possible qualitative assessment of these design factors has been discussed in Chapter 3, Volume I.

3.4.2 Fabric Design

While the program plan did not permit an exhaustive survey of fiber and fabric manufacturers and filter manufacturers and suppliers, a list of 55 firms was prepared (Appendix 4, Volume 2), that is estimated to comprise at least three fourths of such U.S. firms.

There are, however, hundreds of firms throughout the world including the U.S.A. who are engaged in the manufacture of fibers and fabric that are not used by or sold to fabric filter manufacturers. These firms represent additional sources of existing and new filtration materials depending upon advances in technology and changing economic factors.

The filter fabric manufacturing industry appears to be characterized by a relatively small number of principal fabric weavers and filters. This is probably the result of competitive factors. First, the filter fabric market occupies a small portion of the total fabric market for these manufacturers, and second, the capital investment necessary to produce filter fabrics is large. Also, the manufacture of such fabrics continues largely as an art in which experience and reputation are important. At the present time, the following observations can be made: (1) The design of a fabric specifically for dry filtration is limited mostly to applications having sufficient sales volume to make the enterprise profitable; (2) The relatively small number of fabrics used in dry filtration are sold or supplied by numerous firms under a variety of trade names; (3) Much of the design technology that has been developed is proprietary; and (4) There appears to be a considerable opportunity for R&D in the development of the filter fabric.

For the reasons stated above and because of limited performance and cost data, the analyses of fabric design parameters were treated on a qualitative basis. (Design: Chapter 4, Volume I; Cost: Chapter 7, Volume I).

<u>Fabric Design Parameters Reviewed</u>

Fiber Material, Diameter, Length
Yarn Twist, Plies, Weight
Weave Pattern, Felt Construction
Treatments - Chemical, Mechanical
Properties - Chemical, Mechanical

3.4.3 System Design

The collector, the fabric, and the necessary fans, ducting disposal facilities and other auxiliary components constitute the fabric filtration system.

In order to assemble a filter system, it is necessary to consider such factors as the properties of the dust, the steadiness of the process effluent flow, the ventilation needs at various system exhaust points and the quality and location of release of the filtered effluent. The following aspects of system design are discussed in the Handbook, Chapter 5:

Filtration System Design Analyses

- Effluent Definition
- Collector Selection or Design
- Fabric Selection
- Fan Location (Suction or Pressure Operation)
- Cost Trade-offs and Minimization

There are many decisions to be made and many specifications to be prepared in the design of a fabric filter system. Since the factors entering into the design of a system may not carry equal weighting in all situations, no simple design formula can be presented. Consequently, the approach followed in this study was to describe a general design approach with emphasis on interrelationships problems to expect and/or to avoid and methods of minimizing costs. The overall system design process is one area where R&D effort does not appear helpful, because the process is so much a matter of experience and judgment. Design or selection of individual components of the system, however, may be facilitated through R&D, (Chapter 4).

3.5 FUNDAMENTAL ANALYSES

Although the understanding of many aspects of particle and fiber relationships is fairly well developed, theories for predicting the mechanics of collecting and removing particles from a fabric have yet to

Although no results of manufacturers' research have been reported, it is known that their studies also have followed the same path.

3.6 OUTLOOK FOR NEW DEVELOPMENTS

Fabric filtration has a strong future both in well established and in new applications. The use of all types of particulate control equipment will parallel the anticipated industrial growth. In addition, fabric filtration will increase to a greater extent because of its unique capabilities. These are notably the ability to collect dust particles at very high efficiencies which will be of value with stricter emission requirements, and the ability to control smaller sources of emission more economically than other types of control equipment. Furthermore, fabric filtration offers considerable potential for the control of gaseous emissions for which there is little control technology at the present time. Similarly, filtration appears adaptable to the abatement of nuisance odors and visible plumes which will be of increasing value as society continues to emphasize the individual's esthetic senses as well as his health.

Present applications of fabric filters will expand with improvements in filter equipment and technology. With respect to existing fabric and hardware designs, some modest gains can be expected due to improved materials, closer process control, and better understanding of the filtration process. With better understanding, radically new filter designs, enabling, for example, economical particulate collection at filtration velocities of 100 fpm or more, may evolve. Hybridization of control equipment (e.g., electrostatic fabric precipitator-filter; spray-cleaned filter) may also be expected to result in wider application of the filtration principle.

Traditionally, developments in particulate control equipment have been slow in starting, as evidenced by the fact that today's basic equipment differs little from that in use 100 years ago. Most filtration fabrics are very similar to other textiles. One big reason for the lack of progress is that successful innovation requires field trials, where the cost of failure to the trial plant is large. Therefore the risk must be small, and the innovation can be only a small departure from the traditional design. Another reason for slow development is the high cost of experimentation sufficiently extensive to be meaningful. This cost is large compared to the R&D budget of most equipment manufacturers which is low partly because of the highly competitive aspects of filter manufacturing.

While significant new concepts may not be developed by the individual manufacturer, limited as he is in available capital and personnel, new developments nevertheless appear possible. New developments may properly be the function of a joint organization representing the pooled resources of several or all manufacturers, such as the Industrial Gas Cleaning Institute. This practice of joint R&D has been successful in a number of industries in expanding product acceptance. Alternatively, R&D may be funded by government agencies who are responsible for particulate control. Such concerted development efforts might greatly benefit the fabric filtration industry.

3.6.1 Concurrent R&D in the U.S.

Air pollution control equipment manufacturers are estimated to have spent \$5 x 10^6 on 1969 R&D programs, based on figures reported for 1965 through 1967 by the IGCI. This is of the order of 4% of total air pollution control equipment sales, of which about 30% is fabric filtration equipment. Thus approximately \$1.5 x 10^6 was probably devoted by the manufacturers to fabric filtration R&D. These figures are compared with those of other industries given by the U.S. Department of Commerce.*

	Est. 1969 Expend. for R&D	Est. R&D% of Sales
Chemicals & Allied Products	\$1,760 x 10^6	3.7
Stone, Clay, and Glass Products	200 x 10^6	1.3
Fabricated Metal Products	185 x 10^6	0.5
Machinery	1850 x 10^6	2.9
Motor Vehicles and Other Transportation Equipment	1400 x 10^6	3.0
Prof. and Scientific instruments	500 x 10^6	3.3

* 1969 USDC "Abstract of the U.S."

When the fabric filtration equipment R&D expenditure of $\$1.5 \times 10^6$ is divided by the number of manufacturers in the U.S. (about 50) or by the 10 manufacturers accounting for about 80% of the total equipment sales, the expenditure on R&D is estimated to be approximately:

$120,000 for the typical large manufacturer
$350,000 for the largest manufacturer
$ 0 for the smallest manufacturers

According to the IGCI figures, approximately one-third of the R&D monies were spent in each of three areas:

- improvement of existing equipment
- development of new equipment
- research in new areas

To what extent these expenditures should be truly classified as R&D is arbitrary; certainly R&D in sheet metal fabrication differs considerably from that in aerosol physics. Possibly the figure of 4% for fabric filtration manufacturers is misleadingly large. At any rate, since the nominal cost of a fabric filtration R&D program is of the order of $100,000, it would seem that few R&D programs of fundamental nature are funded by equipment manufacturers.

Filter users perform a smaller amount of R&D than manufacturers. Their efforts are generally confined to a specific application and are generally not made public unless the project is supported in part by public funds.

3.6.2 Collector Developments

Because fabric filtration equipment has been available for many years and has been applied to many dusts, it has already been the focus of many design, operational, maintenance, and economic analyses of varying depths. Thus, without new or more radical changes in design concepts, it does not appear likely that much improvement or increased usage of present equipment will ensue. Manufacturers are of the opinion they have exhausted all major avenues to improved performance and reduced costs. The equipment has been subjected to years of competitive selling; indeed, the competitive squeeze has pushed some equipment to the point of being shoddy. Although this same competition has given us the reverse jet and the pulse cleaned principles, such innovations occur only rarely, and are the exception rather than the rule.

Minor innovation continues, of course, in the form of changes in construction materials, fabrics, and instrumentation. These improvements will continue as long as manufacturers are cognizant of the problems their customers are having with the equipment (Chapter 8, Volume 1). But without a much greater effort, only minor developments can be expected.

This pessimistic view is supported by a review of the costs of fabric filtration. As Chapter 7, Volume 1 shows, the cost of the filter itself plus related capital costs represents only about 10% of the total cost of filtration. Thus to cut manufacturing costs by one tenth, a major effort for any well-established product, would amount to a reduction in total user cost of about 1%, which is a rather small incentive. Consequently, it is unlikely that much effort will be made. A similar argument can be made for fabric purchase costs. A longer fabric life is apt to mean a more expensive fabric, but may result in fewer sales per year. The net manufacturer profit level must be maintained in order for the R&D necessary for extending fabric life to be volunteered. (These arguments are superficial to a more complete economic analysis which involves the supply-demand relationship and the manufacturer's overhead and profit structure.)

Fortunately, with radical changes in design viewpoint on the horizon better filtration equipment may result from several potential "breakthroughs". New particle technology, new demands for gaseous and odor controls, and new requirements for emission and control reliability have altered the traditional task of filtration equipment. Changes in the cost of maintenance labor compared to the cost of equipment must now be recognized. New configurations are now of marked interest, and even configurations conceived years ago but rejected because of unfavorable economics or limited technologies may now be practicable.

3.6.2.1 High Velocity Filtration.- Although particles can be filtered over a wide velocity range, the power requirement rises with increasing velocity. In addition, the collection efficiency may not necessarily be favored by high-velocity filtration. Despite higher power costs for increased filter velocity, the size, cost and the space occupied by the collector all decrease with higher air/cloth ratio thus offering interesting trade-off potentials. The cost of maintenance may or may not decrease. The collection efficiency, however, can be influenced considerably by fiber geometry, size, and surface treatment, and by control of the electrostatic relationship between fibers and dust particles. Since efficiency is also dependent on particle size, collection improves with agglomeration ahead of the filter. Thus, although present-day technology appears to require filtration velocities of the order of 1 to 10 fpm, velocities of 100 fpm or considerably higher may eventually soon be practicable.

Adequate efficiency at 100 fpm using a half-inch mat of stainless steel fibers has been reported for a Michigan cupola operation. Open hearth fumes were successfully collected ten years ago using a 2-inch deep mat of slag wool, at velocities of 150 fpm. These applications of high velocity filtration demonstrate the technical feasibility of particle collection at high velocities.

An important requirement for high velocity filtration is the cleanability of the medium. For effective operation, all of the dust deposited during the previous loading cycle must be removed with virtually no damage to the filter. The open hearth deep bed filter could be adequately cleaned, even though a) such beds of high-temperature fibers tend to be more fragile than fabrics, and b) the deposit tends to require more cleaning energy at the higher collection velocities. Although the other pilot applications mentioned are still in progress, there is little question that suitable cleaning methods, probably based on current principles, will be found.

The final and overriding question is the economics of high-velocity filtration. The slag wool filter was finally deemed uneconomical because of the higher-than-expected cost of generating and recycling the slag wool. The cupola application uses a fixed rather than a re-cycled bed; on the other hand the cost of the stainless steel fiber mat is high at the present time (about \$10 per ft^2). Fiber cost per year is hoped to be comparable to present fibers. Although it is difficult to predict what the operating filter pressure loss will be, the fact that the cupola effluent is under considerable pressure will aid in reducing overall power requirements. In comparison with the conventional filtration cost average of \$1/CFM-year, projected high-filtration estimates are attractive.

3.6.2.2 Wet Filtration.- Operating a conventional fabric filter system near, at, or below the dew point of the gas mixture is almost always hazardous for several reasons: Liquid adhering to the fibers blocks the interstices and raises the pressure differential even to the point of stopping the flow; liquid acts as an adhesive between particles and fibers, making a mud not removable by the normal cleaning procedures and which may plug or blind the fabric irreversibly; many condensates are acidic and attack the dust collector panels, the fan, and the fabric. Generally, operation below the dew point is one of the greatest hazards.

On the other hand some cement dust fabric filters are reported to function adequately when damp. These examples of effective particulate control with fabric under dew point conditions may point the way to a reduction of condensation problems in fabric filtration, enabling cooler and more economical operation without fabric blinding and plugging. There are many possibilities for research and development in this area including the opportunity for concurrent wet-process odor control. The field is not a fresh one by any means, but new synthetics and changing economics make reassessment worthwhile.

3.6.2.3 Cleaning Methods.- It appears that at present all possible cleaning methods are being used, e.g., vertical and horizontal shake, radial pulsing, shock, vibration, etc. Nevertheless, careful analysis of these present methods will reduce them to a small number of basic cleaning principles, such as tensile strength rupture, shear and stripping. A rigorous analytical approach may then suggest other useful cleaning methods.

Various combinations of cleaning methods are now being used, for example, shake plus reverse flow, and sonic plus pulse. It is quite probable that new and perhaps more effective combinations will be suggested by the analyses just described. These analyses would involve detailed study of conventional equipment as well as laboratory cleaning studies.

3.6.2.4 Porous Ducting.- Many schemes have been tried over the years to concentrate an aerosol prior to particle removal with the objective of reducing the size required for the final separating equipment. These attempts have included inertial, electrostatic, thermal and other separating methods. Except for large particles, however, they have not been very successful, the main reason being that medium efficiency collection of small particles costs almost as much as high efficiency separation.

The concept of using a porous duct ahead of a pressurized filter to bleed off part of the gas going to the filter has been suggested. As might be anticipated, the problem is how to clean the inside of the duct. Sufficiently high velocities (15,000 fpm) are unquestionably capable of lifting and/or dragging large particles away from a tangential surface. Possibly a special duct lining configuration and/or high gas turbulence levels, could make the duct more self-cleaning at lower velocities. More likely, some additional cleaning process would be needed, such as internal or external gas pulsing, a reverse jet traveling outside the duct, or a spinning hydrofoil inside the duct.

The economics of porous duct separation are only moderately attractive, but would be more attractive if the permeation velocity through the duct could be increased above that through the fabric, taking advantage perhaps of the fact that no collection of particles is necessary in the ducting and should be minimized. In adopting the use of porous ducting, one would be replacing a closely packed system of fabric cylinders with an elongated metal cylinder. The advantage arises through utilizing a presently existent but unused area in exchange for expensive fabric and plant floor area. Additional attractiveness could conceivably come from new filtration technology.

3.6.2.5 Custom Designs.- At present, only large filter collectors are custom designed for specific applications. Smaller collectors are stocked by manufacturers and their distributors, and sometimes by users of large numbers of these collectors. In keeping with trends in other industries, custom designing will become available on smaller units using computer programs, greater standardization of parts and modules and automated assembly, etc. This will enable optimization in shapes and sizes, the use of multiple construction materials and more economical structures. Even new fabrics will be designed by computer. Manuals for operation and maintenance will be more closely tailored to specific applications.

3.6.2.6 Hybrid Filtration.- In the Handbook, various dust collectors using both fabric filtration and at least one other dust control principle have been mentioned. Such hybridizations of conventional types of equipment are summarized below:

I. Fabric filter used as primary stage
   A. As an open mesh fabric leading agglomerates to a secondary collector, e.g., a normal fabric filter, a cyclone, or a settling chamber.

II. Fabric filter used as secondary stage
   A. As a collector of agglomerates from a pre-conditioning process such as
      1. Triboelectric interaction between aerosol and mat, mesh, or granules, in either a fixed or a fluidized bed;
      2. Electrostatic corona charging; or

3. Spray scrubbing with the droplets fully evaporated. Droplets may also be charged for added collection efficiency.

B. As a collector of both wet and dry particulate, either

1. Self-draining if the liquid fraction is sufficient, or

2. Spray-cleaned, primarily with relatively open fabrics or mats.

III. Single stage fabric filtration, with added control;

A. Using an electrostatic control of the deposit structure, during formation;

B. Electrostatic transfer delay of filtration to a downstream part of the filter tube, for greater initial fabric permeability.

C. Electrostatic removal of dust deposit from fabric.

D. Other kinds of fabric or deposit control.

Since some of these prospects have already been explored by manufacturers, the first step in any development program would be an extensive review.

3.6.2.7 Miscellaneous.- Innovations to be seen in future filter collectors may include:

- rotary filter elements, possibly using centrifugal force for cleaning
- rotary cleaning vanes or foils past stationary filter elements
- pleated fabric for more rapid installation in roll lengths than separate filter elements
- water or oil-sealed bag ends, for more rapid installation than thimble attachment, and to eliminate flexure near the thimble.
- formed-in-place filter elements, using heat or time-setting adhesives and blown-in fibers.

3.6.3 Fabric Developments

Glass filter fabric represents an outstanding filter fabric breakthrough, primarily because of its temperature capability at low cost. Considering the materials development programs underway in all fields - ceramics, alloying, metal fibers, adhesives, laminating, molecular structures, etc. - it is virtually certain that new filtration fibers will continually be appearing. Along with these new fibers will be developed better fiber surface treatments for improved performance, for example, more durable lubricants for high temperature applications.

Improvement in fabric performance is the attribute most widely sought by filter users. Longer lived fabrics are especially wanted, notably those capable of withstanding flexure. For some applications of fabrics not tolerant of flexure rigid fibrous mats appear to be more feasible. Fabrics resistant to corrosion from acidic gases and fluorides are much needed. Higher temperature fabrics more capable of functioning in the range between 200 and 1000°F would find immediate applications partly because all fabric durability problems are accentuated at increased temperatures.

One obstacle to the development of more useful fabrics is an understanding of their requirements at the particle-fabric and particle-fiber interfaces. Fabrics have traditionally been 100% one material such as cotton, or glass. The use of two or more materials has more recently been seen in synthetic blends, and combinations of materials are likely to increase. For flexure-tolerant fabric, for example, in a situation where the flexure is primarily two-dimensional, steel-fibered yarn might be used to withstand the flexure, while in the unflexed dimension less expensive glass yarn might be used to collect the particles.

Fabrics or filter elements that are manually controllable may be developed. At present filter elements are passive; once installed the user has very little control over their performance although he has modest control of their life. Fabric or filter elements might be controlled in efficiency, or in porosity and permeability, by differential tension or positional adjustments of warp or fill yarns. Fabrics having electrostatically controllable properties for use in hybrid equipment are within sight, as discussed above. Controllable filter elements would enable optimization of performance, especially a distribution of performance over the life of the fabric.

Progress is also to be expected in fiber processing and fabric cost reduction, including simpler methods of combining fibers and other ingredients into finished filtration materials. Granules or sheet media other than woven or felted textile may become popular.

Part of the cost of present fabric arises from the many steps leading to their preparation, fiber spinning, fiber treating, weaving, finishing, fabric treating, sewing and installation. Possibly an overview of this long process would shorten it. For example, fibers being spun might be blow-cast inside a traveling cylinder, to form an endless filtration tube having predetermined properties. The tube could be sold as a roll and cut to length. Or, fibers might be blown as filter aid is blown into the dust collector, against wire mesh, and then bonded in place for normal cyclic filtration. The techniques for doing this need not be too complex for the filter user, especially if the blowing and bonding equipment were to be incorporated with the basic collector. Incipient holes might be patched with this capability of adding and bonding fibers, somewhat analogous to automobile radiator repair.

3.6.4 System Instruments and Controls

At present, small dust collectors are seldom equipped with instrumentation, and even the largest filter systems see only marginal use of control devices.

Those instruments commonly used or potentially useful to describe or control filter system operations are listed below:

Indicating
Recording
Controlling

Temperature
Pressure
Flow
Dew Point
Acidity
Electrometric Properties
Particle Properties
Fabric Properties

There is a well established trend to select equipment that operates with a minimum amount of attention, because of the increasing cost of labor. Since the cost of standard instruments and controls is not increasing as rapidly as labor, and since the capabilities of these devices are steadily improving, their increased utilization is inevitable. Demands on filter systems for more reliable dust collection at lower costs may also be expected to result in greater application of instruments and controls.

3.6.4.1 Particulate Properties.- Changes in the generating process temperature and materials handling rate may affect the size, shape, stickiness, electric charge and electrical conductivity of the suspended particulates. The influences of these properties on the operation of the filter system requires better understanding. Likewise, the stability and uniformity of the particulate loading and the degree of agglomeration approaching the fabric, will take on added importance. The effect on system operating cost of one or more of these particulate properties may well justify sensing and perhaps control of that property by on-line instrumentation.

There is already a need for on-line continuous duty monitoring of the low-level emissions from fabric filters. Certain emissions are marginally visible, and at present, visibility is frequently the criterion for evaluating collection performance. Since barely visible concentrations are of the same magnitude as legislated values, an instrumental aid to emission evaluation is needed. Laboratory instruments are available, but none are capable of continuous, service-free operation in a harsh industrial environment.

3.6.4.2 Dust Deposit Control.- The addition of large particles to the dust deposit may lower the deposit permeation resistance, improve deposit release from the fabric, and improve the handling of the collected dust. These particles may be a material foreign to the emission system (an additive such as limestone added to a flyash), or the normal larger fraction of emitted particulate kept in suspension by preventing gravitational or inertial separation prior to the filtration phase.

Forced agglomeration of the finer fraction of the process effluent prior to filtering may also serve to provide larger particles. In addition, agglomeration will hinder penetration of the fabric by the fines thus reducing blinding, interstitial abrasion, and seepage problems. Agglomeration might be enhanced by an increase in retention time between source and filtration zone or by controlled turbulence during the pre-filtration period. Electrostatic charging preceeding filtration will accelerate the agglomeration process and may also create more rigid agglomerates. Humidity and temperature doubtless affect agglomeration rate as well as agglomerate structure.

Agglomeration can be achieved with most particulate control equipment when it is deliberately operated at low efficiency. A low efficiency and inexpensive electrostatic precipitator, open mesh grid filter , or even a scrubber can increase the agglomerated fraction of the aerosol. The open mesh filter appears especially promising if cleaned by natural or timed loosening of the deposit in such a way that its steady state efficiency is zero. The "conditioned" or agglomerated material then passes on to the filter. Agglomeration ahead of the filter, which usually enhances filter performance, also should be economical from the system viewpoint. In the extreme case, agglomeration would eliminate the need for the filter, since the particulates could then be removed mechanically by lower cost methods.

The addition of a surfactant might affect the electrostatic properties of the particles, the rate of agglomeration, the strength of the agglomerates, the structure of the filter deposit, the ease of deposit release from the filter, or the ease of handling of the collected material.

The emission or source process might be modified for improved control of particle shape, size and surface properties if the "optimum" particle could be defined and measured. Although not a new idea, little has been done in this area for want of particle technology, instruments, control techniques, and above all, the failure to recognize the high costs of inadequate particle control.

3.6.4.3 Gaseous Properties.- A dewpoint sensing and alarm or control system is widely needed to reduce the danger of condensation damage while allowing operation of the filter system closer to the dew point. Cooling the gases an additional 25°F without danger of condensation could easily mean a 5% smaller flow volume and a commensurate power cost reduction. The greater saving might be in avoiding incipient condensation and its costs.

Temperature, pressure and flow sensors are now readily available. Closer control and hence more economical operation of the filter system is often possible using automatic control equipment based on these sensors. This automatic control equipment is for the most part commercially available.

3.6.4.4 Fabric Instruments.- A notable fabric-related operating problem is determining when the filter element has had sufficient cleaning. This is customarily solved by manually adjusting the cleaning process to obtain a satisfactorily low equilibrium residual filter drag. Although the manual adjustment process may be practical in some cases, the rather elementary logic involved suggests replacement by automatic equipment. Automatic adjustment of the cleaning cycle would enable not merely daily, but hourly or more frequent adjustment if warranted. It is only necessary to define the trade-off between the cost related to the cleaning action and the value received from the lower residual pressure.

A simple instrument for checking tension might be useful. There is, at present, no way of measuring the tension in the filter element, partly because the correct tension is unknown. Another expressed need is for instrumental aid in locating holes in the filter element and even more important, potential failure points.

3.6.4.5 Filter Control System.- An increasing number of sensors that respond rapidly to changes in particle, gas or fabric properties would appear as likely and necessary components in present and future fabric filter systems. For optimum utilization and economy, these sensing instruments could be packaged as standardized modules for insertion in the central control console. A package would consist of a solid state logic circuit fabricated as a plug-in module and standardized to adapt to a large number of filter systems. A multiplicity of the devices could be selected from a catalog to provide operational instructions, data, recorder procedures and alarm or caution signals. The units would display the dependability of solid state equipment with the cost advantages of off-the-shelf large production volume equipment.

A modular design control system could be either very simple or highly sophisticated while using the same basic components. It would enable more accurate operation than periodic manual adjustment by virtue of continuous optimization of the performance/cost relationships. The function of the control system would be the same as that achieved by online computer control in larger processes, but in this case, the "computer" would be merely an assembly of analog logic modules. In designing the control system, the engineer would tend to allow for reserve system capability.

3.6.5 Extensions of Fabric Filtration to Gas Collection

The selective removal of gaseous components or odors from an effluent has not until the last ten years, received the attention of particulate control. Consequently, the technology is still under development, partly due to technical obstacles which make gas and odor control more difficult and more expensive than particle control.

Most air pollution control equipment is designed either for particulate or for gaseous control, mainly because of significant differences in collection parameters. A notable exception is the wet scrubber in which moderate to high efficiencies are attainable with certain combinations of particulates and absorbable gases. Simultaneous control of both solids and gases,however, would be less expensive than separate control systems because of the sharing of ducting, fans, and in the case of fabric filter equipment, the filter medium itself.

Since many particulate emitting operations are accompanied by gaseous pollutants and objectionable odors, collectors designed for multipurpose use should have widespread application. The equipment would presumably incorporate special features for the optimized control of each type of pollutant.

Several experimental studies have shown that the aerolization of finely divided absorptive or adsorptive granular materials into the gas stream entering the fabric filter, will remove certain gaseous components.

The fact that good control of high specific surface powder and contact time are attainable with fabric filter systems suggests advantages over other collector types. Most recently, the removal of up to 98.4% of SO_2 by sodium bicarbonate powder on a fabric filter has been demonstrated at a coal-fired power plant in a joint APCO - Air Preheater Co. study. Fly ash and some NO_2 are removed at the same time.

The optimum equipment design for gaseous and particulate control will probably not be much different from present filter designs, except for the system used to introduce and probably recirculate the adsorbent material. The addition of relatively coarse particle aggregates to a filter cake should reduce power costs by increasing the cake porosity. Recirculation of agglomerated filter deposits appears feasible but there are no reports of this having been practiced. It would appear that agglomerate recirculation in conjunction with absorptive powder recirculation would be attractive in several gas and odor control applications.

Similarly, although use of odor absorbing additives within fabric filter equipment has not been reported, it appears a likely prospect. Granular charcoal, catalysts, or fritted impregnated material could be introduced to and removed from the filter, regenerated in special closely confined equipment, and then recirculated. The regeneration process might, in certain cases, develop chemical products of commercial or combustion value.

A retardant to the development of odor control technology is that very high control efficiencies are necessary, perhaps 99% or higher, in order to notice any reduction in odor, due to the broad response characteristics of the nasal system. Another retardant to equipment development is that odor is generally only a nuisance, and the economic reward for its control is less tenable than that for most other pollutants.

CHAPTER 4

IDENTIFICATION OF RESEARCH AND DEVELOPMENT REQUIREMENTS

4.1 INTRODUCTION

During the survey of fabric filter installations described earlier in Chapter 2 of this volume, those persons most familiar with the day-to-day operation and upkeep of the systems were personally interviewed. Their experience with operating problems and costs were of particular interest and, therefore, included in the approximately 130 questions asked during the interviews were the following:

- What are your principal causes of fabric failure?
- Have you tried other fabrics, and why are you using the present one?
- Do you receive any complaints regarding the quality of your filtered effluent?
- Do you have problems associated with fabric blinding?
- What, if any, are the major difficulties with your filter system?
- What aspects of performance or operation could be improved, based on your experience?
- What suggestions would you make for improvements in design or manufacture?
- What do you see as the principle requirements for research or development?

From the answers to these questions, 112 operating problems were identified and analyzed (see Chapter 8 of Volume I). Also, from the answers given, nearly 100 different suggestions for possible research and development investigations were obtained. These suggestions, which are presented in Appendix 4, together with other comments made in the literature and by equipment and fabric manufacturers, form the basis for the research and development programs that follow. The suggestions of more than 75 users and manufacturers are represented.

These suggestions have been interpreted to be research and development needs, having varying degrees of importance to the industry. The needs concern the overall filter system as well as specific system components and the selection, and the operation and maintenance of the equipment. The following condensed list enumerates the reported research and development need areas:

- Overall System Costs
- Collector Design
- Equipment Accesory to Collector
- Fabrics - Quality and Design
- Bag Fabrication
- Selection of Fabric
- Particles
- Dust Concentration Instrumentation
- Maintenance Aids
- Process Instrumentation
- Problems of Special Industries
- Gas Cleaning via Fabric Filtration
- Mechanical Aspects of Bag Life
- Cake Formation and Cleaning of the Cloth
- Chemical Resistance, and Wetness of the Cloth
- General Fabric Filter Study Extensions

Generally speaking, the R&D programs that follow are justified by the present costs of fabric filtration, by less than complete filtration effectiveness, and by effluents that are presently uncontrolled or controlled by other techniques, but which may be suited to control by filtration. Despite the extensive and continuing development of improvements in fabric filter systems by the equipment manufacturers, however, fabric filtration is still costly, and in many cases operates at less than acceptable efficiencies. In addition, fabric filter systems are not employed in numerous areas in which they could be applied with appropriate applications engineering efforts or with the employment of some of the developing technology in the subsystems or material areas.

We have grouped the research and development requirements into the following three categories: (1) Studies of the fundamental particle-fiber-gas mechanics involved in fabric filtration; (2) Studies aimed at improvement of fabric filter equipment and filter fabrics; and (3) Studies attempting to demonstrate the effectiveness of fabric filtration in specific applications. In terms of the organizations, laboratories and personnel performing the studies, they may be quite different, as are the objectives of the studies. To a plant engineer faced with a dust control problem, a fundamental study on filter-fiber-gas mechanics may appear somewhat academic, while to a research scientist desiring to improve the agglomerate structure of the same dust, a field demonstration may seem quite limited. All three types of study can definitely contribute to the present art, however, and all have been included within our interpretation of the expression "Research and Development Need".

4.2 DEFINITION AND CONTROL OF PARTICLE PROPERTIES

Both the performance and cost of fabric collectors are determined by the properties of the particulate matter being filtered. These properties, which are not completely defined or understood at present, include the diameter, size distribution, shape, surface characteristics, electrostatics, chemical reactivity, adhesiveness and hydroscopicity of the particles. They affect the structure of the deposited cake; its flow resistance; the power required for filtration; the rates of plugging and blinding; and the rate of mechanical abrasion of the fabric. In addition, they influence the particulate penetration through the filter, and thus, affect the collection efficiency of the system.

If it were possible to determine the relationships between the particle properties and the cost-performance effects, in advance of extended operation, significant operating improvements would undoubtedly accrue. Furthermore, some control of the particulate characteristics might be exercised, whereas at present this is rarely practiced. It may be possible, for example, to modify the structural features of the dust deposit, through an understanding of how the deposit is formed. The control of the particle size distribution reaching the filter may, in some cases, improve permeability and possibly the cleanability of the fabric as well.

It is recognized that the selection or design of particulate control equipment is dependent on both the dust-effluent stream parameters and the engineering parameters of the filtration system in operation or planned for installation (i.e., the specific design characteristics of the equipment produced by different fabric filter manufacturers). For this reason research programs dealing with particle properties should concentrate on developing basic data relating these properties to operating performance and cost which can then be applied by the different fabric filter manufacturers to specific applications problems and system designs.

4.2.1 Basic Particle Parameters

Statement of Problem - A fabric dust collector should be designed to meet the filtration requirements of the dust being filtered, but because the pertinent dust properties cannot be completely specified at the present time, collector design and use is now less than optimum for most application areas. The properties requiring theoretical and bench-scale study include: deposition velocity and particle diameter; length-diameter ratio; specific surfaces, angularity, and smoothness; chemi-potential or surface energy, and effects of absorbed molecular layers; initial electrical charge, distribution of charges, and rates and modes of charge dissipation; hardness. Because no compilation of contributing properties is available at this point in time, it is difficult to delineate the relative importance of these factors in dust filtration.

Program Description - A literature, theoretical, and laboratory study should be made of the particle parameters affecting the filter deposition, accumulation, migration, and removal of representative dusts. The processes of deposition and removal should be analyzed from theoretical considerations to determine the pertinent particle parameters and to estimate the range over which they are significant. Micromeritics literature should be surveyed to support the selection of these parameters, and to provide order-of-magnitude estimates of their effects. These effects may then be combined as dimensionless parameters, or in other suitable ways, to form a practicable basis for laboratory study. The laboratory phase should verify that these parameter groupings can adequately represent the characteristics of representative dusts in fabric filtration, and should provide order-of-magnitude indications of the importance of these groupings. The study should thus provide a firm basis for more applied investigations involving specific dust-fabric combinations.

Program Priority - High

Program Duration and Estimated Cost - The total cost for this program area is estimated to be $110,000 allocated as follows across a two year period:

First Year Effort	
Equipment and Material Costs:	$ 7,000
Manpower Costs:	$43,000
Total:	$50,000

Second Year Effort	
Equipment and Material Costs:	$10,000
Manpower Costs:	$50,000
Total:	$60,000

4.2.2 Deposit Modification and Control

Statement of the Problem - There is no universally accepted theory for describing the dust deposit nor any simple means for measuring its properties. There are indications that during the deposition process the dust cake changes from a somewhat open to a more dense structure. The end result may be described as cake collapse in the extreme case. To a lesser degree, compression may be engendered by viscous drag effects, by particle impingement, or by aging processes. Since deposit structure determines in large part the overall performance of the fabric filter system, it is difficult at present to establish suitable criteria for the design of dust collectors.

Program Description - The proposed study must combine the theoretical aspects of particle technology with engineering practicality. Deposit structure must be related to key particle parameters such as shape, size, roughness and cohesive forces. Since the number of such parameters could well exceed any practical manipulation, it appears advisable to introduce, define and measure a small set of intermediate parameters (or indices) such as:

- stickiness or cohesiveness
- deposit structure modulus
- probability of a particle depositing at a fixed site or migrating through the structure.

Fundamental particle parameters would be selected on the basis of their contributions to the intermediate parameters. In turn, the latter would be used to define the engineering aspects of the deposit control mechanisms including costs, and the overall effectiveness of the filter system.

Task 1. Definition of Deposit - The first study task will be to examine deposit structure in terms of fundamental properties of the component particles and relevant structure theory. Deposit parameters may be defined by geometric, rheological or statistical models of the structure incorporating whatever practical measurements can be made in the laboratory by microscope techniques, charge measurement, or other methods. The objectives will be to determine which variables should be incorporated in the intermediate or "working engineering" parameters for use in successor laboratory programs.

Task 2. Deposit Changes During Filtering - Selected dust and fabric combinations along with representative variations of flow and environmental parameters will form the basis for deposit studies. Possible reasons for dust cake compression and collapse should be sought and quantified. Suspect causes of compression are viscous drag which may result in gradual or abrupt collapse, pressure excursions due to shock waves from damper closing, mechanical vibrations, bag flexure, and deposition impact of particles upon the collection surface.

Alterations in cake properties can be measured in terms of permeability, ease of removal, and penetration of particles through the fabric as evidenced by downstream concentrations. Effects of humidity, electrostatic charge, surge chambers to minimize pressure pulses during filtration, additives and other factors that appear to improve cake properties should be investigated during both the Task 1 and 2 programs.

Task 3. Costing of Cake Control - Those mechanisms or processes which appear to enhance cake properties will be examined critically in terms of economic and engineering feasibility. The effectiveness of the cake control process would be assessed in terms of the basic performance parameters, i.e., cake permeability, ease of cleaning, and overall collection efficiency.

Program Priority - High

Program Duration and Estimated Cost - The total cost of the program across a two year period is estimated to be $100,000.

First Year Effort

Equipment and Material Costs:	$ 7,000
Manpower Costs:	38,000
Total:	$45,000

Second Year Effort

Equipment and Material Costs:	$ 3,000
Manpower Costs:	52,000
Total:	$55,000

4.2.3 Particle Size Control

Statement of the Problem - The particle size properties determine in large part the porosity of the filter dust deposit and, hence, the specific resistance of the dust cake. The addition of coarse particles is expected to reduce the resistance and possibly also facilitate cleaning, but the fact that the total dust loading to the filter has increased has a counter effect on filter pressure drop. Other adverse effects might include increased mechanical abrasion and penetration through the filter.

For these latter reasons the coarser size fraction is sometimes diverted by relatively inexpensive inertial devices before the dust reaches the filter. Prior conditioning of the dust by inducing agglomeration has also been used to alter the particle size reaching the filter. While the separate effects of particle size alteration may be estimated, the overall effects on cost and performance are difficult to predict in a general manner, or even in a specific application. Because so many of the basic fabric filter system cost and performance factors are related to particle size, it appears that a separate study of optimum size control is well justified.

Program Description

Task 1. Review of Experience in Particle Size Control - The objective of Task 1 is to provide preliminary estimates of the initial and operating costs of particle control methods. Primary information sources will be the open literature including patents, and the unpublished findings of fabric filter users and manufacturers. Additive techniques not necessarily directed toward filtration application will also be considered with respect to cost, materials and effect on size properties. Pre-separation of large particles by inertial collectors; agglomeration induced by turbulence, increased retention time, or electrostatic precipitators; use of fiber lubricants; and the dimensional aspects of additive particles should also be considered. The results of this study will include estimates of the cost and performance of any auxiliary fabric filter equipment, and project the overall filter system costs and performance. Furthermore, the Task 1 efforts will provide a rational basis for the conduct of laboratory and field experiments outlined below.

Task 2. Experimental Program - In selected applications, engineering studies will be made to verify the feasibility of the more promising particle control methods. Pilot equipment would be designed for laboratory tests and/or whenever possible, field trails. Preliminary studies would be based on the particle treatments investigated during Task 1 efforts, i.e., use of different additives, agglomeration techniques, or recycling of agglomerated hopper dust as the particle conditioner. Subsequently, those techniques which appeared practicable in terms of cost and system collection efficiency would be evaluated with various fabric types, filtering velocities, and cleaning techniques. This program should furnish improved estimates of how particle control techniques can be best utilized. At the same time, evaluation methods developed during this study will permit more rapid assessment of particle control methods proposed in the future.

Program Priority - Medium

Program Duration and Estimated Cost - The total cost for this 18 month program is estimated to be $100,000 allocated approximately as follows:

First Year Effort

Equipment and Material Costs:	$10,000
Manpower Costs:	60,000
Total:	$70,000

Next 6 Month Effort

Equipment and Material Costs:	$ 3,000
Manpower Costs:	27,000
Total:	$30,000

4.3 FABRIC INVESTIGATIONS

A recent survey of problems with operating fabric filter equipment indicated that over half of the problems reported were in some way associated with the fabric. Notable among these were problems of various types of wear abrasion and problems of dust adhesion in which the dust could not be removed with the usual cleaning method. Since fabric wear is often accentuated by a need for excessive cleaning, it is evident that the fabric surface plays a major role in fabric life and cleaning power requirements. The fabric surface also affects the dust cake permeability, and hence, the filtration power requirements. Apart from the fabric surface, the geometry and mechanics of the fabric are related to the cleaning process and fabric performance generally.

While some laboratory work has been completed which relates fabric properties to operating cost and performance factors, the studies have been mainly exploratory. In general, quantitative predictions as to the effects of fabric properties on system performance and operating cost are not possible at the present time. This is undoubtedly one of the major reasons that the needs and requirements have not been fully determined. Even the selection of fabrics for specific installations is handicapped by a sparcity of performance data.

Likewise, the availability of fibers suitable for fabric filtration appears limited at present, even though these fibers determine, to a large extent, the characteristics of the filter fabric. Synthetic fibers have recently made inroads on the traditional use of cotton and wool for filtration. Unfortunately, the total market for synthetic fiber so far outweighs the market for filtration fiber that little, if any, synthetic fiber is designed and produced specifically for dust filtration. This applies as well to glass fiber, although finishing treatments for glass fiber help significantly to tailor the material to specific applications. Thus, in addition to studies of cost and performance of the available fabric media and their surfaces, additional study should determine how improved fibers can be manufactured for use in filtration systems.

4.3.1 Fabric Surfaces Study

Statement of Problem - Little is known about the electrical, geometric, adhesive and mechanical properties of the filter fabric surface despite the fact that the interface between the dust and fabric surface is, perhaps, the single most important feature of the entire filter system. In the present context, the filter fabric "surface" is defined as that region of the fabric which, in successive loading and cleaning cycles, has a significant influence on deposition and removal characteristics. Despite the fact that there are many manufacturing techniques that might be used to produce a broad range of surface properties, the filter user does not possess the technical data required to specify which attributes are most desirable in his fabric. Further, the common practice in the filtration industry has been to adapt available filter materials that appear to meet immediate gas cleaning needs into woven and felted media. In most cases, the fabrics have not been designed with filtration applications in mind.

Program Description - The object of this study is to determine how the surface properties of filter fabrics affect the operational aspects of the fabric filter system. Therefore, the laboratory program should concentrate on the investigation of a large number of fabric surfaces. Related factors entering into overall fabric performance such as dust properties, gas flow rates, temperature, humidity, etc., should be treated as minor variables in this study. This research should follow R&D Program 4.2.2, Deposit Modification and Control, since many dust cake parameters defined in the latter study will provide useful background data.

Task Area 1 - Literature Review, Theoretical Approaches, Experiment Planning - A review of the available literature and, in particular, the results of Task 1 of the Deposit Modification and Control Study represents the logical starting point for this program. The main objectives will be to define and characterize which fabric surface properties should play key roles in filter performance. This will entail consideration of weave, nap, smoothness, chemical treatments, mechanical and electrostatic properties, and other related factors. In assessing fabric properties, it must be recognized that in field practice one is dealing almost entirely with "used" media that contain residual dust deposits, have undergone stress, and may show altered charge or coating characteristics. The output from the above study will be a listing of selected variables that: (a) will be investigated in the successor laboratory program; and (b) represent a first estimate of what constitutes important procurement specifications.

Task Area 2 - Laboratory Evaluation of Fabric Surface Parameters - A concurrent laboratory program is proposed since the Task 1 screening studies cannot be accomplished based on theoretical considerations alone. By performing a series of experiments intended to confirm or negate postulated theories, one can decide which surface properties are most important. Typical experiments would include the following:

- Determination of the effect of a given property upon permeability and cleaning characteristics.
- Determination of pressure drop and collection efficiency for several fabric permutations after lengthy fabric conditioning under specified loading conditions.
- Investigation of cake removal uniformity, on both a macro-scale and filter pore scale, possibly using scanning electron microscopy in the later case.
- Investigation of in-depth particle penetration by microscopic examination and, possibly, by x-ray scanning.

Generally, the experiments should be designed so that the fabric filter property can be shown to exert some quantitative effect on a readily measured operating parameter, i.e., permeability, collection efficiency, or cleaning power requirements. For this reason, studies of individual particle-fiber interactions should not be included in this program. The end product of the Task Area 2 studies should: (a) suggest guidelines for fabric surface optimization, and (b) suggest approaches to the improved operation of filter collectors.

Program Priority - High

Program Duration and Estimated Cost - The total cost for this program area is estimated to be $450,000 allocated across a 3½ year period:

First Year Effort

Equipment and Material Costs:	$ 5,000
Manpower Cost:	95,000
Total:	$100,000

Second Year Effort

Equipment and Material Costs:	$ 15,000
Manpower Costs:	110,000
Total:	$125,000

Third Year Effort		
Equipment and Material Costs:		$ 10,000
Manpower Costs:		140,000
	Total:	$150,000

Last Six Month Effort		
Equipment and Material Costs:		$ 5,000
Manpower Costs:		70,000
	Total:	$ 75,000

4.3.2 Fabric Performance

Statement of Problem - The overall cost and performance of a fabric filter system are determined principally by the filter media, the primary element of the system. The cost of the media itself may represent only 5 to 20 percent of the overall annual cost, but because the fabric contributes indirectly to the costs of maintenance, fabric-related costs may sometimes be as much as 50 percent of the annual operating cost. Thus, the selection of the most suitable fabric available becomes an important factor. Usually, fabric selection is based on prior experience or, at best, on time-consuming trails. Experience is not always an adequate criterion, because it does not necessarily follow that high efficiency collection at costs believed to be reasonable is an indication of the optimum fabric choice. Furthermore, all fabrics now used in filter systems have limitations that can conceivably be circumvented through better design. Since only limited data are available at the present time, a comprehensive study of all factors entering into the cost and performance of fabric filter media should be undertaken.

Program Description - All programs outlined in this five task study are strictly applications oriented. Fundamental aspects will be considered only as necessary to guide the experiment designs. These studies relate to common field operating problems, e.g., design of filter elements; fabric life; reasons for failure such as attrition, temperature effects, overcleaning; cost factors and overall performance. Data sources will include the results of field inspections, interviews with users, and pilot and bench scale laboratory tests.

Task 1. Review of Fabric Manufacturing Methods, Capabilities and Costs - This study is intended to provide a comprehensive review of fabric technology as applied to the design and manufacture of woven and felted media for gas filtration. One objective is to acquaint the fabric filter user and manufacturer with the capabilities and present limitations in textile production technology so that proposed new designs or recommended improvements in filter media will be practically oriented. Another objective is to direct the attention of the textile manufacturer to the special needs of the filter user and to encourage further research in this area.

A survey of fiber properties, spinning and weaving methods, and mechanical or other finishing techniques, including definitive statements as to how desired fabric properties can be designed or controlled should be performed. Data pertaining to materials sources, cost, precision in regulation of properties, and textile suppliers will also be furnished. In addition, special problems attendant with the cutting, sewing, surface treatments, or attachments of hardware to fabric configurations (bags, tubes, or envelopes) will be examined with respect to their impact on filter system costs.

Task 2. Field Study of Fabric Attrition - This study will constitute a field survey of 30 to 50 different filter applications to determine what role fabric attrition plays in the filter system. At the present time, neither the individual filter user nor the dust collector manufacturer have investigated this problem in a truly effective manner. Furthermore, testing methods commonly used for evaluating fabrics for non-filtration purposes are not directly applicable to the attrition problem. Rating of fabrics for thermal, corrosive, or moisture resistance properties, however, have provided useful guidelines for filter users.

It is recognized that several factors may combine to cause surface abrasion and internal abrasion or chafing, e.g., bag tension, grittness of dust, and flexure rate. For this reason, a field examination of these problems permits a much broader coverage of suspect factors and their inter-relationships than can be attained in the laboratory. The results of the analysis of field problems, however, should provide logical guidelines for laboratory pilot scale investigations. In addition, the study output should contain realistic suggestions for extending fabric life in each of the types of field applications investigated.

Task 3. Laboratory Study of Fabric Attrition by Abrasion - The frequency of occurrence and the economic losses attributed to fabric failure due to attrition related to dust particles justify a separate laboratory study of this problem. The direction for this study should be guided by the results of the Task 2 studies from which one can decide which operating parameters, fabric types, and dust properties are most frequently associated with fabric failure. The current literature describing the effects of gritty materials upon fabrics relates mainly to carpeting, clothing canvas and other protective or decorating coverings. There is little information on surface or interfiber effects, particularly for the much smaller particle sizes encountered in fabric filter systems.

Therefore, the laboratory study will include the evaluation of some 20 to 30 typical filter fabrics with at least five dusts. Dust properties of interest should be size, hardness, sphericity, angularity and possibly chemical reactivity. Rating procedures will entail loading the fabrics under standard filtration conditions followed by flexural endurance techniques of the types used in the textile industry. Those materials showing marked indications of damage will be subjected to testing at higher temperature or other variations typical of environmental parameters. Damage would be assessed in terms of increased dust penetration, fabric rupture point, interstitial fiber breakage, and loss of fiber nap. The results of this program, aside from amplifying the Task 1 studies are intended to suggest improvements in fabric design and in cleaning technology.

Task 4. High Temperature Filtration Substrate Developments - Fabric filter applications are generally limited to gas temperatures below about 500^{o}F. Fabric developments over the past 25 years have resulted in: (1) improved polymeric materials to achieve chemical compatibility with particulates or carrying gas, and (2) improved temperature resistance. There is, however, a class of high temperature applications associated with furnace and reactor technology that requires expensive gas cooling for use of fabric filters. Although developments in higher temperature fabrics appear promising, more effort and support are required to establish their technical and economic feasibility. The proposed study should be directed to thorough review of all metallic, ceramic and polymeric fibrous or needle developments. It would include the selection and laboratory testing at high temperature of fabric, web, or other arrangements on simulant gases and dusts representative of specific high-temperature applications.

Task 5. Coordinate Fabric Performance Information - The Handbook of Fabric Filter Technology, although based upon the best information available at the time, contains limited information on fabric performance. It is expected that the results of Cleaning Mechanisms and Kinetics Study and the other R&D programs on fabric filter systems enumerated in these R&D recommendations will generate considerable new and valuable information. These findings should be presented in document form, probably as revisions of the appropriate Handbook Chapters.

Program Priority - High

Program Duration and Estimated Cost - The total estimated cost for this 4 year program is $570,000 allocated as follows:

First Year Effort

Equipment and Material Costs:	$ 15,000
Manpower Cost:	105,000
Total:	$120,000

Second Year Effort

Equipment and Material Costs:	$ 25,000
Manpower Costs:	145,000
Total:	$170,000

Third Year Effort

Equipment and Material Costs:	$ 20,000
Manpower Costs:	150,000
Total:	$170,000

Fourth Year Effort

Equipment and Material Costs:	$ 5,000
Manpower Costs:	105,000
Total:	$110,000

4.3.3 New Fabric Material Investigations

Statement of the Problem - Directly or indirectly, filtration fiber materials are related to a large fraction of the costs of fabric filtration, and these costs could possibly be reduced by the availability of improved fibers and also fabric filters could possibly be employed in a wider range of applications.

Program Description - The recommended study of current fibers should compare the fiber requirements imposed by dust collectors with the present production capabilities of fiber manufacturers. This will require two parallel investigations: first, a survey of the fiber characteristics contributing to dust collection together with a selection of those characteristics notably lacking; and second, a survey of techniques now used by manufacturers to control fiber characteristics. The study should provide an economic justification for the production of improved fibers, and should outline the type and degree of APCO support required.

As a result of the initial study efforts, one or more areas of fiber improvement may require laboratory exploration and field tests. A present manufacturer of somewhat similar fiber would produce a pilot quantity of the new fiber. This would then be made into a filter fabric and given suitable testing.

Program Priority - Low

Program Duration and Estimated Cost - The total cost of this program area is estimated to be $250,000 allocated as follows across a 4 year period:

First Year Effort

Equipment and Material Costs:	$ 5,000
Manpower Costs:	95,000
Total:	$100,000

Second Year Effort

Equipment and Material Costs:	$10,000
Manpower Costs:	65,000
Total:	$75,000

Third Year Effort

Equipment and Material Costs:	$ 5,000
Manpower Costs:	32,000
Total:	$37,000

Fourth Year Effort

Equipment and Material Costs:	$ 8,000
Manpower Costs:	30,000
Total:	$38,000

4.4 SYSTEM DESIGN STUDIES

Recent pollution control and industrial economics trends are increasing the importance ascribed to fabric filtration equipment. Higher efficiency and more reliable dust collection calls for improved equipment which must be better designed than that traditionally available. This equipment will probably be more expensive, but careful design and selection of the cleaning process and equipment, the materials of the collector, and the instruments and controls of the collecting system will minimize the cost. At present, although only about 5 percent of the daily dust collection cost is due to the purchase cost of the collector alone, the indirect costs relating to the design and choice of the collector may be as much as 20 percent of the daily cost. This includes the effect of the collector design on maintenance requirements, space requirements, fabric cleaning, etc. Other aspects of the design of the collecting system have similar indirect although far reaching effects, notably the fabric cleaning sub-system and the control instrument sub-system. These are each of sufficient importance to justify a separate study, as outlined below.

Because so many aspects of the design of filtration systems have far reaching effects and depend on numerous characteristics of the dust and gas effluent streams, a study is also needed to synthesize systems-related information as it develops. Finally, it is recommended that certain information gathering and dissemination activities be continued as an aid to the other studies outlined in this document.

4.4.1 Cleaning Mechanisms and Kinetics

Statement of Problem - The successful performance of a fabric filter system depends upon the continuous or intermittent removal of the accumulated dust deposit. In current practice, filter surfaces are cleaned mainly by mechanical methods (shaking, flexing, or vibrating) and aerodynamic methods (high or low velocity reverse flow air, and pulse jetting). With respect to fabric filter systems, the cleaning operation is the only step requiring the application of external energy aside from the gas moving and dust disposal equipment common to all dust collecting apparatus. The cleaning operation bears directly or indirectly upon almost all aspects of filter system cost.

Despite the importance of cleaning, there still remains much uncertainty as to which mechanisms predominate in separating the dust from the fabric surface and what form of energy application produces the most effective cleaning. Therefore, in order to attain maximum collection efficiency at the lowest possible cost, it is essential that a systematic study of cleaning mechanisms and related phenomena be performed.

Program Description - The study emphasis should be directed to defining the relationship between the bonding (adhesion and cohesion) and removal forces (i.e., acceleration, flexure, shear, aerodynamic drag, and pressure contribute to particle removal) existing at the dust-layer fabric interface. The effectiveness of the cleaning process should be evaluated in terms of the amount of dust removal, the permeability of the residual deposit, and the collecting efficiency of the cleaned fabric.

For best utilization of the experimental measurements, tests should be performed on a pilot scale, although bench scale experiments may at times provide improved direction to the pilot plant effort. This approach is intended to provide a maximum extrapolation capability to full scale equipment.

Experimental measurements should include the following:

Effluent Characteristics - gas velocity, dust concentrations, dust type, dust size distribution, pressure drop, deposit profiles.

Cleaning Parameters - frequency, amplitude, duration, etc.

Collection Efficiency - initial, final and average.

Direct outputs from this study will include:

Indices of cleaning effectiveness related to cleaning inputs, generalized for dust and fabric properties and filtration conditions.

Comparison of cleaning energy or forces to adhesion and cohesion energy or forces.

Analytical relationships generalizing the cleaning performance.

Program Priority - High

Program Duration and Estimated Cost - The total cost of the program is estimated to be $430,000 across a two year period of time:

First Year Effort

Equipment and Material Costs:	$ 40,000
Manpower Costs:	180,000
Total:	$220,000

Second Year Effort

Equipment and Material Costs:	$ 20,000
Manpower Costs:	190,000
Total:	$210,000

4.4.2 Improved Fabric Filtration Equipment

Statement of Problem - An estimated 15 to 20 percent of the costs of dust filtration are directly or indirectly related to the design of the dust collector. Improved design and selection should lower costs and eventually lead to wider acceptance of this method of particulate control.

Program Description

Task 1. Compilation of Data on New Collector Designs - Information is available from manufacturers of collector equipment and certain of the larger equipment users, concerning numerous trials involving novel configurations, cleaning methods, fabric arrangements, fabric types, construction materials, etc. These records of R&D effort would be invaluable in projecting ahead the types of equipment which can be developed. A procedure for remuneration to these manufacturers would be established. Patent literature searches of such topics as fabric design, tensioning methods, cleaning methods, and collector designs will also yield information now unused by the industry, but nonetheless valuable.

A systems analysis of the potential for new collector designs would be performed. This analysis would begin with conceptual restraints on filtration media and filter-aided collection devices, media configuration and packing, deposit removal mechanisms, and human factors (construction and maintenance). The resulting conceptual possibilities would be combined into engineering designs for possible subsequent laboratory exploration.

Task 2. Selection Guidelines for Collector Users - A concise guide to the selection of fabric dust collectors should be prepared for the inexperienced purchaser. This might well be a condensation of portions of the Fabric Filter Systems Handbook. The guide should be made available at minimum cost to any interested firm including equipment manufacturers and research organizations. It will serve not only in the selection of equipment, but with little modification, will enable the preliminary design of collectors and of filtration systems as well.

Program Priority - Low

Program Duration and Estimated Costs - The total cost of this program is estimated to be $250,000 across a 2½ year period of time:

First Year Effort

Equipment and Material Costs:		$10,000
Manpower Costs:		80,000
	Total:	$90,000

Second Year Effort

Equipment and Material Costs:		$15,000
Manpower Costs:		75,000
	Total:	$90,000

Last 6 Month Effort

Equipment and Material Costs:		$12,000
Manpower Costs:		58,000
	Total:	$70,000

4.4.3 Control Equipment and Instrumentation

Statement of the Problem - Field inspection of existing industrial fabric filter systems has indicated that the employment of control instrumentation is minimal. The descriptions of many problems reported for filter systems suggests strongly that inadequate control equipment and instrumentation have led to costly breakdowns. Since it is expected that the developing technology will require increased sophistication in system operation, there is a need to determine what types of sensing, indicating and control equipment should be used to achieve optimum filter system performance.

Under the present strict ambient air quality regulations it may be necessary to monitor particulate effluents continuously to ascertain that emission standards are being met. Such monitoring will undoubtedly require stricter control of all aspects of the gas cleaning process. Furthermore, the need for increased investment in filtration equipment will compel the user to protect his investment with adequate control instrumentation.

Pressure loss, temperature, and humidity represent three areas where current measurements are often lacking or inadequate. Excursions beyond predetermined working ranges for the above variables can lead to bag rupture through over-pressure, fabric deterioration by heat, or fabric blinding by moisture condensation. Other variables affecting system performance include gas flow rates, bag tension, degree of bag cleaning achieved, dust concentration (inlet and outlet), particle size and electrical properties of dust. Measurement of the above variables may be used to operate flow dampers, supply reheat air, regulate cleaning cycles and initiate emergency control procedures. There are currently some instruments on the market which can be directly applied to filter applications. There is an apparent need, however, to develop new instruments specifically for fabric filter operation. Concurrently, the question of the degree to which instruments will benefit the filter user should be explored, from the points of view of cost and system performance.

Program Description - The main objective of this study will be to establish the combinations of control devices and sensing instruments that will provide optimum filter performance.

Task 1. Instrument Survey - This task will entail a detailed survey of sources, cost, and performance of available instrumentation; an analysis of equipment needs with anticipated costs for purchase, installation, maintenance, estimated size of the instrument market; and the feasibility of and suggested approaches for development of the needed instruments. The results of this study will be in the form of a market guide to instrumentation available to fabric filter users, and the documentation to encourage instrument manufacturers or other agencies to provide new and improved instrumentation.

Task 2. Control Methods Survey - This task area will involve a survey of current methods and devices used to control key filter system variables such as pressure, temperature, dew point and gas flow rates. Emphasis would be placed upon the cost benefits and effectiveness of these devices in terms of their respective advantages and disadvantages.

For example, temperature, a critical factor in many systems must be controlled by radiative cooling, spray cooling or air dilution. However, precise regulation is required to maintain temperature levels above the dew point and in all cases problems of cost, space requirement and reliability must be considered. In such areas as described above, control systems should be examined in terms of necessary improvements or alternative systems. The output from this study would be presented in essentially the same form as that from the Task 1 instrument survey.

Program Priority - Low

Program Duration and Estimated Cost - The total cost for this one year program is estimated to be $100,000 allocated as follows:

Material and Equipment Costs:	$ 5,000
Manpower Costs:	95,000
Total:	$100,000

4.4.4 Fabric Filter System Modeling

Statement of Problem - Many parameters influence the performance and the total annual cost of filter system operation. They are so interwoven, however, that it is difficult even with extensive experience and dealing with only a single parameter, to see the overall picture and to appreciate the effects of parametric changes. For example, a change in dust size properties upstream of the filter may affect the deposit permeability, adhesion, plugging and blinding, seepage, residual profile, and fabric life. Similarly, dust concentration changes, variations in gas volume, and humidity, will affect system pressure loss and power requirements in numerous ways.

There are, at the present time, only fragmentary models describing the performance of individual system components based upon laboratory measurements, field measurements or purely theoretical considerations. It should be possible to develop models covering a broader scope and having greater utility based upon data already available or in the process of generation by on-going programs. A comprehensive and flexible model could be applied to the immediate needs of optimizing system design; estimating installation and operating costs associated with different design approaches in specific application areas; and investigating the predictions made by different theoretical approaches for describing dust cake structure and removal. Such a model or series of sub-models would prove useful as a tool for evaluating proposed R&D programs and as a predictor of fabric filter system cost and performance.

Program Description - The program effort should be directed at developing a computer program adapted to as wide a range of digital equipment as possible. It should be readily comprehensible and simple to use. The model should provide such information as cost, efficiency, and other performance factors in terms of inlet dust properties and system design parameters. It should be applicable to practically all types of fabric filter systems, and accommodate the range of particulate materials (coarse dust to fine fume) requiring filtration. An important program output would be a table of "influence coefficients" showing the percentage change in given output parameters for changes in selected input parameters. The model should be flexibly structured to facilitate the inclusion of new technology as it develops.

Program Priority - Medium

Program Duration and Estimated Cost - Since this program is dependent on the results of the other research program, it is recommended that it be conducted with a low level effort across a three year period. It is estimated that the total program cost would be approximately $150,000 allocated, by year, as follows:

First Year Effort

Computer Cost:		$ 5,000
Manpower Cost:		30,000
	Total:	$35,000

Second Year Effort

Computer Cost:		$10,000
Manpower Cost:		65,000
	Total:	$75,000

Third Year Effort

Computer Cost:		$ 5,000
Manpower Cost:		35,000
	Total:	$40,000

4.4.5 Continuation of the Fabric Filter System Study

Statement of the Problem - The fabric filter system study isolated several areas of fabric filter technology and industry characterization which were too extensive for complete coverage in the initial program effort. Moreover, the continuing development of information from on-going (and contemplated) R&D indicates the need for additional and continuing compilation, integration and directive activities.

Program Description - The requirements of this study area have been grouped into a series of three program tasks which are considered necessary to maximize the development of fabric filtration systems; (a) compilation of design data on new fabric filtration equipment, (b) extension of the technology surveys in fabric filtration and updating of Fabric Filter Handbook, and (c) conduct of a fabric filtration seminar. Each of these areas are discussed in the following text.

Task 1. Compilation of Design Data - Until the last twenty years, fabric filtration equipment was basically unchanged from that existent in the late 1800's. Recently, substantial innovations in fabrics and cleaning methods have been made. Further innovation has been projected, as a result of need for closer control, improved materials, deeper understanding of the related particle mechanics, etc. In particular, the dust collector itself may undergo further modification as a result of these recent developments. A survey of the prospects for collector modification should be made. Information is available from manufacturers of collector equipment and certain of the larger users of the equipment, concerning the results of miscellaneous trials involving novel configurations, cleaning methods and fabric arrangements, fabric types, etc. These records of R&D effort, together with the design guidelines now being used by the manufacturers, would be invaluable in projecting ahead the types of equipment which may be developed. A procedure for remuneration to these manufacturers would be established. Patent literature searches of such topics as fabric design, tensioning methods, cleaning methods, and novel collector designs will also yield valuable information.

A systems analysis of the potential for new collector designs would be performed. This analysis would begin with conceptual limitations for filtration media, and filter aided collection devices, media configuration and packing, deposit removal mechanisms, and human factors (construction and maintenance). The possibilities would be developed into conceptual engineering designs for possible subsequent laboratory exploration.

Task 2. Up-dating of the Handbook of Fabric Filter Technology - There are a number of areas of fabric filtration technology which should be examined in greater depth, and summarized as revisions of portions of the Handbook. These are enumerated below:

1. Wider survey of fiber, fabric, and filter element sewing firms, and of literature relating to filtration fabrics.
2. Survey of foreign applications and technology relating to present and future applications; engineering, fundamental, or economic data; and experiential problems and needs. There is believed to be a considerable German, Russian, Japanese, and Czechoslovakian literature body, in particular.
3. Projection of future needs of fabrics and equipment. This is a difficult task, as little information regarding future industrial processes is available in any detail. The projections should consider expected temperatures, economics of alternative gas cleaning processes, legislative requirements, and market sizes based on current trends.
4. Literature survey extensions, including up-dating of the most recent surveys, incorporation of basic science references (e.g., adhesion bonds, deposition mechanics, etc.) and review of literature of the 1950's and earlier. This task would complement similar effort in other programs).

<u>Task 3. Fabric Filter Seminar</u> - There is a need for open discussion among and between filter users and manufacturers in such areas as filtration fundamentals, engineering technology, experience relating to specific applications, and performance test methods. In the past, users have seldom had the opportunity to discuss together common interests in fabric filtration. Manufacturers representing about 80 percent of filter sales are united by the Industrial Gas Cleaning Institute; however, the information disseminated by the IGCI has generally not been of a type beneficial to the development of new methods or equipment. Research organizations would also be interested in a discussion of filtration practices, potential needs, etc.

It is proposed to hold a Seminar extending over a period of a few days, to which major fabric filter users, interested research organizations, and equipment manufacturers would be invited. The seminar would include:

1. Presentation of results of recent studies in fabric filtration, fabric and equipment development, and related technology;
2. Panel and group discussions of organized topics, such as specific applications of widespread interest, common usage problems, types of equipment or configuration;
3. Technical laboratory sessions including participation as well as demonstration; testing methods, maintenance techniques, computations.

This Seminar should be held at a laboratory facility. One objective of the Seminar would be to determine whether there is sufficient interest to form a special laboratory or filtration institute, which would be available for specialized measurements, test equipment, and consultation to any member manufacturer, purchaser, or user of fabric filtration equipment.

Program Priority - Medium

Program Duration and Estimated Cost - The total cost for this program area is estimated to be $150,000 allocated across a five year period:

First Year Effort	40,000
Second Year Effort	40,000
Third Year Effort	30,000
Fourth Year Effort	20,000
Fifth Year Effort	20,000

4.5 APPLICATION STUDIES

The improvement and widening of the application of fabric filter control equipment to particulate collection problems depends on both the skillful utilization of existing equipment designs and the development of new designs to meet demanding control requirements which have not been widely handled by filtration equipment in the past. For example, there are currently industrial process effluents which are uncontrolled, or controlled by low efficiency systems, which might be controlled to satisfactory levels using presently available fabric filtration technology. These application areas require in-depth engineering studies if the optimum design approaches are to be employed and if the filtration system is to be validly evaluated for the specific application at hand. There are also, at present, effluents which are difficult or expensive to control by fabric filtration equipment and which should be investigated by pilot-scale equipment if we are to satisfactorily determine the applicability of filtration equipment. Such pilot-scale investigations should use standardized test methods, instrument systems and measurement parameters.

4.5.1 Identification and Evaluation of New Fabric Filter Applications

Statement of Problem - Several potential applications of fabric filtration technology have been considered in a cursory fashion in the Fabric Filter System Study, but few with the detail required to fully determine the applicability of filtration systems or to justify prototype fabrication and demonstration programs. A lack of design criteria for field measurement techniques, including instrumentation geared specifically to filter systems, and limited experience with pilot plants have contributed to the slow progress in this area. Furthermore, the initial costs of undertaking survey and/or research and development programs has obscured, perhaps, the long term benefits to be realized with respect to improved air quality and expanded markets for fabric filtration equipment.

Program Description - Three distinct program tasks are outlined. First, improved and standardized test methods and test equipment are widely needed. Second, versatile pilot plant equipment is needed which can be quickly used in evaluating the performance effects of system design changes. Third, several industrial processes must be studied to determine whether and how fabric filtration equipment can best be utilized. These three tasks may run concurrently, although there will be considerable advantage to sequential programming if the time frame permits.

Task 1. Development of Test Methods and Equipment - Performance data reported for both laboratory and field investigations of fabric filters has often been invalidated because of careless or incorrect sampling procedures. In addition, experimental methods suitable for laboratory testing may not be applicable to the broad range of operating conditions encountered in the field. It is necessary, therefore, to develop an assemblage of field instruments in the form of a readily transportable kit which can be used to evaluate the performance of new or existing filter installations. The intention is to provide standardized equipment so that meaningful and readily correlatable data can be obtained from several field installations.

This study should include: (a) review and ranking of the parameters important in fabric filtration pilot and laboratory studies; (b) survey of useful methods for measuring these parameters; (c) review and selection of types of data analysis and reporting parameters commonly used; (d) design of a versatile instrument kit for performing important field measurements; and (e) development of data reduction methods compatible with data inputs. Relative to laboratory studies, the precision required for measurements should be less rigid than the capability for adaptation to a broad range of field parameters. The output from this program constitutes a necessary input for the effective evaluation of any fabric filter system.

Task 2. Development of Pilot Testing Equipment - New filtration concepts and/or significant changes in existing systems should undergo laboratory bench and pilot scale screening before any field trails are considered. Final field evaluations under actual operating conditions, are usually required prior to fabricating prototype systems. At present, a few filter manufacturers and user industrial organizations have experience with field pilot plant installations. Generally, the main problem areas appear to lie in the bulk of the equipment, the need for special site preparation, its limited application range, and incomplete instrumentation. The principal objective of this study is to examine the practicability of developing versatile, well instrumented pilot testing systems whose basic dimensions would be of the order of inches rather than feet. Reduced cost and ease of transport, installation, and operation would encourage increased field evaluation of new filter applications by both filter manufacturers and users.

This study would incorporate a review of existing pilot plant systems and test approaches including those types of instrumentation which provide the best measures of filter performance. Special emphasis should be placed upon scaling factors so that the results of small scale tests can be safely extrapolated to prototype experience. The end result of this study would be a truly portable pilot plant that can be produced economically so that extensive field applications can be made.

Task 3. Selection, Description and Demonstration of Fabric Filter Systems in New Applications Areas - Several sources of particulate air pollutants may be potentially controllable with fabric filtration. Filter methods have not been used for a variety of sources because: (a) suitable fabric media are not as yet available; (b) users or filter manufacturers are not aware of the possibilities; (c) the particulate effluent is not recognized as presenting a problem at present; or (d) fabric filtration is believed, correctly or otherwise, to be unsuited to the application. Preliminary studies have demonstrated the need for more detailed studies in the following areas: low sulfur, coal-fired and oil-fired utility boilers; municipal incineration; Kraft pulping, digester and kiln operation; iron and steel production, cupola and basic oxygen process furnaces; secondary zinc processing; tail gas treatment, sulfuric acid manufacture; coke production; and calcium carbide, electrometallurgical operations.

Analyses should be made of effluent characteristics and current control efforts in the complete spectrum of likely applications areas. To accomplish this it will be necessary to undertake visits to representative plants, discussions with knowledgeable manufacturers, and preliminary engineering studies. These initial studies would provide enumeration of the potential application areas for fabric filters and outline those areas which hold the most promise as candidates for filtration systems. Thus, the studies will result in: (a) the determination of the number of sources, quantity and nature of the effluents, and related economics; (b) engineering analyses of the appropriate filtration equipment; and (c) fabrication of demonstration systems and the conduct of demonstration programs to demonstrate the economic and performance advantages of selected fabric filter systems. The results of these studies are expected to extend the use of fabric filtration methods into areas where existing control methods (or the lack of) has led to excessive particulate emissions.

Program Priority - High

Program Duration and Estimated Cost - It is recommended that this program area extend across a 4½ year period at a total estimated cost of $2,400,000, allocated approximately as follows:

First Year Effort

Equipment and Material Costs:	$ 50,000
Manpower Costs:	150,000
Total:	$200,000

Second Year Effort

Equipment and Material Costs:		$150,000
Manpower Costs:		250,000
	Total:	$400,000

Third Year Effort

Equipment and Material Costs:		$200,000
Manpower Costs:		300,000
	Total:	$500,000

Fourth Year Effort

Equipment and Material Costs:		$250,000
Manpower Costs:		450,000
	Total:	$700,000

Fifth Year Effort

Equipment and Material Costs:		$250,000
Manpower Costs:		350,000
	Total:	$600,000

4.5.2 Demonstration of a High Temperature and High Filtration Velocity System

Statement of the Problem - Approximately one-third of the particulate emissions from industrial sources come from sources in which the effluent streams are in the $900^{o}F$ or higher range. The employment of fabric filtration systems in these environments typically requires the utilization of gas stream cooling by radiative/convective means, dilution cooling or active cooling by water systems. Even in cases where cooling systems are employed, temperature surges sometimes occur which may exceed the capacity of the cooling systems, and which may cause damage to the operating elements of the filtration system. It appears desirable, therefore, to investigate more fully the application of filtration systems specifically designed to operate in high temperature environments.

The grey iron foundry industry is an industrial source that is experiencing particulate emissions in excess of current and projected emission standards and which has traditionally utilized wet caps, inertial separators and wet scrubbers for particulate control. Since current and contemplated emission standards effectively preclude the use of wet caps and inertial separators, the present trend is to use wet scrubbers or fabric filters to meet efficiency requirements. While more fabric filters are presently in use than wet scrubbers, no distinct economic advantage appears for either system. The need to reduce typical cupola gas exit temperatures from about 2000°F to 500°F to keep within the operating range of existing fabrics is a cost disadvantage relative to wet scrubbing operations. In addition, the combination of fine fumes and many potentially corrosive materials (acid gases, fluorides) makes many types of filter media susceptible to plugging and chemical attack.

Thus, there is a definite need for the development of a fabric filter system that can: (a) operate in high temperature and highly corrosive environments; (b) that offers collection efficiencies equal to or better than high-energy scrubbers; and (c) can be installed and operated at costs lower than those of present fabric filter systems or high energy scrubber systems.

It appears that a reasonable approach to meeting this need is to apply the recent developments in filter media materials (i.e., temperature and corrosion resistance and ability to operate in high filtration velocity environments) to the specific requirements of cupola emission control. If a system to meet these requirements can be developed, then the technology should be applicable to a wide range of industrial applications that have equally or less demanding emission control requirements and/or operating environments.

In recent years a number of new fiber media have been developed (i.e., polyimides, Fiberfrax®, and metallic fiber media) which offer: (a) physical properties compatible with high filtration-velocities; (b) significant increases in temperature and corrosion resistance; and (c) capability for fabrication into felted media which are compatible with reverse flow or pulse jet cleaning methods. Preliminary laboratory and field studies have also suggested that a felted metal fiber media used to filter the effluent gas may provide more effective and economic particulate removal than that afforded by existing systems. The potential advantages would appear to be in: (a) the high filtration velocities, ~ 100 FPM, (b) the in-place cleaning capability by either reverse flow air or wet sluicing, and (c) the resistance to chemical and thermal attack.

Program Description - The main objectives of this program are to demonstrate the engineering feasibility and performance characteristics of a high velocity filter system, first on a laboratory scale to establish design parameters, media life, and optimum cleaning methods, and then on a full scale filter system applied to a real foundry cupola installation.

Task 1. Laboratory Pilot Plant Study - A laboratory pilot plant system will be constructed in which several types of filter media in various experimental configurations will be evaluated under simulated field operating conditions. Emphasis will be placed upon the fiber resistance to thermal and temperature effects as well as the ease with which particulates can be removed by different methods of cleaning. This study will embrace the complete range of cupola effluent operating conditions such that design parameters deriving from this study will enable the construction of a field prototype system.

Task 2. Design and Fabricate Full Scale System - A full scale system will be designed for an operational cupola installation of the 20-30 ton/hour capacity range. The system will utilize metallic fiber media, will operate in the 100 FPM filtering velocity range and will utilize filter cleaning methods which have been demonstrated as being compatible with the media and effluent characteristics. The design goal will be such that the most stringent, current or projected, emission standards for cupola sources will be met or exceeded.

Task 3. System Performance Evaluation - Following installation, a complete evaluation of the system will be completed including system performance determination, operating cost determination and system operating and failure analysis. A large number of effluent mass and size distribution measurements will be made and compared with measurements made under identical operating conditions prior to installation of the filtration system.

Program Priority - High

Program Duration and Estimated Cost - The total cost for this 2 year program is estimated to be $440,000 allocated approximately as follows:

First Year Effort

Equipment and Materials Costs:	$ 25,000
Manpower Costs:	125,000
Total:	$150,000

Second Year Effort

Equipment and Materials Costs:	$175,000
Manpower Costs:	115,000
Total:	$290,000

4.6 INTEGRATED RESEARCH AND DEVELOPMENT PROGRAMS

Two research and development programs were prepared based on the overall study results and the definition of specific R&D projects as enumerated above. Both programs extend five (5) years in duration, with one based on an assumed total expenditure of five million dollars and the other on an assumed total expenditure of two million dollars.

Figure 1 presents the program schedule for the five year programs, with the projected expenditures for each major program arranged in adjacent columns. This permits a ready comparison of how the task funding has been allocated for the five and two million dollar programs, respectively. The program sequence appears as given in the preceeding text in which the composition of the studies range from basic laboratory investigations to field measurement programs. Although it might be argued that any fundamental research should precede pilot or development studies, the need to implement effective emission controls at the earliest possible date requires a more pragmatic approach. For example, our preliminary estimates of research needs indicate that relatively large sums should be directed towards applications studies. Hence, it appears that a concurrent pursuit of an applied program promises not only a more rapid solution of a field problem, but also provides added guidance and direction to the fundamental studies, particularly those cited at medium or low priority programs.

Figure 1. Schedules for Five-Year Filter Research and Development Program at the Five-Million and Two-Million Dollar Level.

	R&D Program Area	Priority	Program Year 1 2 3 4 5	Five Million* Dollar Program Cost ($000)	Two Million* Dollar Program Cost ($000)
4.2	Definition and Control of Particle Properties				
4.2.1	Basic Particle Parameters	High		110	110
4.2.2	Deposit Modification and Control	High		100	70
Task	1. Definition of Deposit			(35)	(35)
	2. Deposit Changes During Filtering			(35)	(25)
	3. Costing of Cake Control			(30)	(10)
4.2.3	Particle Size Control	Med.		100	30
Task	1. Review of Experience in Particle Size Control			(40)	(30)
	2. Experimental Program			(60)	--
4.3	Fabric Investigations				
4.3.1	Fabric Surfaces Study	High		450	200
Task	1. Literature Review, Theoretical Approaches			(100)	(100)
	2. Laboratory Investigation of Surface Parameters			(350)	(100)
4.3.2	Fabric Performance	High		570	200
Task	1. Review of Manufacturing Methods, Capabilities and Costs			(75)	(75)
	2. Field Study of Fabric Attrition			(100)	(75)
	3. Laboratory Study of Fabric Attrition by Abrasion			(200)	(50)
	4. High Temperature Filtration Substrate			(100)	--
	5. Coordinate Fabric Performance Information			(95)	--
4.3.3	New Fabric Materials Investigation	Low		75	--
4.4	Systems Design				
4.4.1	Cleaning Mechanisms and Kinetics	High		430	330
4.4.2	Improved Fabric Filtration Equipment	Low		125	50

*Numbers in parentheses indicate subtask funding.

Figure 1 (Continued)

	R&D Program Area	Priority	Program Year 1 2 3 4 5	Five Million* Dollar Program Cost ($000)	Two Million* Dollar Program Cost ($000)
Task	1. Compilation of Data on New Collector Designs			(75)	(50)
	2. Selection Guidelines for Collector Users			(50)	--
4.4.3	Control Equipment and Instrumentation	Low		100	50
Task	1. Instrument Survey			(50)	(50)
	2. Control Methods Survey			(50)	--
4.4.4	Fabric Filter Systems Modeling	Med		150	--
4.4.5	Continuation of Fabric Filter System Study	Med		150	75
Task	1. Compilation of Design Data			(60)	(50)
	2. Updating of Fabric Filter Handbook			(50)	(25)
	3. Fabric Filter Seminar				
4.5	Applications Studies				
4.5.1	Identification and Evaluation of New Fabric Filter Applications	High		2200	800
Task	1. Development of Test Methods and Equipment			(100)	--
	2. Development of Pilot Testing Equipment			(400)	--
	3. Selection, Description and Demonstration of Fabric Filter Systems in New Applications Areas			(1700)	(800)
4.5.2	Demonstration of High Temperature and High Velocity Filter System	High		440	100
Task	1. Laboratory Pilot Plant Study			(100)	(100)
	2. Design and Fabricate Full Scale System			(240)	
	3. System Performance Evaluation			(100)	

The priorities shown in Figure 1 are based upon the best information available at the time of report preparation. With respect to basic research, a high priority means that some systems or applications studies should be approached cautiously until the relationships among basic parameters are better understood. On the other hand, high priority assignments for strictly applied research programs reflect control needs for which solutions should be attempted on the premise that the results of parallel basic studies can be made available at the proper time. It is realized that the listings (i.e., areas of research, priorities, funding, performance periods) in Figure 1 should, of course, be reviewed constantly in accordance with new technological developments and regulatory standards.

In reducing the funding level from a five million to a two million dollar five year program, it was difficult to decide which research activities should be restricted since all programs are considered important to the advancement of filtration technology. Three criteria were used to formulate the reduced program. First, certain programs should be continued even at a reduced level since it is necessary to draw upon several areas in order to affect a practical engineering solution to a specific filtration problem. Second, tasks within certain research categories should be pursued in some logical sequence such that execution of the first task must preceed the second or third. In these cases, it would appear more reasonable to perform the sub-task at the originally scheduled level of effort and to decide later whether further pursuit is justified. Third, those sub-tasks which might be investigated independently and which represent correlation and review of previous findings rather than new research have been assigned a lower priority.

APPENDICES

APPENDIX 1 - POTENTIAL APPLICATIONS FOR FABRIC FILTRATION, NEW AREAS AND/OR EXPANDED USE IN CURRENT APPLICATIONS

APPENDIX 2 - FABRIC FILTER SYSTEM SURVEY - USER REPORT

APPENDIX 3 - U.S. FABRIC FILTER MANUFACTURERS AND PRODUCTS - 1969

PRINCIPLE MANUFACTURERS OF FABRIC FILTER DUST AND FUME COLLECTORS

APPENDIX 4 - R&D SUGGESTIONS BASED ON INTERPRETATION OF COMMENTS MADE DURING SURVEYS

ACKNOWLEDGEMENT

APPENDIX 1

POTENTIAL APPLICATIONS FOR FABRIC FILTRATION, NEW AREAS AND/OR EXPANDED USE IN CURRENT APPLICATIONS

Process	Existing Control* Methods	Comments
1. Combustion		
a. 100 MW Coal and Oil	ESP, FF	Promising, Odor problems
b. 10 MW Coal and Oil	ESP, I	Promising
c. Low Sulfur Fuels	As Above	Lower conductivity does not favor ESP
d. Domestic Heating, Larger plants	None	See 1a, b
e. Incineration,		
Municipal Institutional	S, WS, FF	Promising, Cake conditioning Required
Industrial (Scrap, Sewage)	I, ESP, WS	Some FF Applications
2. Pulp and Paper		
a. Recovery Furnace	ESP, WS	Promising, Odor problems
b. Kiln	ESP, VS, I	
c. Calciner	I, WS	
3. Inorganic Chemicals		
a. Fertilizers		
Super phosphate Triple phosphate	ESP, I, WS, FF	Promising, curing is uncontrolled
b. Lime (CaO)		
Kiln	ESP, FF	Promising, not widely used
Handling	I, WS, ESP, FF	
c. Catalysts		Promising
4. Petroleum Refining		
a. FCC Reform	I, ESP	Promising, FF not tried
b. TCC Hydrogen	I	See 4a
c. Waste Boilers		See 1a, b
d. Process Heaters	None	See 1a, b
5. Non-Metallic Minerals		
a. Cement		
Kiln (wet and dry)	ESP, I, FF	Promising, use limited at present
b. Asphalt Concrete	I, WS, FF	See 5a

*I = Inertial Collector
ESP = Electrostatic Precipitator
WS = Wet Scrubber
VS = Venturi Scrubber
FF = Fabric Filter
S = Screen

Process	Existing Control* Methods	Comments
c. Glass		
Furnaces	WS, FF	Promising, need for improved high temperature fabrics
Frit Mfr.	VS, FF	As above
d. Gypsum		
Kiln, Kettle	ESP, FF	Promising, FF not widely used
e. Crushed Stone and Gravel	I, FF	For old uncontrolled plants
f. Coal Screening	FF	Promising, more control needed
g. Abrasives-Furnaces	FF	Promising, not widely used
h. Mining (Underground)	WS, FF	Promising, compact equipment required
6. Iron, Steel and Related Operations		
a. Cake Production		FF appears feasible, studies required
b. Ore Handling and Concentrating		Promising
c. Sintering	I, ESP, WS, FF	Promising, FF not widely used
d. Steel Furnaces		
Open Hearth	ESP, WS, FF	Promising, more incentive needed
Basic Oxygen	ESP, WS	Promising, studies required
Electric	I, WS, FF	Promising, FF use expanding
e. Steel		
Pouring		Promising
Scarfing	I, WS	Promising, water problem controllable
f. Founding		
Cupola Furnace	ESP, WS, FF	Promising, not widely used
Sand Handling	I, WS, FF	FF use should be expanded
Continuous Casting		Promising, enclosure the main problem
g. Electrometallurgical Processes	WS, FF	Promising, FF use should be expanded
7. Non-Ferrous Metals		
a. Aluminum Refining	WS, FF	Promising, studies required
b. Scrap Fluxing	ESP, WS, FF	Promising, FF use expanding
c. Copper Smelting, Roasting	ESP, I, FF	Promising, studies required
d. Lead Smelting	WS, FF	Promising, limited FF application
e. Zinc		
Sintering	I, ESP	Promising, studies required
Smelting	ESP, I, WS	As above

*I = Inertial Collector
ESP = Electrostatic Precipitator
WS = Wet Scrubber
VS = Venturi Scrubber
FF = Fabric Filter

Bureau of Budget No. 85-S69016
Approval Expires Feb. 28, 1970

APPENDIX 2

FABRIC FILTER SYSTEM SURVEY - USER REPORT

Section I. **GENERAL INFORMATION** Date:________________

1. Name & location of company:

   a. Name:____

   b. No., Street:________________________

   c. City:______________ State:______________ Zip Code:________

2. Location of plant if different from above:

   a. Plant/Division:________________________

   b. No., Street:________________________

   c. City:______________ State:______________ Zip Code:________

3. Person to contact regarding information contained in this report:

   a. Name:____

   b. Department/Division:____________________________

   c. Telephone: Area Code / ______________

4. Principal products manufactured at this plant: ________________

   ____

   Standard Industrial Classification, if known:________________

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Section II. GENERAL APPLICATION

Please indicate units when numerical replies are provided, for example: pounds per hour; tons per day.

1. a. Name of process served by filter: ____________________

   b. Name of operations generating dust or fume passed to filter: ________

   ____

2. a. Process equip. capacity: __________ b. Approx. proc. rate: _________

   c. Approx. process temperature: ____________

   d. Process (Circle): continuous batch. Batch timing: ____________

3. Gas characteristics entering collector:

   a. Total flow rate, cubic feet per minute (standard or ambient): _______

   b. Moisture rate or relative humidity: __________________

   c. Temperature entering collector: ______________

   d. Type of cooling before collector: ____________________

4. Dust or fume particles entering collector:

   a. Name of material collected: ______________ b. Approx. composition: ______________

   c. Weight per hour: __________ or grains per cubic foot: ______________

   under (Circle) standard ambient conditions.

   d. Is the dust hygroscopic? _____ e. Typical particle size: ___________

5. a. Fraction of time the fabric filter system is in use on process: _______

   b. What other cleaning methods have been tried? ____________________

   ____

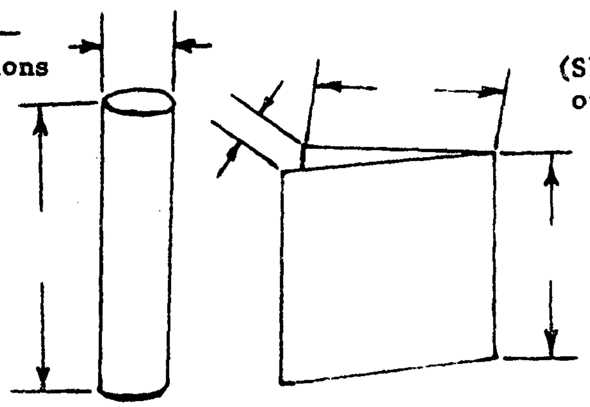
   c. Reasons for using fabric filtration: ____________________

   ____

Section III. FABRIC FILTER SYSTEM DESIGN

1. Installation - Date:_______________
   a. Manufacturer:____________________________Model No:____________________
   b. Approx. cost, collector alone:____________Fans,ductwork:________________
      Other auxiliary equipment:____________________Total:___________________

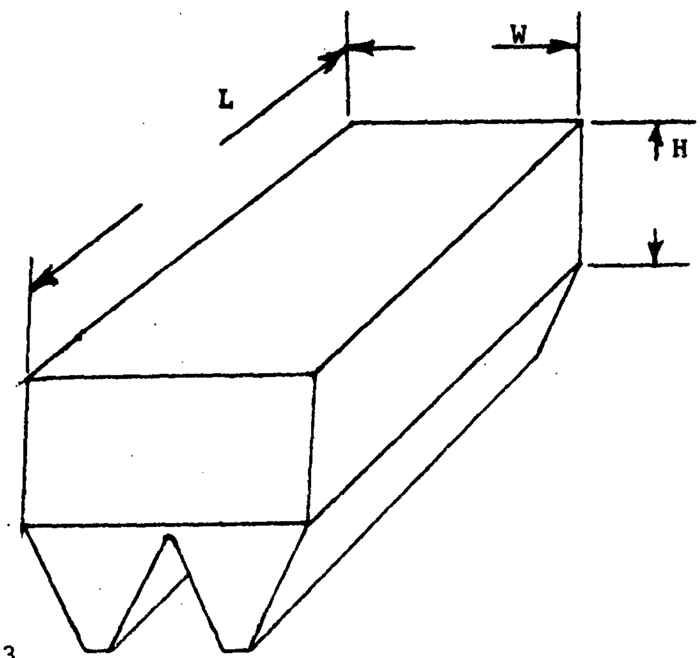
2. Filter elements
   a. Number of compartments:_______ b. Arrangement, number of elements per compartment:______ wide by ______long by _______high; Total per comp.:______
   c. Total filter system area:______________
   d. Please indicate filter element dimensions on appropriate sketch at right:
   e. Dust collects on (Circle):
      inside   outside
      Dust enters (Circle):
      bottom   top



3. Filter material
   a. Fabric (Circle): Cotton, woven   Wool felt   Nylon (polyamide)
      "Nomex" nylon   Dacron (polyester)   Orlon (acrylo nitride)   Glass
      Orlon-Wool   Dynel   Vinylidene Chloride   Polyethylene   Teflon
      Polyvinyl acetate   Polypropylene   Asbestos   Other (specify):________
   b. Manufacturer or supplier:________________________Cat. No:____________
   c. Permeability, if known; New ; _________________ Used ;_______________
   d. Could you provide a sample of fabric for inspection? (Circle): Yes   No

4. Please indicate on sketch at right the gas inlet and outlet locations, and approx. overall collector dimensions. Indicate arrangement of compartments.

   Are construction prints available for inspection? (Circle) : Yes   No



Section IV. FILTER PERFORMANCE (during normal operation)

1. Pressure drop (inches of water):
   a. Pressure drop fully loaded, before cleaning cycle:______
   b. Pressure drop after dust removal:______
   c. Static pressure level, ± 10%:______
   d. Is a record of pressure drop variation available?______

2. Air to Cloth Ratios, or total gas volume filtered per unit time:
   a. Fully loaded:______ b. After dust removal:______ c. Overall ave.:______

3. Performance
   a. Collection efficiency:______ b. Approx. no. of system failures per year:__
   c. Principal causes of bag failure:______________________________

   ____

   ____

4. Operating costs
   a. Filter elements: Typical life:______Bag or element costs per year:______
      Salvage value:________ Restoration or cleaning of used bags,
      process:____________________Approx. process cost:__________
   b. Estimated labor costs per year in man-hours:
      Element replacement:__________Labor categories:__________
      General maintenance:__________Labor categories:__________
   c. Other costs, e.g., dust disposal:____________________

5. Fan manufacturer:____________________ Design:______________
   Wheel size:____________ Horsepower:______________

6. Have you tried other fabrics on the same dust (Circle): Yes No
   Which ones? ______________________________
   What problems did you encounter and why did you change to the
   presently used fabric? ______________________________

   ____

   ____

Section V. REMOVAL OF DUST DEPOSIT OR CAKE

1. Intermittent cleaning (Circle): shake reverse flow fabric flexing reverse pulse reverse jet Other (Specify):____________

   a. Initiation of cleaning (Circle): manual timer pressure limit

   b. Frequency of cleaning each element:__________

   c: Approx. time taken to clean: ______ d. No. elements cleaned at once:______

2. Continuous cleaning (Circle): reverse jet pulsed air vibration reverse air traversing carriage Other (Specify):____________

   a. Compartments shut off by (Circle): damper traveling blower carriage Other (Specify):__________

   b. Frequency of cleaning each compartment:__________

   c. Approx. time taken to clean each compartment:__________

   d. Number of compartments cleaned at once:______

   e. Reverse jet or reverse air characteristics: air volume:______ velocity:______ ring slot size or carriage aperture:______ traverse rate:______ fan motor horsepower:______ Other(Specify):____________

   f. Reverse air volume set by (Circle): blower capacity orifice Orifice size if known:__________

3. Intensity of cleaning: motor horsepower:______ vibration frequency:______ stroke length:______ air pressure:______ Other(Specify):______

4. a. Estimated deposit properties: density:________ thickness:________

   b. Est. uniformity over bag(Circle): more near bottom than top fairly even more near inlets Other(Specify):____________

   c. Est. uniformity and effectiveness of removal:____________

5. Disposal of dust(Circle): return to process manual removal to waste automatic removal to waste

6. Dust appearance:

   a. Collected dust - visual (Circle): dusty fluffy fluidized loose heavy flaked caked sticky oily damp hard

   b. Collected dust - microscopic (Circle): agglomerates over 10 microns size agglomerates around 1 micron too fine to resolve mixture Other(Specify):____________

   c. Original dust particles (Circle): spherical granular irregular fibrous elongated uniform size agglomerates mixture Other(Specify):____________

   d. Is there a dust sample available for inspection? (Circle): Yes No

Section VI. OTHER GAS TREATMENT

1. Pre-treatment
   a. For dust (Circle and describe):
      Settling chamber
      Cyclone
      Pre-filter
      Other
   b. For gaseous components, etc. (Circle and describe):
      Scrubber
      Other

2. Cleaned gas or air (Circle): returns to process discharges outdoors returns to inside plant volume

3. Quality of effluent gases (Circle): within required limits no complaints complaints

4. Is your dust generally considered to be a seeper (Circle): Yes No

   If yes, do you require or specify special fabrics or fabric treatment to control seeping (Define and describe): ______________________

   ____

   ____

5. Do you have problems associated with fabric blinding (Circle): Yes No

6. Please indicate:

   a. Any major difficulties with your filter system: ________________

   ____

   ____

   ____

   b. What aspects of performance or operation could be improved, based on your field experience: ______________________________

   ____

   ____

   ____

   c. Suggestions for improvements in design or manufacture: __________

   ____

   ____

   d. Research requirements: ______________________________

   ____

   ____

Section VII ADDITIONAL DETAILS

1. Fabric design:

   a. Weave (Circle): plain twill sateen Other: ______________

   b. Yarn: (Circle): monofilament multifilament spun staple mixture

   c. Weight per unit area: ____________

   d. Working thickness: ______________

   e. Napped? Yes No

   f. Max. usable temperature: __________

   g. Pre-treatment (Describe treatment):

      Fibers: ____

      Filter: ____

2. Gas properties:

   a. Specific density (standard or ambient) or constituent makeup: _______

      ____

   b. Other pollutants, special constituents: ____________________

      ____

3. Special problems:

4. Comments -(bag tension, retainment; flow diagram):

APPENDIX 3

U.S. FABRIC FILTER MANUFACTURERS AND PRODUCTS - 1969
(From GCA Survey)

Key to Abbreviations

Configuration

E	Envelope or panel type equipment
O	Bag or tube type equipment filtering on the outside of the cylinder
I	Bag or tube type equipment filtering on the inside of the cylinder
U	Upward flow of the dirty gases (bottom entry)
D	Downward flow of the dirty gases (top entry)

Cleaning Method:

P	Reverse and forward pulsing of single or multiple elements
RJ	Reverse jet or traveling blow ring equipment
RF	Reverse or backflow of clean air with a minimum of fabric flexure or motion
RFC	Reverse or backflow collapse or flexure of the filter element
S	Induced oscillation
V	Vibration, rapping, shock, or sound waves
M	Direct control of the cleaning intensity and duration.

Assembly:

M Modular, Assembled from self-consistent identical units

C Compartmented, Housing divided into two or more chambers for semi-independent operation

I Intermittent, Collector must be shut down for fabric cleaning

Co Continuous, Collector need not be stopped for cleaning

CoA Contin. Access, Access to the filter elements is possible during operation of the same compartment

APPENDIX 3

U.S. FABRIC FILTER MANUFACTURERS AND PRODUCTS - 1969

Manufacturer and Model	Configuration E	O	I	Cleaning Method P	RJ	RF	RF C	S	V	M	Cloth Area Sq.Ft. Min	Max	Assembly M	C	I	Co	Co A	Comments
Aerodyne Machinery																		
VS		U				x				x	625	and up	x	x		x		
RAS		U				x					625	and up	x	x		x		
SJ		U		x							8	800				x		Cylindrical
HPE		U		x							1400	and up	x	x			x	
RSI			U	x		x					2000	and up				x		
Aget Mfg. Co.																		
FH		U						x			700	2800	x		x			
FT		U	D					x			120	383			x			
1-Bag										x	(20)	(300)			x			
Air Preheater																		
Ray Jet		U		x							450	3600				x		
American Air Filter																		
Amerjet			D		x						310	2390				x		Cylindrical
Amerpulse		D		x							61	4400				x		Bottom plenum
Amer Therm			U				x				1320	9660				x		
Amer Tube			U			x		x			1339	11675			x	x		
Arrester	x								x		80;150	and up	x		x			
Arrestall	x							x		x	30	180			x			
Bahnson			x					x		x	-	(1000)						

APPENDIX 3 (Continued)

Manufacturer and Model	Configuration E	Configuration O	Configuration I	Cleaning Method P	RJ	RF	RF C	S	V	M	Cloth Area Sq.Ft. Min	Max	Assembly M	C	I	Co	Co A	Comments
Buell-Norblo																		
Automatic			U			x		x			960	and up	x				x	Vertical shake
Intermittent			U					x			360	and up	x		x			
Portable			U					x		x	36	135			x			
Atmos-Filter			U					x			392	and up			x			Ultrafiltration
Shakerless			U				x				---	---	x	x				
Buffalo Forge																		
Aeroturn B			D		x						90	and up	x				x	
Aeroturn S			U					x			628	and up	x		x		x	
Carter-Day																		
Daynamic DF				x		x					---	---				x		
CS	x	U		x		x					58	1530				x		Cylindrical
RJ	x	U				x					58	1530				x		Cylindrical
RT,RTR			U					x			50	660			x			
AC			D		x						50	1217				x		
Cincinnati Fan																		
Dust Master			x							x	(6)	---						With Cyclone
Cox Assoc.			U					x			300	and up			x			
Dracco/Fuller																		
Plenum Pulse		U		x							(500)	and up	x	x		x		Cylindrical or regular
Uni-Filter			U					x			100	600			x			

APPENDIX 3 (Continued)

Manufacturer and Model	Configuration E	O	I	Cleaning Method P	RJ	RF	RF C	S	V	M	Cloth Area Sq.Ft. Min	Max	Assembly M	C	I	Co	Co A	Comments
Mark II			U					x			720	and up	x	x				
Glass Cloth			U,D				x				80	and up	x	x		x		
Retro Pulse			U				x				1000	and up	x	x		x		
Atmos-Filter			U															Ultra-filtration
Ducon Co.																		
UVB			U					x			20	200			x			
UFS			U					x			40	200			x			
Uniflow			D			x					880	and up	x			x		
FD			U							x	50	400			x			
Dustex/Am Prec.																		
Inductaire			U	x		x					800	and up	x			x		
RA		U				x					225	8500				x		
Dusty Dustless																		
4 Models			U					x		x	12	6000			x			
Environ. Res. Corp.																		
HI, HA			U					x			784	and up	x	x	x	x		
HC			U					x			125	1300			x			Cylindrical
Flex-Kleen																		
BV,RA,UD		U		x							17	and up	x			x		
FK,CT		U		x							15	2000				x		Cylindrical

APPENDIX 3 (Continued)

Manufacturer and Model	Configuration E	O	I	Cleaning Method P	RJ	RF	RF C	S	V	M	Cloth Area Sq.Ft. Min	Max	Assembly M	C	I	Co	Co A	Comments
Fluidizer		U		x		x										x		
Hoffman																		
Dustuctor			U					x			---	---			x			
Hoffcovac			U					x			30	63			x			Portable
Hydromation			D?	x							100	1000				x		
Johnson-March																		
MB			U			x		x			250	1250			x	x		
1000			U			x		x			1750	and up	x				x	
Kice																		
Dyna-Jet C,S,M.		U		x							10	and up	x			x		
R		U		x							75	891				x		Cylindrical
Kindt Collins																		
Master			U					x		x	20	---			x			Single Bag
Lamson																		
Exidust			U					x			38	727			x			
Macleod																		
SV	x							x			880	and up			x	x		
Unit	x							x			80	1500			x			
Tube			U					x			880	and up						

APPENDIX 3 (Continued)

Manufacturer and Model	Configuration E	O	I	Cleaning Method P	RJ	RF	RF C	S	V	M	Cloth Area Sq.Ft. Min	Max	Assembly M	C	I	Co	Co A	Comments
Mahon	U			x							265	and up				x		
			U					x			---	---		x				
Meyer																		
Roto-flo				x							85	930				x		
Pangborn																		
CH-3	x					x					400	and up				x		
CM,CN,CT			U					x			200	and up	x		x			Multi-Tube Filter Element
CH-2,CD	x								x	x	180	and up			x	x		
CO			U	x		x					1000	and up		x		x		
Poisi-pulse		U		x		x					11	and up	x			x		Cylind. or Regular Ultra-filtration
Totalaire								x			---	---						
Perlite Corp.																		
H			D			x								x		x		Multiple Reverse Fans
Precipitair			D			x												
Pulverizing M/C																		
Mikro-pulsaire		U		x							25	and up	x			x		
Mikro-cyl.		U		x							42	900				x		Cylindrical
Mikro-collector			D		x						25	and up				x		
Mikro-Custom			U				x				3300	and up		x				

APPENDIX 3 (Continued)

Manufacturer and Model	Configuration E	O	I	Cleaning Method P	RJ	RF	RF C	S	V	M	Cloth Area Sq.Ft. Min	Max	Assembly M	C	I	Co	Co A	Comments
Rees Blow Pipe																		
Standard			U					x			1400	22,000			x			
AE			U					x			700	22,000		x		x		
ANS			U			x					1500	24,000		x		x		
Unit								x		x	380	860			x			
Research Cottrell																		
Air-shake			U					x			3927	and up			x	x		Horizontal air shake
Shake-kleen			U					x			1600	and up			x	x		
Uni-kleen			U					x			295	1860			x			
Also Flex-kleen(see)																		
Ruemelin																		
Unit			U					x			53	755			x			Portable
Standard			U					x			1000	9155		x	x	x		
Smico																		
Suction Filter				x														
Systems (Semco)																		
DC,DCV		U		x							8	3112				x		Cylindrical/ Rectangular
Setco																		
7 AR, 7 GAR, A B1	x									x	50	---						
Seversky			U				x	x			200	and up	x					

APPENDIX 3 (Continued)

Manufacturer and Model	Configuration E	O	I	Cleaning Method P	RJ	RF	RF C	S	V	M	Cloth Area Sq.Ft. Min	Max	Assembly M	C	I	Co	Co A	Comments
W.W. Sly																		
Pactecon-PC	x			x							88	1065				x		
Pactecon-PS	x			x				x		x	88	1065			x			
Dynaclone	x					x					748	and up				x		
Intermittent	x					x		x			242	and up			x			
Economy	x							x		x	176	352			x			
Smico																		
Suction Filter				x														
Sprout-Waldron																		
Multi-Tube			U					x			74	100			x			
BV, Series			U							x	12	453			x			
Sterling																		
R			U						x		111	552			x			
Sternvent																		
Cabinet		x						x			32	1200			x			
Filter Tube			U					x			426	1800			x			
Tailor																		
Controlled Cycle			U	x				x			400	and up	x			x		Controlled Start-up
Torit Corp.																		
Cabinet	x							x		x	30	1200			x			

APPENDIX 3 (Continued)

Manufacturer and Model	Configuration E	O	I	Cleaning Method P	RJ	RF	RF C	S	V	M	Cloth Area Sq.Ft. Min	Max	Assembly M	C	I	Co	Co A	Comments
United McGill																		
RF,VAV	x					x			x							x		
MHS, High Temp.			U			x		x							x			
U.O.P																		
Aeropulse		U		x							4200	22K	x	x			x	
Western Precip.																		
Thermo-flex			U				x	x					x	x		x		
Pulsejet-C8		U		x							75	1135					x	Cylindrical
Pulsejet-M8		U		x							1130	and up	x				x	
Wheelabrator																		
Ultra-Jet		U		x							---	---				x		
Dustube			U					x			273	and up			x	x		
Dustube			U					x			(10K)					x		Also Ultra-filtration
Young Machinery																		
Uni-Cage		U		x							39	and up	x			x		Cylindrical/ Regular
Uni-Horiz.		H		x							27	368				x		Horizontal Tubes
Shaker			U					x			94	631			x			

APPENDIX 3 (Continued)

PRINCIPLE MANUFACTURERS OF FABRIC FILTER DUST AND FUME COLLECTORS

Aerodyne Machinery Corporation
6330 Industrial Drive
Hopkins, Minnesota 55343

Aget Manufacturing Co.
1408 E. Church St.
Adrian, Michigan 49221

Air Preheater Co.
A Subsidiary of Combustion Eng'g.
Wellsville, New York 14895

American Air Filter Co., Inc.
215 Central Avenue
Louisville, Kentucky 40208

Bahnson Company
1001 South Marshall St.
Winston-Salem, N. Carolina 27108

Buell Engineering Co., Inc.
Northern Blower Division
6409 Barberton Avenue
Cleveland, Ohio 44102

Buffalo Forge Company
490 Broadway
Buffalo, New York 14204

Carter-Day Company
655 19th Avenue, N.E.
Minneapolis, Minn. 55418

Cincinnati Fan & Ventilator Co.
6521 Wiche Road
Cincinnati, Ohio 45237

R.F. Cox Associates
Essex, Massachusetts

Dracco Division
Fuller Company
124 Bridge Street
Catasauqua, Penn. 18032

Ducon Company, Inc.
157 East Second St.
Mineola, Long Island, N.Y. 11500

Dustex Division
American Precision Industries
2777 Walden Avenue
Buffalo, New York 14225

Dusty Dustless
2914 E. Genesee Street
P.O. Box 86
Baldwinsville, N.Y. 13027

Environmental Research Corp.
3725 N. Dunlap St.
St. Paul, Minnesota 55112

Flex-Kleen Corporation
Division of Research-Cottrell
407 South Dearborn St.
Chicago, Illinois 60605

Fluidizer, Inc.
Hopkins, Minnesota

Hoffman Air & Filtration Division
Clarkson Industries, Inc.
P.O. Box 214
Eastwood Station
Syracuse, N.Y. 13206

Hydromation Engineering Co.
39201 Amrhein Road
Livonia, Michigan 48150

Johnson-March Corporation
3018 Market St.
Philadelphia, Pa. 19104

Kice Metal Products Co.
2040 South Mead Avenue
Wichita, Kansas 67211

Kindt-Collins Company
12631 Elmwood Avenue
Cleveland, Ohio 44111

Lamson Division
Diebold, Inc.
306 Lamson Street
Syracuse, N.Y. 13201

Macleod Company
125 Mosteller Road
P.O. Box 452
Cincinnati, Ohio 45421

Mahon Industrial Division
R.C. Mahon Co.
P.O. Box 808
Warren, Michigan 48090

Wm. W. Meyer and Sons, Inc.
8262 Elmwood Avenue
Skokie, Illinois 60076

Pangborn Corporation: Now =
Pollution Control Division
The Carborundum Company
P.O. Box 1269
Middlebrook Industrial Park
Knoxville, Tennessee 37901

Perlite Corporation
200 E. Duttonmill Rd.
Chester, Pennsylvania 19014

Precipitair Pollution Control, Inc.
Chimney Rock Road
Bound Brook, New Jersey 08805

Pulverizing Machinery: Now =
Mikropul Division
The Slick Corporation
10 Chatham Road
Summit, New Jersey 07901

Rees Blow Pipe Manufacturing Co.
2929 Fifth Street
Berkeley, California 94710

Research Cottrell, Inc.
P.O. Box 750
Bound Brook, New Jersey 08805

Ruemelin Manufacturing Co.
3860 North Palmer St.
Milwaukee, Wisconsin 53212

Systems Engineering & Manufact. Co.
6330 Washington Avenue
P.O. Box 7634
Houston, Texas 77007

Setco Industries, Inc.
5880 Hillside Avenue
Cincinnati, Ohio 45233

Seversky Electronatom Corp.
30 Rocketfeller Plaza
New York, N.Y. 10020

W.W. Sly Manufacturing Co.
P.O. Box 5939
Cleveland, Ohio 44101

Smico, Inc.
500 N. MacArthur Blvd.
Oklahoma City, Oklahoma

Sprout-Waldron & Co., Inc.
Muncy, Pennsylvania 17756

Sterling Blower Company
771 Windsor Street
Hartford, Connecticut

Sternvent Company, Inc.
12 Van Dyke Street
Brooklyn, New York 11231

Tailor and Company, Inc.
2403 State Street
Bettendorf, Iowa 52722

Torit Corporation
1133 Rankin Street
St. Paul, Minnesota 55116

United McGill Corporation
Dust Collector Division
883 North Cassady Avenue
Columbus, Ohio 43219

UOP Air Correction Division
P.O. Box 1107
Darien, Connecticut 06820

Western Precipitation Division
P.O. Box 2744 Terminal Annex
Los Angeles, California 90054

Wheelabrator Corporation
Air Pollution Control Division
400 South Byrkit Street
Misawaka, Indiana 46544

Young Machinery Company
Painter Street and Schuyler Avenue
Muncy, Pennsylvania 17756

APPENDIX 4

R&D SUGGESTIONS BASED ON INTERPRETATION OF COMMENTS MADE DURING SURVEYS

A. Overall fabric filter system costs

1. No comments from field. Cost-effectiveness analysis conspicuous by absence. Lower costs would make more competitive with other cleaning technology for certain specific applications (e.g., fly ash, combustion effluents).

B. Baghouse design

1. Construction materials: steel, concrete, aluminum, etc., in various conditions of corrosivity.

2. The economics of good baghouse construction; why are they so flimsy?

3. The economics of building your own baghouse.

4. Need of an inexpensive standard design baghouse, portable, with adequate instruments and test procedures for pilot studies.

5. A better system of dampers for sealing off a compartment; to aid in service and maintenance of bags; to enable entering the compartment during system operation; and to prevent intrusion of moisture during down periods.

6. Better quality sealant materials and mechanical assembly to reduce air leakage.

7. Better flow control at bag inlet, to reduce lower and abrasion of cloth, e.g., by a study of baffles and their effect on turbulence and velocities at tube entrance; also to promote large-particle settling; baffles should be designed for a minimum of abrasive wear.

8. Design of inlet side of baghouse and hopper to minimize places for dust accumulation (residual material sometimes catches fire).

9. Designs to minimize maintenance time within the compartment, especially desired when the dust is hot, noxious, etc.

10. Technique for checking and obtaining the proper bag tension quickly during replacement, assuming the ideal tension has been determined.

11. Consideration of various combinations of demisters/ESP/ FF/ rinsed screens, etc.; for example, a wet electrostatic filter.

C. Equipment accessory to baghouse

1. Means to cool a hot compartment rapidly prior to maintenance entry. (Oxygen or moisture content in coolant is not always permitted.)

2. Study of optimum fan design for various applications. Fans wear and sometimes fly apart with great damage.

3. Better understanding of duct design, to avoid caking and plugging and if possible to minimize abrasion of duct elbows.

D. Fabrics - Quality and Design

1. Higher temperature, less expensive cloths are needed.

2. Temperature range of cloths is now adequate: longer life, especially more resistance to flexure, is the major need.

3. Establishment of the relation between temperature and life of various common fabrics as a guide to their selection.

4. Standardization of cloths: standardization of quality to enable specification of the desired characteristics and to obtain a guarantee of cloth performance which is unobtainable at present; need for more science and less art in filter fabric making.

5. Non-blinding cloths.

6. Elastic cloths which will give rather than tear.

7. Finishes: Need to investigate this important area since little public information is available. The roles of release agents, metallic finishes and electrostatic treatments.

8. Projection of future fabric material needs.

9. Need to promote fabric research at installations other than the traditional fabric manufacturers.

10. Need to survey a wider variety of fiber, cloth, and bag makers.

11. Design of exotic fabrics, for permeability and seepage control and varying process conditions.

12. Broad study of fabric composite materials, e.g., use of steel fiber in glass cloth, use of alminates, non-wovens versus cloths,

in other words, a "systems" expansion of the composite field and a consideration of possible applications of the resulting materials.

13. Possible use of scrim or mesh ahead of the fabric to agglomerate fines without plugging, as an aid to pre-loading the fabric or to add large very permeable agglomerates to the dust layer on the fabric; means to dislodge the collections from the scrim periodically.

E. Bag Fabrication

1. Investigation of all possible materials for use in filter elements.

2. Need of an ultra-high temperature filter element which might be non-flexing. Systems analysis needed.

3. Need for understanding, or for establishing, specifications for cloth and for bags, to help insure uniformity from order to order and from supplier to supplier. A listing of the important fabrication parameters.

4. Need for a better thread for sewing seams.

5. A breakdown of the costs and profit margins for the finished bag, the raw cloth, and the yarn and fiber, as a key to development and cost reduction.

6. Need for larger fabrics from the weavers.

F. Selection of Fabric

1. What are the rules for selection of the best cloth, if the available experience isn't enough?

2. A vast study of combinations of dusts and cloths might be made, but the task would never be done. Laboratory work is at best a guess since many variables are inevitably missed; yet it is necessary for a new dust application; it often misses the mark widely. Needed is a statement of what the considerations ought to be in setting up a lab project; what variables and parameters ought to be included; and how good can the result be expected to be at best (and at worst)?

3. Brief survey of the economics of salvaging, cleaning and repairing bags; or discarding them, on an as-needed basis; or on a fixed period maintenance basis.

G. Particles

1. Study of agglomeration methods.

2. Understanding of electrostatics in particle collection and cake removal.

3. Means of control of particles that are sticky when hot or are pasty when cool.

4. Can turbulence aid pre-agglomeration, and under what conditions?

H. Dust concentration instrumentation

1. Need of method of determining FF load when the collected material returns to process via a closed system.

2. Need for ultra-low concentrations of toxic material, on an automatic, continuous basis.

3. Standard reliable methods of sampling in low concentrations with turbulence.

4. Reliable monitor for dirty FF effluent.

5. Quick method or instrument for locating difficult-to-see holes in bags.

6. Improvements in methods of obtaining particle size distributions.

I. Maintenance Aids

1. Method of keying each bag to its appropriate collector and location, to avoid misinstallation of the wrong bags.

2. Study to develop a nomogram showing the effect of dust loading on FF costs along with the reasons.

J. Process Instrumentation

1. Study of standard instrumentation available to control the FFS to fluctuating processes, to avoid temperature surges, condensation, etc. Include economics and tell what good instrumentation can accomplish in terms of reduced power, longer bag life, etc.

2. Development of reliable, inexpensive device to warn against incipient condensation.

3. Non-plugging pressure sensor for draft control in direct extraction furnace roof.

4. Device to warn of baghouse and hopper fires, or to control against fires.

K. Problems of Special Industries

1. FF research needed toward small combustion sources in urban areas, heat and power plants, and incinerators. Money and incentive are especially scarce in these areas.

2. Market study of certain collected materials, to increase their value and the attractiveness of FF as a process rather than APC.

3. Closer looks at these applications, and the possible government subsidiation of trials, pilot or full scale, to establish the performance of FF:

   Kraft pulp mill recovery furnace, or lime kiln effluent
   Open hearth furnace (pilot feasibility is established)
   Sinter process, steel mill
   Electric furnace for abrasives
   Basic oxygen furnace
   Coke plants, several possible applications

4. Instruction for better use of hoods on electric steel furnaces.

5. Need for cake release studies on various dusts in the steel industry.

6. Large study of the non-ferrous metals area, as an old but very tough FF application because of fires in the collected material and sticky fumes among many other adverse factors.

L. Gas Treatment via FF

1. Further development of FF to treat odors as well as to collect particulate.

M. Mechanical Aspects of Bag Life

1. Study of bag wear wanted by many users.

2. Elimination of bag rips.

3. Study of ring specifications and life (both internal and fastening rings)

4. Optimization of internal support method for bags, for external filtering or to prevent collapse when cleaning; must allow for quickest possible replacement of bags over the support apparatus.

5. Control of bag collapse by strategic yarns and weaves.

6. Reinforced fabric, wires, or stiffer thread or variations in weave to control collapse or shake oscillations, effects on cleaning and general operations.

   Longitudinal weave variations to control collapses on reverse air/glass; high temperature applications; pucker bag shape, versus various combinations of fabric, dust, treatment, process, etc.

7. Determination of ideal length/width ratio of bags

8. Method of determining the proper tension a bag should have for best performance

9. Study of tension, life, and cleanability; the collapse catenary

10. Study the abrasion of fabrics by interstitial deposits of all types of dusts; develop a standard test device, and obtain indices of fabric/dust combinations.

11. Study the abrasion of fabrics by surface impact or friction of moving dust streams or possibly of deposits of caked material.

12. Study the abrasion of fabrics against support rings, tube collars, housing walls or wall projections, in the presence of dust. Also bag-to-bag abrasion.

13. Cutting of cloth by stiff fiber quills.

14. Certain bags fail ten times faster than others in the baghouse; why?

15. Higher air/cloth ratios wanted.

16. Study the effects of underloading and of overloading a FF; give a cost report.

17. Flexure specified as cause of failure in many cases; extensive study needed of the mechanisms

18. Popping mentioned also as a cause of failure; how does it contribute to wear, and what are the pros (cake removal) and the cons of popping following cleaning.

19. Glass fabric needs a special study ; a number of glass bags are being shaken for cleaning, by responsible manufacturers.

20. Attempt to lay out ground-rules for the proper choice of fabric and cleaning mechanism combination. It may be possible to over-clean bags; how much is right and how can the right amount be obtained automatically during operation?

21. A general survey or study of cleaning mechanisms should include sonic energy, organ pipe effects, electrostatic reverse polarity.

22. Broad study of effects of sonic frequencies and pulsating frequencies on caking process and removal process. Employment of hard conductors in the fabric to carry the vibrations.

23. One reason for short bag life on reverse jet units is the mechanism on the clean side of the cloth sooner or later gets fouled by leaking dust, and thereafter the mechanism begins to destroy itself. This kind of mechanism should be redesigned to protect the machinery, and thereby increase bag life.

24. Consider an air-borne lubricant to replenish one already on the cloth, or to enhance operations.

N. Cake Formation and Cleaning of the Cloth

1. Non-blinding cloths are wanted.

2. Cake properties as affected by removal, or addition, of larger particles in the dust stream by baffles, skimmers, settling chambers, hoppers, cyclones, etc. for various combinations of dust, cleaning method, and fabric.

3. Seepage of dust is expected as a matter of course study should be made for that kind of dust to prevent seepage.

4. A study of adhesion theory should be made, bringing in as many dust-cloth combinations as possible. Lead chloride doesn't release well although it did when wool felt was used. A cloth with fine, slippery fibrils is wanted rather than merely a smooth cloth. In another case a cementitious deposit gradually builds up which eventually cracks the bag.

5. Pulsation from the fan is a critical factor in cake formation or in cake removal. Likewise the pressure surges occurring in one compartment as another compartment is dampered off may be a factor in cake mechanics.

O. Chemical Resistance, and Wetness of the Cloth

1. More corrosion resistant fabrics are wanted, as well as baghouse and mechanical parts that will stand up better to corrosive conditions.

2. Need exists for better control of the gas temperature with respect to condensible constituents dew point

3. A fabric that could become damp and yet continue to function would be a help. A substantial economic study of the costs of supercooling the gas, removing the condensed particulate, and then slightly reheating the gas above the dew point is needed; in this way it may be possible to in effect filter below the dew point. Other approaches may be possible.

4. Control with respect to dew point is needed to prevent accumulation of mud on the cooler end of the bags and to prevent plugging of the hopper material.

P. General FF Study Extensions

1. User survey data should be reviewed by the appropriate FF manufacturer to be sure he concurs.

2. Also Projected R&D plans should be reviewed by FF and other manufacturers, possibly in a joint seminar, to obtain suggestions and avoid duplicating work that may have been done and might become public through such a review.

3. A periodic literature review should be established, to maintain the FFS Data Bank if work is to continue along these lines. In particular, an effort should go to reviewing the foreign literature. We should determine which FF manufacturers should review the fogeign literature, and also avoid duplication of effort at APTIC.

4. A list of likely, qualifying R&D bidder for programs like these should be collected.

5. APC needs should be projected ahead for several years to see what temperatures, etc. will be in vogue; what may the economies of the alternative gas cleaning methods be, and will FF be competitive? What will the FF needs be?

6. A general computer model of the general FFS could be made up now, which would be useful in exploring several accumulated theories of cake structure formation, cake removal, etc. This would more likely be a tool in feeling out suggested R&D projects than a producer of data, or a publicized predictor of FF performance.

7. A number of suggestions were made during the survey that are not R&D suggestions; rather they are clues to better selections of existing technology, or to better maintenance of equipment now being used. Accordingly, they should be assembled along the lines of the handbook, or in the handbook, for FF users, etc.

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15. Supplementary Notes

16. Abstracts

A Final report is presented which describes a study directed to the definition of two alternative five-year research and development programs based on different levels of funding for fabric filter systems used in air pollution control applications. These plans provide specific performance, to improve economics of usage, and to promote extension of fabric filtratio to control of a greater number of applications. Specific tasks undertaken include: A survey of engineering technology available as data or analytical design and operation equations; the identification and investigation of current practices, limitations, and problems of fabric filter systems in present usage and in possible future applications; and a review of the major types of fabric filter equipment available.

17. Key Words and Document Analysis. (a). Descriptors

Air pollution control equipment
Filters
Filter materials
Fabrics
Performance
Design criteria
Cost analysis
Particles
Review

17b. Identifiers/Open-Ended Terms

Fabric filters
Air pollution control

17c. COSATI Field/Group 13/B

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