AUTOMOTIVE DIESEL FUEL FILTER QUALIFICATION METHODOLOGY AND PRELIMINARY SCREENING RESULTS

INTERIM REPORT
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This report covers a program to develop a methodology to evaluate military vehicle fuel filters that would become part of a proposed military fuel filter specification. For this program, thirteen different fuel filters used on military and commercial vehicles were tested using a multipass fuel filter test stand. Each filter type was tested in triplicate. Test parameters measured included differential pressure across the filter, particulate contamination in both the influent and effluent fuel (measured gravimetrically), filter load capacity, and filter efficiency.

The filter test results varied widely. Analysis of the results illustrated the need for better specification and control of filters used in Army fuel systems. The filtering media in some of the filters tended to separate or allow channeling at widely varying pressure drops. Some of the higher efficiency filters tested were also found to allow a significant number of large diameter particles to pass through.

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19. ABSTRACT

A rating system was designed that incorporated filter load capacity and filter efficiency. The product of these two parameters was plotted for each of the filters tested and a rating scale was determined. The results based on this rating scheme were compared to results obtained by ranking the filters according to other commonly used rating schemes. No two of the rating schemes ranked the filters in the same way.

A summary of a government/industry meeting to discuss the military's fuel filtration needs and a proposed specification are also provided in the report.

EXECUTIVE SUMMARY

Problems and Objectives: At present, a military specification for evaluating automotive diesel fuel filters is not available. All current specifications are concerned with fuel systems, i.e., airport distribution points and depots, and typically involve only aviation turbine fuel. A major concern has developed involving the fuel filters in diesel-powered wheeled and tracked vehicles. Either the commercial standards used to evaluate fuel filters are not being adhered to or the specifications are inadequate.

The objective of this program was to develop a methodology by which fuel filters can be tested and to prepare a preliminary military fuel filter specification.

Importance of Project: Although fuel filters recommended by the manufacturer usually protect the fuel system components under normal driving conditions, the military must be sure that the filters will protect its vehicle/equipment fuel injection systems under the most diverse and stringent conditions but not prematurely plug due to insufficient filtering capacity. The lack of engine protection is best illustrated by the continuing documentation of engine and pump failures in military wheeled and tracked vehicles due to the ingestion of grit and sand during Operation Desert Shield/Storm.

Technical Approach: A new procedure and methodology were developed using a "multipass" fuel filter system that tested the fuel filter(s) under extreme test conditions. This procedure tests the fuel filter(s) using high test fuel flow rates and particulate contamination that simulated both dust and fuel degradation products.

Accomplishments: Various fuel filters used on military and commercial vehicles were tested. The results were tabulated, and a preliminary rating system was developed that evaluates the filter according to the loading capacity and filter efficiency. These criteria were considered the most important for the military application.

Military Impact: The development of a fuel filter specification should allow the Army to obtain fuel filters to meet the military's unique battlefield requirements, and reduce the current logistical burden of maintaining large stocks of a wide range of filters.

FOREWORD/ACKNOWLEDGMENTS

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I. INTRODUCTION AND BACKGROUND

Current military diesel- and gas turbine engine-powered ground vehicles contain a variety of fuel systems and engines. Fuel system design guides have been developed for diesel and gas turbine powered military vehicles (1)* and for the Standard Army Refueling System.(2) Engines require clean fuel to operate properly. This fuel is subject to contamination and/or deterioration throughout normal distribution and storage/handling processes as well as in the vehicle fuel system. Despite the required filtration of all fuel throughout this distribution system, the fuel in the vehicle fuel tank may still be contaminated. As such, it is incumbent upon the vehicle fuel filters to remove any contamination and to provide fuel of sufficient cleanliness to the engine.

Most engines use a progressive filtration system consisting of two or three filter components in series: a strainer, which is usually a metal screen or cleanable metal-edge type filter to remove large particles; a primary filter, usually with a replaceable-type element capable of removing particles down to 25 to 30 micrometers; and a secondary or final filter, which consists of a sealed and noncleanable unit capable of removing particles of 10 micrometers (for diesels) and 5 micrometers (for gas turbines). The primary filter and strainer should be drainable and be installed in an accessible location between the fuel tank and the fuel pump. If on the suction side of the fuel pump, the filter must offer low restriction to flow.

Secondary filters, located on the pressure side of the transfer pump, are designed primarily to protect the injectors. Efficiency rather than restriction is the determining factor in secondary filter design; it is most often a surface-type filter. The filter element must be capable of handling the flow of the fuel pump and be able to withstand a differential pressure of 25 psi. The element should be carefully selected to provide high efficiency and long service life—a combination that is not available in all filters.

For fuel systems in which there is no external line after the transfer pump, a compromise between low restriction and high efficiency must be considered for the filter to handle the required fuel flow and still provide adequate protection. Usually a surface type primary filter is used.

* Underscored numbers in parentheses refer to the list of references at the end of this report.

Military vehicles often operate in adverse conditions, where large quantities of water and dirt will eventually be present in the fuel tank. Therefore, a fuel/water separator should be installed between the tank and transfer pump. Most separators are of a two-stage design, with the first and second stage combined concentrically or with the second stage mounted tandem to the first stage. The first stage filters out solid particles and coalesces small water droplets. The second stage usually has a hydrophobic barrier to prevent entrainment of the water droplets.

Fuel filter media include yarns, papers, binder-free fibers, resin-bonded fibers, woven wire cloth, polypropylene, and other synthetics. The mechanism of filtration also differs: some are depth (or tortuous path) type filters (yarns, binder-free or resin-bonded fibers) and some are surface filters (papers, felts, and woven wire cloth).(3)

In general, when diesel fuel filter qualifications have been used, they include Test Method SAE J905 ("Fuel Filter Test Methods").(4) This test method uses air cleaner fine test dust as a contaminant for rating filter efficiency and capacity. ISO 4020/102, "Road Vehicle Fuel Filters for Automotive Compression Engines" includes two parts: one on test methods and the other on test values and classification.

Generally, no government standards or specifications currently exist for the selection of automotive-type filter elements. Each engine manufacturer designates its own choice of filter type or manufacturer, forcing the government to stockpile filters under several national stock numbers. In the case of 2.5- and 5-ton Army trucks, the technical requirements and test methods for fuel filter Army Part No. (APN) 116 10298 are provided by Memorandum for Record, dated 21 April 1983 by Tank Automotive Command (TACOM). Highlights of this requirement include:

a. Filtering efficiency of 99.8-percent minimum using MIL-F-46162B (5), "Fuel, Diesel, Referee Grade" test fuel. AC fine test dust (ACFTD) slurried with referee fuel. Five grams of ACFTD added every 5 minutes until a total of 30 grams are added. Flow rate is 0.5 gpm flowed through millipore filter.

b. Dirt-holding capacity: 1 gram of ACFTD, 5 grams of asphaltene, and 10 milliliters of water, dispersed and slurried with referee fuel. This slurry is added to the test referee fuel in the test stand every five minutes until a differential pressure of 21 psi across the filter element is attained. The time to attain this 21 psi is 105 minutes minimum. Flow rate is 2 gpm.

c. Pore size as determined by SAE J905.

d. Media migration limited to 0.002 grams/8 hours as determined in SAE J905.

e. Differential collapse pressure requirement of 80 psid minimum.

f. Test fluid is per MIL-F-46162B referee fuel, Viscor L4264V91 fuel filter fluid could be used.

g. Clean flow pressure drop limited to 0.82 psid maximum. Flow rate is 2 gpm.

Filters (meeting the requirement of APN 116 10298 for engineering approval) are generally designed with a coarse outer filter material that retains large quantities of asphaltenic-type debris and an inner filter (such as pleated paper) to trap small particles (2 to 3 μm). The most commonly seen dual stage filter of this type has string wound around an inner pleated paper filter. Newer designs are made of more complex materials.

In a joint TACOM and Belvoir RDE Center program to develop a performance specification and a Qualified Products List for engine fuel filters, a fuel filter test rig was designed and built. The following criteria were used in the design of the test rig:(1)

1. Reasonably small and portable
2. Able to pump fuel at flow rates up to 4 gallons per minute
3. All stainless steel fittings, valves, and tubing
4. Able to inject water and solid contaminants.

Fig. 1 is a photograph of the front view of this rig, and Fig. 2 is a schematic diagram of the test rig. This rig allows for controlled injection of both solid contaminants and water. Previous work has shown that the efficiency of a filter is affected only marginally by the rate of solids contamination injection and that lower injection rates are somewhat more severe when evaluating a filter.(6) However, the efficiency will be affected if the fuel filter needs to form a "filter bed" to improve its efficiency.(3)

A contaminants package for use in the filter test rig was developed to more closely resemble the typical contaminants encountered in the field. Organic particulates, either fuel deterioration products or asphaltenes (i.e., high molecular weight asphalt-like impurities from residual or No. 6 burner fuel contamination), may be present in some diesel fuels. Although fuel filter performance is typically measured using fine inorganic test dust, filter choking is often caused by the accumulation of such particulates long before the filter has collected an amount of dust that, by itself, would have choked the filter. Filter media should resist choking by organic particulates, as measured on actual diesel fuel, while still providing the required particle collection. The contaminants package includes the following:

- PV Resin - Simulates fuel degradation products
  PV Resin No. 514
  GEO Liquids
  1618 Barclay Blvd.
  Buffalo Grove, IL 60089

- AC Fine Test Dust ACFTD - Simulates dirt and dust
  AC Fine Test Dust
  AC Spark Plug Division
  General Motors Corporation
  Flint, MI 48556

These contaminants were selected based on the results of a previous program to identify fuel system debris (7,8) and subsequent analysis of several contaminated fuel samples and plugged filters. Analysis of numerous contaminated fuels varied in the quantity of fuel degradation products and dirt. Since the relative amounts of contaminants varied, the composition of the contaminants package used for this test procedure was set at 50 wt% PV Resin and 50 wt% AC Fine Test Dust. The PV Resin was chosen to simulate fuel degradation products or fuel organic sediment.

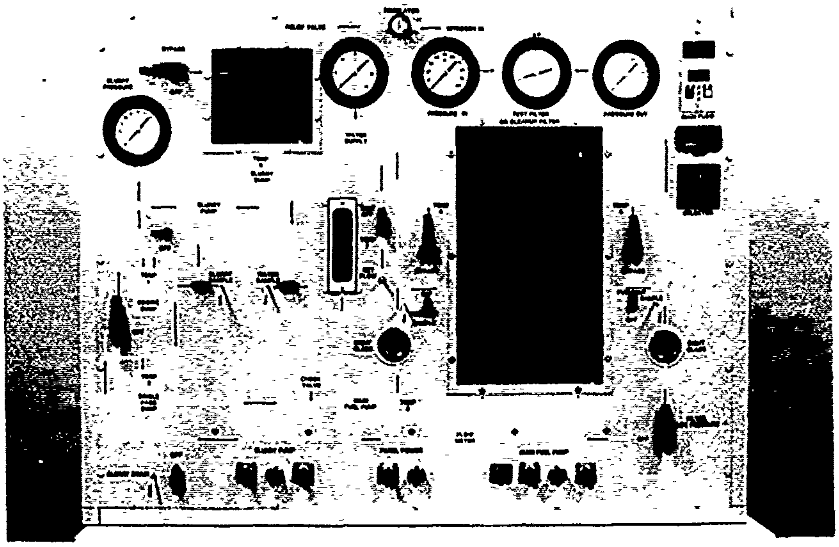


Figure 1. Diesel fuel filter test rig — front view

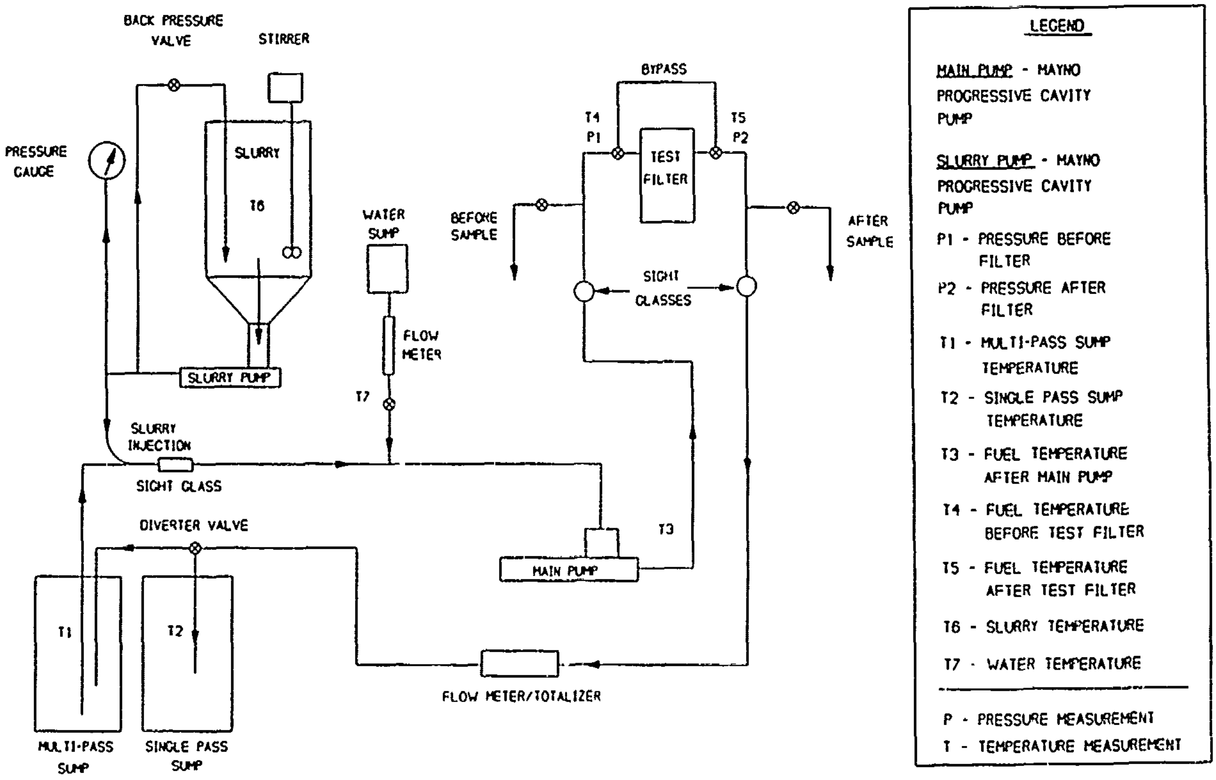


Figure 2. Schematic drawing of the diesel fuel filter test rig

Microbiological contamination is a serious problem and is often sufficient to plug a fuel filter. However, filter plugging by microbiological contamination is difficult to simulate in a reproducible manner for two reasons. The first is that many microorganisms, such as ***Hormoconis resinae,*** have a resinous pellicle that greatly enhances their ability to plug filters. This pellicle is not easily simulated. The second reason is that microbiological debris/contamination does not always plug a filter in a uniform manner. A part of a microbiological colony growing in the fuel tank may dislodge and travel to the filter. Often this remnant of a colony remains intact until it reaches the filter, at which point it plugs a portion of the filter's surface area. Additionally, the microbiological growth may occur in the filter housing or even directly on the element itself. For these reasons, no attempt was made in this program to simulate filter plugging due to microbiological debris.(7)

II. APPROACH

The initial approach to defining automotive diesel fuel filter qualification methodology involved evaluation of several currently used military and commercial automotive fuel filters. The filters were evaluated in a laboratory test rig for differential pressure across the test filter, gravimetric fuel contamination of the influent and the effluent, filter loading capacity, and filter efficiency. Results of all filter tests were compared, and attempts were made to rank the performance characteristics of all filters tested. Using these results as reported in this report, a government/industry meeting was held to develop a military fuel filter specification that satisfies military requirements while not being too stringent to be manufactured. Recommendations for restructuring of the test procedure for filter qualification were then formulated for future evaluation.

III. PROCEDURE

Various diesel fuel filters were used for determining this methodology. The filter types and filter parameters are listed in TABLE 1. The filters have been coded (see Filter Code in TABLE 1) to indicate the BFLRF identification number and the general application of the filter, e.g., F1-P indicates F1 is a primary filter.

TABLE 1. Fuel Filters to be Evaluated

Filter Code	General Application Type	Filter Media	Nominal Pore Size, μm*	External Dimensions (H × W), cm
F1-P	Primary	Cotton Sock	30	21.3 × 7.9
F2-P	Primary	Cotton Sock	30	15.3 × 7.5
F3-X	Secondary	Pleated Paper	12	20.0 × 7.4
F4-P	Primary	Pleated Paper	--	19.5 × 7.7
F5-P	Primary	Pleated Paper	--	19.5 × 7.7
F6-C	Coalescer	Glass/Paper	NA†	18.8 × 6.9
F7-S	Filter/Separator	Pleated Paper	10	19.6 × 8.4
F8-S	Filter/Separator	Pleated Paper	5	17.1 × 8.4
F9-C	Coalescer	Glass/Paper	NA†	18.8 × 6.9
F10-S	Filter/Separator	Pleated Paper	--	10.5 × 6.3
F11-P	Primary	Pleated Paper	--	5.9 × 8.2 × 15.9 (L)

* Pore size is commonally referred to as porosity by filter manufacturers.
† NA = Not Applicable.

These filters were evaluated using the following test parameters:

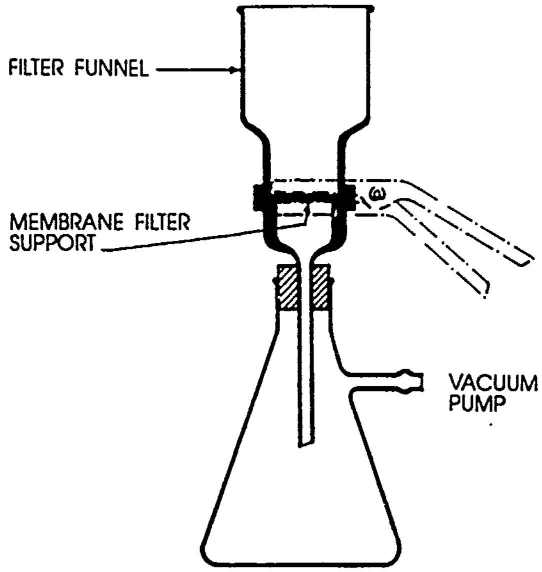
1. Fuel contamination level, 0.25 gram/gallon,
2. Flow rate, 1.5 gallon/minute,
3. Contaminants, PV Resin and AC Fine Test Dust, 0.125 gram/gallon of each.

Typical fuel consumption rates for wheeled and tracked vehicles range from 0.24 to 2.22 gallon/minute.(9) Most of these rates are below 0.5 gallon/minute. Since the majority of the fuel is returned to the fuel tank from the injectors, the flow rate through the fuel filter will be greater than the consumption rate. Therefore, a 1.5-gallon/minute flow rate was chosen as a representative flow rate.

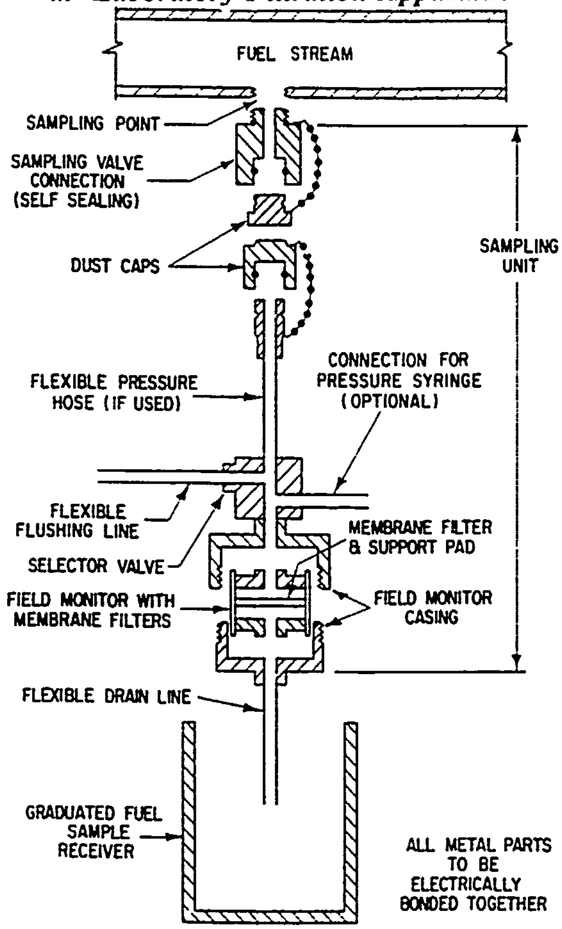
A clean filter was installed in the filter test rig, and clean fuel was pumped through it to test for leakage. To begin the filter test, the fuel pump was turned on, and the fuel slurry injection and the data acquisition system (LOTUS Measure) were started. Pressure and temperature data were acquired every 15 seconds. In addition, the fuel was sampled before and after the filter for gravimetric contaminant analysis in the laboratory. The detailed procedure is described in Appendix A.

The test procedure (using the filter test rig shown in Figs. 1 and 2) was designed to measure both filter efficiency and load capacity. The sampling ports allow for batch sampling into bottles for particle counting and determination of particulate contamination. The procedure used in this study was a modification of the ASTM D 2276 method using a smaller sample size, 0.7 micrometer porosity glass fiber filter membranes, and an apparatus similar to the one pictured in Fig. 3a. The method for bulk laboratory filtration of samples for particulate contamination is described in American Society for Testing and Materials (ASTM) Standard Test Method D 2276-89 (10), Annex A3. These ports are also configured to allow for direct, on-line filtration for the determination of particulate contamination. On-line filtration can be accomplished using preweighed (or matched weight) 0.8 μm poresize monitors as described in Annex A2 of D 2276-89. The on-line filtration apparatus is shown in Fig. 3b. The filter efficiency was based on gravimetric measurements of the particles measured in the influent (fuel before the filter) and effluent (fuel after the filter). The load capacity used the same data for summing the quantity of debris collected by the filter.

The gravimetric data provided the fuel contamination level before and after the filter. Load capacity and filter efficiency were calculated from these results.



a. Laboratory Filtration Apparatus



b. On-Line Monitors

Figure 3. <u>American Society for Testing and Materials Standard Test Method D 2276-89</u>

With a few exceptions, three filters of each type were tested. The results reported include differential pressure (psid) versus time, differential pressure and particulates (before and after the filter) versus time, the calculated load capacity, and filter efficiency. Particle size analysis was performed during the evaluation of four filters at the end of the program. The results from each filter analysis are presented in this report, and its performance and a preliminary rating are discussed. Illustrations of the data are presented in Appendix B.

IV. FUEL FILTER QUALIFICATION RESULTS

A. F1-P Filter

Filter F1-P was evaluated six times, and the data are illustrated in Figs. B-1 through B-12. The three additional runs were requested by U.S. Army Tank-Automotive Command (TACOM) during Operation Desert Storm. In the first three runs, the differential pressure data, Fig. B-1, reveals a possible rupture or separation of the filter media in runs 1 and 3. This hypothesis is confirmed by the "pressure-particulates" data shown in Figs. B-2 and B-4. In Fig. B-2, the "particulates-after" increased from <0.05 gram/gallon to approximately 0.25 gram/gallon. In Fig. B-4, the results are similar, with the "particulates-after" approaching 0.30 gram/gallon. Run 2 reached the desired differential pressure of 15 psid in approximately 115 minutes.

The three runs performed for TACOM were consistent with the above results. The filter in run 1, Fig. B-7, ruptured/separated as in runs 1 and 3 from above. However, runs 2 and 3 reached 15 psid in approximately the same time (100 minutes).

The load capacity for these six runs, Figs. B-5 and B-11, averaged approximately 19 grams. The efficiencies, Figs. B-6 and B-12, varied widely due to the rupture/separations in three filters. The efficiency of the initial three tests averaged approximately 65 percent, while tests performed by TACOM averaged approximately 90 percent. The lower efficiency is due, in part, to two of the three filters rupturing or separating during the test.

B. F2-P Filter

As shown in Fig. B-13, the differential pressure data of Filter F2-P have the same characteristics as F1-P. The pressure increases to a certain value, then remains constant or deteriorates. When the differential pressure reaches this plateau, the "particulates-after" data, Figs. B-14 through B-16, show a rapid increase. The same type of rupture or separation as with Filter F1-P has occurred. The average "particulates-after" data increased from <0.05 gram/gallon to >0.4 gram/gallon. This rupture or separation occurs at between 50 and 75 minutes of run time.

The load capacity, Fig. B-17, varied widely due to these rupture or separations. The range was from 40 grams to -5 grams retained. The negative load capacity indicates the filter is beginning to pass previously entrained particles. The efficiency data, Fig. B-18, are also distributed over a large range, starting at approximately 80 percent and dropping as low as -60 percent.

C. F3-X Filter

Tests on Filter F3-X were run five times. The additional tests were requested by TACOM during Operation Desert Storm.

The data resulting from the F3-X runs are shown in Figs. B-19 through B-29. The differential pressure reached the designated 15 psid in two runs, Figs. B-19 and B-24. However, it appears that two other runs would also have reached 15 psid if the runs had not been terminated. Run 2, Fig. B-19, was terminated at 180 minutes. This earlier parameter was later increased to 240 minutes. Run 3, Fig. B-24, was terminated due to seizure of the transfer pump. Therefore, four of the five runs are considered successful. Run 1, Fig. B-24, appears to have been damaged or to have had a hole in the pleated paper since the differential pressure, Fig. B-25, never increased and the efficiency, Fig. B-29, continually declined during the run. The average load capacity for the five runs was approximately 26 grams. The average efficiency was approximately 88 percent.

D. F4-P Filter

The filter data for F4-P were very repeatable and are shown in Figs. B-30 through B-35. All three runs reached 15 psid within a 25-minute span (75 to 100 minutes), Fig. B-30. However, the "particulates-after" data, Figs. B-31 through B-33, average almost 0.1 gram/gallon. The "particulates-after" value is high at the beginning of the run and gradually decreases as a filter bed was formed.

The average load capacity was approximately 19 grams and was consistent for all three runs, Fig. B-34. The efficiency data (Fig. B-35) reveal how the filter bed increased the efficiency as the test progressed. At the beginning of the test, the efficiency was approximately 55 percent, while the efficiency increased to approximately 85 percent at the end of the test. However, the average efficiency was only approximately 65 percent.

It appears that this filter needs to form a filter bed before the efficiency reaches an acceptable level.

E. F5-P Filter

Filter F5-P has results similar to the F4-P filter. All three runs were very repeatable with an average time to 15 psid of approximately 100 minutes, Fig. B-36. However, the "particulates-after" data, Figs. B-37 through B-39, averaged almost 0.1 gram/gallon.

The average load capacity was relatively high and consistent at approximately 43 grams, Fig. B-40. The efficiency was approximately 80 percent, Fig. B-41. Filter F5-P did not show the dramatic need for a filter bed to be formed that was demonstrated in the F4-P filter.

F. F6-C Filter

The data for the F6-C filter are illustrated in Figs. B-42 through B-47. The differential pressure rise for the F6-C filter was very repeatable, Fig. B-42, but reached 15 psid in only 10 minutes. This low value was not surprising since this filter is a coalescer and is not designed to perform as a primary or secondary filter. However, this test shows that if the primary and/or secondary filter fails, this filter will plug immediately. The load capacity for this filter was approximately 5 grams, Fig. B-46, with an average efficiency of approximately 90 percent, Fig. B-47.

G. F7-S Filter

The data for the F7-S filter are shown graphically in Figs. B-48 through B-53. All three runs with the F7-S filter reached 15 psid or were terminated at 240 minutes. However, as shown in Fig. B-48, the run times varied dramatically, ranging from 100 to 240 minutes. The average time was approximately 170 minutes. The "particulates-after" data are high at the beginning of each run, indicating a filter bed was being formed. After approximately 75 minutes, the "particulates-after" decreased to less than 0.03 gram/gallon.

As shown in Fig. B-52, the load capacities of this filter were among the highest of the filters tested. Run 3, which was terminated at 240 minutes, had a load capacity of almost 100 grams. The average load capacity was approximately 77 grams. The efficiencies were inconsistent while the filter bed was being formed. However, after approximately 75 minutes, the filter has an efficiency of 95 to 100 percent. As noted in Fig. B-53, the average efficiency is approximately 90 percent.

H. F8-S Filter

The data for the F8-S filter are shown in Figs. B-54 through B-59. Fig. B-54 shows that the differential pressures of the F8-S filter for these three runs were very repeatable and all reached 15 psid at approximately 200 minutes. The "particulates-after" data, Figs. B-55 through B-57, show that the filter needs to form a filter bed to increase its efficiency. However, this need for a filter bed is not as pronounced as with the F7-S filter.

The average load capacity was consistent and showed to be the highest of all the filters tested at 80 grams. After the filter bed was formed, the efficiency fluctuates between 85 to 98 percent with an average of approximately 90 percent. These fluctuations are believed to be due to debris falling from the filter while fuel samples were being taken.

I. F9-C Filter

The F9-C filter data are illustrated in Figs. B-60 through B-65. This filter is similar to the F6-C filter and has almost identical results. The differential pressure reaches 15 psid in 10 to 15 minutes, Fig. B-60. As shown in Fig. B-64, the load capacity ranges from 5 to 10 grams. The average efficiency for this filter was 92 percent, shown in Fig. B-65.

J. F10-S Filter

The tests on Filter F10-S were also very repeatable, and the data are shown in Figs. B-66 through B-71. The differential pressures all reached 15 psid in 25 to 45 minutes, Fig. B-66. The load capacity varied from 5 to 20 grams, with an average of approximately 13 grams, Fig. B-70. The efficiency ranged from 82 to 95 percent, Fig. B-71, with an average value of approximately 88 percent.

K. F11-P Filter

The parameters for Filter F11-P were slightly different because the initial differential pressure was already greater than 15 psid. This high differential pressure is due to the high flow rate used for this procedure. The rated flow for the F11-P filter is less than 0.2 gallon/minute. Therefore, the test was terminated when the differential pressure was 10 psid greater than the initial differential pressure. The flow rate was also reduced to 1.2 gallon/minute, but the fuel contamination was corrected to maintain 0.25 gram/gallon.

The initial differential pressure was approximately 17 psid. All three runs reached the desired psid between 40 and 90 minutes with an average of approximately 60 minutes, Fig. B-72. The "particulates-after" values are among the lowest for the filters tested, as shown in Figs. B-73 through B-75.

The load capacity averaged approximately 36 grams with runs 1 and 2 having capacities of 29 grams each, Fig. B-76. The efficiency data, Fig. B-77, were the best for actual value and for consistency with an average value of approximately 98 percent.

V. RATING SYSTEMS

A filter is rated for its ability to remove particles of a specific size from a fuel, but quantitative figures are valid only for specific operating or test conditions.

Various methods are used for rating fuel filters: nominal rating, filter permeability, Beta ratio, and CETOP RP70, to mention a few. Each of these methods has different criteria as its parameters for rating the filter. These four rating systems are discussed below.

A. Nominal Rating

A nominal filter rating is an arbitrary value determined by the manufacturer and expressed in terms of percentage retention by weight of a specified contaminant (usually glass beads) of a given size. It also represents a nominal efficiency or degree of filtration. The percentage retentions normally used are 90, 95, or 98 percent retention of a specific particle size, i.e., 10 micrometers.(3)

B. Filter Permeability

Permeability is the reciprocal expression of the resistance to flow offered by a filter. High permeability represents low resistance to flow, while low permeability represents a high resistance. Permeability is normally expressed in terms of a permeability coefficient (k) related to pressure drop, ΔP, at a given flow rate (Q):(11)

$$k = \frac{Q\mu t}{A\Delta P}$$

where: μ = Fluid viscosity, Pa•s

t = Filter thickness, m

A = Filter area, m^2

ΔP = Pressure drop, Pa

Q = Flow rate, m^3/s

The permeability coefficient (k) is expressed in units of length squared, e.g., m^2.

In practice, this formula is unnecessary. Permeability is better expressed in terms of pressure drop versus flow rate. Such curves are then specific for a certain filter under prescribed test conditions.

C. Beta Ratio

The objective of using the Beta ratio is to incorporate a rating system that gives both the filter manufacturer and user an accurate and representative comparison of the filter media. It is determined by a "multipass test," which establishes the ratio of the number of influent particles larger than a specific size to the number of effluent particles larger than the same size. The Beta ratio is expressed by:

$$\beta_x = \frac{Nu}{Nd}$$

where: β_x = Beta rating for contaminants larger than X µm.
Nu = Number of particles larger than X micrometers per unit of volume effluent.
Nd = Number of particles larger than the X micrometers per unit of volume influent.

It follows that the higher the Beta ratio, the more particles that are retained by the filter, therefore, possessing a higher efficiency for the filter. Efficiency, expressed as a percentage (E_x) for a given particle size (x), can be derived directly from the Beta ratio by the following equation:(3)

$$E_x = \left(1 - \frac{1}{\beta_x}\right) \times 100$$

D. CETOP RP70 System

The European Oil Hydraulic and Pneumatic Committee (CETOP) has developed a method of expressing sample particle counts in terms of a simple code (TABLE 2).(3) The method does not indicate the method of sampling nor measuring the particles.

TABLE 2. CETOP RP70

Number of Particles Per 100 mL	RP70 Range Number
1 to 2	1
2 to 4	2
4 to 8	3
8 to 16	4
16 to 32	5
32 to 64	6
64 to 130	7
130 to 250	8
250 to 500	9
500 to 1,000	10
1,000 to 2,000	11
2,000 to 4,000	12
4,000 to 8,000	13
8,000 to 16,000	14
16,000 to 32,000	15
32,000 to 64,000	16
64,000 to 130,000	17
130,000 to 250,000	18
250,000 to 500,000	19
5,000,000 to 1,000,000	20
1,000,000 to 2,000,000	21
2,000,000 to 4,000,000	22
4,000,000 to 8,000,000	23
8,000,000 to 16,000,000	24

The table specifies an RP70 range number for different size particles ranging from 1 µm to 16 million µm. This range is divided into 24 groups according to a rounded-off geometric progression. In practice, only two parameters are normally used:

1. Total count of all particles >5 micrometers.
2. Total count of all particles >15 micrometers.

Each count is then allocated a range number, and the contaminant level expressed as */*. For example, a number of 17/9 represents a count of between 64,000 and 130,000 for all particles greater than 5 µm in a 100-mL sample and a count of between 250 and 500 particles above 15 µm in size in the same 100-mL sample. Where applicable, ratings from these additional systems will be presented for comparison.

VI. RATING SYSTEM FOR THE TESTED FILTERS

This testing procedure was a severe test of the filter's capabilities in regards to high flow rate and high contamination level. For some filters, these parameters may bias the data since, if a filter bed is needed, one will be formed quicker than in less severe conditions. However, as stated earlier, a rating is only good for a certain set of parameters.

Since this testing varied its test procedures and analysis during the program in order to establish the best criteria for rating, no established method is appropriate. Therefore, a comparative rating system was developed after the completion of the testing according to the overall results. This system uses the fuel contamination level, flow rate, run time, load capacity (the total weight of contaminant the filter retains before the filter reaches a differential pressure of 15 psid), and average efficiency (the weight percent of contaminant retained by the filter) for its criteria. This rating system takes into account that a "good" filter should have a high load capacity, a long run time, and a high efficiency. The rating is divided into four categories starting with "A" (best) to "D" (worst). The categories were determined by the following procedure:

1. The average run times and average efficiencies for all tests were tabulated in descending order, as shown in TABLE 3.

2. Each parameter was divided into three groups according to any naturally occurring breaks in the data, as indicated by the bold entries.

3. Each group was averaged and used in the rating formulas shown at the bottom of TABLE 3.

TABLE 3. Rating Data and Formulas

Average Run Times, (min)		Average Efficiencies, (%)	
200		98	
170	Avg = 173	92	
150		92	Avg = 92
115		90	
110	Avg = 104	90	
110		**90**	
95		88	
90		85	
65		82	Avg = 83
30	Avg = 29	**80**	
10		65	
10		65	Avg = 65

Rating Formulas

(0.25 gram/gallon) (1.5 gallon/minute) (173 minutes) (0.92 efficiency) = 59 grams
(0.25 gram/gallon) (1.5 gallon/minute) (104 minutes) (0.83 efficiency) = 32 grams
(0.25 gram/gallon) (1.5 gallon/minute) (29 minutes) (0.65 efficiency) = 7 grams

A. Rating and Test Filters

The average load capacity, average efficiency, and their product are tabulated for each filter and are shown in TABLE 4. The sample number versus load × efficiency is plotted in Fig. 4. The rating sections, as determined in TABLE 3, are indicated by the bold lines.

TABLE 4. Filter Ratings

Sample No.	Filter Code	Load Capacity	Efficiency	Load × Efficiency
1	F8-S	80	0.90	72.0
2	F7-S	77	0.90	69.3
3	F11-P	36	0.98	35.3
4	F5-P	43	0.80	34.4
5	F3-X	28	0.92	25.8
6	F3-X	25	0.85	21.3
7	F1-P	20	0.82	16.4
8	F4-P	19	0.65	12.4
9	F1-P	18	0.65	11.7
10	F10-C	13	0.88	11.4
11	F9-C	8	0.92	7.4
12	F2-P	8	0.80	6.4
13	F6-C	5	0.90	4.5

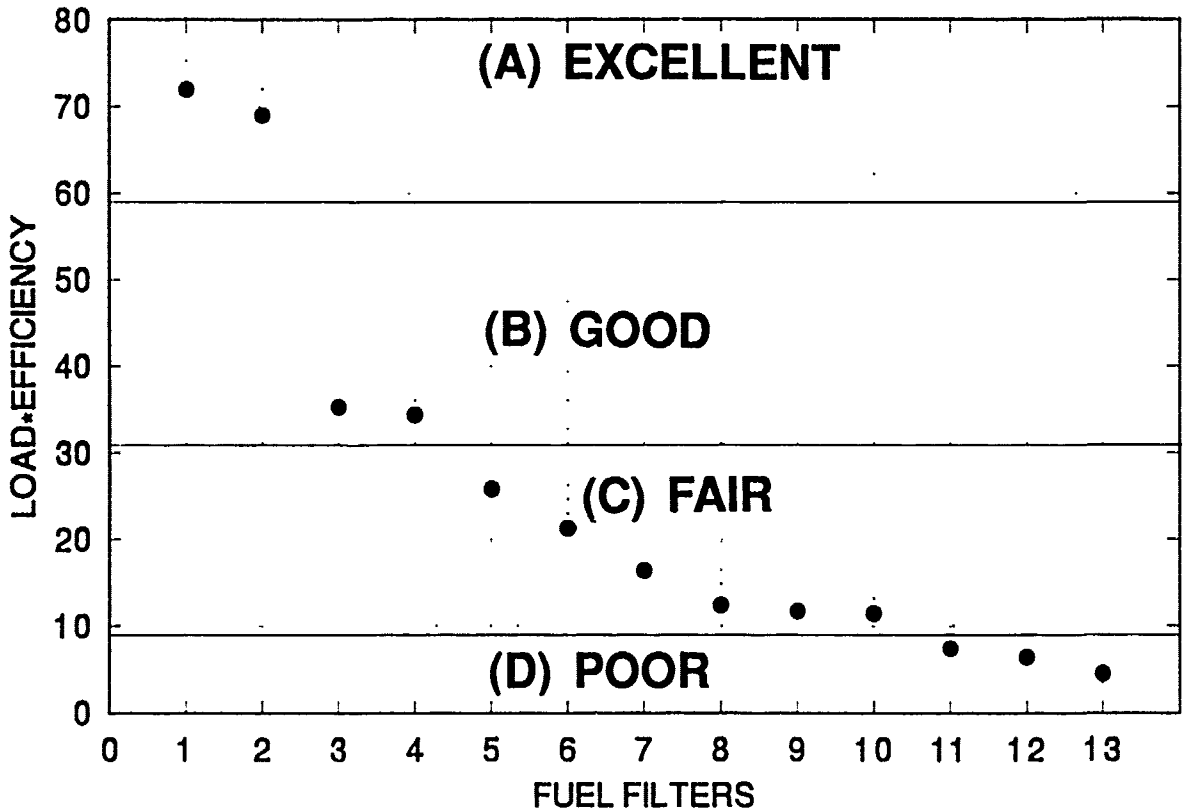


Figure 4. Rating system

B. Results

According to the graph data in Fig. 4, the tested filters should be rated in the following order:

Rating	Filter Code
A	F7-S F8-S
B	F11-P F5-P
C	F3-X F1-P F4-P F10-C
D	F9-C F2-C F6-C

TABLE 5 displays the ratings by the various methods for each filter where data are available.

TABLE 5. Rating the Filters by Various Methods

Filter Code	BFLRF/ SwRI	Beta Ratio β_6	Beta Ratio β_{16}	CETOP	Nominal Porosity, Micrometers
F8-5	A	--	--	--	5
F7-5	A	--	--	--	10
F11-P	B	60	470	16/10	--
F5-P	B	--	--	--	--
F3-X	C	41	27	15/10	12
F1-P	C	4	6	18/13	30
F4-P	C	--	--	--	--
F10-C	C	127	246	14/10	--
F9-C	D	--	--	--	--
F2-P	D	--	--	--	--
F7-C	D	--	--	--	--

The four filters in which Beta ratio and CETOP are appropriate rate in this order:

Beta Ratio	CETOP
F10-C	F10-C
F11-P	F3-X
F3-X	F11-P
F1-P	F1-P

It should be noted that the Beta and CETOP rating systems consider only particle count and not load capacity.

VII. PARTICLE SIZE ANALYSIS

Particle size analysis was performed on four filters: 1) F1-P, 2) F3-X, 3) F11-P, and 4) F10-C. This analysis determined the sizes of particles retained by the filter and the sizes of particles not being retained. An arbitrary reference point will be selected at a population level of 1000. This reference point will indicate the distribution of particles that is passing through the filter.

A. F1-P Filter

The particle size analysis was performed only on the runs tested for TACOM. As shown in Fig. B-78, at the reference point, the F1-P filter passes particles from 15 micrometers and smaller.

B. F3-X Filter

This analysis was also performed on the three runs requested by TACOM. Fig. B-79 shows that this filter passed particles 8 micrometers and smaller, with the damaged filter passing particles as large as 16 micrometers.

C. F11-P Filter

The particle size analysis, Fig. B-80, reveals that this filter does not need to build a filter bed to become an efficient filter. At 10 micrometers, the 0-minute and 30-minute samples are the same, with the 15-minute sample being slightly more efficient.

D. F10-C Filter

The particle size analysis, Fig. B-81, demonstrates the effects of a filter bed. At the beginning of the test, at 10 micrometers, the population is almost 4000 particles. However, after 15 minutes, the population dropped to approximately 250 particles. After 30 minutes, the particle count was still only 500 particles. The insert in Fig. B-81 better illustrates the effect of a filter bed formation. The particle size analysis for the F11-P and the F10-C filter were averaged for their respective runs, and the effect of the filter bed analyzed.

VIII. TEST WITH FILTERS IN TANDEM

The F1-P and the F8-S were tested in tandem with the coalescer, F6-C and F9-C. Figs. B-82 through B-85 show the results of these four tests.

A. Primary Filter-F1-P With Secondary Filter-F6-C

The F1-P filter performed as it did in the other tests. The differential pressure increased to 14 psid, then decreased, indicating the filter failed. As a result of this failure, the coalescer filter F6-C was inundated with contaminant and plugged immediately.

B. Primary Filter-F1-P With Secondary Filter-F9-C

These results are similar to the results obtained previously. The differential pressure across the F1-P filter increased to approximately 14 psid and failed. The coalescer F9-C then plugged due to the lack of protection from the primary filter.

C. Primary Filter-F8-S With Secondary Filter-F6-C and Primary Filter-F8-S With Secondary Filter-F9-C

In these two tests, the primary filter (F8-S) protected the secondary filter, but plugged in a very short period. In the preliminary tests, the F8-S filter ran for as long as 200 minutes. However, installing the two filters in tandem decreased the life to 40 minutes or less. Consultation with the manufacturer's technical staff did not provide an explanation of this phenomenon. This phenomenon is worth investigating to determine what caused the filter to plug so early, which may give further insight into other problems that may shorten the life of a fuel filter.

IX. GOVERNMENT/INDUSTRY DISCUSSIONS

A meeting was held at the Belvoir Fuels and Lubricants Research Facility (SwRI) in San Antonio, TX, to develop a military fuel filter specification for ground vehicles and equipment that would result in a filter that satisfies the military's requirements, while not being too stringent for manufacturers to produce. This meeting was held because industry had expressed the same concerns as the government in that fuel filter testing needed to be standardized. A summary of the meeting, a list of attendees, a draft proposed fuel filter specification, and the proposed new specification are included in Appendix C.

X. CONCLUSIONS

These tests illustrate the wide spread of results possible when analyzing a variety of fuel filters ranging from high capacities to low efficiencies. Some filters gave consistent results (F8-S) while others were very inconsistent such as F1-P. However, as widespread as the results were, no two rating systems agreed on the results. Also, when a filter was "efficient," it still often passed particles of significant size.

XI. RECOMMENDATIONS

The test procedure should be restructured as follows:

1. Reduce the run time to 120 minutes. Only three filters required the additional time for plugging.

2. Run the tests at two concentration levels. One test should be performed at the present level, 0.25 gram/gallon, and the second test should be run at a lower value of 0.10 gram/gallon. This analysis would help define the effects of the formation of a filter bed.

3. Run particle counts on the influent (upstream) and effluent (downstream) at 5 and 15 micrometers. This count will allow for rating the filters according to the Beta ratio and the CETOP RP70 system.

4. A new rating system can incorporate the system developed in this report, the Beta ratio, the CETOP RP70 system, and evaluate the permeability coefficient.

5. Lower temperatures should be investigated since the viscosity of the fuel is a variable of filtration.

6. Determine the critical particle size that causes wear. A rotary fuel pump could be used for this analysis, since a rotary pump demonstrated wear problems during Operation Desert Storm.(12)

7. Differentiate between primary, secondary filters, and coalescers. Each type filter should have its own qualifying requirements.

Using the above test method would allow for each filter to be tested under two test conditions and then be rated according to four systems. Using all the rating systems or revised version would not bias the data towards only particle size distribution because it would also consider load capacity.

XII. LIST OF REFERENCES

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GLOSSARY

Many of these definitions were taken from Sax, N., and Lewis, R. Sr., Hawleys Condensed Chemical Dictionary, Eleventh Edition, Van Nostrand Reinhold, New York, 1987.

AC Fine Test Dust — A fine siliceous test dust that has a known particle size distribution as specified by the manufacturer.

Beta Efficiency — The percent removal efficiency of a filter at a given particle size can be calculated as follows:

$$\% \text{ Removal} = \left[1 - \frac{1}{\beta_x} \right] \times 100$$

Beta Ratio — A rating system developed at Oklahoma State University in the 1970s. A Beta value is defined as:

β_x = Number of particles of a given size and larger upstream of the filter/number of particles of the same size and larger downstream of the filter, where x is the particle size.

CETOP RP70 — A method of expressing sample particle count in terms of a simple code.

Coalescer — A special type of separator utilizing a hydrophilic medium designed to collect dispersed droplets of water present in the fuel and form these droplets into larger drops, which will readily separate out.

Differential Pressure — The difference in pressure between the inlet to the filter and the exit from the filter.

Effluent — Stream of fluid at the outlet of a filter. Opposite of influent.

Filter Bed	Contaminants collecting on the filter surface impart a blocking action, decreasing the permeability of the element and improving the filter efficiency.
Filter Efficiency	The gravimetric weight of contaminants in the effluent divided by the gravimetric weight of contaminants in the influent.
Filter Permeability	The reciprocal expression of the resistance to flow offered by the filter.
Filter/Coalescer	A mechanical device designed to coalesce and separate water from fuels. Usually part of a filter/separator.
Filter/Separator	A mechanical device designed to remove solid contaminants and to coalesce and separate water from fuels. Incorporates a filter/coalescer separator.
Gravimetric Analysis	A type of quantitative analysis involving precipitation of a compound that can be weighed and analyzed after drying.
Influent	Stream of fluid at the inlet of a filter. Opposite of effluent.
Load Capacity	The quantity of a particulate retained by the filter before the differential pressure reaches 15 psid.
Microbiological Contamination	Biological growth, usually develops at the fuel/water interface.
Multipass Fuel Filter System	A test system that injects a contaminated fuel into the circulated fuel so that make-up contaminant is added to replace the contaminate trapped by the filter being tested.
Nominal Porosity	A value determined by the filter manufacturer describing the average porosity of the filter media.
Nominal Rating	A value determined by the filter manufacturer and expressed in terms of the percentage retention by weight of a specified contaminant of a given size.
Particulates-After	The weight of contaminants in the effluent.
Primary Filter	The first filter encountered by the fuel. This filter filters the larger particles.
PV Resin	A resin used to simulate fuel degradation products.
Secondary Filter	This filter follows the primary filter. It filters the smaller particles.

ACRONYMS AND ABBREVIATIONS

ACFTD	-	Air Cleaner Fine Test Dust
APN	-	Army Part Number
ASTM	-	American Society for Testing and Materials
Belvoir RDE Center	-	U.S. Army Belvoir Research, Development and Engineering Center
BFLRF	-	Belvoir Fuels and Lubricants Research Facility (SwRI)
BRDEC	-	U.S. Army Belvoir Research, Development and Engineering Center
CETOP	-	European Oil Hydraulic and Pneumatic Committee
gpm	-	Gallons per minute
psid	-	Pounds per square inch, differential
PV	-	Polyvinyl
SwRI	-	Southwest Research Institute
TACOM	-	U.S. Army Tank-Automotive Command

APPENDIX A

Test Procedure for Filter Evaluation

Test Procedure for Filter Evaluation

I. Fuel Clean-up Process

A clean-up filter, rated at 0.5 micrometers, is installed and used to remove any debris from the fuel. This clean-up process should run a minimum of 2 hours. This allows all the fuel to pass through the filter a minimum of two times and ensures that the fuel is clean. This process should be run before any filters are evaluated and between tests.

II. Calibrating the Slurry Flow Rate

One gallon of clean test fuel is poured into the slurry bin. The slurry recirculating pump, the slurry pump, and the main fuel pump are started. Adjust the bypass valve to the slurry bin to regulate the slurry flow to the main fuel stream. Set the back pressure to the desired reading to achieve 0.25 gram/gallon. To measure the flow rate, turn on the on/off valve and start the timer. Run the test for 5 minutes and stop the slurry addition. Drain the remaining fuel from the slurry bin into a 2-liter graduated cylinder. Subtract this remaining fuel from the original gallon of fuel and divide this number by the test time (minutes). This will determine the injection rate. Use the back pressure valve to make any necessary corrections.

This procedure should only be necessary at the beginning of the testing. The operator should be able to set the bypass valve and start the test.

III. Contaminants

The slurry bin is filled with 26 liters of fuel. For this quantity of fuel, 12.25 grams of each contaminant is added. A recirculating pump and an air stirrer keep the contaminants mixed and suspended.

IV. Mounting the Filter

The clean-up filter and housing are removed and replaced with the proper housing and test filter. It is essential to have the proper housing for each filter in order for the test filter to perform as specified by the manufacturer.

V. Test Conditions

The filter was subjected to the following test conditions:

1) The flow rate was 1.5 gallon/minute (gpm).
2) Test fuel contaminated with 0.25 gram/gallon.
3) Test time was 4 hours or when differential pressure reached 15 psid.

VI. Testing the System

With the test filter mounted, start the main fuel pump. Check the system to determine if the housing or any fittings may be leaking. Let the system run for approximately 2 minutes. This also fills the housing, so there will be no lag time at the start of the test.

VII. Starting the Test

The beginning gallon reading is recorded from the total flow meter. The main fuel pump, computer, slurry addition valve, and the timer are started in that sequence. Samples are taken befoie and after the filter at the start (0 minutes). Additional samples are taken as required. This procedure allowed for samples to be taken before the filter every 30 minutes and after the filter every 10 minutes.

VIII. Sample Analysis

The contamination level was determined using Specification ASTM D 2276 modified. The sample volume was measured and recorded. The sample was filtered through a Whatman GF/F glass fiber filter (0.7 micrometer porosity). The weight difference of the filter is divided by the sample volume, multiplied by 3.785 to reduce the data to grams/gallon.

IX. Terminating the Test

The test is terminated when the differential pressure exceeds 15 psid or the tests runs for 4 hours, whichever comes first. The ending gallons is recorded from the flow meter. The difference between the beginning and ending readings is the quantity of fuel passed through the filter. The test filter is removed and the clean-up filter installed to start the clean-up process.

APPENDIX B

Particle Size Analysis and Distribution Data

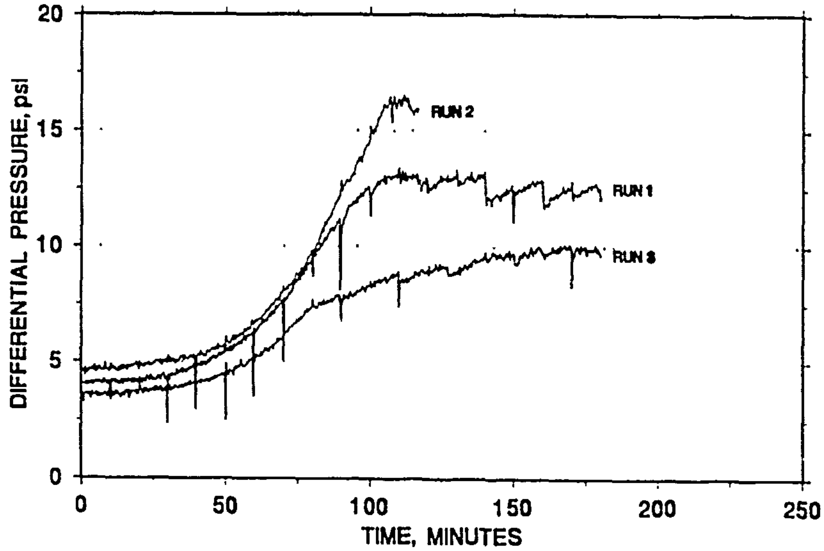


Figure B-1. Differential pressure, F1-P

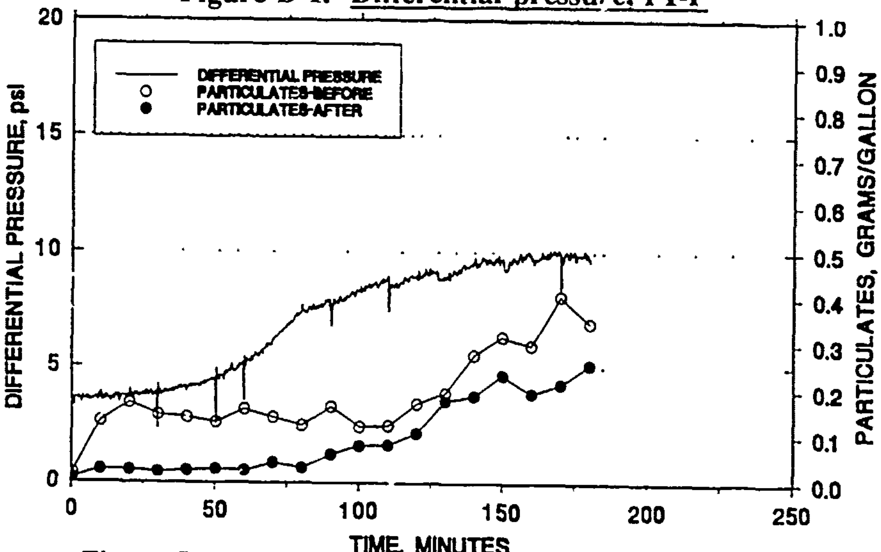


Figure B-2. Pressure versus particulates, F1-P Run 1

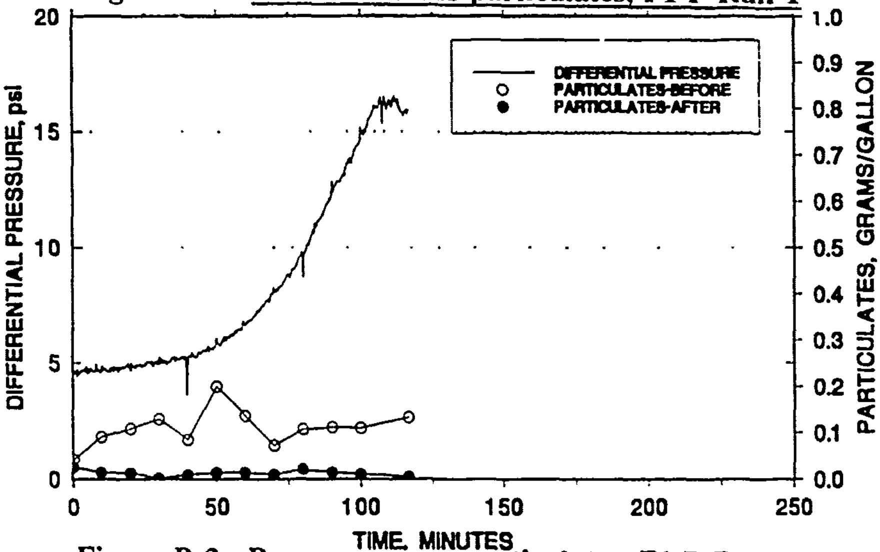


Figure B-3. Pressure versus particulates, F1-P Run 2

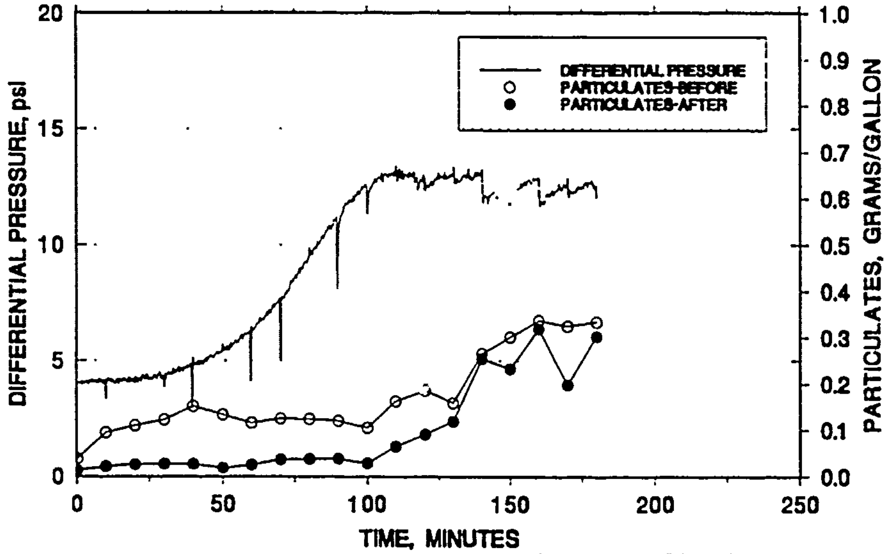


Figure B-4. Pressure versus particulates, F1-P Run 3

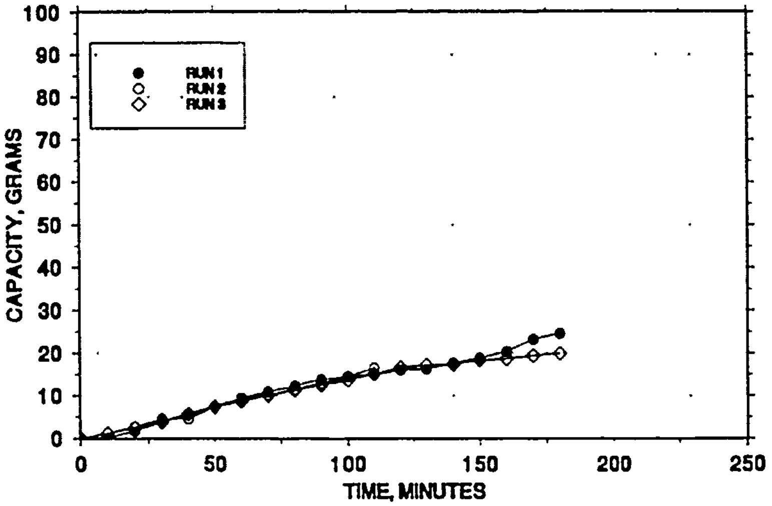


Figure B-5. Load capacity, F1-P

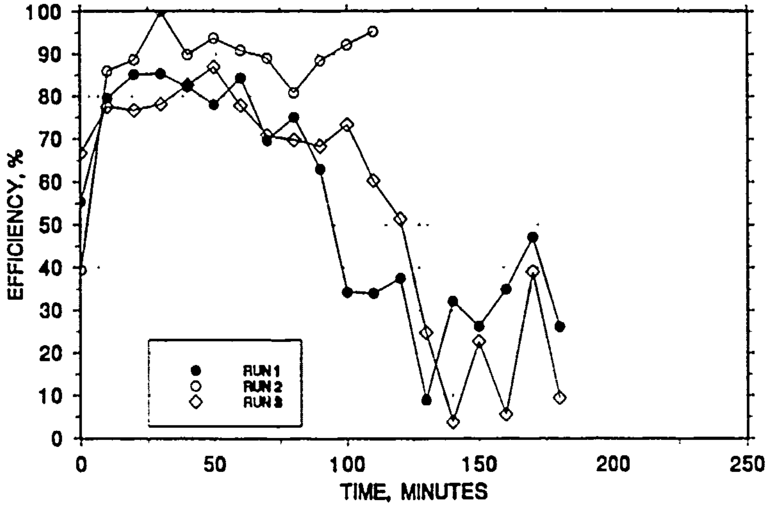


Figure B-6. Filter efficiency, F1-P

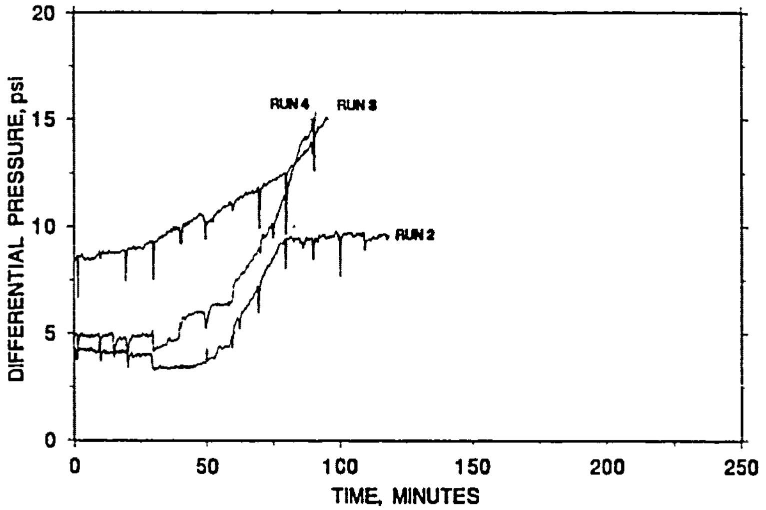


Figure B-7. Differential pressure, F1-P

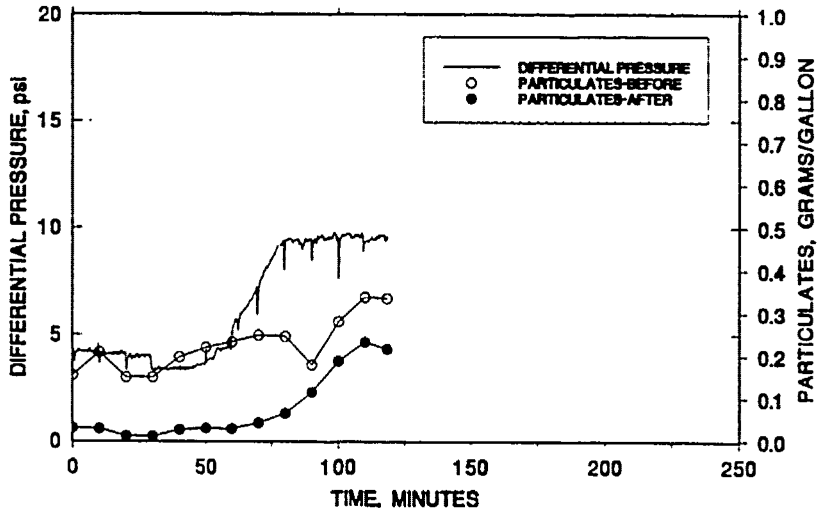


Figure B-8. Pressure versus particulates, F1-P Run 2

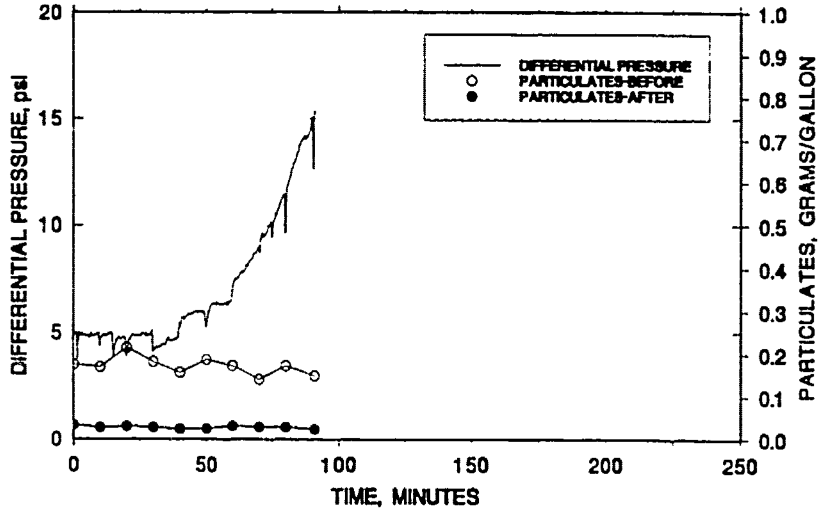


Figure B-9. Pressure versus particulates, F1-P Run 3

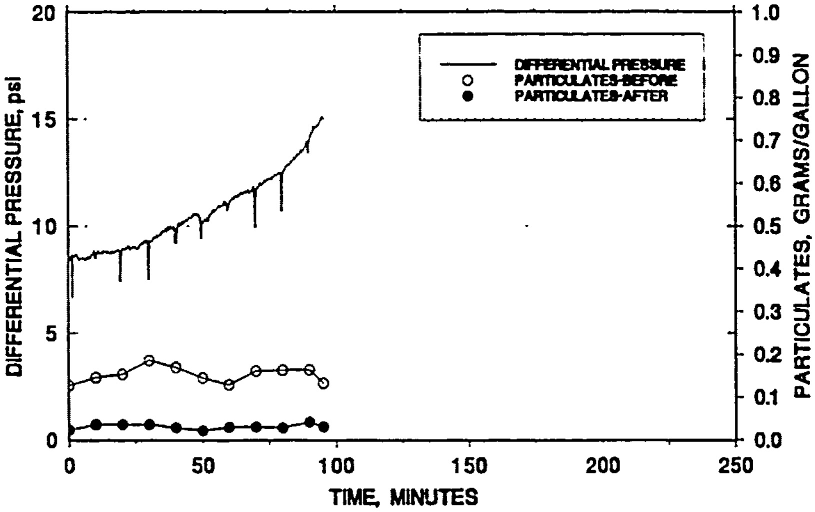


Figure B-10. Pressure versus particulates, F1-P Run 4

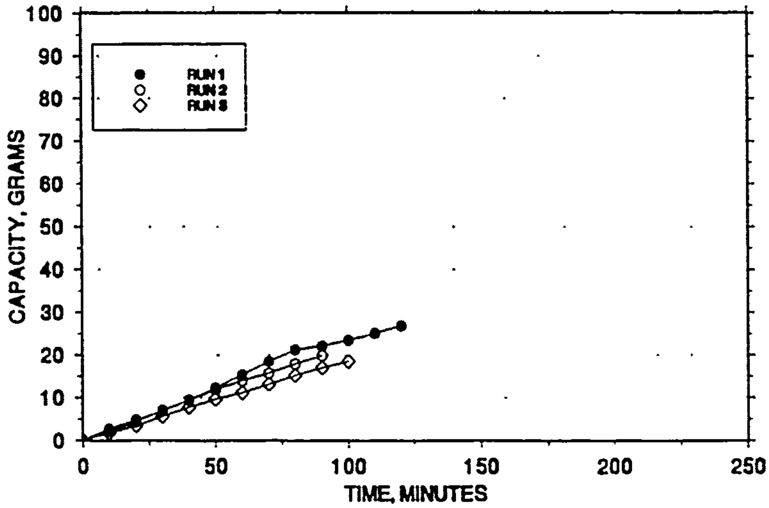


Figure B-11. Load capacity, F1-P

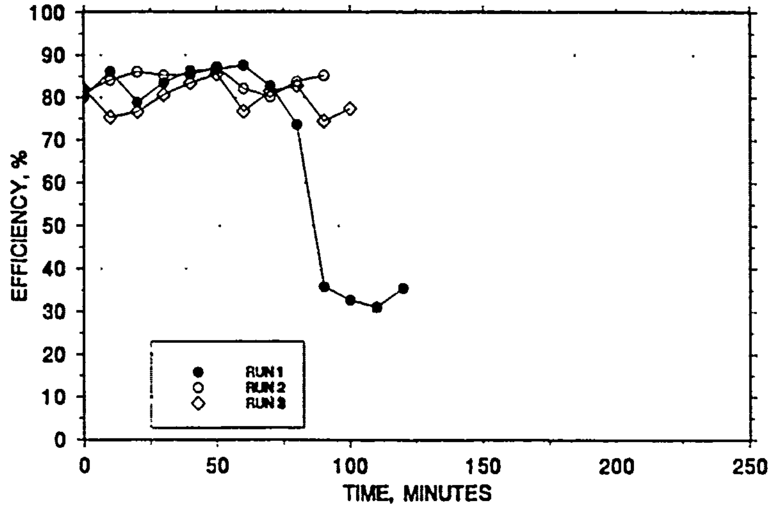


Figure B-12. Filter efficiency, F1-P

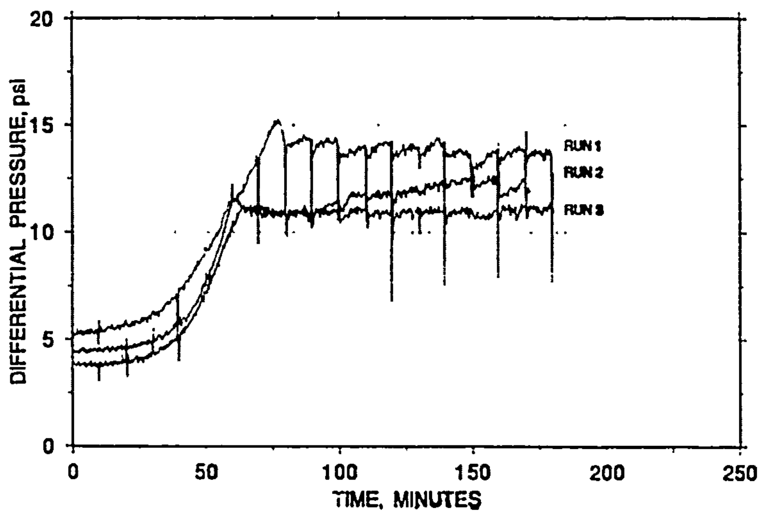


Figure B-13. Differential pressure, F2-P

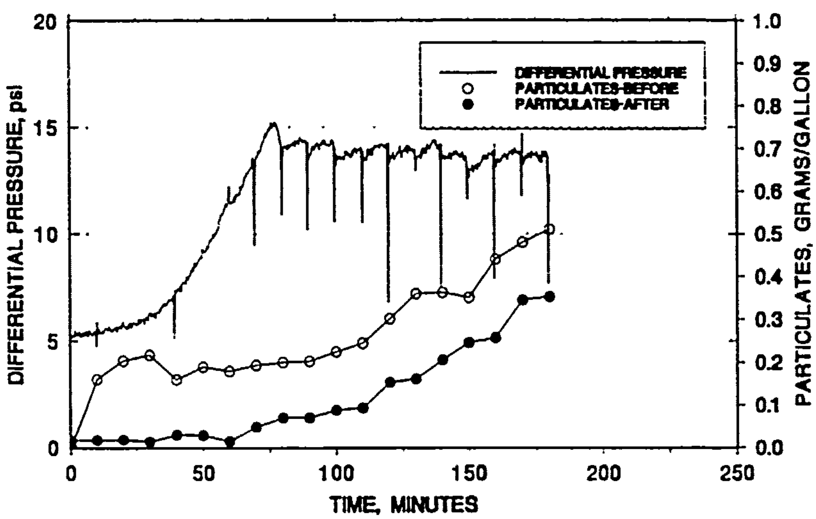


Figure B-14. Pressure versus particulates, F2-P Run 1

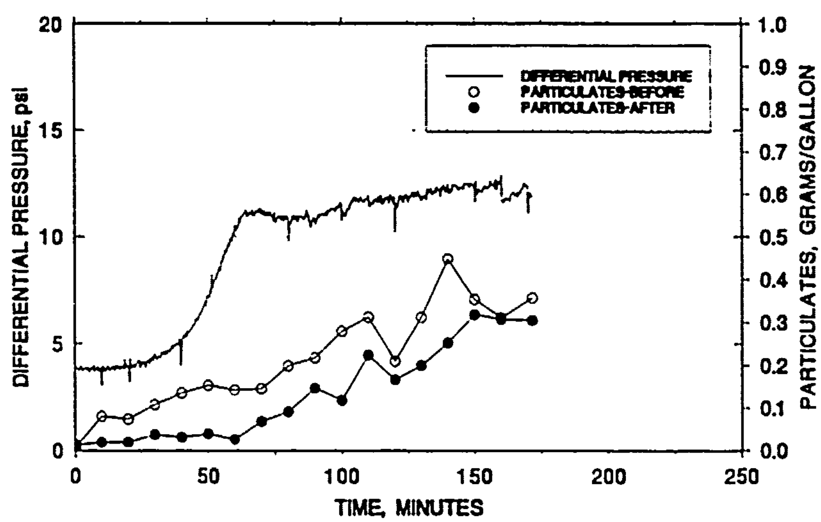


Figure B-15. Pressure versus particulates, F2-P Run 2

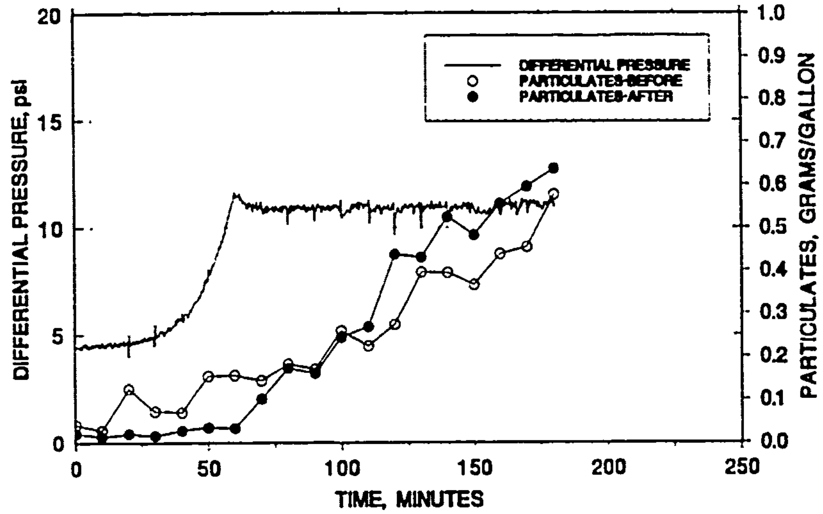


Figure B-16. Pressure versus particulates, F2-P Run 3

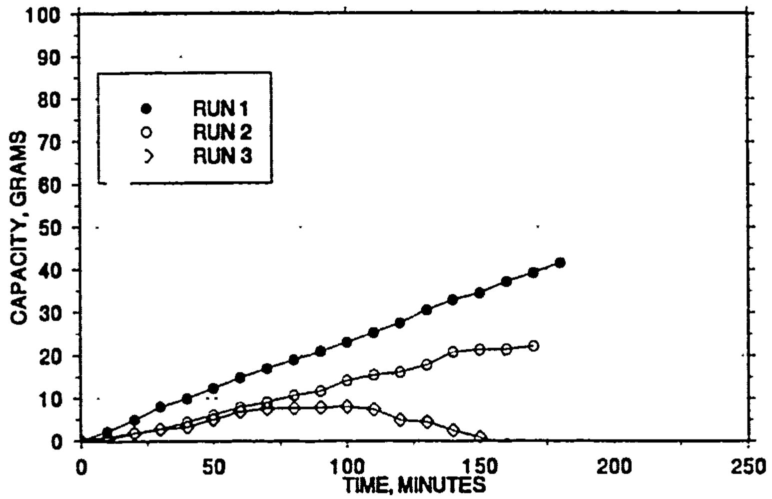


Figure B-17. Load capacity, F2-P

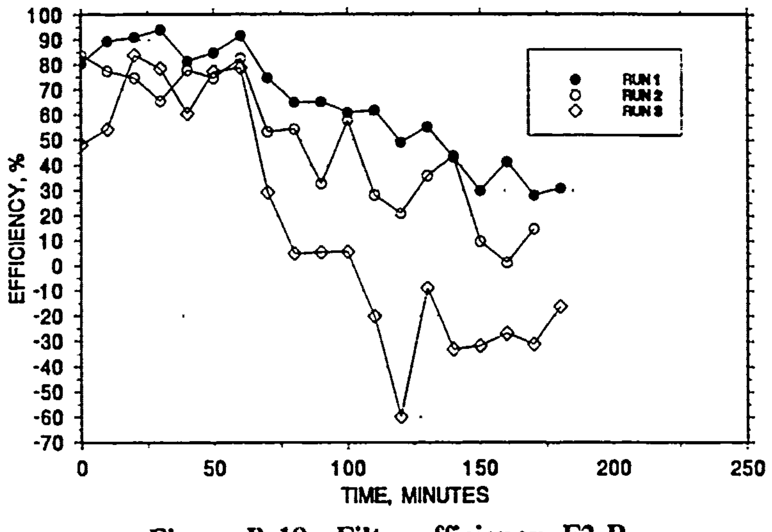


Figure B-18. Filter efficiency, F2-P

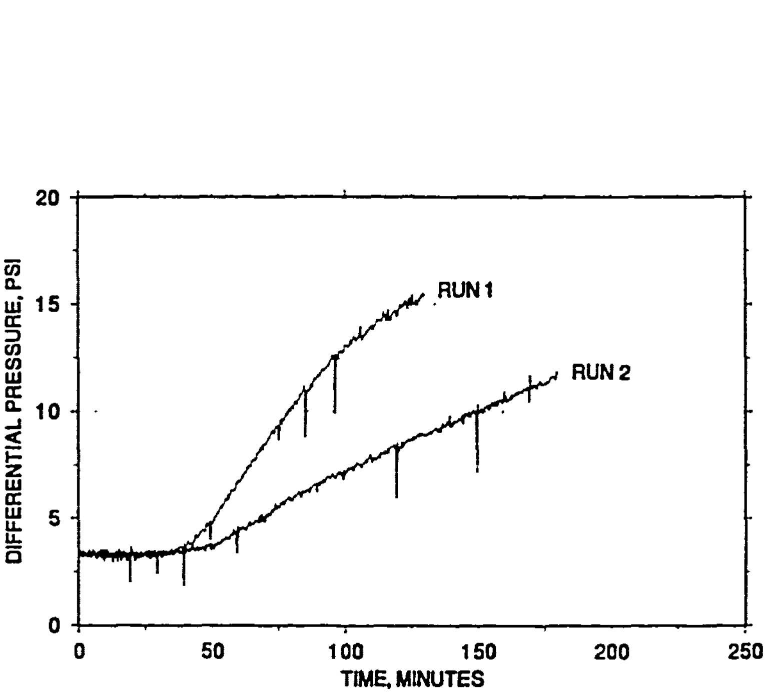


Figure B-19. Differential pressure, F3-X

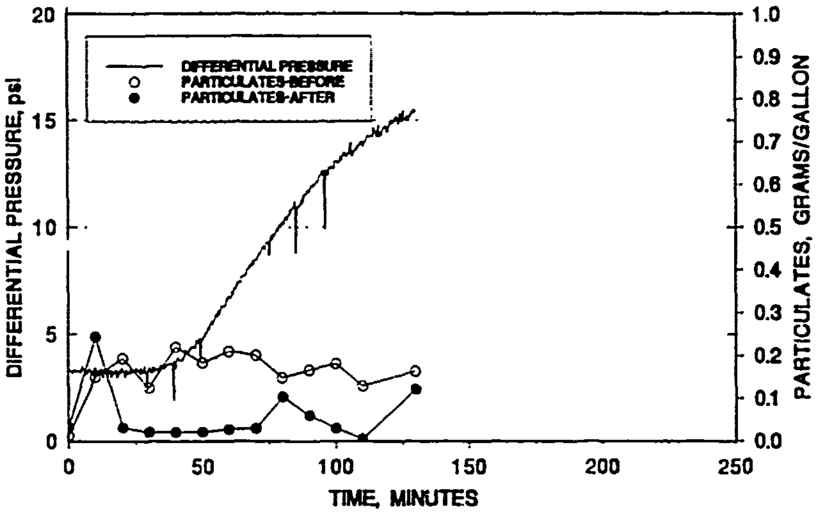


Figure B-20. Pressure versus particulates, F3-X Run 1

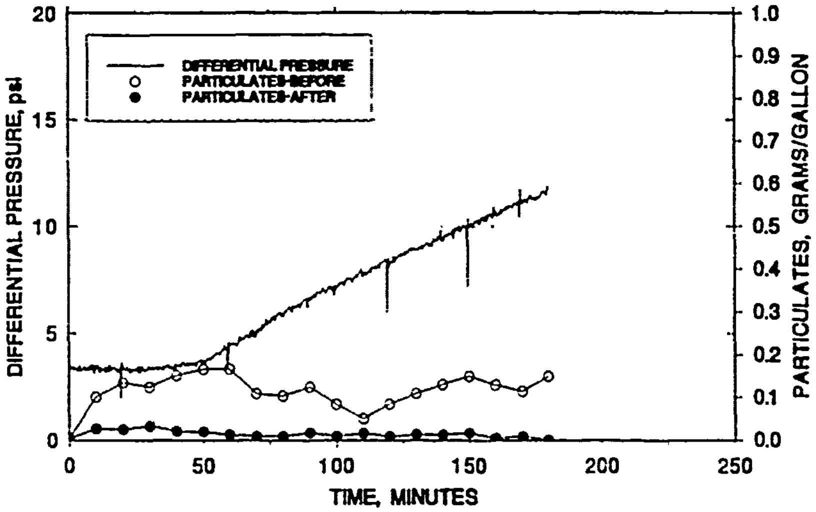


Figure B-21. Pressure versus particulates, F3-X Run 2

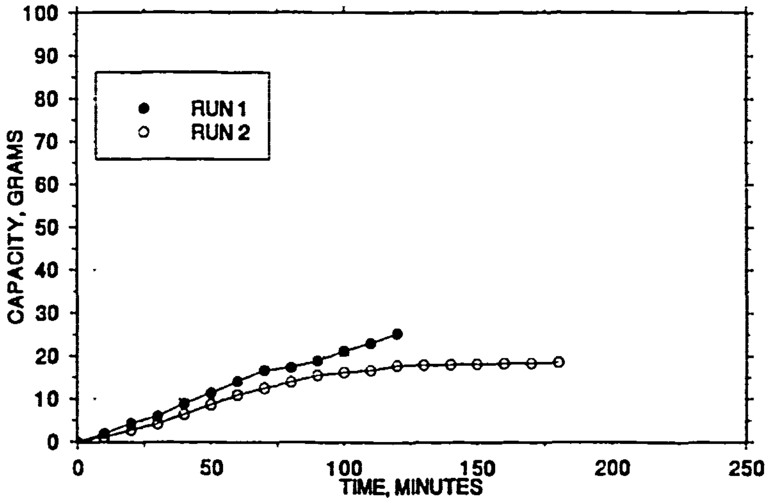


Figure B-22. Load capacity, F3-X

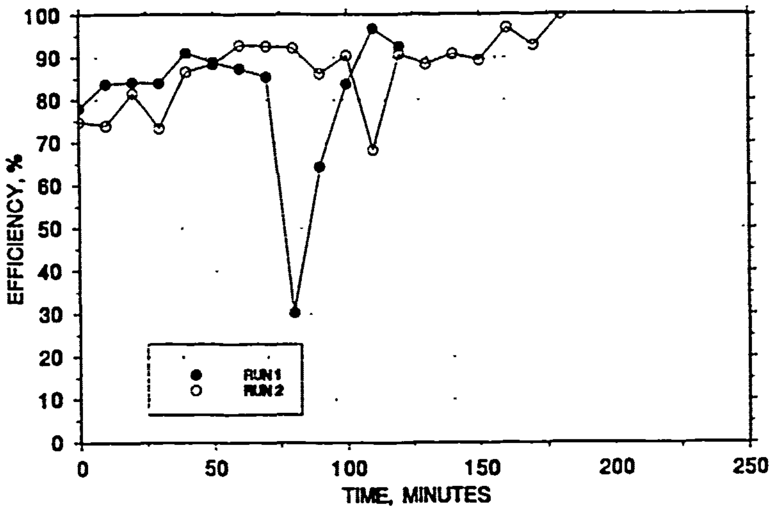


Figure B-23. Filter efficiency, F3-X

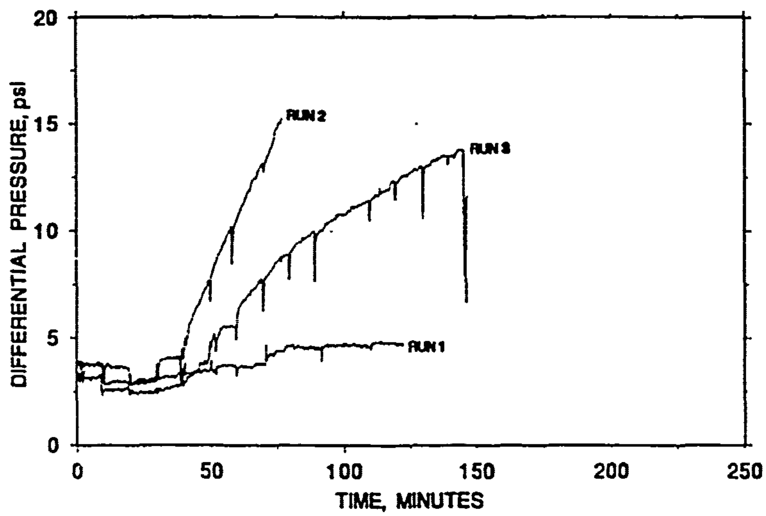


Figure B-24. Differential pressure, F3-X

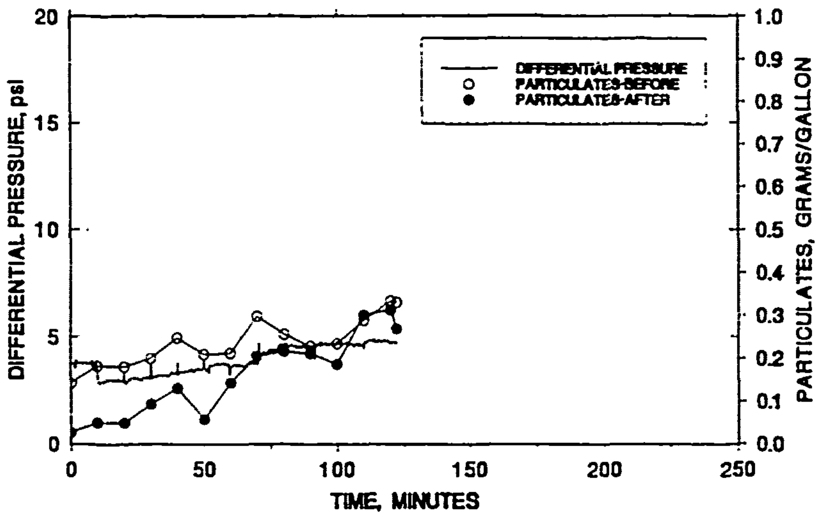


Figure B-25. Pressure versus particulates, F3-X Run 1

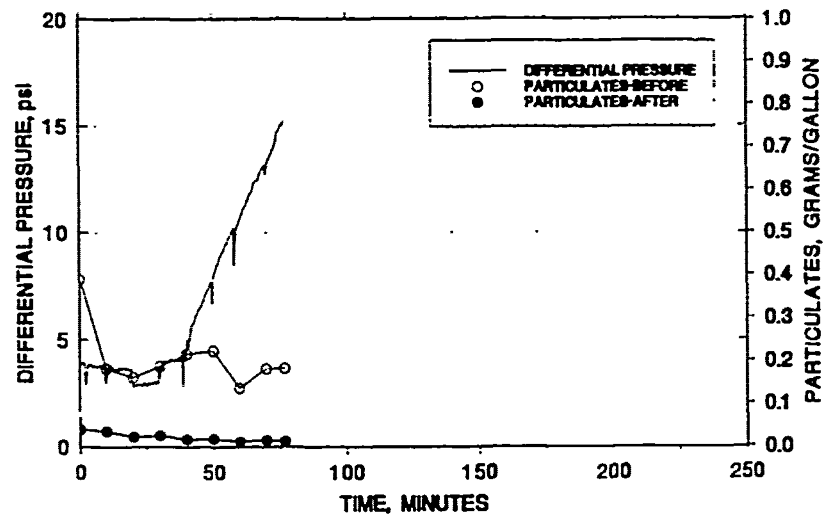


Figure B-26. Pressure versus particulates, F3-X Run 2

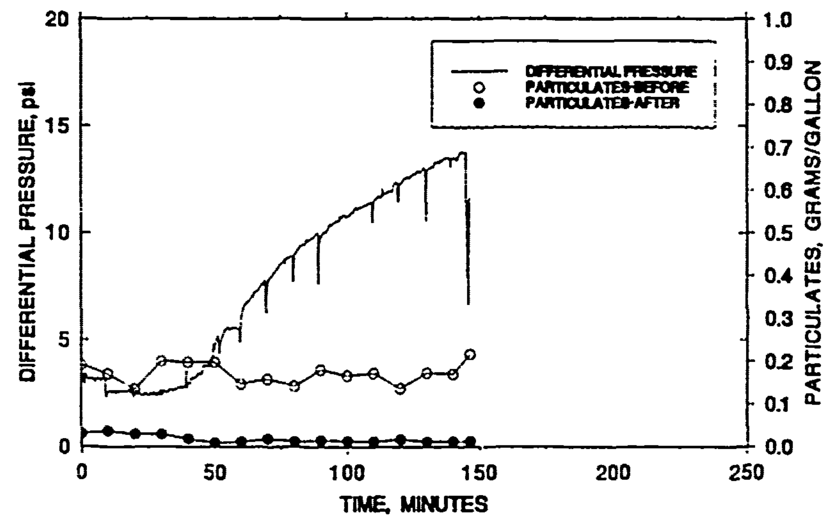


Figure B-27. Pressure versus particulates, F3-X Run 3

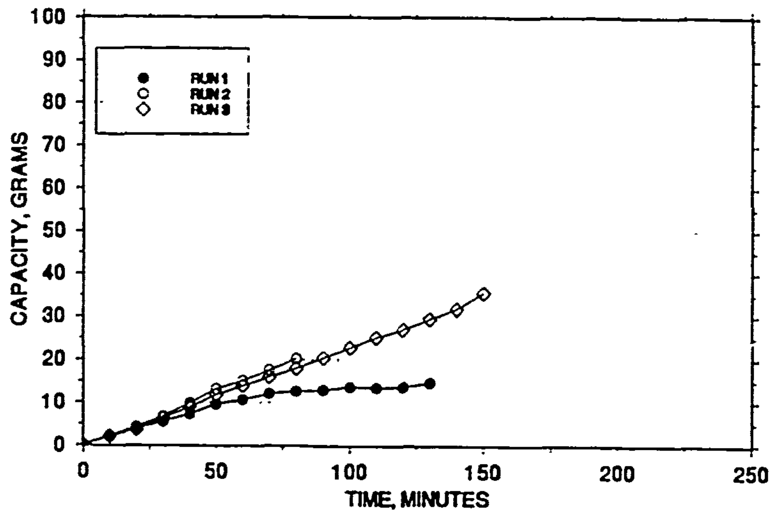


Figure B-28. Load capacity, F3-X

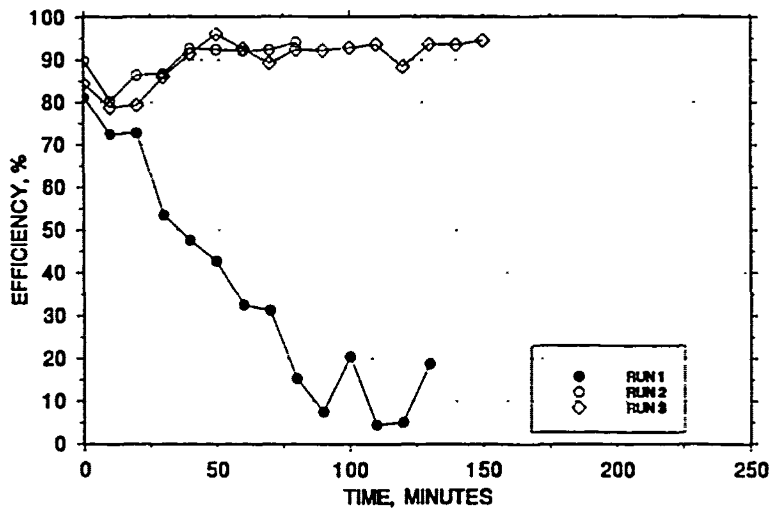


Figure B-29. Filter efficiency, F3-X

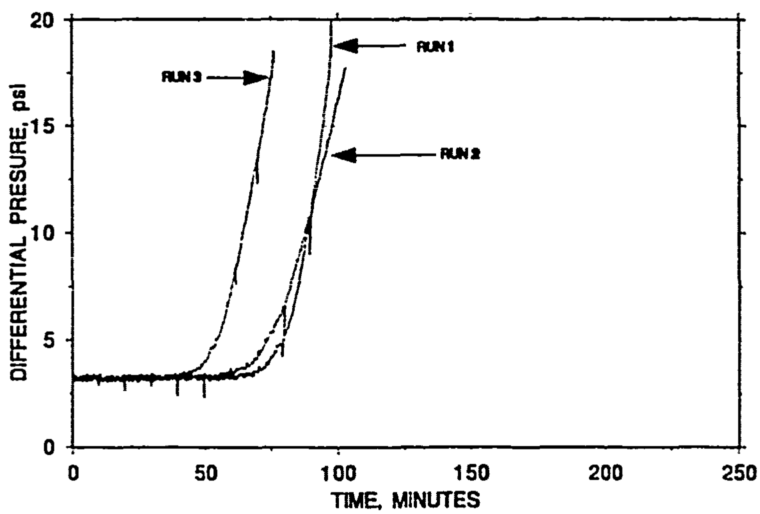


Figure B-30. Differential pressure, F4-P

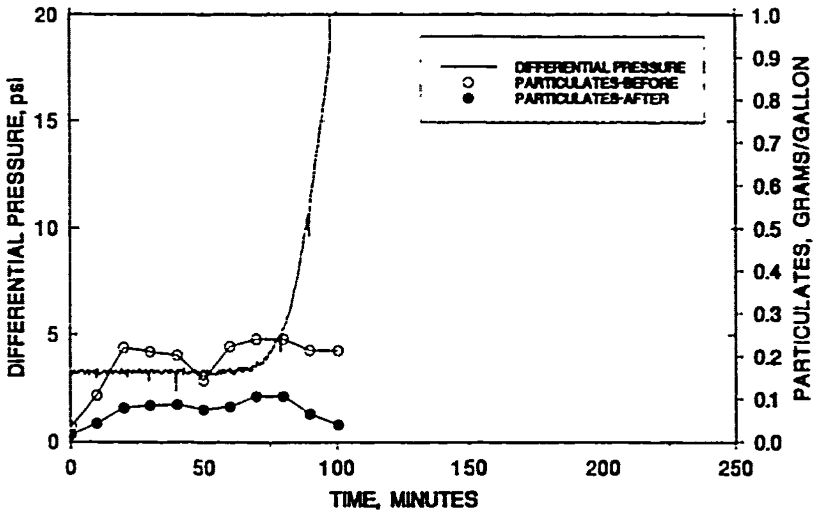


Figure B-31. Pressure versus particulates, F4-P Run 1

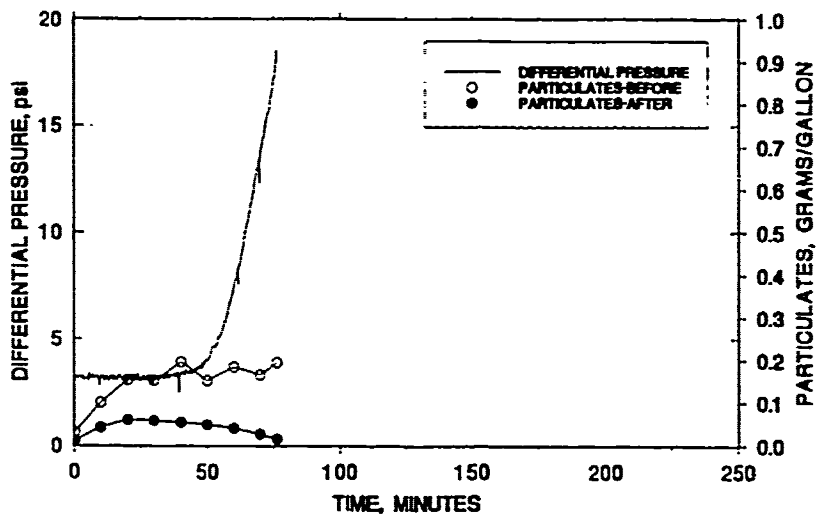


Figure B-32. Pressure versus particulates, F4-P Run 2

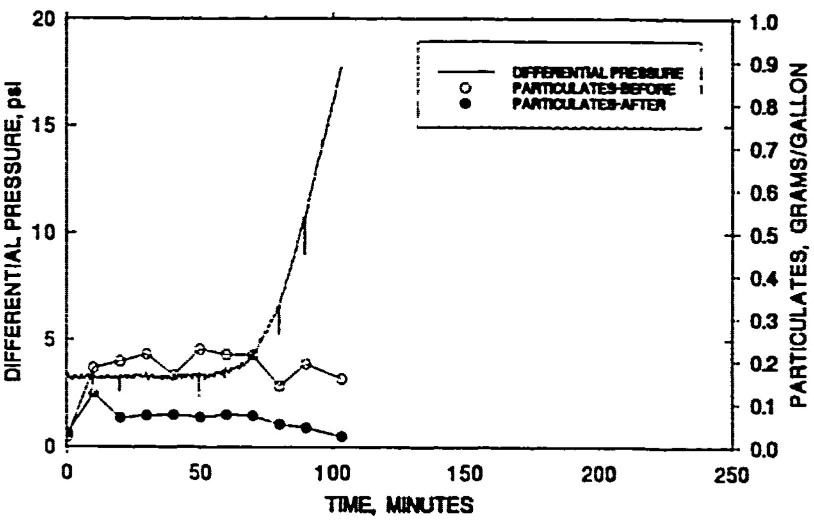


Figure B-33. Pressure versus particulates, F4-P Run 3

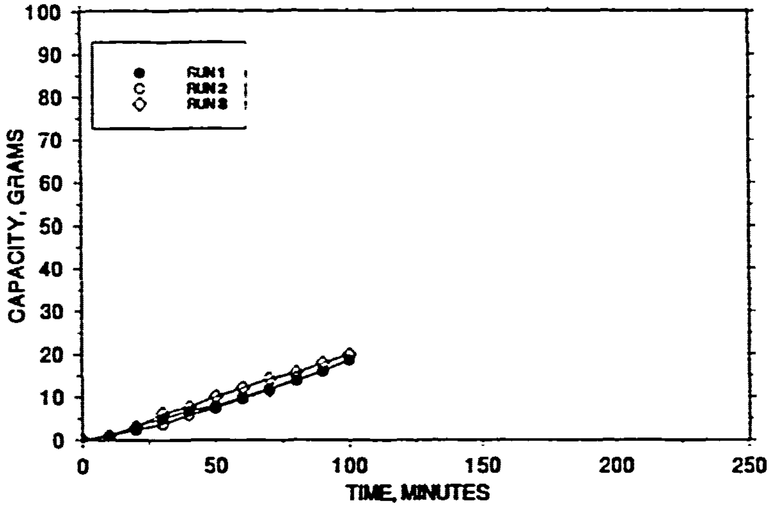


Figure B-34. Load capacity, F4-P

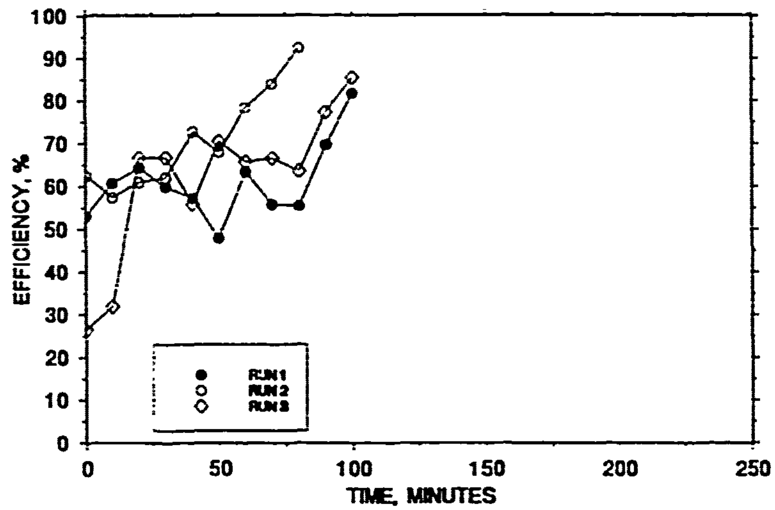


Figure B-35. Filter efficiency, F4-P

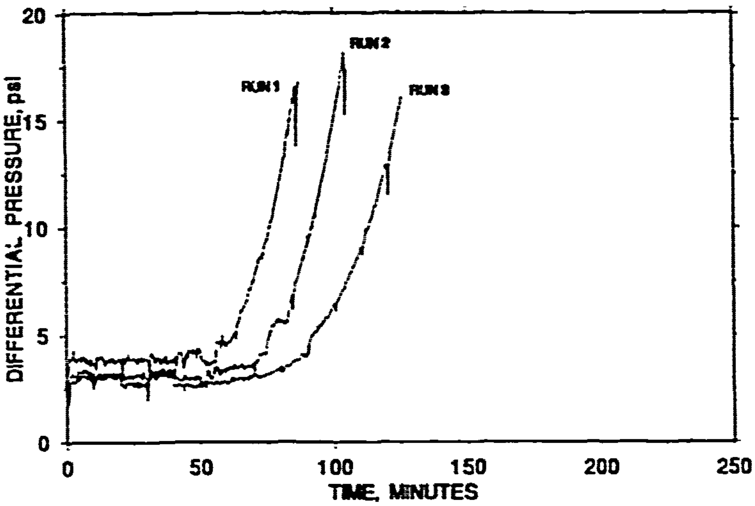


Figure B-36. Differential pressure, F5-P

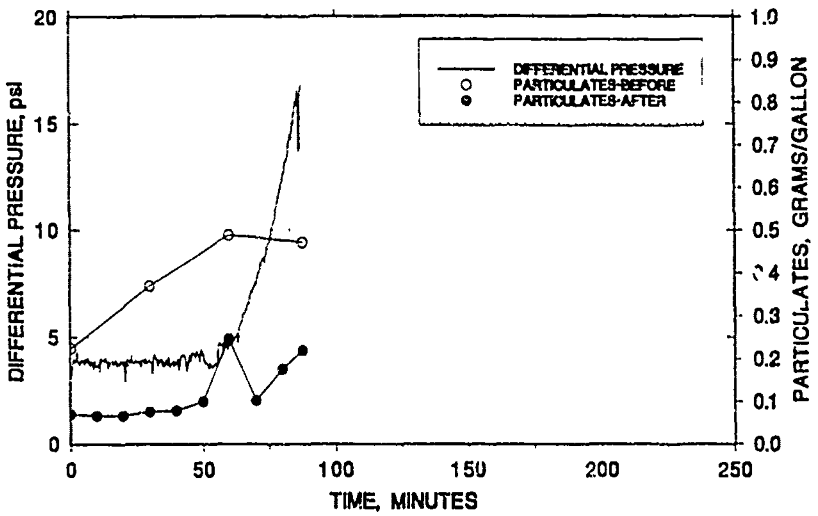


Figure B-37. Pressure versus particulates, F5-P Run 1

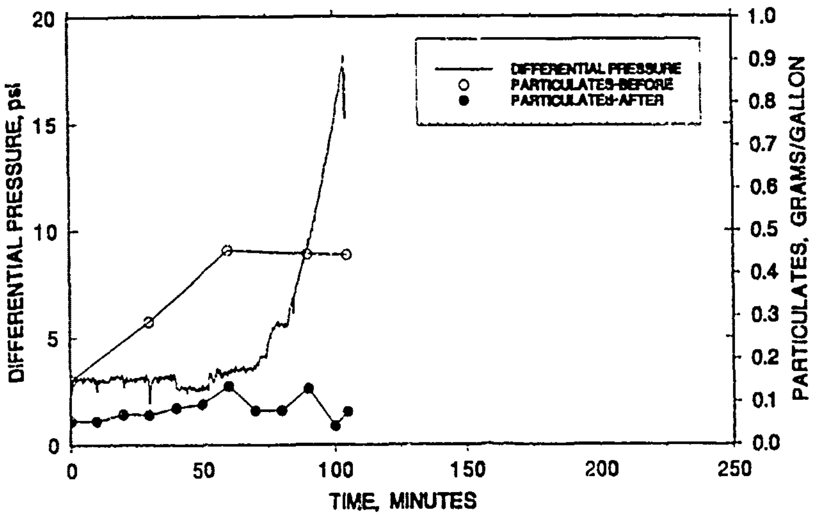


Figure B-38. Pressure versus particulates, F5-P Run 2

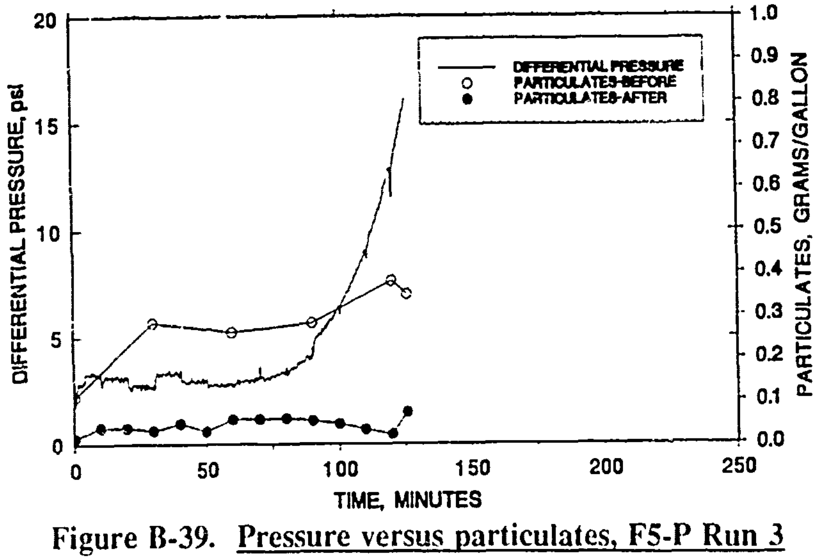


Figure B-39. Pressure versus particulates, F5-P Run 3

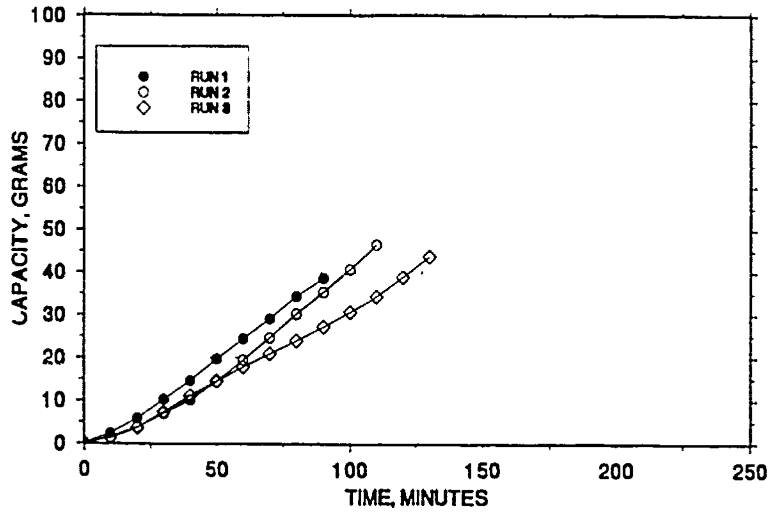


Figure B-40. Load capacity, F5-P

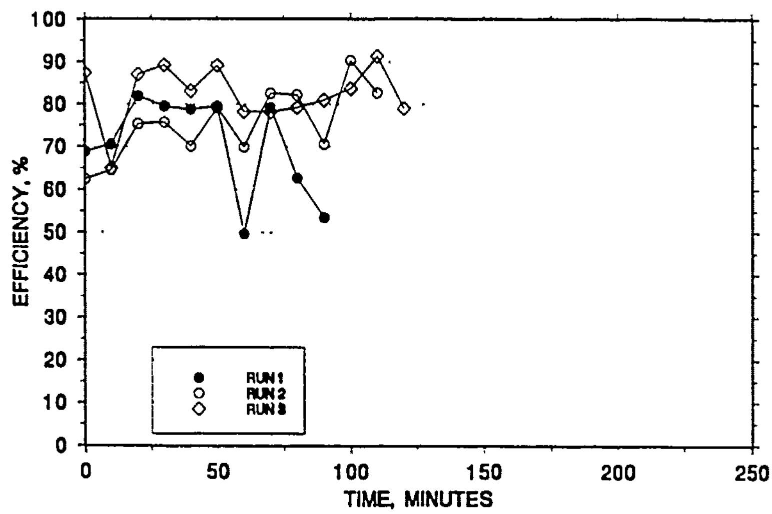


Figure B-41. Filter efficiency, F5-P

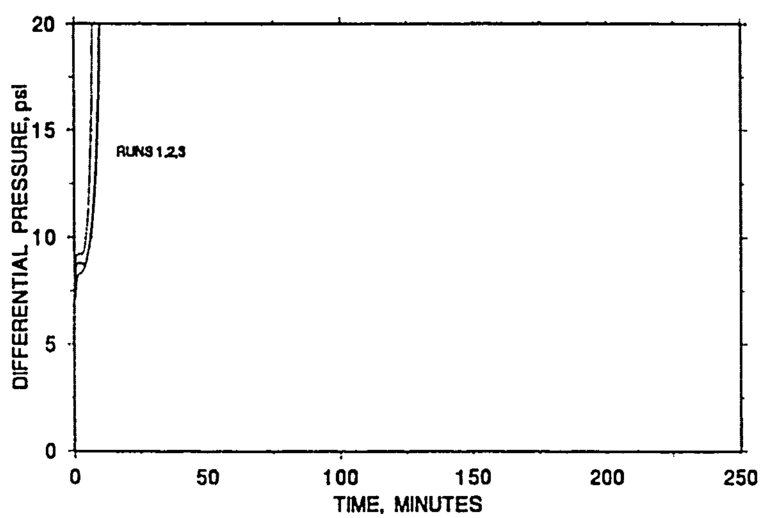


Figure B-42. Differential pressure, F6-C

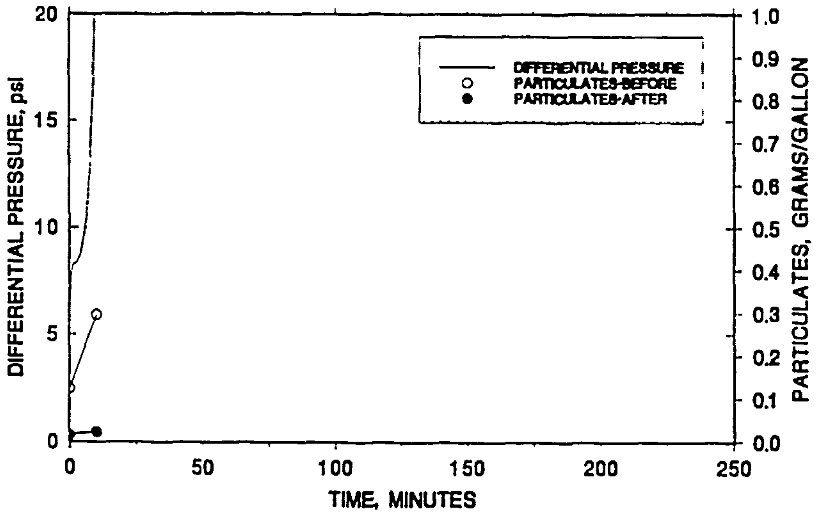


Figure B-43. Pressure versus particulates, F6-C Run 1

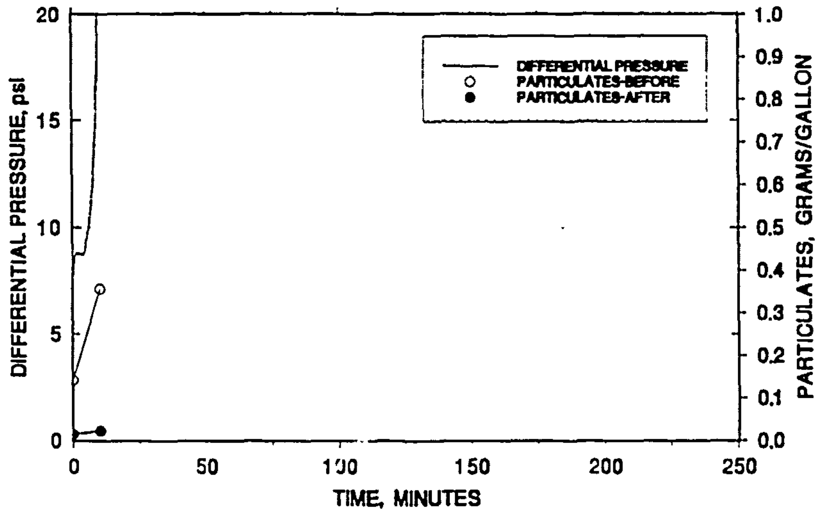


Figure B-44. Pressure versus particulates, F6-C Run 2

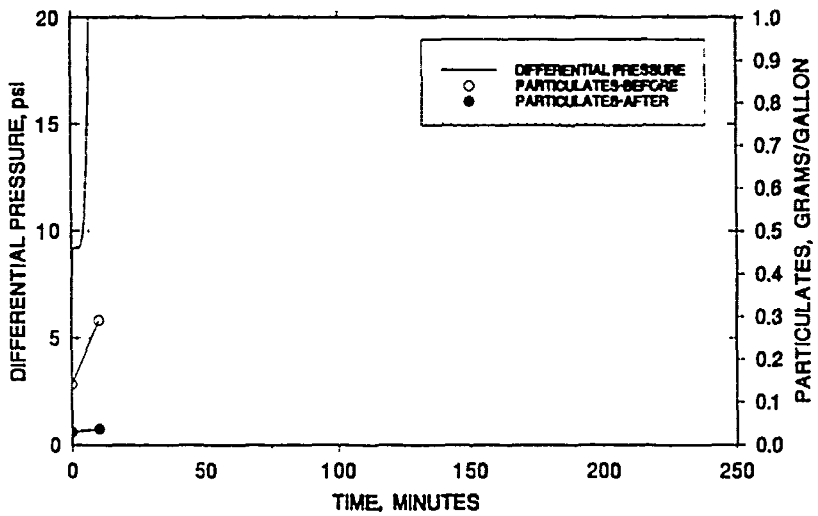


Figure B-45. Pressure versus particulates, F6-C Run 3

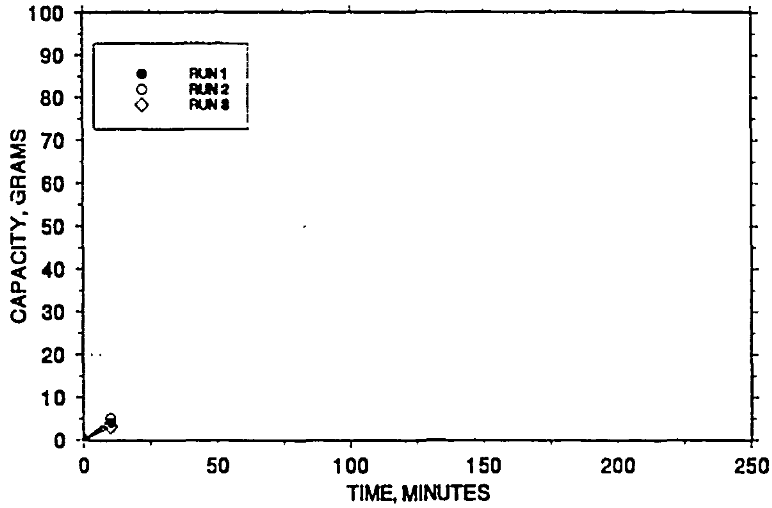


Figure B-46. Load capacity, F6-C

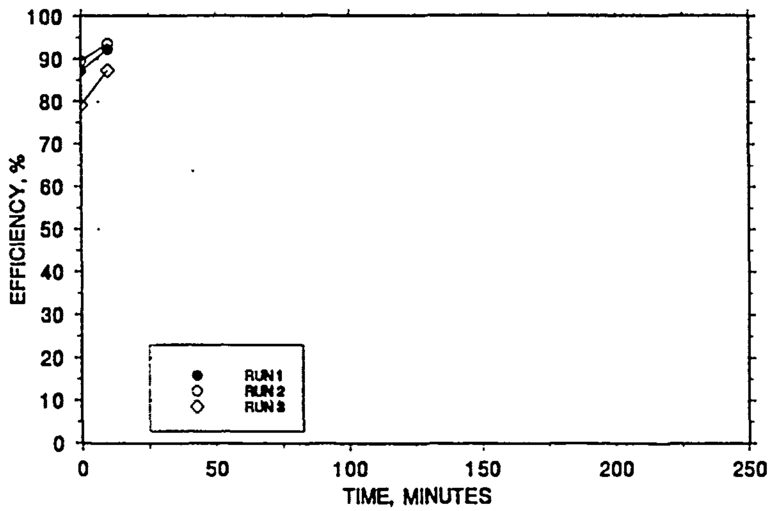


Figure B-47. Filter efficiency, F6-C

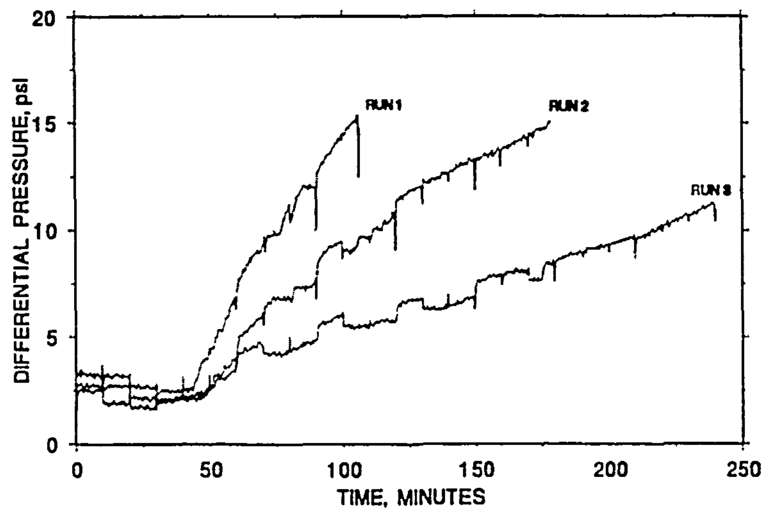


Figure B-48. Differential pressure, F7-S

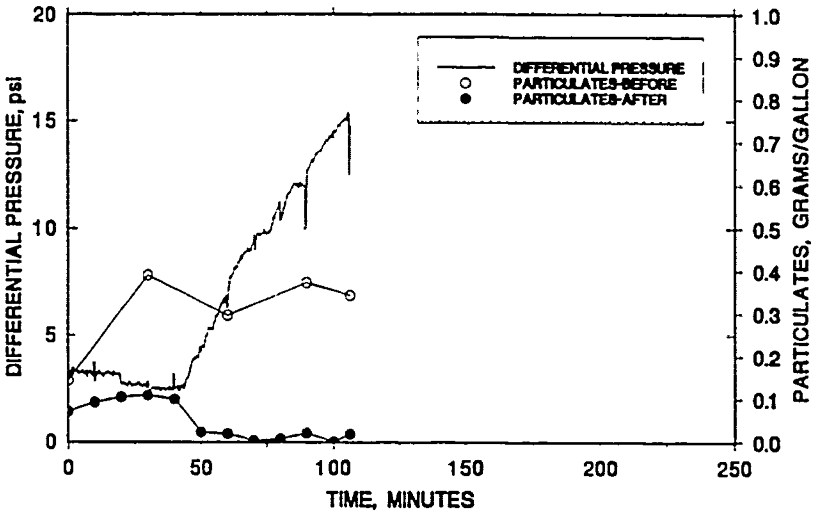


Figure B-49. Pressure versus particulates, F7-S Run 1

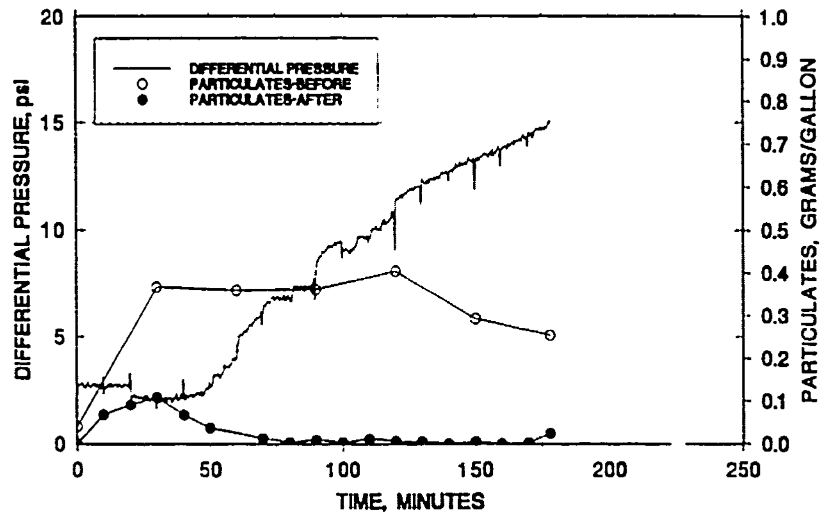


Figure B-50. Pressure versus particulates, F7-S Run 2

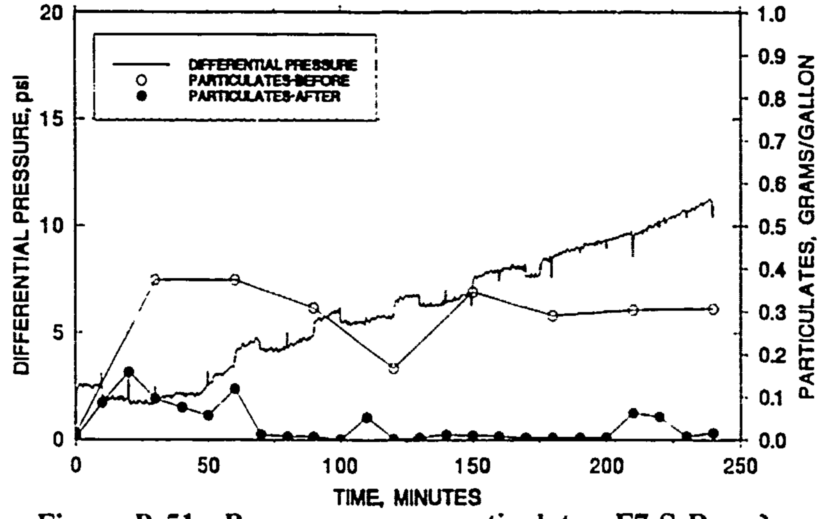


Figure B-51. Pressure versus particulates, F7-S Run 3

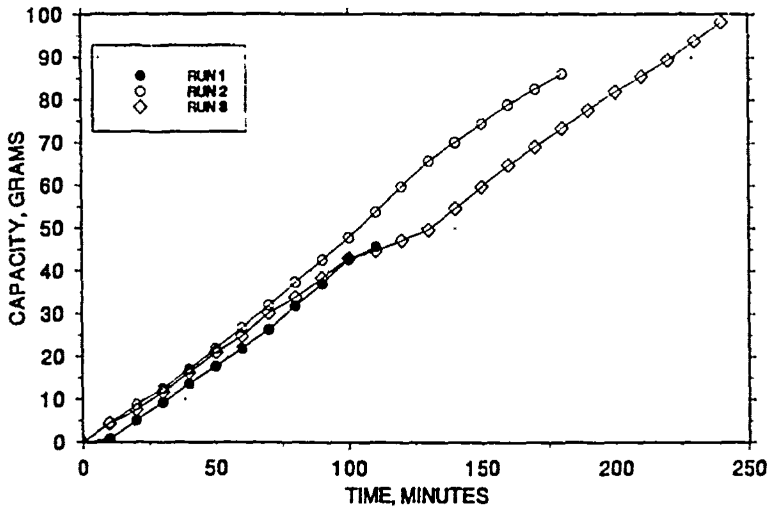


Figure B-52. Load capacity, F7-S

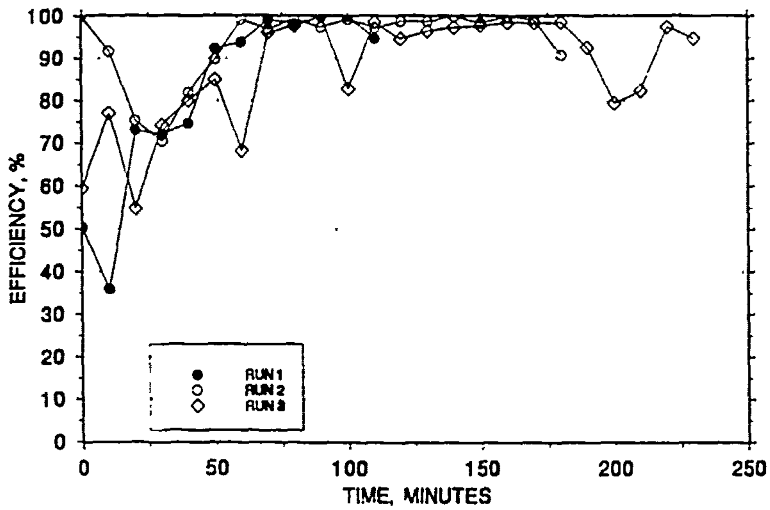


Figure B-53. Filter efficiency, F7-S

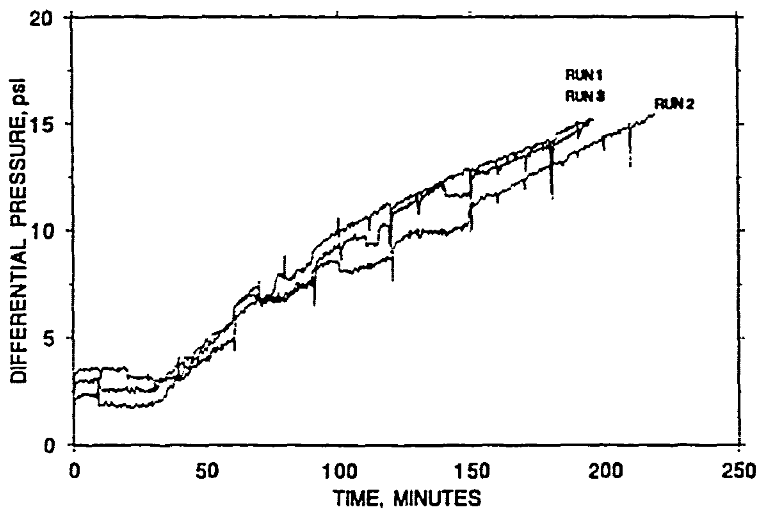


Figure B-54. Differential pressure, F7-S

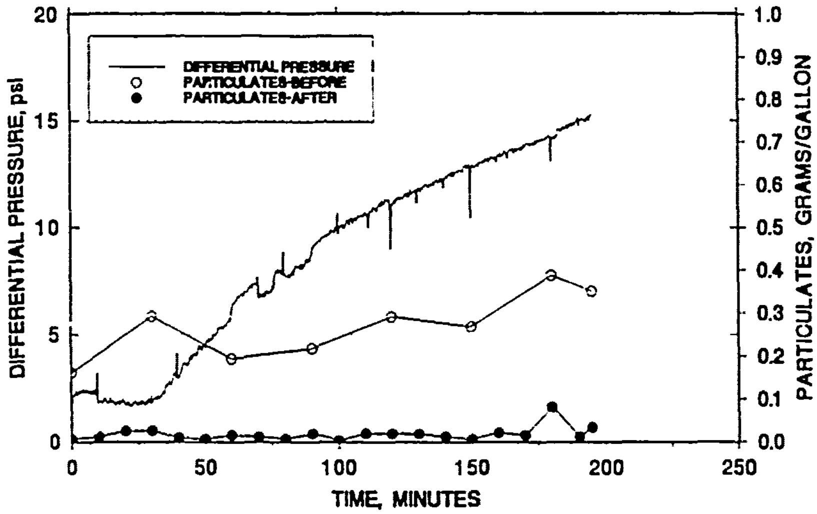


Figure B-55. Pressure versus particulates, F8-S Run 1

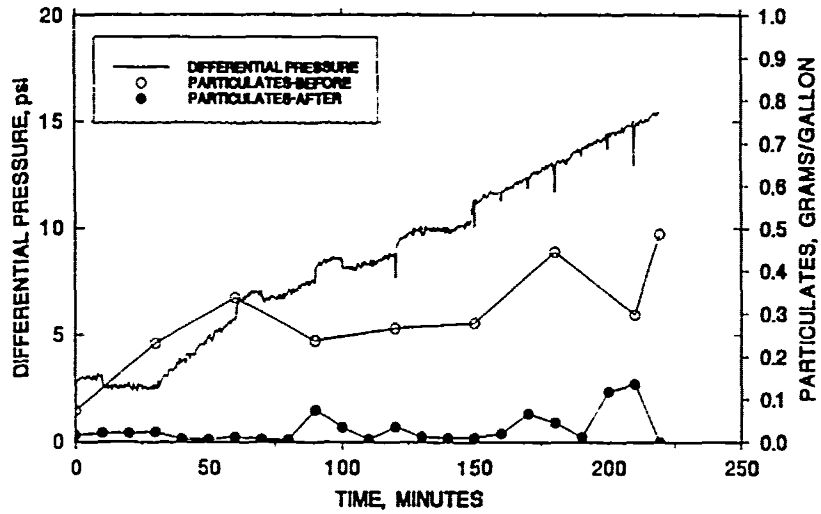


Figure B-56. Pressure versus particulates, F8-S Run 2

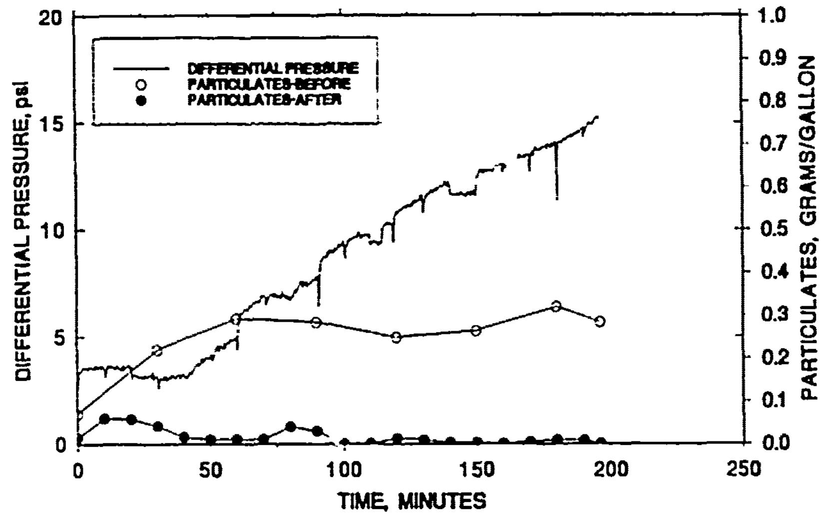


Figure B-57. Pressure versus particulates, F8-S Run 3

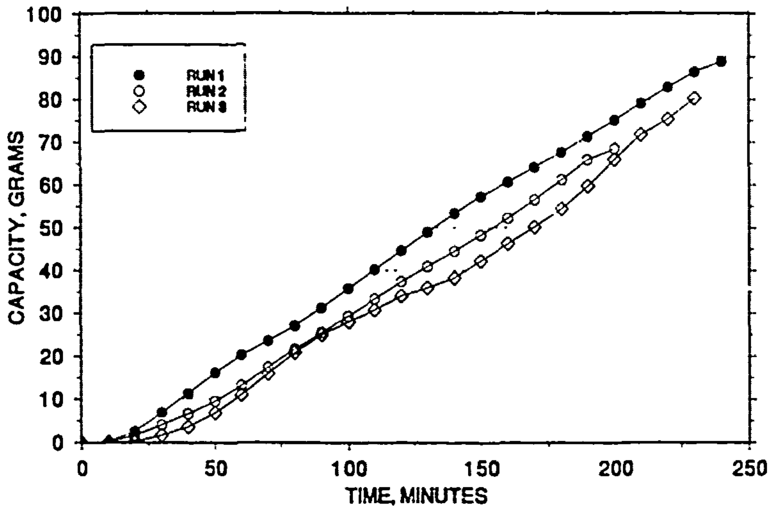


Figure B-58. Load capacity, F8-S

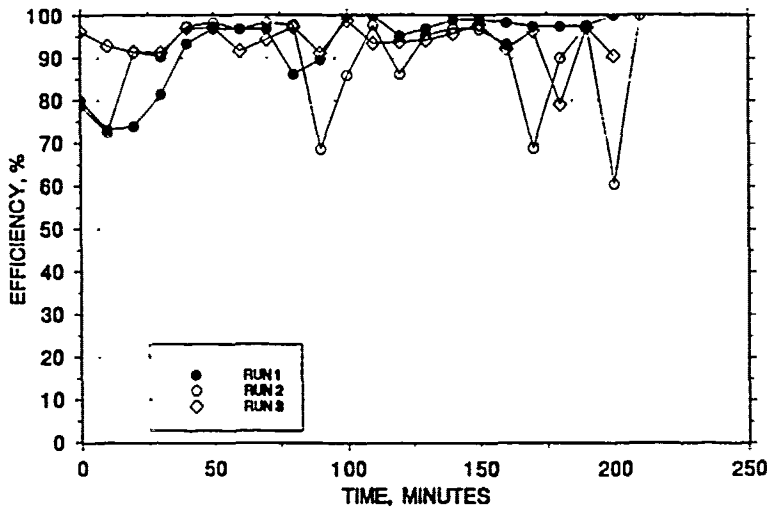


Figure B-59. Filter efficiency, F8-S

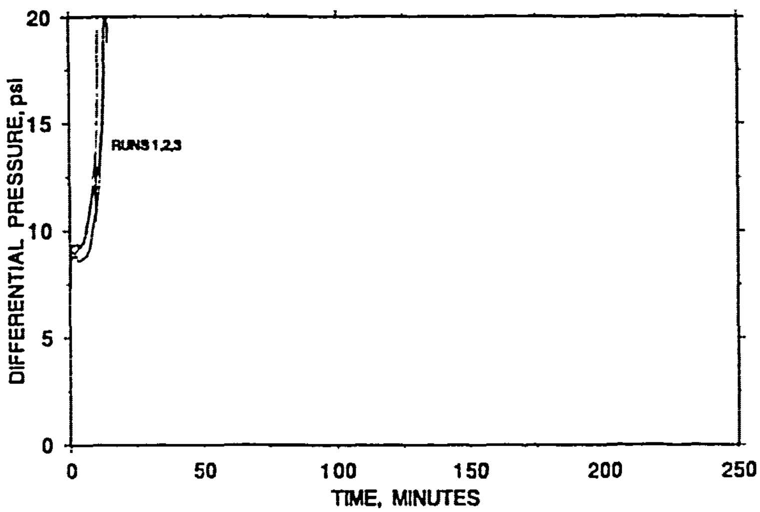


Figure B-60. Differential pressure, F9-C

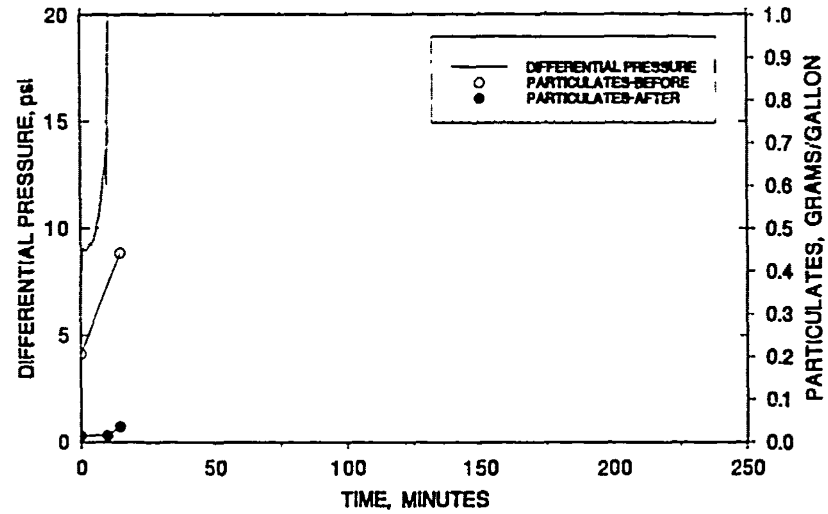


Figure B-61. Pressure versus particulates, F9-C Run 1

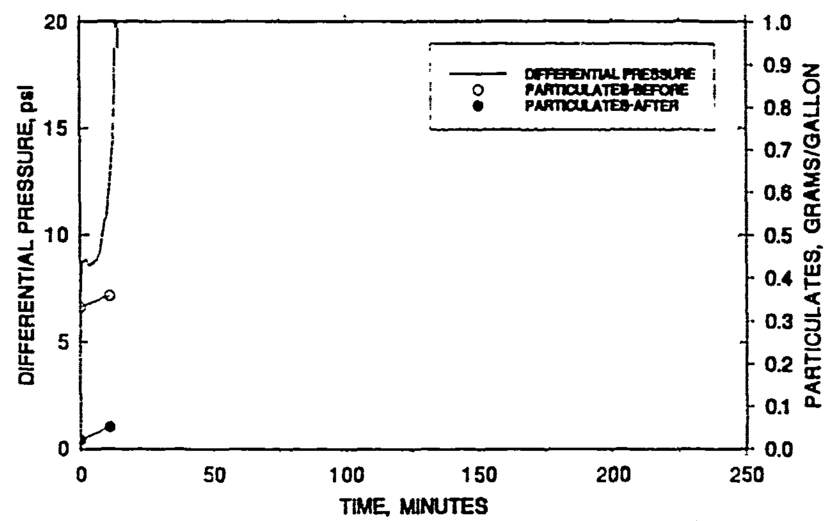


Figure B-62. Pressure versus particulates, F9-C Run 2

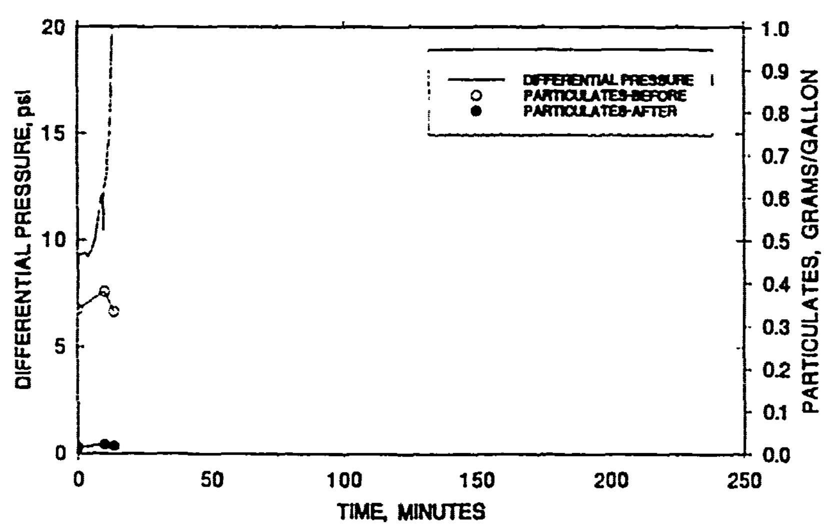


Figure B-63. Pressure versus particulates, F9-C Run 3

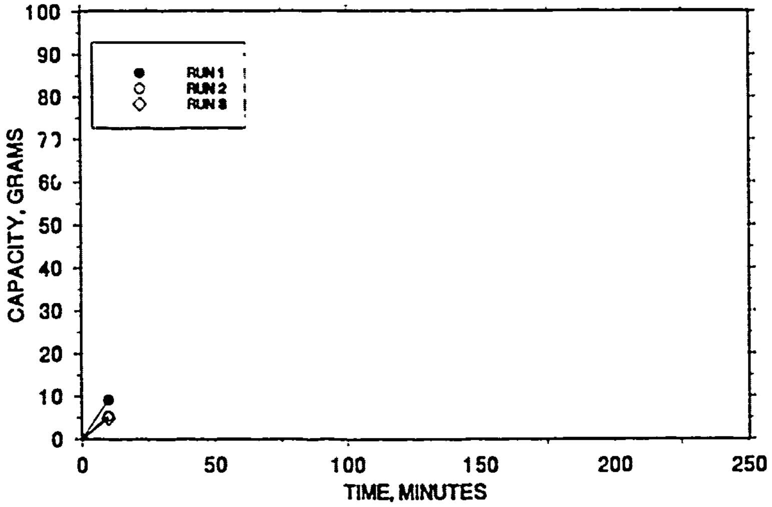


Figure B-64. Load capacity, F9-C

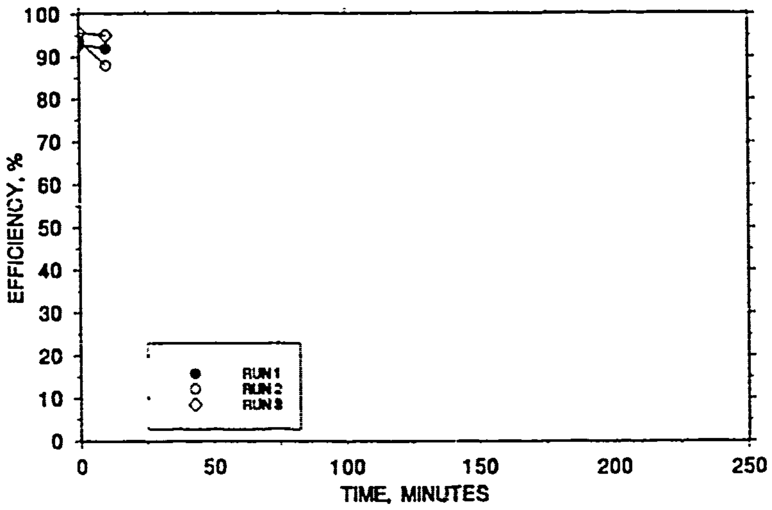


Figure B-65. Filter efficiency, F9-C

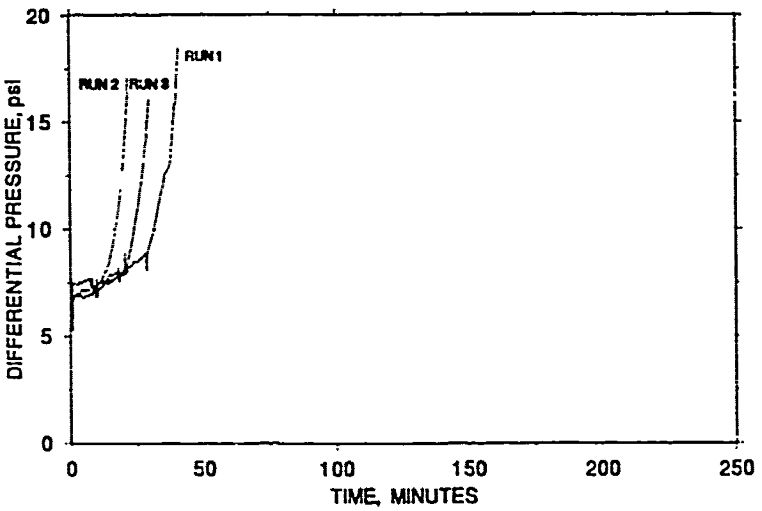


Figure B-66. Differential pressure, F10-C

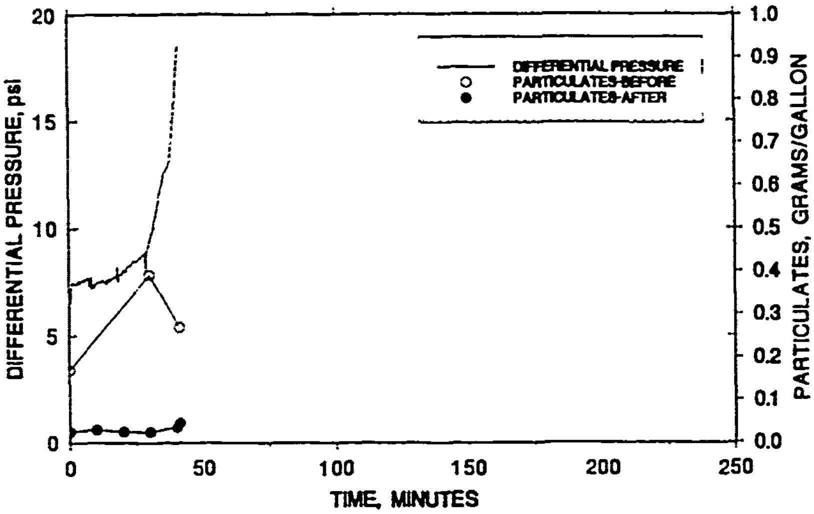


Figure B-67. Pressure versus particulates, F10-C Run 1

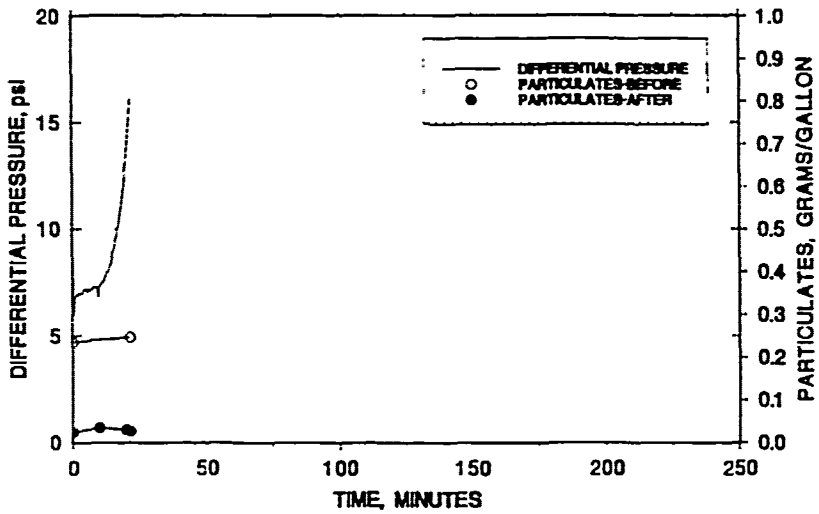


Figure B-68. Pressure versus particulates, F10-C Run 2

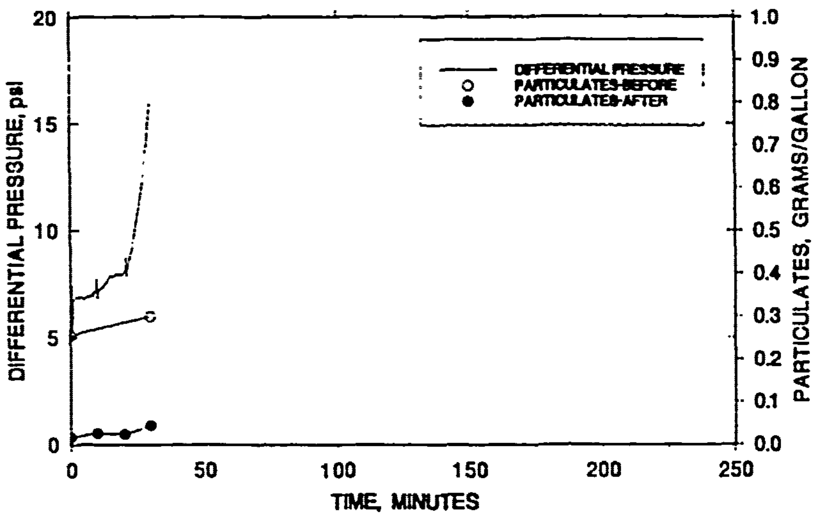


Figure B-69. Pressure versus particulates, F10-C Run 3

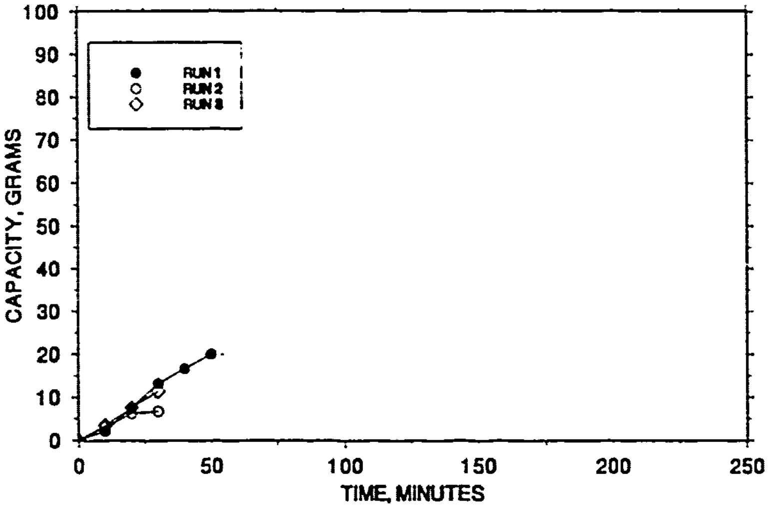


Figure B-70. Load capacitv, F10-C

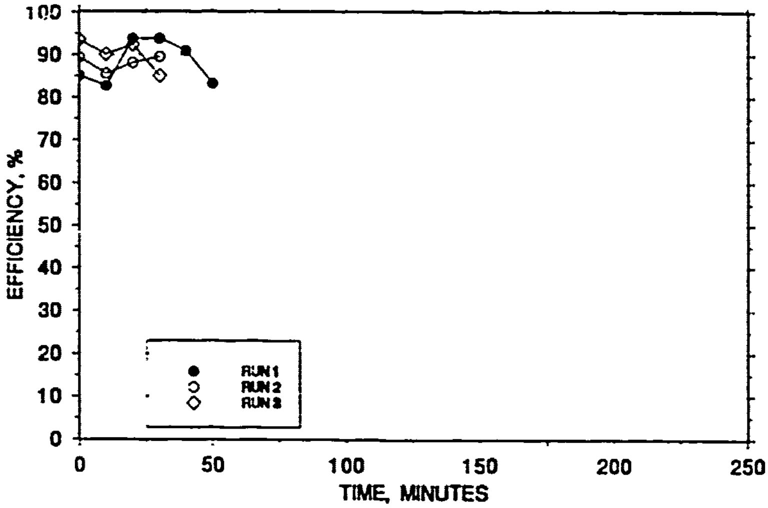


Figure B-71. Filter efficiencv, F10-C

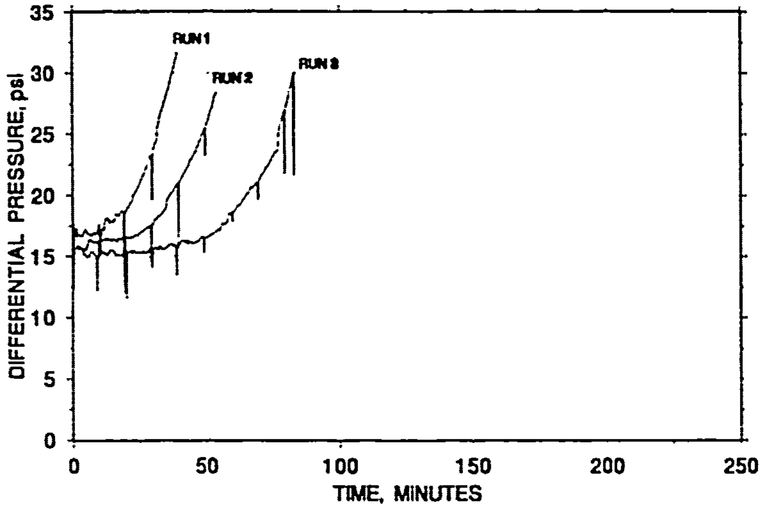


Figure B-72. Differential pressure, F11-P

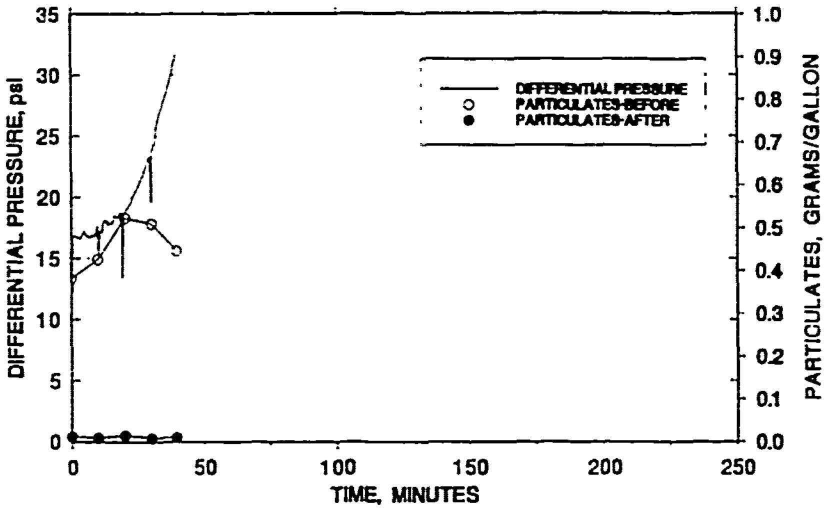


Figure B-73. Pressure versus particulates, F11-P Run 1

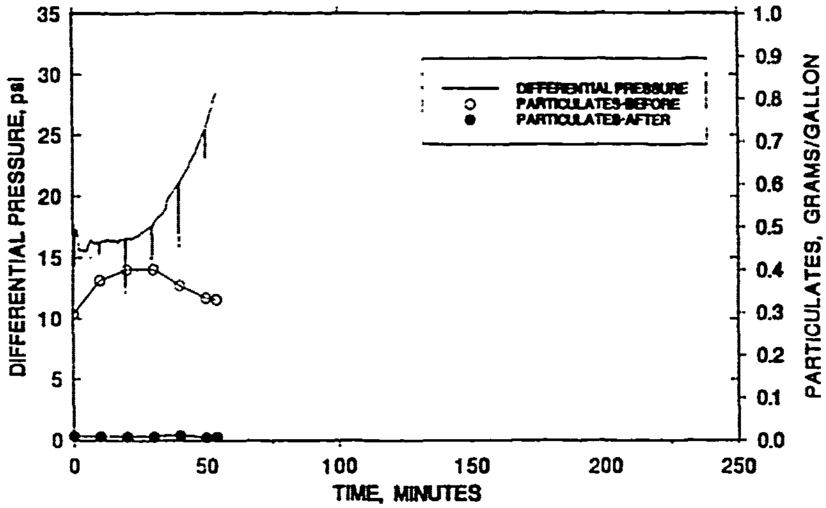


Figure B-74. Pressure versus particulates, F11-P Run 2

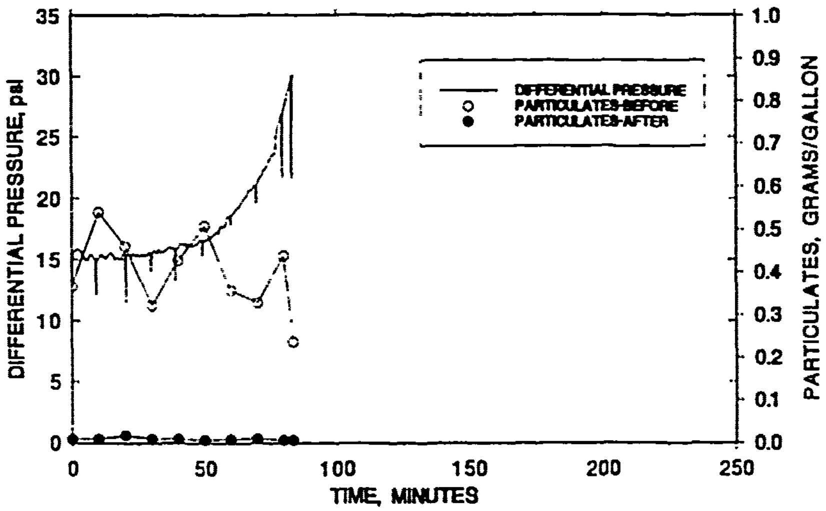


Figure B-75. Pressure versus particulates, F11-P Run 3

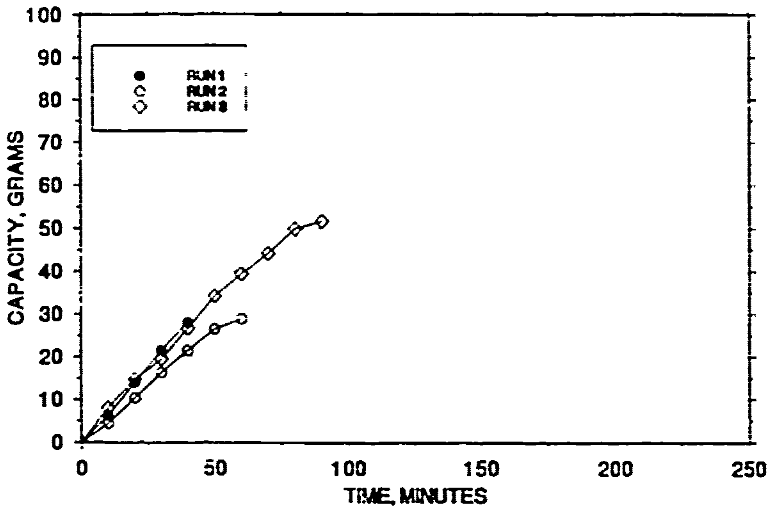


Figure B-76. Load capacity, F11-P

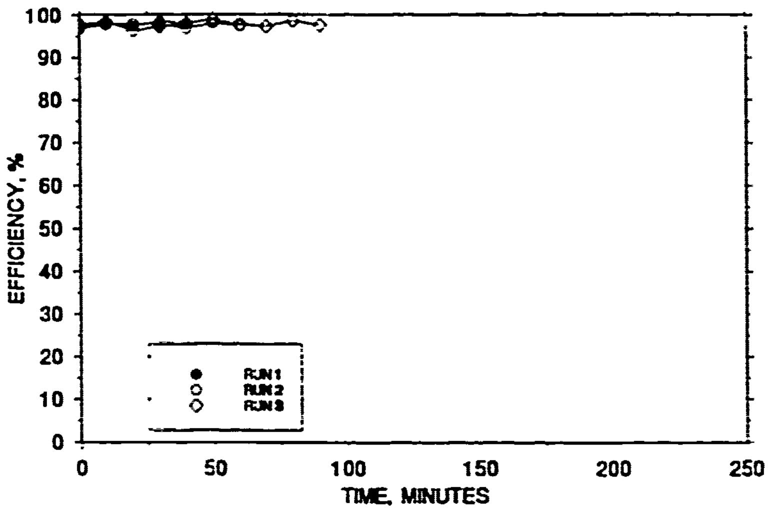


Figure B-77. Filter efficiency, F11-P

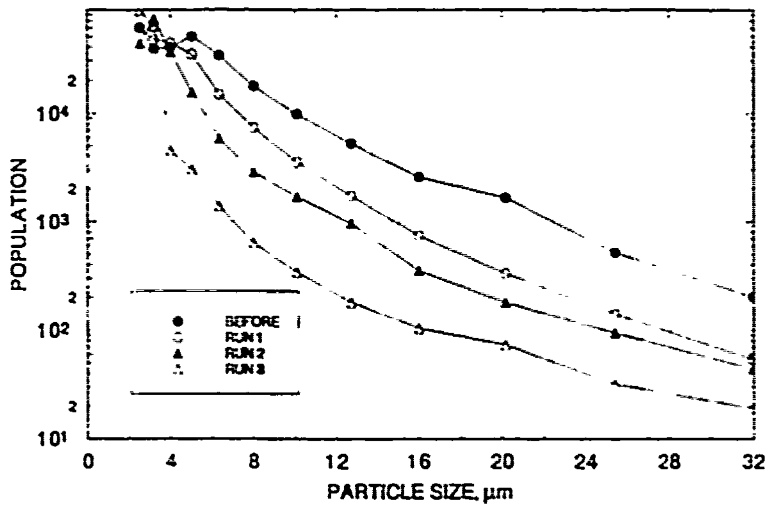


Figure B-78. Particle distribution, F1-P

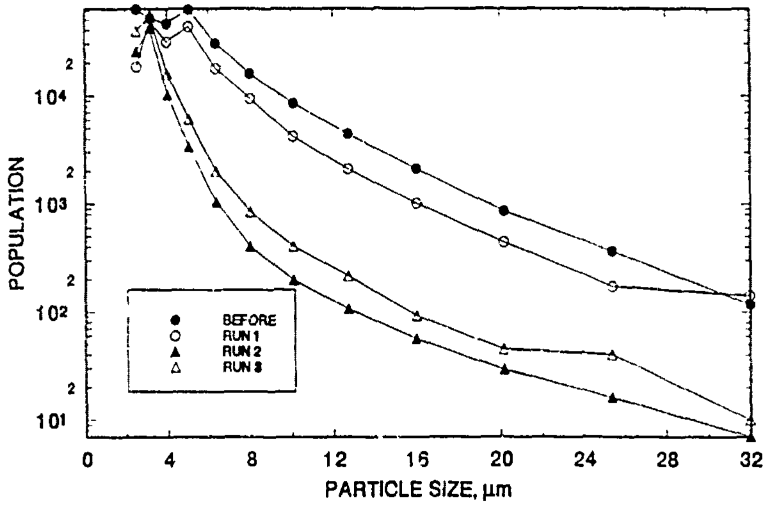


Figure B-79. Particle distribution, F3-X

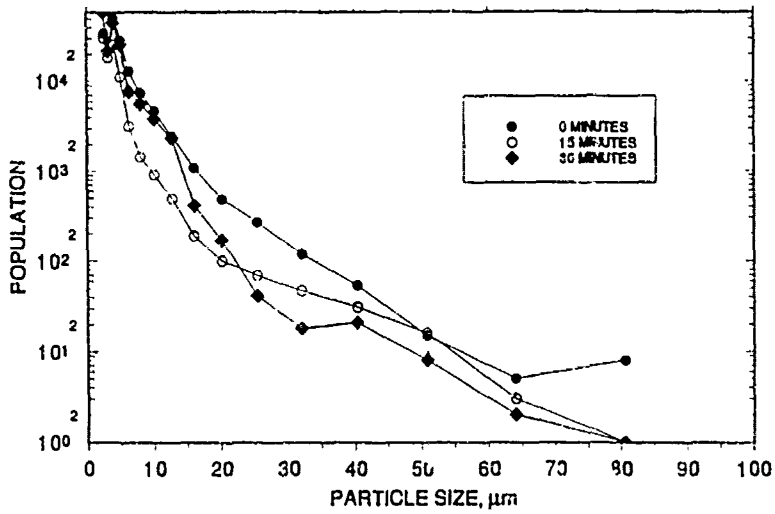


Figure B-80. Effluent particle distribution, F11-P

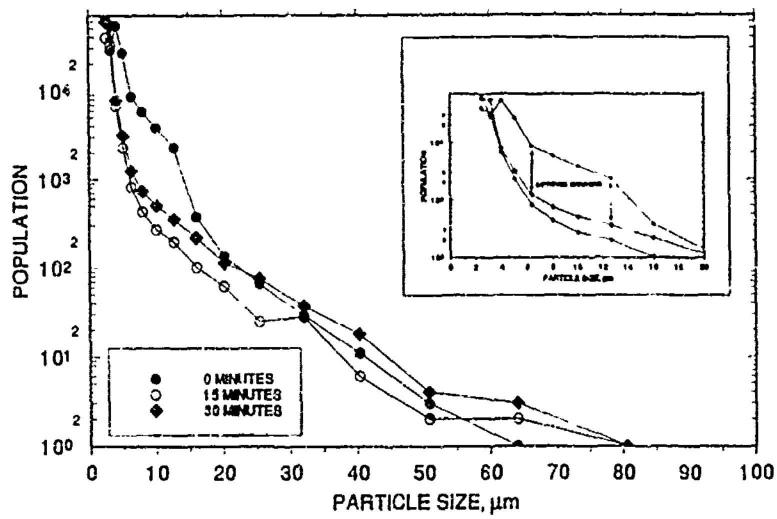


Figure B-81. Effluent particle distribution, F10-C

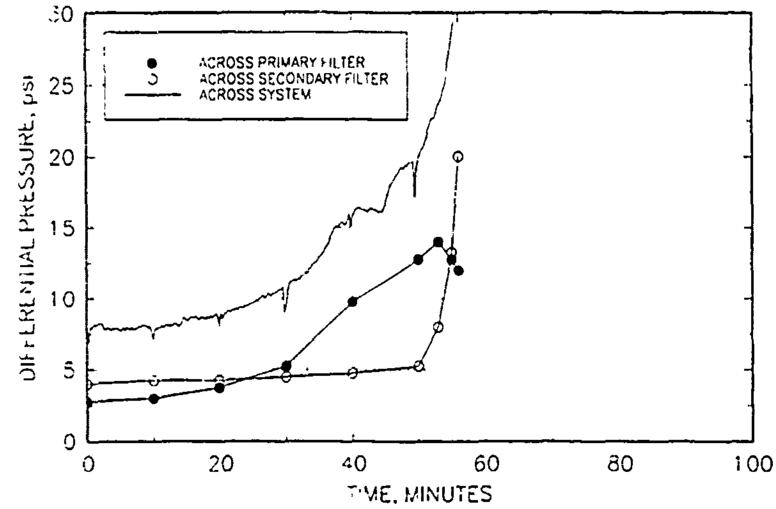


Figure B-82. Primary filter-F1-P with secondary filter-F6-C

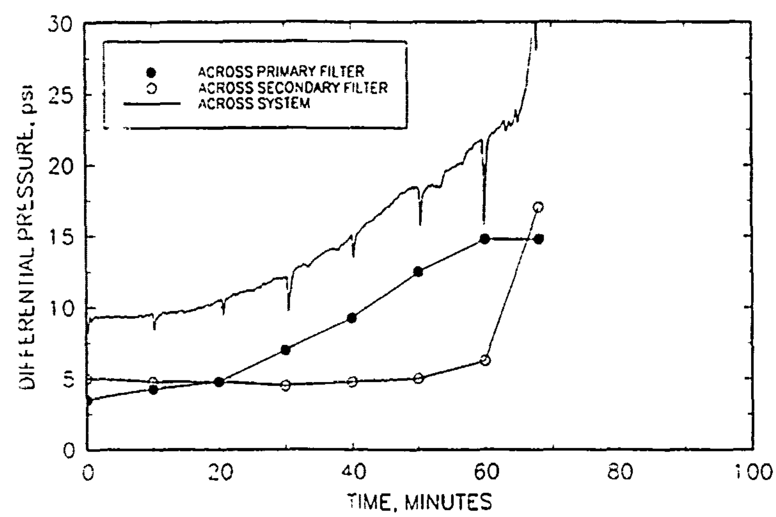


Figure B-83. Primary filter-F1-P with secondary filter-F9-C

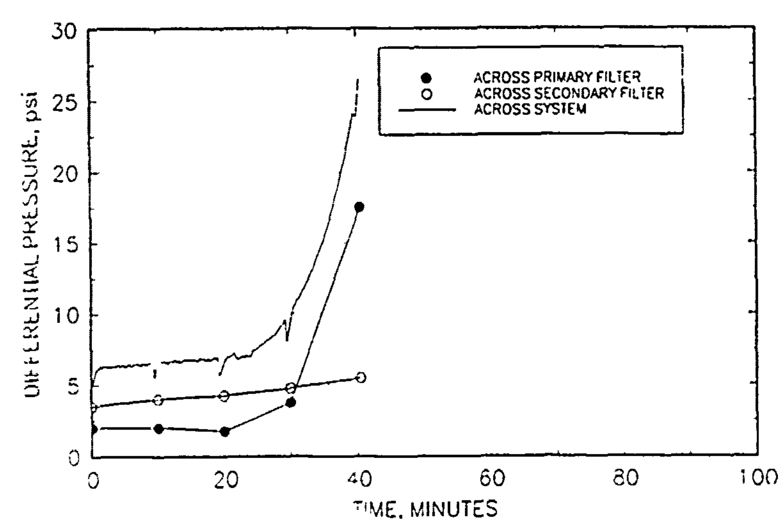


Figure B-84. Primary filter-F8-S with secondary filter-F6-C

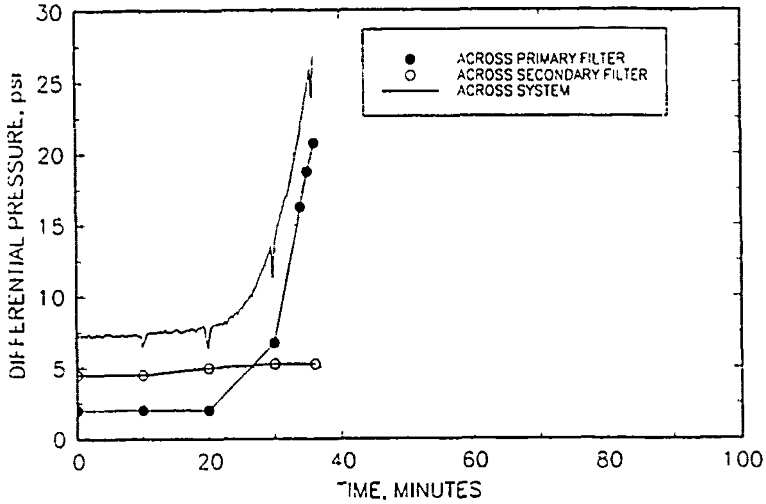


Figure B-85. Primary filter-F8-S with secondary filter-F9-C

APPENDIX C

Military Fuel Specification Meeting Summary

SUMMARY OF THE MILITARY FUEL FILTER SPECIFICATION MEETING HELD AT BELVOIR FUELS AND LUBRICANTS RESEARCH FACILITY (SwRI), SAN ANTONIO, TEXAS
24-25 September 1991

Purpose: **The objective of this meeting was to develop a military fuel filter specification for ground vehicles and equipment that would result in a filter that satisfies the military's requirements, while not being too stringent for manufacturers to produce.**

The attendees of this meeting included 27 members representing 15 organizations, including government and industry. The list of attendees is included at the end of this summary. During the meeting, eight presentations were given, three from government agencies and five from industry. These presentations discussed fuel filtration techniques, procedures, fuel debris, evaluation of filtration data, and concerns for the Army to attempt to use existing methods and procedures, if possible. Also included in this meeting report are the members of the Ad Hoc Committee (Steering) and additional papers or reports concerning filters.

The criteria for the military fuel filter specification was to attempt to use current military specifications when possible or accepted methods, i.e., Society of Automotive Engineers, American Society for Testing and Materials, or ISO standards. The procedures were to attempt to simulate "worse case" conditions when possible, yet still be realistic.

Three main topics were discussed, and preliminary procedures were agreed upon by the attendees that give this document a strong base. In cases in which two possible techniques were recommended, both were initially accepted, and testing will determine which technique gives the more representative data. These areas will be expanded upon to complete the specification. The three main performance topics agreed upon for the filter specification are: 1) filter efficiency, 2) filter plugging, and 3) water separation. Other parameters need to be defined; however, these other parameters have some very good tests that are already fairly accepted or need only minor adjustments. Parameters and procedures to be considered for measuring each of the three main performance topics (above) are discussed in the following sections.

FILTER EFFICIENCY

The parameters for measuring filter efficiency are:

- The system will be evaluated using both AC Fine Test Dust and AC Coarse Test Dust in Viscor L4264V91.
- The concentration of test dust in the test fluid will be 5 milligrams/liter.
- The test will be conducted as a single-pass test with continuous injection.
- If the test fluid is recirculated, a clean-up filter will be installed after the test filter.
- The contaminant will be injected before the pump.
- The test will be conducted for 2 hours or to a net differential pressure of 5 psid.
- The flow rates for the test will be the rated flow rates for each filter as specified by the manufacturer.
- The test temperature will be 38°C ± 2°C.
- Particle size analysis will be performed either in-line and by bottle sampling. The method will be stated on the test document.
- Sampling will be at 2.5, 5, 10, 20, 40, 80 percent of the net terminal pressure and every 10 minutes. Sampling at differential pressures versus time will be evaluated to determine which method yields the better results.
- The particle size ranges that will be measured are:

  3 to 5 microns
  5 to 8 microns
  8 to 10 microns
  10 to 15 microns
  15 to 20 microns
  >20 microns
- Each test and injection system will meet validation requirements according to ISO 4572.

LOAD CAPACITY

The parameters for determining the load capacity (or plugging/choking value) include:

- The test stand shall meet SAE J905 standards.
- The test fluid will be Viscor L4264V91.
- Two plugging agents will be evaluated:
    - SOFT C 2A produced by PTI.
    - One gram ACFTD, 5 grams asphaltene, and 10 milliliters of water, dispersed and slurried with referee fuel as described in test methods for fuel filter APN 116 10298 as provided by Memorandum for Record, dated 21 April 1983 by TACOM.
- The contamination level has yet to be determined.
- The flow rates for the test will be the flow rates for each filter as specified by the manufacturer.
- Each lab may use continuous feed or batch feed according to its own setup. The method will be stated in the test document.
- The test will be terminated at 15 psid net or 2 hours, whichever comes first.
- The test temperature will be 38°C ± 2°C.
- The stand will be a multipass system with a 5-gallon sump.
- Batch feed will sample every 4.5 minutes and add contaminant every 5 minutes.
- Continuous feed will sample every 5 minutes.
- Slurry will be sampled every 15 minutes.
- Validate slurry by gravimetric measurements.

WATER SEPARATION

The parameters for water separation are:

- If the vehicle fuel system uses only a filter/separator, the filter will be tested according to SAE 1488 Emulsified Water Fuel Separator for Secondary Filters or Single Filter/Separator Systems.
- If the vehicle fuel system uses a primary and secondary fuel filter, the primary filter will be tested according to SAE 1839 Fuel/Water Coarse Droplet Separation for Suction Side Applications for Primary Filters and the secondary filter will be tested according to SAE 1488 Emulsified Water Fuel Separator for Secondary Filters or Single Filter/Separator Systems.

ADDITIONAL COMMENTS

- A representative of Fluid Technologies, Inc., volunteered calibration fluid for all round-robin participants.
- RACOR, Stanadyne, and BFLRF will evaluate two test filters supplied by Kaydon Corporation, to compare bench results to actual filtration of diesel fuel. Each test lab will use diesel fuel from its area of the country; California, Connecticut, and Texas. Each filter will be tested at its rated flow rate, and the total number of gallons passing through the filter to generate a net differential pressure of 15 will be recorded.
- The next meeting was tentatively set for August 1992 at BFLRF (SwRI), San Antonio, Texas.
- Inspection of the current fuel filter test rig used by BFLRF revealed that it will need major modifications to meet the proposed test standards.
- The Ad Hoc Committee will review the proposed specification, then pass it along to the rest of the committee for comments. Upon receipt of the comments, the Ad Hoc Committee will revise the document and initialize testing in accordance with BFLRF. The revised proposed military filter specification should be available for comments by December 1991.
- Any SAE documents specified in this proposal are available by contacting the Society of Automotive Engineers, Troy, Michigan.

MILITARY FUEL FILTER SPECIFICATION DEVELOPMENT MEETING ATTENDANCE

NAME	COMPANY	PHONE NO.	TEST PROCEDURES USED: SAE J-905	API 1581	ASTM	ISO 4020	N/A
Gary Bessee	BFLRF/SwRI	(512) 522-5580	X				
Paul Lacey	BFLRF/SwRI	(512) 522-3367					
Edwin Frame	BFLRF/SwRI	(512) 522-2515					
Steve Westbrook	BFLRF/SwRI	(512) 522-3185	X				
Leo Stavinoha	BFLRF/SwRI	(512) 522-2586	X	X			
Doug Yost	BFLRF/SwRI	(512) 522-3126					
Sid Lestz	BFLRF/SwRI	(512) 522-2582					
Daniel Cottone	TACOM	(313) 574-7346					
John Lewakowski	TACOM	(313) 574-8538					
Gordon Jones	Allied Signal	(401) 431-3306	X				
Bijan Kheradi	Allied Signal	(401) 431-3378	X				
Dennis English	Ft. Belvoir RDE Center	(703) 664-5081					
David Hodgkins	RACOR Div Parker Hannifin	(209) 521-7860	X			X	
Craig Maxwell	Stanadyne Automotive	(203) 525-0821	X			X	
Bill Williams	U.S. Army BRDEC	(703) 704-1820					
Roger Miller	Kaydon Corporation	(404) 884-3041	X	X	X		
Tom Northrup	SAE	(313) 649-0422	X				
Dave Staley	AC - General Motors	(313) 257-2015	X		X		
U. Holzhausen	Fleetguard Inc.	(615) 528-9563	X				
Bill Needleman	Pall Corporation	(516) 671-4000		X			X
Gerry Estrada	SwRI	(512) 522-3006	X				
Jim Benson	Donaldson	(612) 887-3737					
Steve Wagner	Donaldson	(612) 887-3465	X				
Dave Elliott	USAF/Kelly	(512) 925-6708					
Jim Eletherakis	Fluid Technologies	(405) 624-0400					
Bill Brockwell	USAF	(512) 684-7206					
Curtin Franke	Winn-Coleman Filters	(512) 344-9099					

Proposed Military Specification

This document is a working draft only, it is currently under revision. Distribution is not restricted. However, this is not an official document and shall not be quoted or used as such.

Vehicle Fuel Filter Specifications and Qualification

1.0 SCOPE

1.1 Scope. This specification covers requirements and test procedures for fuel filters used in vehicle and automotive fuel supply systems of diesel fuel consuming ground equipment.

1.2 Classification. Fuel filters shall be of the following types as described in 1.2.1 and 1.2.2:

Primary fuel filter
Secondary fuel filter

1.2.1 Primary Fuel Filter. The element which is first introduced in the fuel system that is used to filter the large particles from the fuel.

1.2.2 Secondary Fuel Filter. The element which is introduced after the primary filter that is used to filter the fine particles from the fuel.

2.0 APPLICABLE DOCUMENTS

2.1 Government documents

2.1.1 Specifications and standards. The following specifications and standards form a part of this specification to the extent specified herein. Unless otherwise specified, the issues of these documents shall be those listed in the issue of the Department of Defense Index of Specifications and Standards (DODISS) and supplement thereto, cited in the solicitation.

SPECIFICATIONS

Federal
VV-F-800 - Fuel Oil, Diesel

Military

MIL-G-3056 - Gasoline, Automotive, Combat

MIL-G-5572	- Gasoline. Aviation. Grades 80/87. 100/130. 115/145
MIL-T-5624	- Turbine Fuel. Aviation. Grades JP-4 and JP-5
MIL-F-8901	- Filter Separators. Liquid Fuel and Filter-Coalescer Elements. Fluid Pressure: Inspection Requirements Test Procedures For
MIL-F-16884	- Fuel Oil. Marine
MIL-F-52308	- Filter Element. Fluid Pressure
MIL-T-83133	- Turbine Fuel. Aviation. Kerosene Type. Grade JP-8

2.1.2 Other publications.

SAE J-905	- Fuel Filter Test Methods
API Publication 1581	- Specifications and Qualification Procedures for Aviation Jet Fuel Filter/Separators.

3.0 REQUIREMENTS

3.1 Qualification. The fuel filter elements furnished under this specification are for use in U.S. Army wheeled and tracked vehicles. The elements shall be a product that has passed the applicable qualification requirements of 3.1.1 or has been listed on or approved for listing on the applicable qualified products list.

3.1.1 Qualification requirements. All approved fuel filter elements shall meet the requirements of 3.2 through 3.10.6 to be qualified for use in military vehicles. Each filter will be rated as a primary or a secondary filter.

3.1.2 The primary filter must pass all specifications and have a nominal porosity of 15 microns or less.

3.1.3 The secondary filter must pass all specifications and have a nominal porosity of 5 microns or less.

3.2 Identification qualification data. The filters will be qualified using the fuel filter test ng (or comparable units) as shown in Appendix 1. The following properties of the element shall be determined during qualification: element efficiency (gravimetric), particle size analysis on the influent and effluent. Beta ratio efficiency, Beta ratio. CETOP RP70. permeability. free fiber content. and load capacity.

3.3 Test fuel. The test fuel used for the evaluation shall conform to the requirements of Caterpillar 1H2 Test Fuel, a diesel fuel widely used in evaluating the performance of crankcase lubricants.

3.3.1 Test fuel clean-up. The test fuel will be run through a clean-up filter with an absolute rating of 0.5 micron and particle count performed and used as baseline.

3.4 Fuel contaminants. The fuel will be contaminated with 50 % AC Fine Test Dust (ACFTD) and 50 % PV resin. The ACFTD simulates the dust the filter will encounter. The PV resin simulates the fuel degradation products. No attempt will be made to simulate biological growth at this time.

3.4.1 The concentration of the contaminants will be such that the filter element is exposed to 0.25 gram/gallon.

3.4.2 Place a specified mass of ACFTD and PV resin into a 500 mL beaker and place the beaker in an ultrasonic bath for 3 ± 0.5 minutes.

3.4.3 Remove the beaker and add the slurry mixture to the slurry bin on the test rig. Continue to stir and recycle the slurry until the test is completed.

3.5 Flow rate and load capacity requirements. The flow rates and load capacities shall meet the requirements as specified below.

HP of Engine	Flow Rate, GPM	Primary Filter Capacity, grams	Secondary Filter Capacity, grams
<200	0.20	60	30
200 - 500	0.40	80	40
>599	1.00	100	60

3.6 Filter description. Physical measurements will be taken on all elements when possible. If not possible, measurements should be obtained from the manufacturer. Measure the element diameter, length, and media thickness (cm). Describe the element as pleated paper, polypropylene, cotton sock, etc. Also, record if the filter is a primary or secondary filter.

3.7 Test time. The test will be continued for two hours (120 minutes) or until the differential pressure (psid) reaches 15.

3.8 Particulate measurement. Two 100 mL samples shall be collected from the influent and the effluent. One sample will be analyzed for particle size distribution; the second sample will determine the solids by gravimetric measurement (ASTM D-2276 modified). The ASTM modified procedure is described in Appendix 2.

3.9 Computer measurements. LOTUS Measure or other comparable data acquisition software shall be programmed to take pressure and temperature measurements before and after the filter at 15 second intervals. If the test apparatus is not linked with a computer, one reading per minute minimum needs to be recorded for pressure and temperature.

3.10 Data Presentation. The data will be presented as shown in 3.10.1 through 3.10.6.

3.10.1 The differential pressure will be plotted with time (minutes) as the abscissa and differential pressure (psid) as the ordinate.

3.10.2 The gravimetric weight, milligrams/100 mL, will be plotted as the second y-axis on the plot from 3.10.1.

3.10.3 The Beta ratio will be evaluated at 5 micron and 15 micron. The ratio will be calculated for samples taken at 5,10 and 15 psid.

3.10.4 The Beta ratio efficiency will be calculated for the same samples as above. The efficiencies should be greater than or equal to 98.6%

3.10.5 The CETOP RP70 will evaluate the particle size distribution at 5 and 15 micron.

3.10.6 The filter permeability will be calculated and recorded.

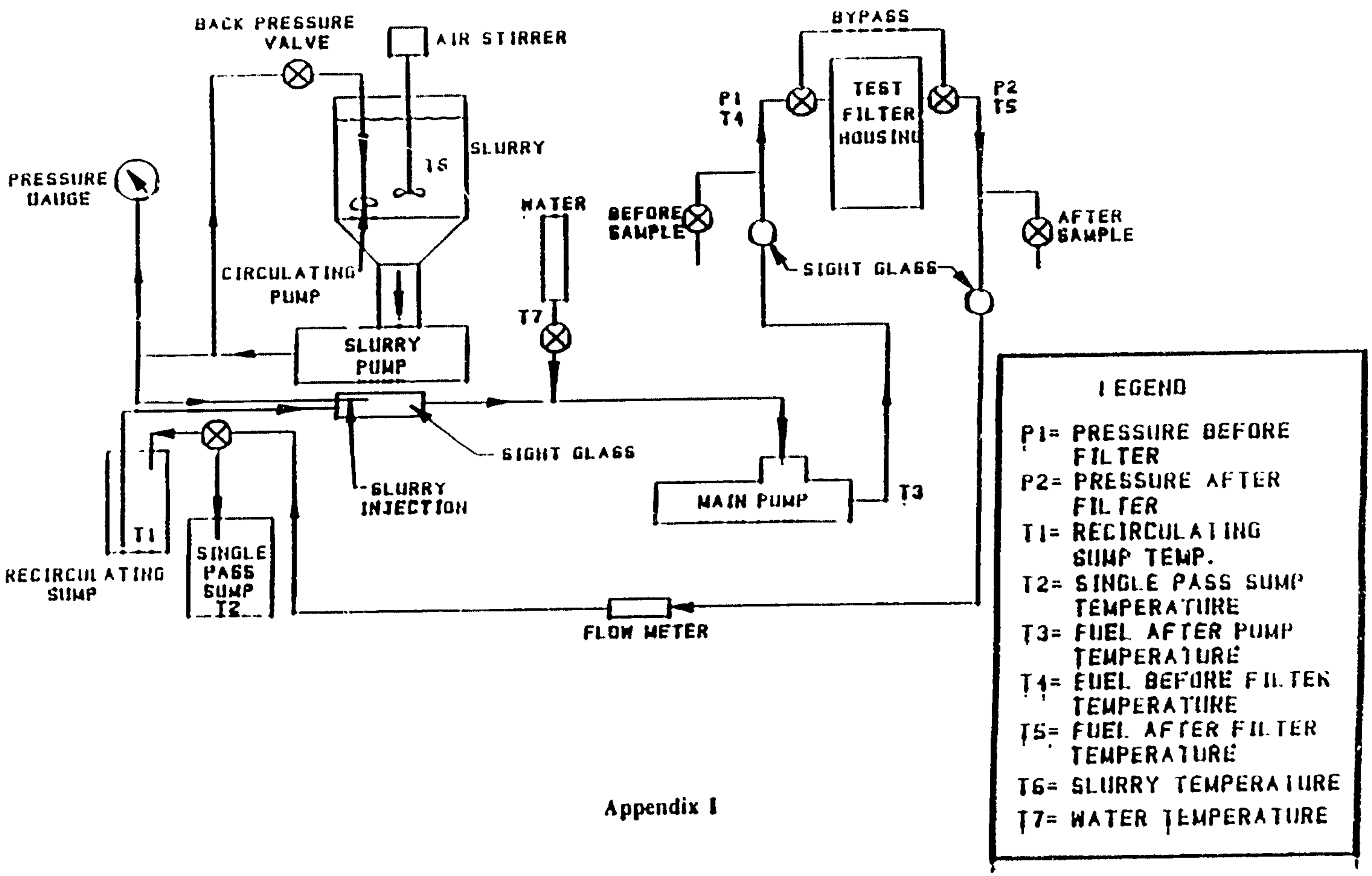
4.0 NOTES

4.1 Intended use. The fuel filters are intended to be used on wheeled and tracked military vehicles to protection the engine and other components from harmful dirt and degradation products.

5.0 Qualification. With respect to products requiring qualification, awards will be made only for products which are qualified for inclusion in Qualified Products List QPL-xxxx, whether or not such products have actually been so listed by that date. The attention of the contractors is called to these requirements, and manufacturers are urged to arrange to have the products that they propose to offer to the Federal Government tested for qualification in order that they may be eligible to be awarded contracts or purchase orders for the products covered in this specification. The activity responsible for the Qualified Products List is the USA Belvoir Research, Development, and Engineering Center, Attn: STRBE-VF, Ft. Belvoir, Virginia 22060-5606, and information pertaining to qualification of products may be obtained from that activity.

6.0 Subject term (key word) listing.

Absolute porosity
Beta ratio
CETOP RP70
Diesel fuel
Differential pressure
Efficiency
Fuel contaminants
Fuel filters
Load capacity
Military specifications
Nominal porosity
Permeability
Primary filter
SAE J905
Secondary filter
Tracked vehicles
Wheeled vehicles
Filtration
Decontamination
Coalescence
Beta Ratio


BACK PRESSURE VALVE
AIR STIRRER
SLURRY
T6
PRESSURE GAUGE
CIRCULATING PUMP
SLURRY PUMP
WATER
T7
SIGHT GLASS
SLURRY INJECTION
T1
RECIRCULATING SUMP
SINGLE PASS SUMP T2
FLOW METER
MAIN PUMP
T3
BYPASS
TEST FILTER HOUSING
P1 T4
P2 T5
BEFORE SAMPLE
AFTER SAMPLE
SIGHT GLASS
LEGEND
P1= PRESSURE BEFORE FILTER
P2= PRESSURE AFTER FILTER
T1= RECIRCULATING SUMP TEMP.
T2= SINGLE PASS SUMP TEMPERATURE
T3= FUEL AFTER PUMP TEMPERATURE
T4= FUEL BEFORE FILTER TEMPERATURE
T5= FUEL AFTER FILTER TEMPERATURE
T6= SLURRY TEMPERATURE
T7= WATER TEMPERATURE

Appendix I

DRAFT

Appendix 2

Method for Gravimetric Analysis

200.0 SCOPE

200.1 This method covers the gravimetric procedures for the determination of solids in the fuel samples obtained during each test.

210.0 SUMMARY OF METHOD

210.1 In this method, 100 mL of test fuel taken before and after the filter is filtered through a 0.45 micron nylon filter membrane. The mass of contaminants removed by the membrane filter is reported as milligrams/100 mL. This is an indication of the efficiency of the test filter.

220.0 METHOD

220.1 This method is according to ASTM D-2276. The method is under revision at this time. However, the procedure will be followed according to ASTM except that the sample size will be 100 mL instead of 1 Liter.

DISTRIBUTION LIST

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PM 113 FOV, ATTN: AMCPM-M113 1
PM M9 ACE, ATTN: AMCPM-MA 1
PM IMP REC VEH, ATTN: AMCPM-IRV 1
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AEAGD-TE (MAJ CURLEY) 1
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ATSM-PWD 1
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