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Spark Arrester Test Carbon Replacement Study—

Final Report

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ABSTRACT

The findings of a 1-yr study conducted at the San Dimas Technology and Development Center (SDTDC) are presented. The study objective was to identify a suitable replacement carbon for that currently used to conduct spark arrester qualification testing at SDTDC. The study had to be undertaken when SDTDC could not find a source to resupply the carbon currently required by testing specifications and standards. This need was reported to Fire and Aviation Management in 1989 and, as a consequence, funding was provided to conduct the study in Fiscal Year 1990. This report defines the methods used to perform the study, the testing conducted, data analysis, and replacement carbon selection criteria. In the conclusion is a recommended replacement carbon and source of supply.

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INTRODUCTION

Purpose and Report Organization

The USDA Forest Service requires that—prior to use on national forests—equipment and off-road vehicles, powered by internal combustion engines, be equipped with a Forest Service-approved spark arrester. Spark arrester manufacturers obtain such approval by submitting their new products to the San Dimas Development and Technology Center (SDTDC) for qualification testing. Arresters are tested in the spark arrester test facility at SDTDC, which was designed to provide the performance information necessary for qualification in accordance with applicable sections of Forest Service standard 5100-1a *(6)*.

To perform spark arrester qualification testing in accordance with 5100-1a, the carbon used in the test must meet requirements of Society of Automotive Engineers (SAE) standard J997 *(5)*. SAE J997 requires the use of petroleum coke carbon that conforms to the physical and chemical requirements defined therein. Currently, SDTDC has enough of this test carbon in stock to meet projected testing needs through FY 1991. To continue testing past October 1, 1991, would require that a replacement supply of carbon be purchased. However, due to recent environmental restrictions imposed on carbon suppliers, petroleum coke carbon that meets SAE J997 requirements is no longer available in the United States. Thus, it has become necessary to define an alternative carbon for spark arrester testing and to revise 5100-1a and SAE J997 to permit the use of the new carbon.

This report defines the objectives, elements, and results of a study conducted at SDTDC during FY 1990 to identify a suitable alternative spark arrester test carbon. To effectively present the findings of this study, and to support the recommendations given in its conclusion, the report has been organized to provide an in-depth understanding of the method used to perform the study by first discussing the basis for, and a description of, the testing conducted. Following this, a comparison of test results is given. Appended to the report are data in the form of tables and figures (photographs and graphs).

Study Objectives

The primary objective of this study was to define a suitable replacement for the petroleum coke carbon defined in SAE J997. To accomplish this, the replacement carbon had to be proven an acceptable test media capable of preserving the initial intent of standard 5100-1a. Also, any carbon selected for this study had to be readily obtainable from a reliable supplier who could furnish it in the quantities necessary to support projected future testing needs at SDTDC.

The secondary objective of this study was to define the changes required to 5100-1a and SAE J997 such that the recommended replacement carbon shall be properly specified and permitted for use in future testing.

STUDY METHOD

Selection of Spark Arresters for Study

To meet the stated objective of the study, it was necessary to assure that nearly 30 yr of spark arrester accumulated test data and the basis for qualification of the large number of spark arresters listed in the Spark Arrester Guide, "SAG," *(4)* be preserved. The SAG is the primary reference used by field personnel of the Forest Service and other enforcement agencies to provide a uniform basis for law enforcement and regulation. Thus, SDTDC selected a cross section of arrester types to conduct the study. The selection was based on the following criteria:

1. *Arrester geometry:* Arresters were divided into currently used groupings with similar applications, design, and size.

2. *Unique performance characteristics:* From the general geometric groupings, previously qualified arresters with unique performance data were selected as potential testing candidates. The basis for selection was effectivity verses flow variations that, when graphed, produced a readily discernible performance signature for the arrester. This signature, produced initially by using the SAE J997 carbon to test the arrester, could than be readily compared with the signature produced by any other carbon selected for the study.

3. *Final selection:* The group of arresters finally selected for the testing were those thought to be the best representative of a major grouping of arresters and that met the other, previously defined, criteria.

Arrester Categories Defined. Four types were selected:

Type 1: Locomotive (high flow, large size), 1,800 to 2,000 cfm or higher flow capacity.

Type 2: Motorcycle/all-terrain vehicle, flow capacity up to 80 cfm.

Type 3: Low capacity, 50 to 200 cfm.

Type 4: Medium capacity, 200 to 500 cfm.

Geometric Selection. Details on the four types follow:

Type 1: Locomotive-type arrester qualified for both horizontal and vertical applications that utilizes high flow to pulverize and trap carbon by the use of flow obstructions that redirect (vary) the flow general direction as it passes through the arrester.

Type 2: All-terrain vehicle (ATV) exhaust system qualified for horizontal application that uses an internal bullet shaped diffuser with louvers to separate and trap the carbon in the exhaust stream as it passes through.

Type 3: Low-flow capacity arresters installed inside of a muffler qualified for horizontal application that use internal louvers to separate and trap carbon in the exhaust stream as it passes through.

Type 4: Medium-flow capacity arresters qualified for vertical application that utilize internal louvers and flow redirection to separate and trap carbon in the exhaust stream as it passes through the arrester.

Arresters Selected. Although there are many varied geometry arresters which could probably be divided into more specific categories than defined for this study, the variety represented herein was deemed to represent a broad enough range of types and flow capacities to successfully determine if a carbon would or would not be suitable for future use. The arresters used for the study are not identified by brand name or model number since the purpose of this study was solely to select a suitable replacement test carbon. This assures that the results given herein are not used for other purposes which could possibly be detrimental to this study or to the manufacturers of the selected arresters.

The selected arresters can be identified, categorized, and described as follows:

Arrester A **(Type 1):** Large engine or locomotive spark arrester with a rated flow of 1,800 cfm for vertical application and 1,950 cfm for horizontal application (see fig. 1). Flow verses effectivity characteristics using SAE J997 carbon are given in figure 2. This arrester has a 6-1/4-in diameter inlet and a 6-in diameter outlet (inlet/outlet ratio = 1.04).

Arrester B **(Type 2):** Motorcycle or ATV arrester for horizontal application with a rated flow of 80 cfm (see fig. 3). Flow verses effectivity characteristics using SAE J997 carbon are given in figure 4. This arrester has a 2-5/8-in diameter inlet and a 2-1/8-in diameter outlet (inlet/outlet ratio = 1.125).

Arrester C **(Type 3):** Horizontal application arrester with a rated flow of 55 cfm (see fig. 5). Flow verses effectivity characteristics using SAE J997 carbon are given in figure 6. This arrester has a 1-in diameter inlet and a 1-1/4-in outlet (inlet/outlet ratio + 0.67).

Arrester D **(Type 3):** Horizontal application arrester with a rated flow of 128 cfm (see fig. 7). Flow verses effectivity characteristics using SAE J997 carbon are given in figure 8. This arrester has a 3-3/4-in diameter inlet and a 4-7/8-in outlet (inlet/outlet ratio = 0.77).

Arrester E **(Type 4):** Vertical application arrester with a rated flow of 460 cfm (see fig. 9). Flow verses effectivity characteristics using SAE J997 carbon are given in figure 10. This arrester has a 2-7/8-in diameter inlet and outlet (inlet/outlet ratio = 1.00).

Arrester F **(Type 4):** Vertical application arrester with a rated flow of 220 cfm (see fig. 11). Flow verses effectivity characteristics using SAE J997 carbon are given in figure 12. This arrester has a 2-5/8-in diameter inlet and a 2-1/8-in outlet (inlet/outlet ratio = 1.24).

Test Carbon Selection

Using physical properties defined in SAE J997 as the primary basis for selecting potential carbons for the study (with an exception that the base material did not have to be petroleum coke), suppliers were identified and six carbons were selected to conduct the study. None of the carbons selected had physical properties that exactly matched those defined in SAE J997. However, whether these property variations would be significant or not could not be known until they were tested and compared with the SAE J997 carbon. Table 1 defines the carbons selected and compares their physical properties with SAE J997 carbon.

Comparison of Carbons and Performance Testing

Since it was not certain at the onset of the study if any of the selected carbons would be suitable, some of the tests and examinations defined in this section were conducted to try and understand which properties of the carbon were the most significant to its performance in a spark arrester. If these properties could be identified and none of the carbons in this first set could be used, then perhaps suitable test material (carbon or other) could be found by use of this additional knowledge.

Some of the testing and examinations conducted are defined in detail in applicable SAE, American Society for Testing and Materials (ASTM), and Forest Service standards and procedures. Whenever this was the case, the test procedure and method used is not reiterated in this report. In its place, a specific reference to the standard or procedure used to define the testing or examination performed is given. Thus, one must read these referenced documents if a detailed description of those procedures is desired.

The following examinations and tests were conducted on each of the test carbons selected to determine which would best meet the objectives of this study and provide spark arrester qualification test results that closely approximate those expected from the currently used SAE J997 carbon:

1. *General Performance Testing:* The performance of each of the test carbons was compared to that of the SAE J997 carbon by conducting testing in accordance with Forest Service standard 5100-1a. Carbon performance was determined in the SDTDC spark arrester test facility by tests using each of the selected test arresters defined herein. The testing was conducted using the SDTDC document "Standard Test Procedure for General Spark Arresters" *(7)*.

2. *Apparent Density Comparison:* The apparent density of each carbon was compared to that of the SAE J997 carbon by density measurements conducted in the SDTDC laboratory. The measurements were made in accordance with the procedure defined in SAE J997.

3. *Sieve Analysis:* Rough and final screening of each of the test carbons was performed in accordance with the procedure defined in SAE J997. This analysis was conducted for two reasons, the first was to prepare the carbon for performance testing in accordance with SAE J997, and the second was to determine the amount (percentage) of useable carbon (carbon suitable for performance testing) in a "normal" manufacturers shipment (as supplied).

4. *Physical Properties Comparison:* The following relevant manufacturer-furnished physical properties of each carbon were compared to those of the SAE J997 carbon:

- Apparent density in accordance with ASTM D2854 *(1)*
- Hardness in accordance with ASTM D3802 *(2)*
- Activity in accordance with ASTM D3467 *(3)*.

These physical properties are compared in table 1 and, excluding activity, are believed to be those most relevant to the understanding of carbon performance in a particular spark arrester. Apparent density was also used to compare the measurements made at SDTDC on each carbon with manufacturer-published data to determine if there was a significant difference between the published data and the density measurements made at SDTDC. Other manufacturer-furnished physical properties are compared in table 2 for reference only.

5. *Surface Characteristics Comparison:* Using scanning electron microscope (SEM) produced photographs, particles of each test carbon were compared for surface texture and unique differences in appearance. The purpose of this analysis was to determine if there were any obvious differences that might effect the carbon's behavior inside of a spark arrester. No conclusive information was obtained from this analysis.

6. *Visual Carbon Particles Comparison:* Gross visual comparisons of the study carbons were conducted to determine the general geometric shape, and any definable or unique surface characteristics by examining and photographing each using a 20x microscope. Geometric shape and surface anomalies were thought to be significant in terms of particle aerodynamic behavior in an arrester exhaust stream. As a result of this analysis, the carbons were given geometric classifications (see table 3).

COMPARISON OF RESULTS

Arrester Performance

In the evaluation and comparison of results, the primary emphasis was on spark arrester performance when using a particular carbon as compared to the arrester's relative performance when tested using SAE J997 carbon. Results of the performance comparisons are given in tables 4 through 6. To accomplish the performance comparisons the following three methods were used to present and evaluate the data.

Arrester Effectivity vs. Spark Arrester Flowrate and Measured Back Pressure. Data were taken using the test methods defined in 5100-1a. The resulting data were then plotted for each carbon and the SAE J997 carbon on the same graph (see fig. 13 through 34). The relative differences between each carbon was then noted by visual examination of the graphs. The carbon(s) which appeared to yield a result near to that of the SAE J997 carbon were considered as a possible selection for a particular arrester. Those carbons which yielded an overall result that was slightly less efficient (apparent effectivity of -1 to -3 percent less than SAE J997) than that obtained using SAE J997 carbon were considered a more favorable choice than those which appeared to have positive apparent effectivities or produced apparent negative effectivities greater than -3 percent. Since none of the test carbons produced test results that exactly matched SAE J997, allowing more weight to those that displayed slightly negative effectivity differences yielded a conservative choice and preserved the intent of 5100-1a.

Average Difference and Standard Deviation. The sum of the differences between each test point and that of SAE J997 carbon divided by the number of points taken in each test was used to define the average difference (arithmetic mean difference) for each set of tests conducted. Also, by use of small sample theory, "Student's t" was defined and used with the sum of the differences to estimate the standard deviation for each performance data set. Plots of this information are given in figures 35 through 40 for each of the arresters used in the study. To evaluate this representation of the data, a similar criteria to that used for the performance data was used. That is, those carbons that displayed a mean difference less than or equal to -3 percent were considered a better choice than those which displayed a mean negative difference greater than -3 percent or greater than or equal to zero. The standard deviation was used to show the variance possible in each of the mean differences given.

Point-to-Point Discrete Differences. Figures 41 through 52 give the point-to-point variations (differences) in performance from the performance of SAE J997 carbon for each arrester tested. Again, overall negative performance in the range defined for evaluation of the graphs as defined in the methods presented in the two preceding paragraphs was considered the most desirable when making a carbon selection for a particular arrester.

Visual and Microscopic Analysis

The carbons were classified by particle geometry and surface characteristics using primarily a 20x microscope to perform the classification. Those carbons with particles which closely resembled the geometry and surface texture of SAE J997 carbon were assumed to have similar aerodynamic behavior to that carbon in a spark arrester. If no other factors were conclusively significant then the most geometric similar carbon would be considered as the best choice. As discussed earlier, the results of this analysis is presented in table 3.

Apparent Density

Results of apparent density measurements for each of the carbons used in the study are, as mentioned earlier, presented in table 1. Apparent density was thought to be the most significant physical property. Those carbons which had apparent densities significantly greater than that of the SAE J997 carbon were expected to yield overall higher arrester effectivities than those which were close to or less than that of the SAE J997 carbon. Thus, those carbons which had an apparent density nearly equal, or equal to, the SAE J997 carbon were considered to be the better choice if arrester testing performance differences proved not to be significant.

Hardness and Activity

Carbon supplier-furnished test data for hardness and activity was compared for each carbon. The impact of carbon activity rating (as determined in accordance with ASTM D3467) in terms of arrester performance is not known. Carbon particle hardness was considered to be a rough indicator of the ease of, or degree of, difficulty in using an arrester to pulverize or reduce the average size of carbon particles in an exhaust stream. Hardness that varied significantly from that of SAE J997 carbon—either softer or harder—was considered to be undesirable. The best choice was deemed to be a carbon with a hardness equal or nearly equal to that of SAE J997. Hardness and activity comparisons are given along with apparent density in table 1.

Selection Process

Because of the variations in carbon performance and physical properties, a system was devised to select the carbon with the best overall performance. To apply the system, the comparison criteria discussed in the previous sections was used, and the carbon(s) which met the criteria defined for arrester performance, or a particular physical property, were given a rating of one point for each occurrence. The number of points accumulated by each of the study carbons was then totaled, and the highest scoring candidates were considered to be the best overall choice. Other less objective factors also had to be considered; these included availability, product quality control, useable product in any one lot, and packaging. In nearly all cases these factors were considered to be solvable if a particular carbon turned out to be the best, or perhaps the only reasonable candidate.

Using the system defined above, the rating results for the carbons tested are given in table 7.

CONCLUSION AND RECOMMENDATIONS

Conclusion

Based on the results given table 7, the carbon with the best overall characteristics is NUSORB G60-8X16.[1/] The carbon is supplied by Nucon International, P.O. Box 29151, Columbus, Ohio 43229. The carbon provided by Westates Carbon, Inc., is considered to be an alternative, should unforeseen difficulties arise in obtaining an adequate supply of the Nucon carbon.

Recommendations

It is recommended that the NUSORB G60-8X16 carbon be selected by the Forest Service to replace the SAE J997 carbon currently used. To implement this recommendation, Forest Service standard 5100-1a and SAE J997 should be revised to allow the new carbon's use in FY 1991. However, no changes are required to standard 5100-1a if changes are made to SAE J997 that will allow the use of carbons manufactured from coconut shells. If necessary, an interim revision can be issued to 5100-1a; one that references this report and requires that testing be conducted with carbon which meets either the most recent revision of SAE J997 or the following recommended carbon specification:

1/Trademark of Nucon International, Inc.

1. Spark arrester test carbon shall be manufactured from coconut shells.

2. Test carbon apparent density shall be determined in accordance with the latest revision of ASTM D2854 and shall be a minimum of 0.50 g/ml.

3. Test carbon hardness shall be determined in accordance with the latest revision of ASTM D3802 and shall be 97.0 percent minimum.

Procurement specifications which define carbon physical requirements, quality control, packaging requirements, lot certification required, and shipment quantities needed should be defined in accordance with the requirements listed above and such that a supply of the recommended carbon can be obtained by the end of FY 1991 for use at SDTDC. Interface with the SAE and spark arrester manufacturers should commence in FY 1991 to assure revision of SAE J997 and any other SAE standards and recommended practices which may be effected by the end of FY 1992 to allow the use of NUSORB G60-8X16 carbon.

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2. American Society for Testing and Materials. Standard test method for ball-pan hardness of activated carbon. D 3802. Philadelphia, PA: ASTM; latest revision. 4 p.

3. American Society for Testing and Materials. Standard test method for carbon tetrachloride activity of activated carbon. D 3467. Philadelphia, PA: ASTM; latest revision. 4 p.

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Table 1. Comparison of Physical Properties

Carbon	Apparent Density per ASTM D2854 Measured at SDTDC g/cc, Average Particle Size:		Apparent Density per ASTM D2854 Provided by Mfg. Density Range g/cc	Hardness Number per ASTM D3802	Activity per ASTM D3467	Base Material
	Large	*Small*				
SAE J997	0.53	0.51	n/a	75-90	45.0	Petroleum Coke
CA	0.50	0.42	0.48	not provided	not provided	Coal Coke
CF	0.50	0.48	0.44-0.50	90	not provided	Coal Coke
GC	0.52	0.42	0.52-0.54	98	68.0	Coal Coke
HO	0.59	0.57	0.50-0.60	98	45.5	Coal Coke
NU	0.53	0.53	0.48-0.52	97	60.0	Coconut Shell
WE	0.55	0.56	0.50	99	62.5	Coconut Shell

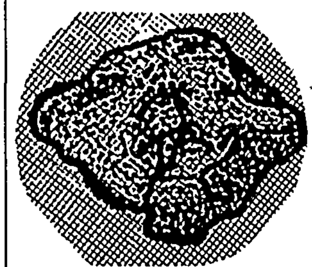
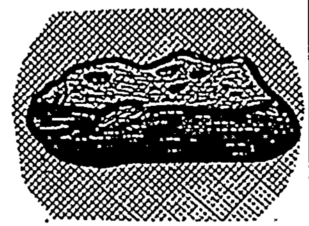
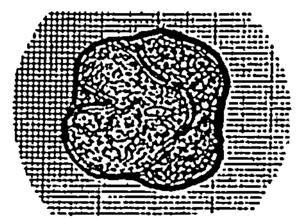
LEGEND

Carbon Designation	*Supplier*
CA	Carbtrol Corp.
CF	Envirotrol, Inc.
GC	General Clarifier Corp;
HO	Mitsui Pharmaceuticals, Inc.
NU	Nucon International, Inc.
WE	Westates Carbon, Inc.

Carbon	CA	CF	GC	HO	NU	WE
Physical Properties:						
Iodine No. mg/g min.	925-950	900-1000	850 min.	not furnished	not furnished	not furnished
Abrasion No. (Ro-Tap) min.	not furnished	75 min.	70 min.	not furnished	not furnished	99
Mean Particle Diameter (mm)	not furnished	0.9-1.7	1.5-1.7	not furnished	not furnished	3.4
Moisture Content (as packed, weight percent) per ASTM D2867	2% max.	2% max.	2% max.	not furnished	5% max.	2% max.
Apparent Density (dense packing, g/ml) per ASTM D2867	0.48	0.44-0.55	0.52-0.54	0.50-0.60	0.48-0.52	0.50
Hardness (percent min) per ASTM 3802	not furnished	90	98	75-90	98	99
Carbon Tetrachloride Activity (weight percent CCL4) per ASTM D3467	not furnished	not furnished	68	45-50	60 min	not furnished
Particle distribution as shipped measured per ASTM D2862 at SDTDC for selected carbons, large carbon:						
U.S. Standard Sieve Size						
Retained on No. 8 sieve (weight percent)	not measured	not measured	43	not measured	1	30
Retained on No. 12 sieve (weight percent)	not measured	not measured	54	not measured	61	54
Retained on No. 16 sieve (weight percent)	not measured	not measured	2	not measured	37	16
Retained on No. 20 sieve (weight percent)	not measured	not measured	<1	not measured	1	<1
Retained on No. 30 sieve (weight percent)	not measured	not measured	<1	not measured	<1	<1
Pan	not measured	not measured	1	not measured	<1	<1
Particle distribution as shipped measured per ASTM D2862 at SDTDC for selected carbons, small carbon:						
U.S. Standard Sieve Size						
Retained on No. 8 sieve (weight percent)	not measured	not measured	0	not measured	<1	<1
Retained on No. 12 sieve (weight percent)	not measured	not measured	<1	not measured	<1	<1
Retained on No. 16 sieve (weight percent)	not measured	not measured	45	not measured	46	47
Retained on No. 20 sieve (weight percent)	not measured	not measured	34	not measured	41	47
Retained on No. 30 sieve (weight percent)	not measured	not measured	17	not measured	12	5
Pan	not measured	not measured	4	not measured	<1	<1

Table 2. Comparison of Study Carbon Manufacturer Furnished Physical Properties.

Table 3: Geometric Classification of Study Carbons

Classification	Description	Typical Shape	Base Material
Type A SAE J997 CF GC	Very rough surface with relatively large cavities and small surface spikes apparent over all the surfaces. About 1/2 of the surface spikes have one shiny side, indicating a crystalline fracture. The particles are a very dark shade of black.		Petroleum Coke Coal Coke Coal Coke
Type B CA NU WE	Surfaces appear flat & smooth with scattered small cavities. Particle has a fibrous texture. Appear to be chips instead of the chunk like appearance of type A. Rectangular shape. Color is a dull black.		Coal Coke Coconut Shell Coconut Shell
Type C HO	Spherical shape. Porous surface with visible cracks. Surface is very smooth. Black with shiny spots.		Coal Coke

Carbon	CA	CF	GC	HO	NU	WE
Arrester effectivity versus flowrate & back pressure comparison to SAE J997 carbon (figures 13-34)						
Arrester A:						
Small carbon			1		1	1
Large carbon					1	1
Arrester B:						
Small carbon					1	1
Large carbon						1
Arrester C:						
Small carbon	1				1	
Large carbon					1	1
Arrester D:						
Small carbon					1	1
Large carbon					1	
Arrester E:						
Small carbon				1		
Large carbon				1		
Arrester F:						
Small carbon		1	1		1	
Large carbon		1	1			
TOTALS	**1**	**2**	**3**	**2**	**8**	**6**

Table 4. Comparison and Evaluation of Study Results, Performance Ratings.

Table 5. Comparison and Evaluation of Study Results, Performance Ratings.

Carbon	CA	CF	GC	HO	NU	WE
Average effectivity difference to SAE J997 carbon and standard deviation (figures 35-40)						
Arrester A:						
Small carbon			1		1	1
Large carbon			1			1
Arrester B:						
Small carbon					1	
Large carbon						1
Arrester C:						
Small carbon				1	1	1
Large carbon					1	1
Arrester D:						
Small carbon					1	
Large carbon					1	
Arrester E:						
Small carbon				1		
Large carbon				1		
Arrester F:						
Small carbon		1	1		1	
Large carbon		1	1		1	
TOTALS	0	2	4	3	8	5

Carbon	CA	CF	GC	HO	NU	WE
Point-to-point discrete effectivity difference to SAE J997 carbon (figures 41-52)						
Arrester A:						
Small carbon					1	1
Large carbon					1	
Arrester B:						
Small carbon				1		
Large carbon				1	1	1
Arrester C:						
Small carbon				1		
Large carbon				1		
Arrester D:						
Small carbon					1	1
Large carbon					1	
Arrester E:						
Small carbon				1		
Large carbon				1		
Arrester F:						
Small carbon					1	
Large carbon			1			
TOTALS	0	0	1	6	6	3

Table 6. Comparison and Evaluation of Study Results, Performance Ratings.

Table 7. Comparison and Evaluation of Study Results.

Carbon	CA	CF	GC	HO	NU	WE
Overall performance Totals **Tables 4, 5 & 6**	1	4	8	11	22	14
Selection by Geometry **Table 3**		1	1			
Selection by Physical Properties **Table 1**						
Apparent Density						
Small Carbon **Large Carbon**			 1		1 1	
Hardness Number		1				
Total Selection Scores	1	6	10	11	24	14

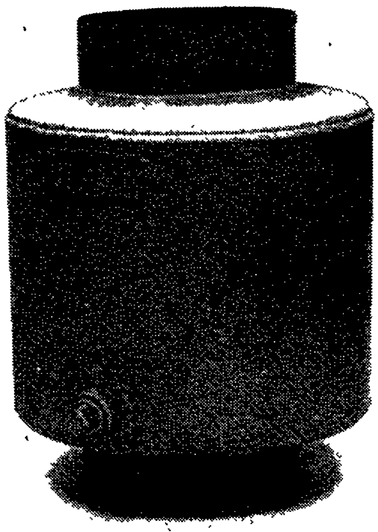


Figure 1.
Arrester A
Classification Type 1

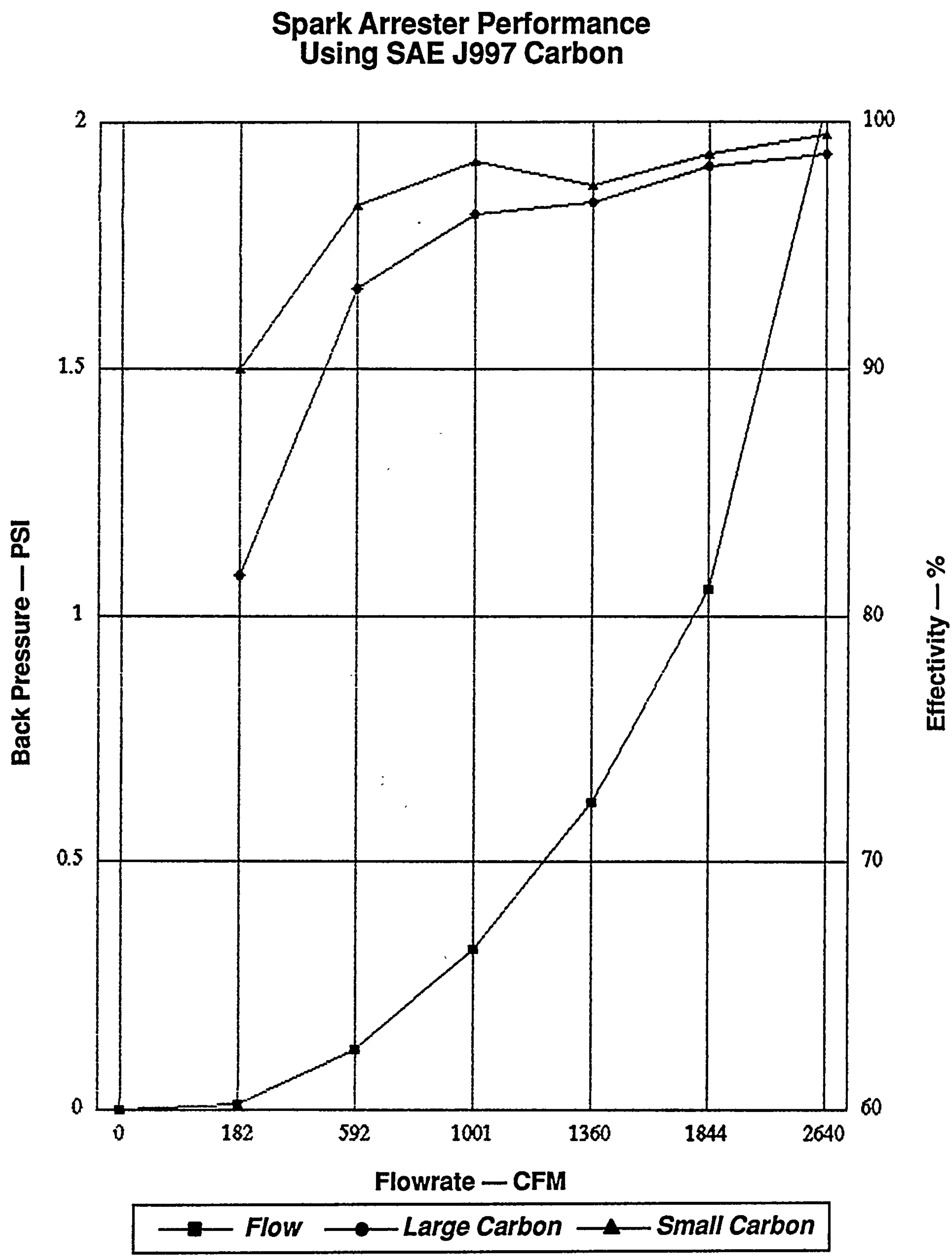


Figure 2.
Arrester Effectivity versus Flowrate and Back Pressure Arrester A.

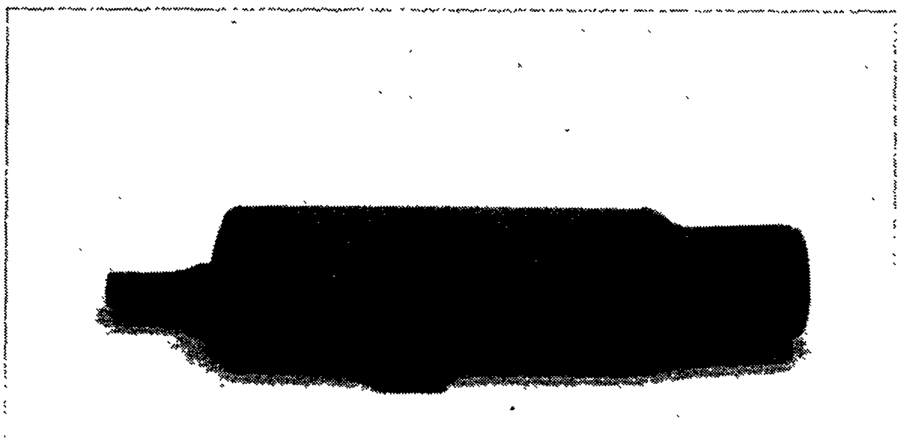


Figure 3.
Arrester B
Classification Type 2

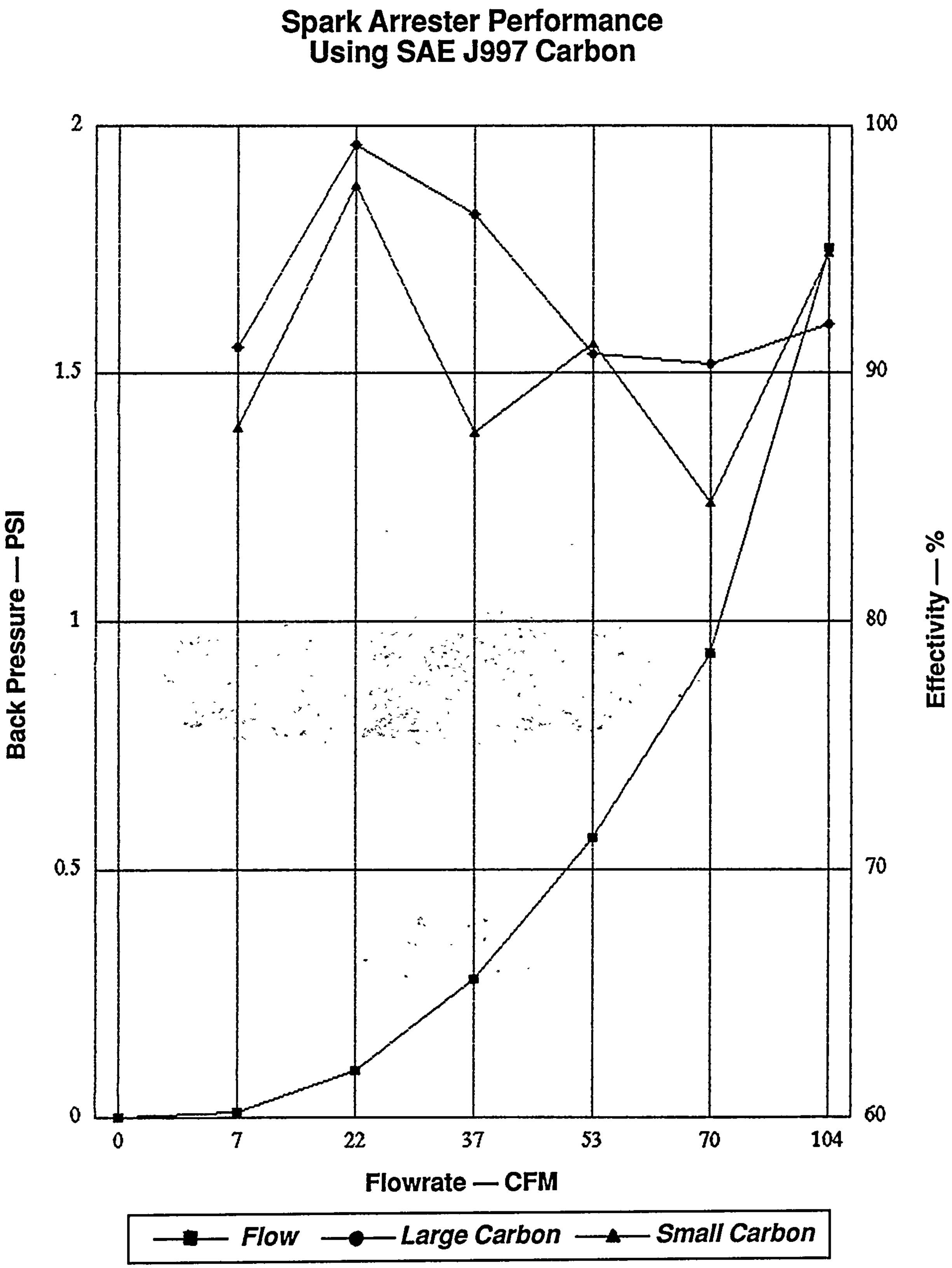


Figure 4.
Arrester Effectivity versus Flowrate and Back Pressure Arrester B.

Figure 5.
Arrester C
Classification Type 3

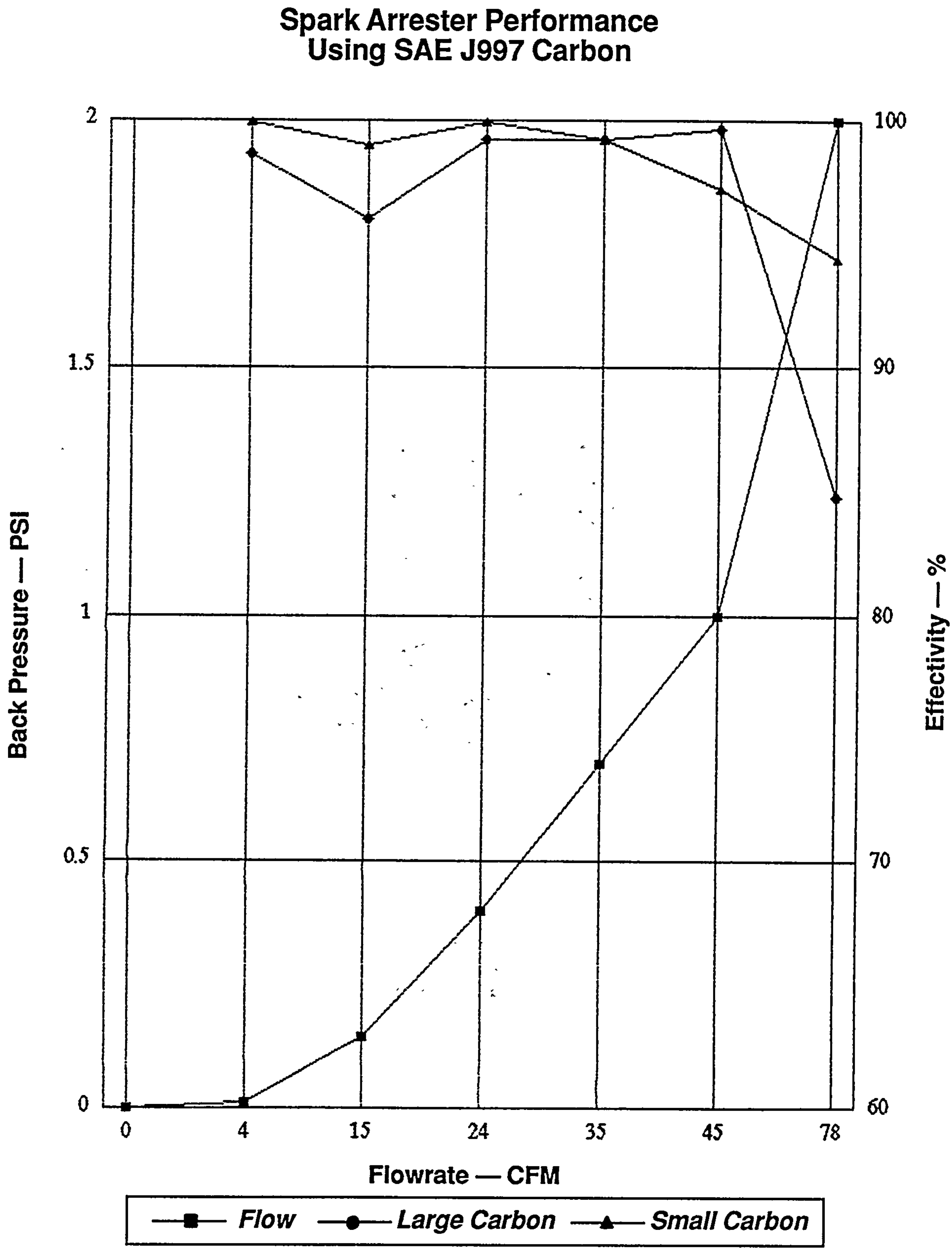


Figure 6.
Arrester Effectivity versus Flowrate and Back Pressure Arrester C.

Figure 7.
Arrester D
Classification Type 3

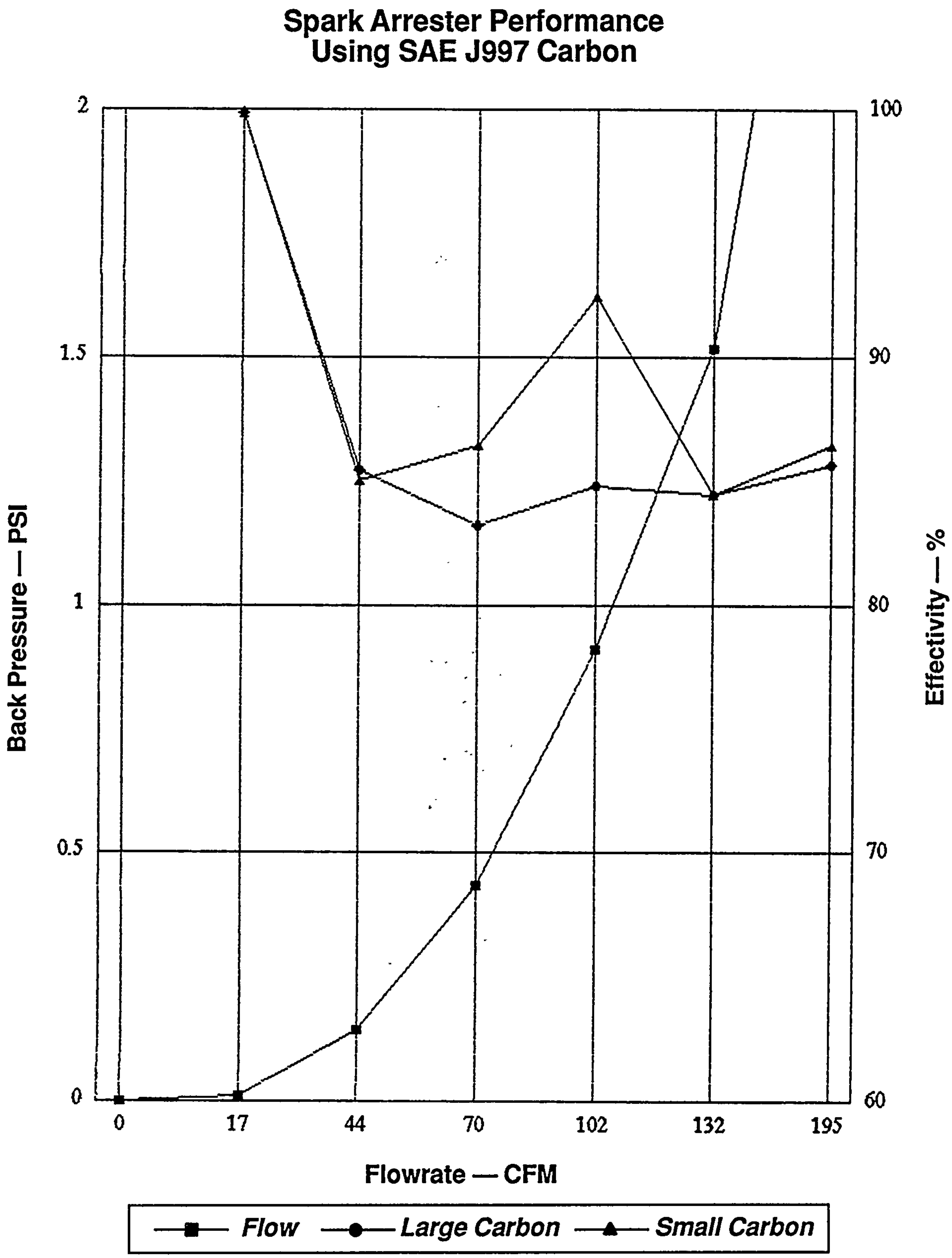


Figure 8.
Arrester Effectivity versus Flowrate and Back Pressure Arrester D.

Figure 9.
Arrester E
Classification Type 4

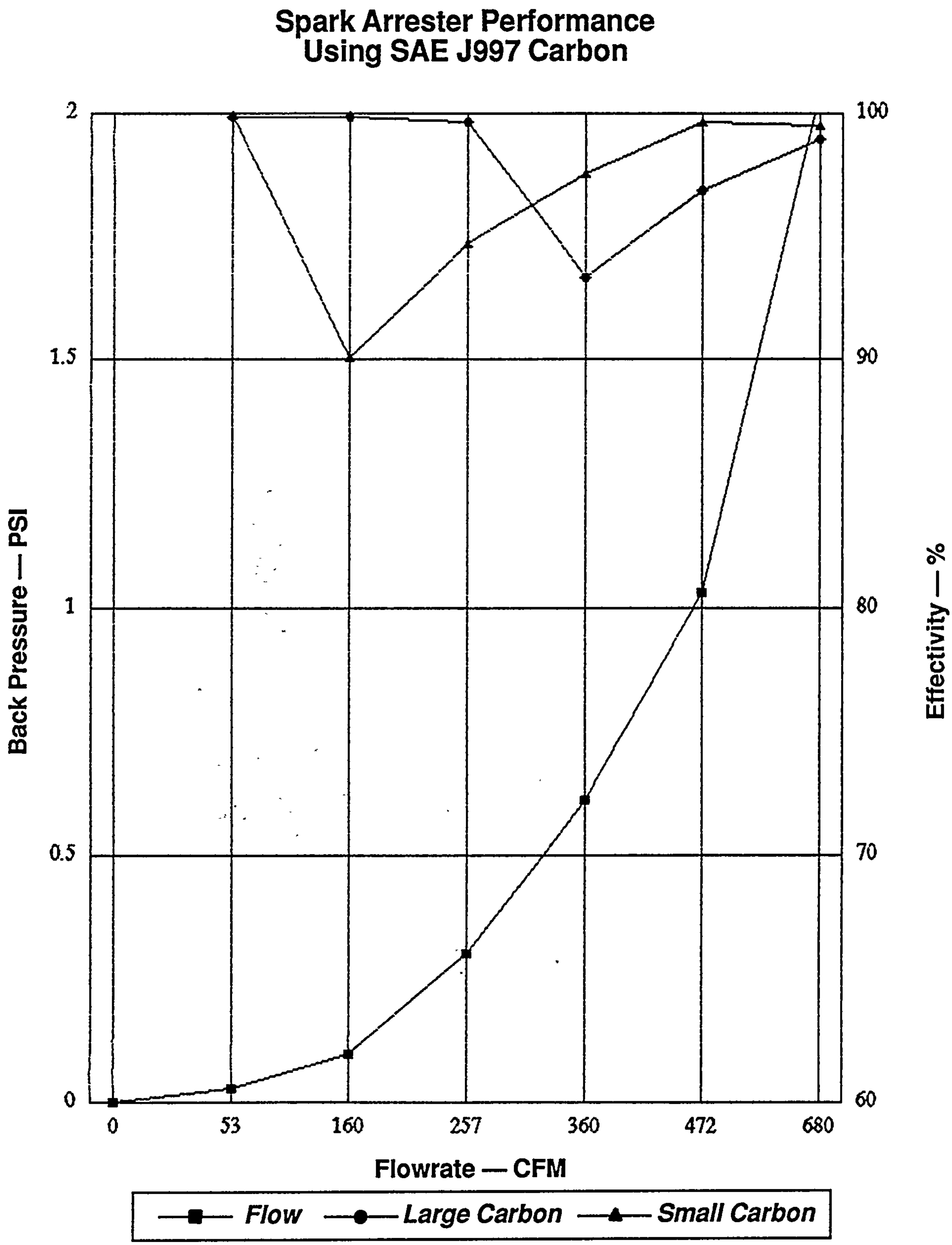


Figure10.
Arrester Effectivity versus Flowrate and Back Pressure Arrester E.

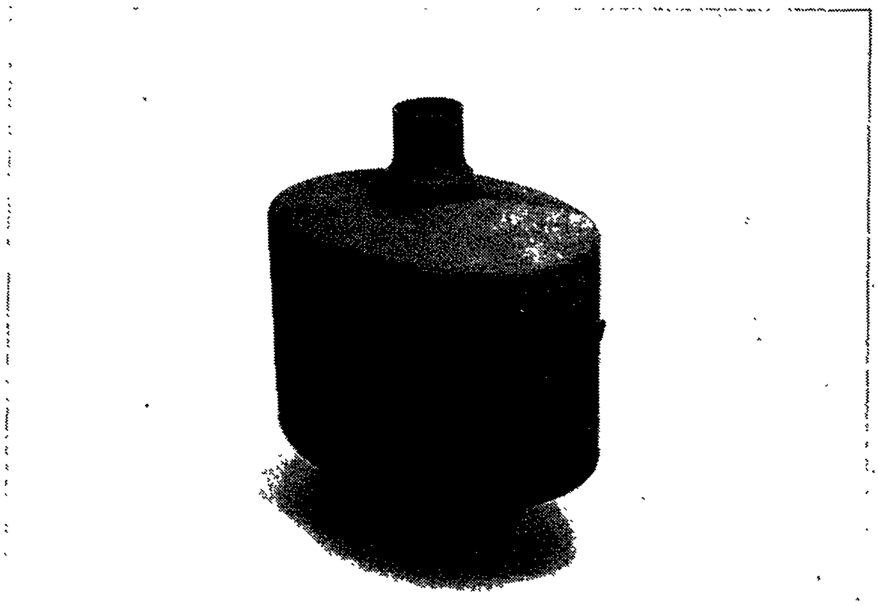


Figure 11.
Arrester F
Classification Type 4

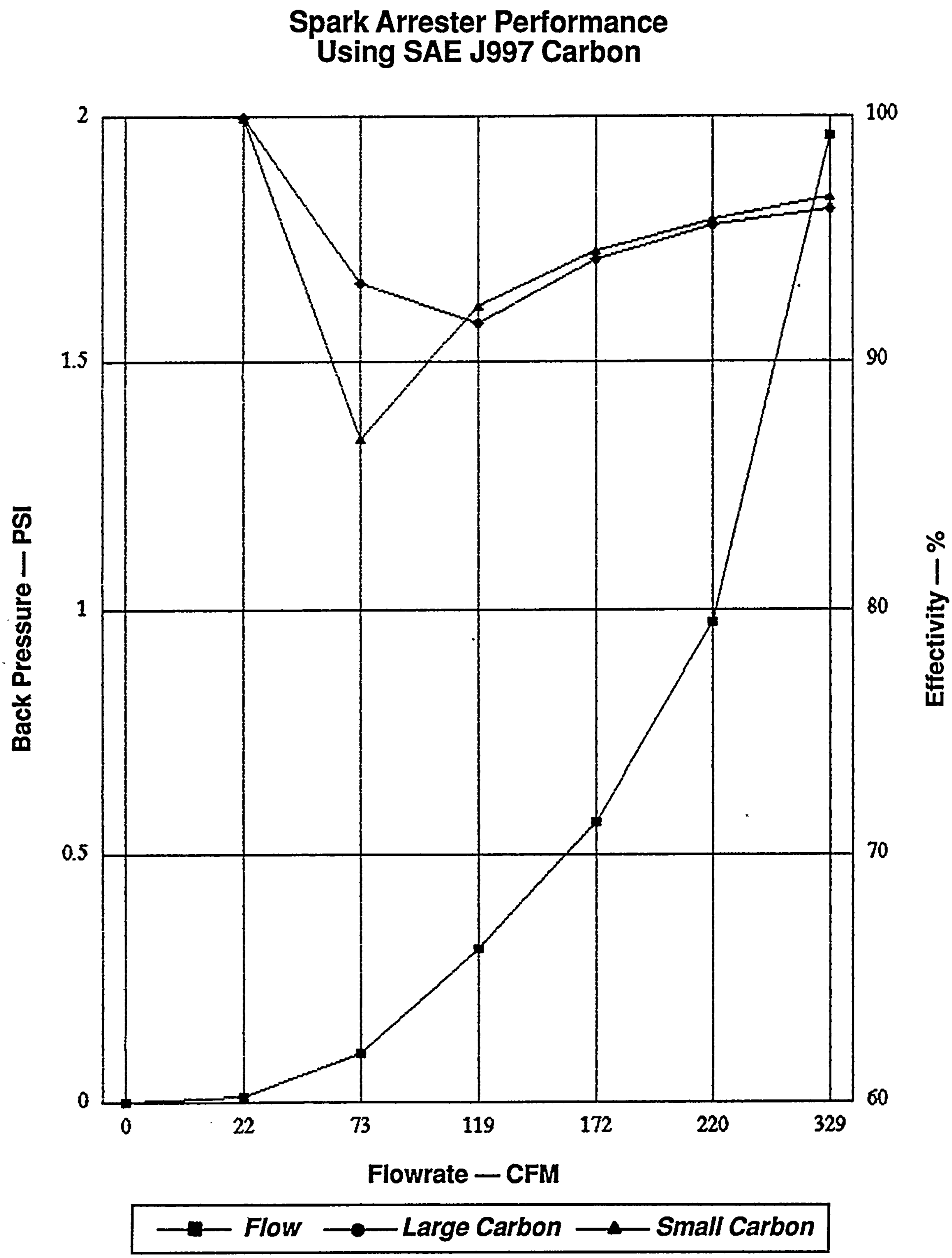


Figure 12.
Arrester Effectivity versus Flowrate and Back Pressure Arrester F.

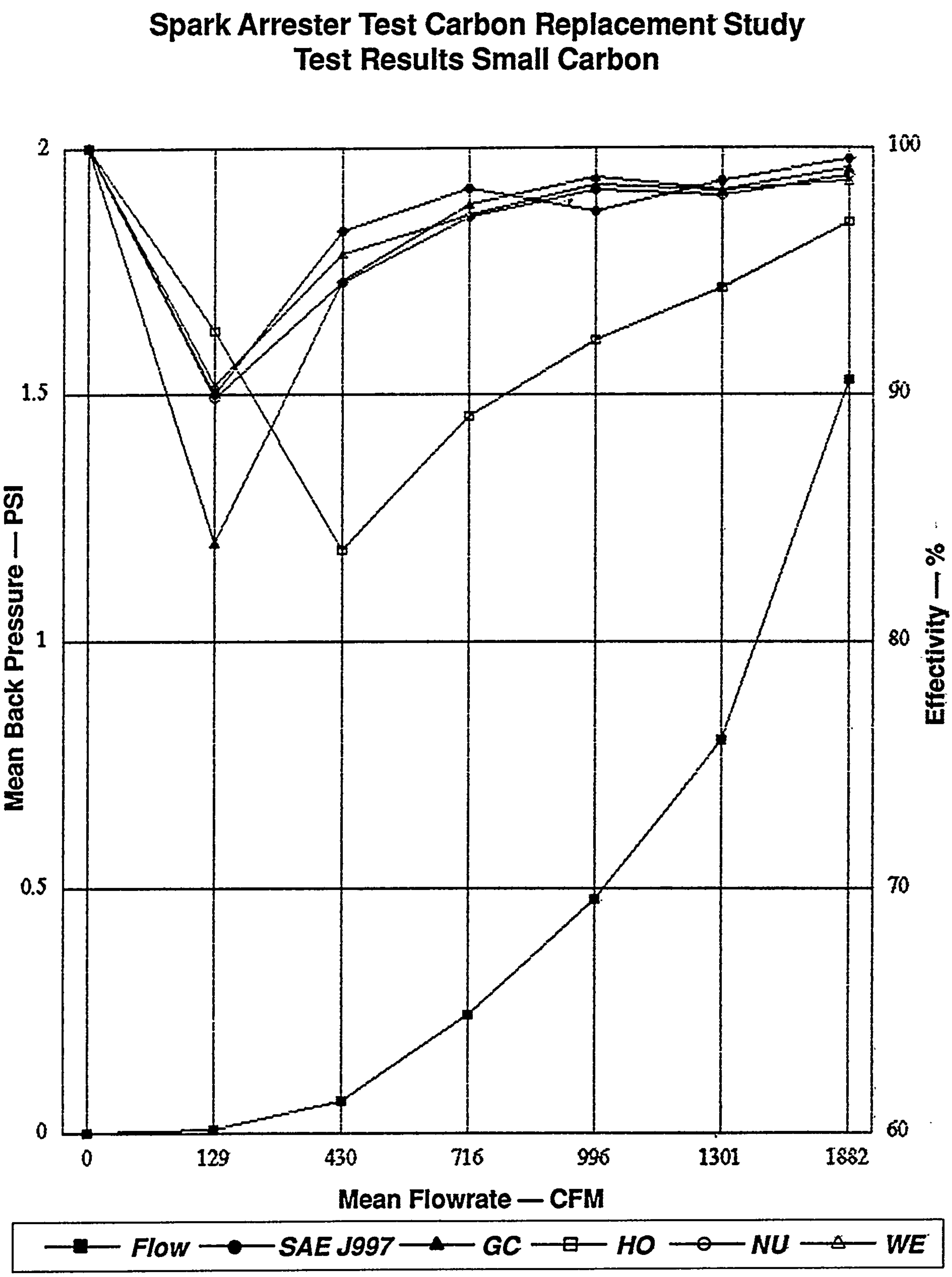


Figure 13.
Arrester A
Comparison of Effectivity Difference to SAE J997 Carbon

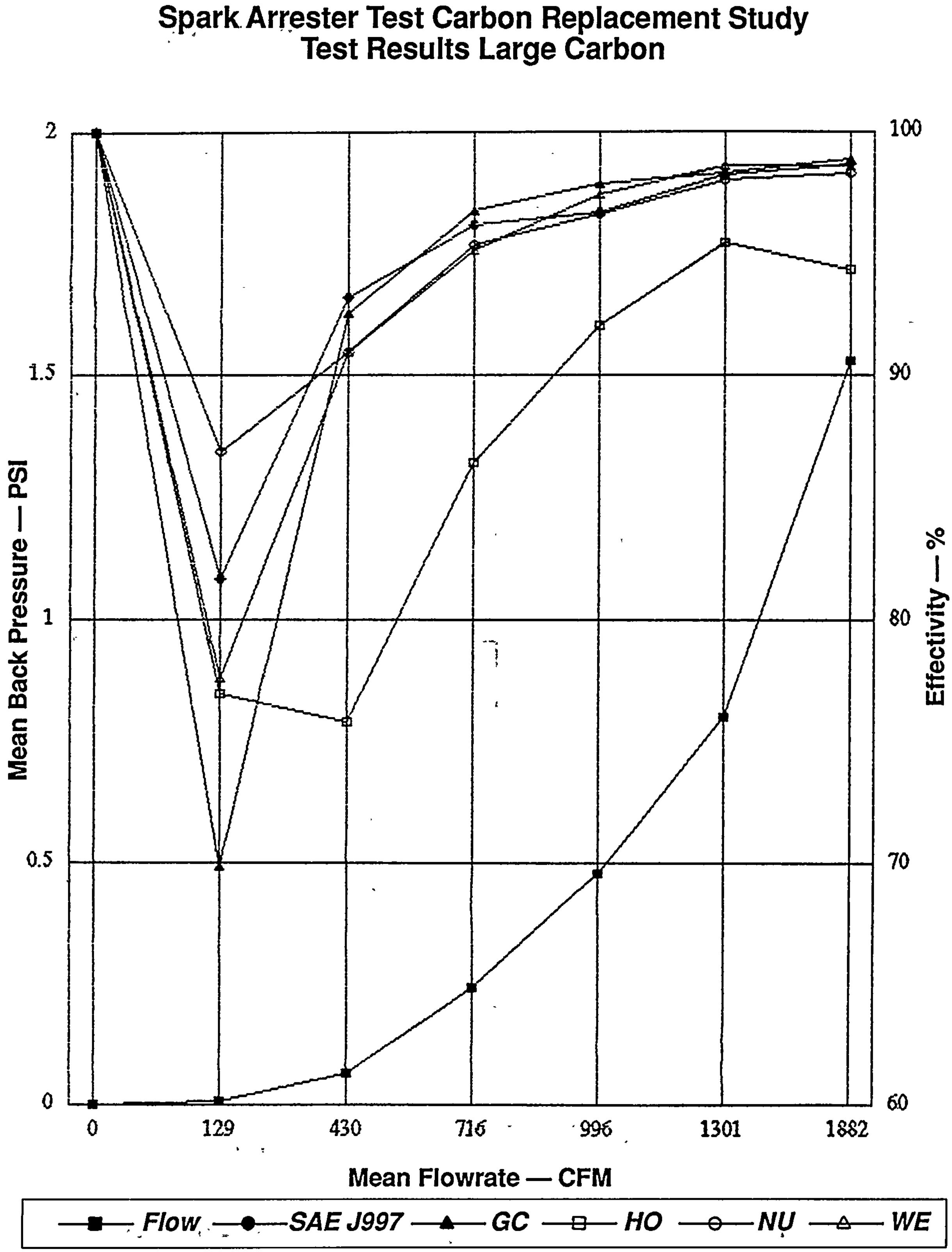


Figure 14.
Arrester A
Comparison of Effectivity Difference to SAE J997 Carbon

Spark Arrester Test Carbon Replacement Study
Test Results Small Carbon

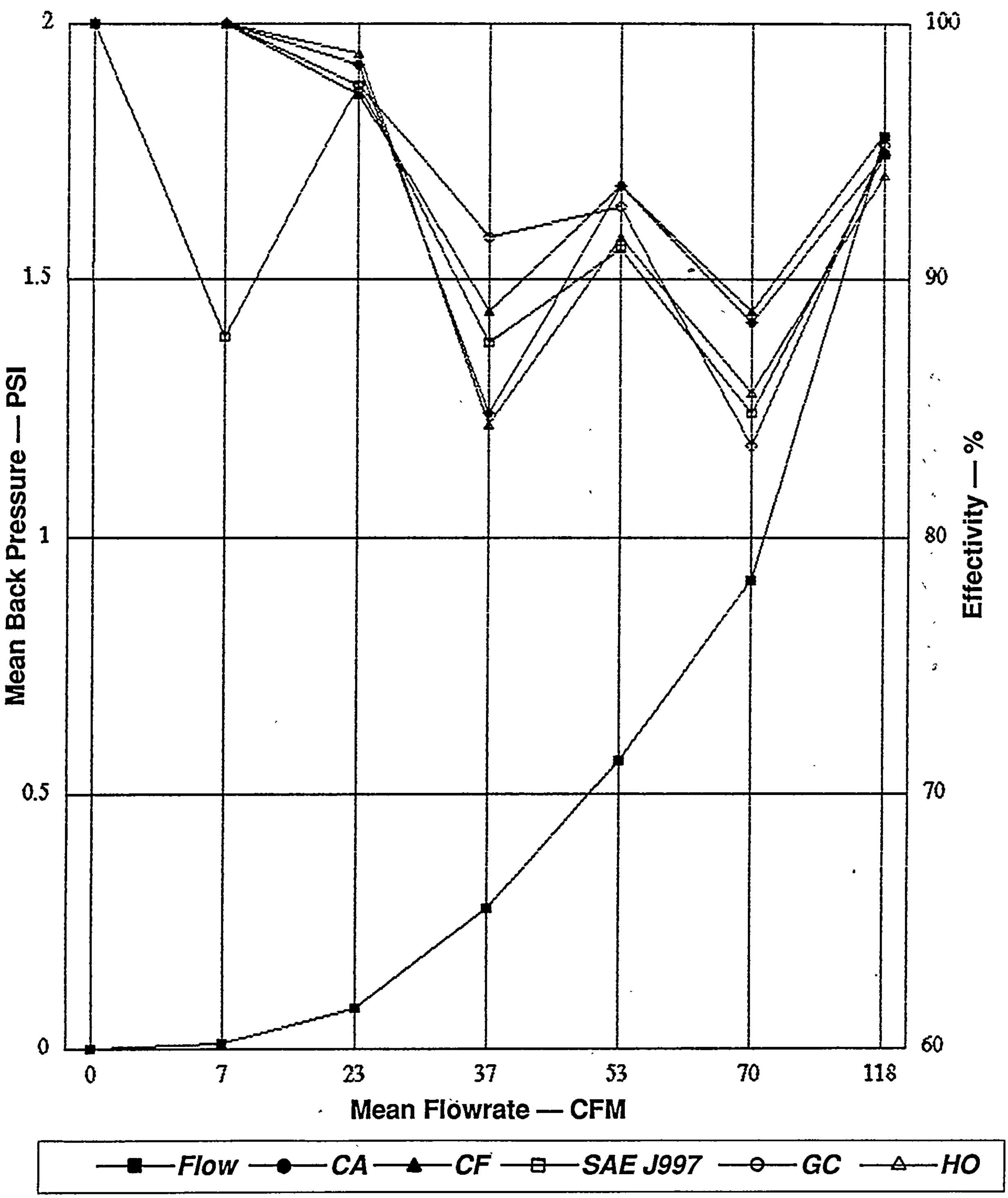


Figure 15.
Arrester B
Comparison of Effectivity Difference to SAE J997 Carbon

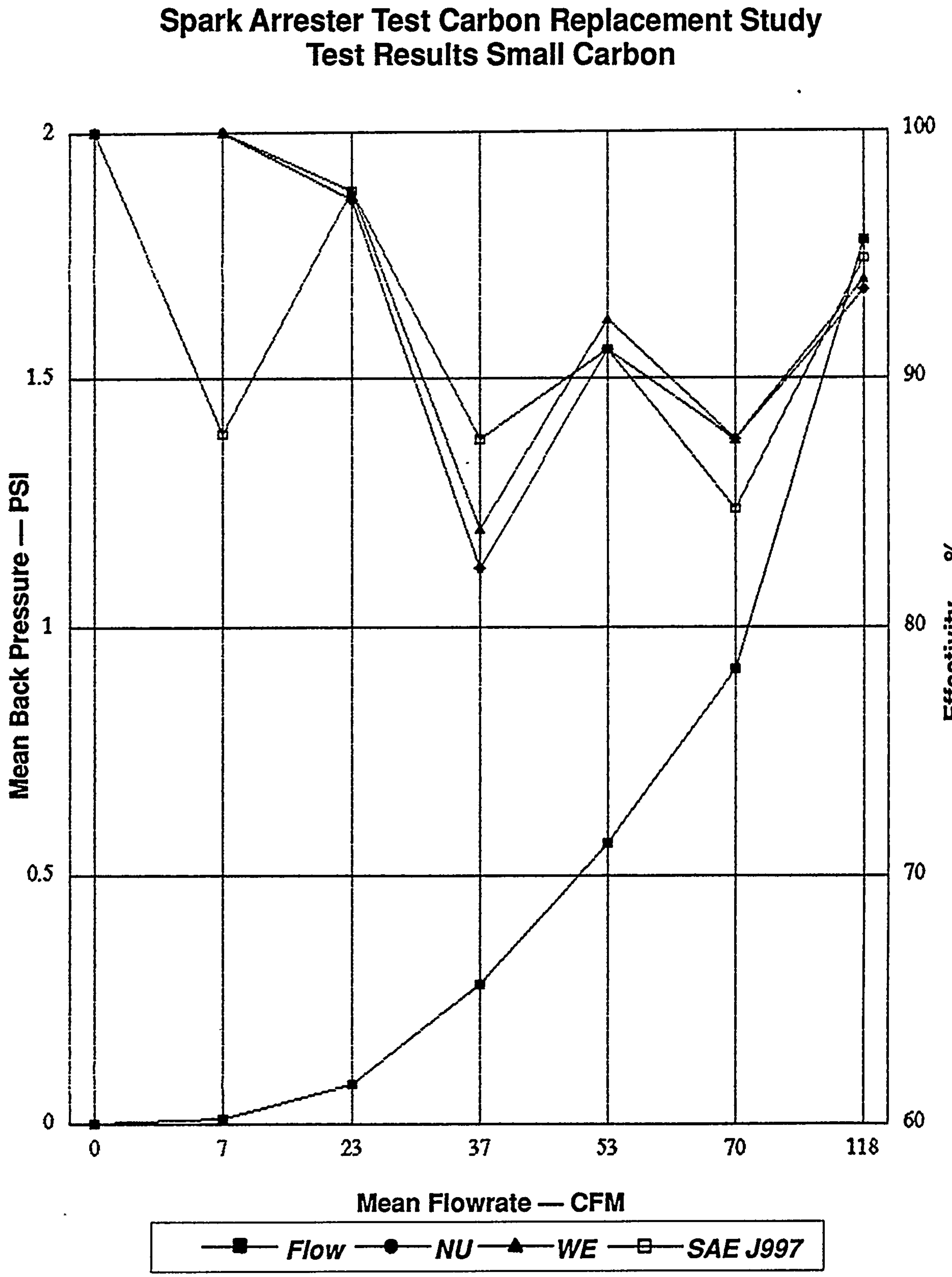


Figure 16.
Arrester B
Comparison of Effectivity Difference to SAE J997 Carbon

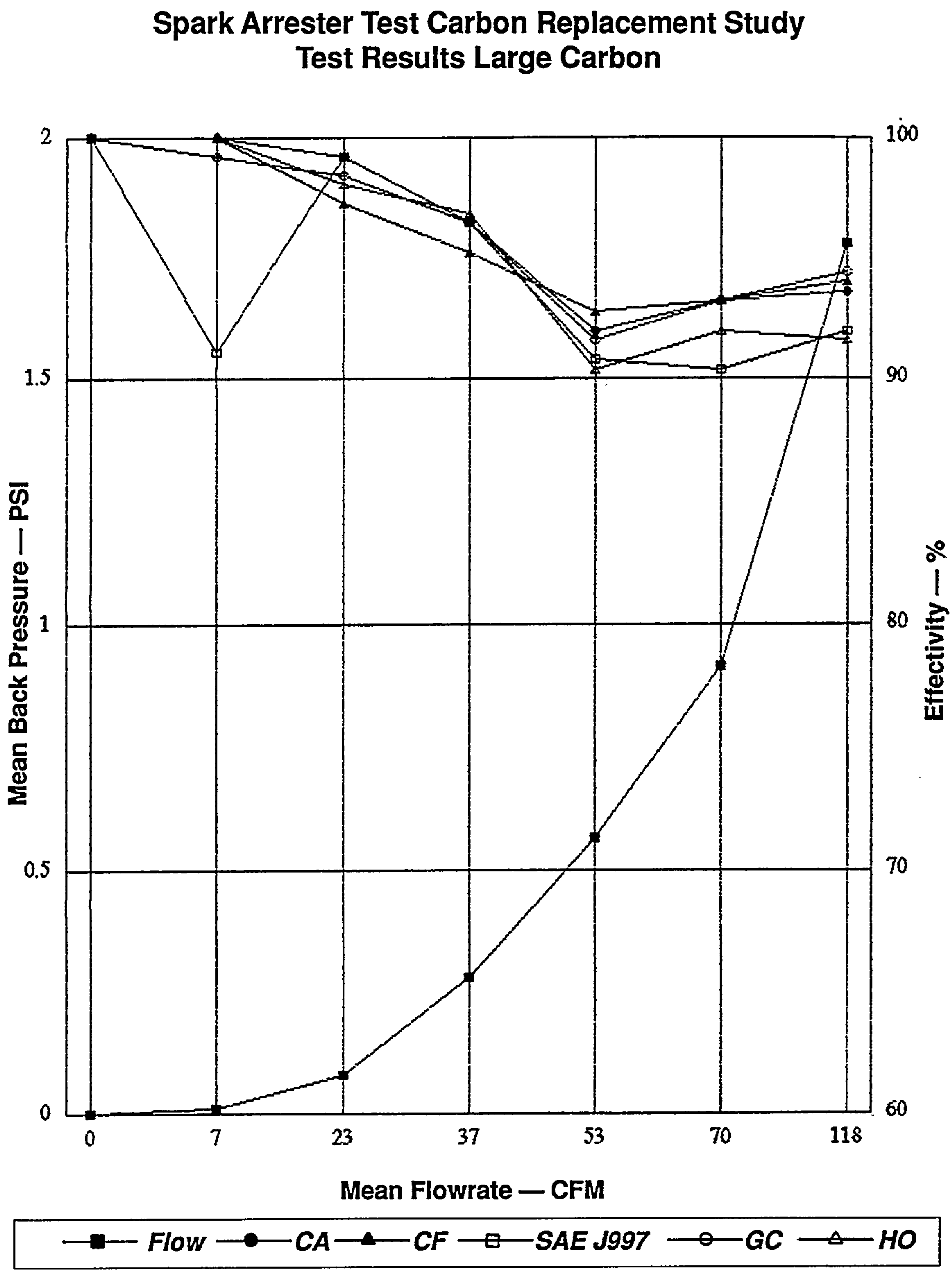


Figure 17.
Arrester B
Comparison of Effectivity Difference to SAE J997 Carbon

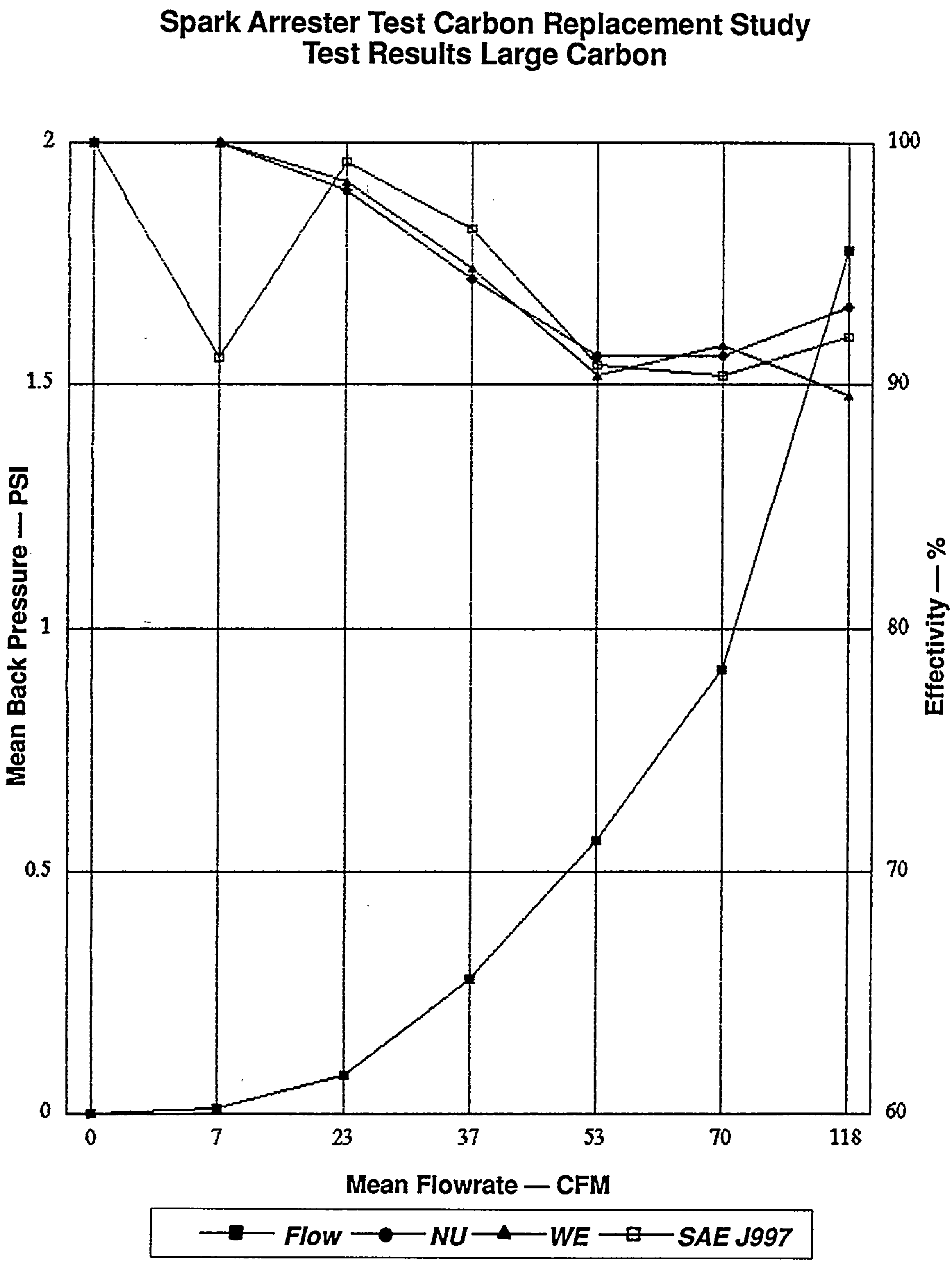


Figure 18.
Arrester B
Comparison of Effectivity Difference to SAE J997 Carbon

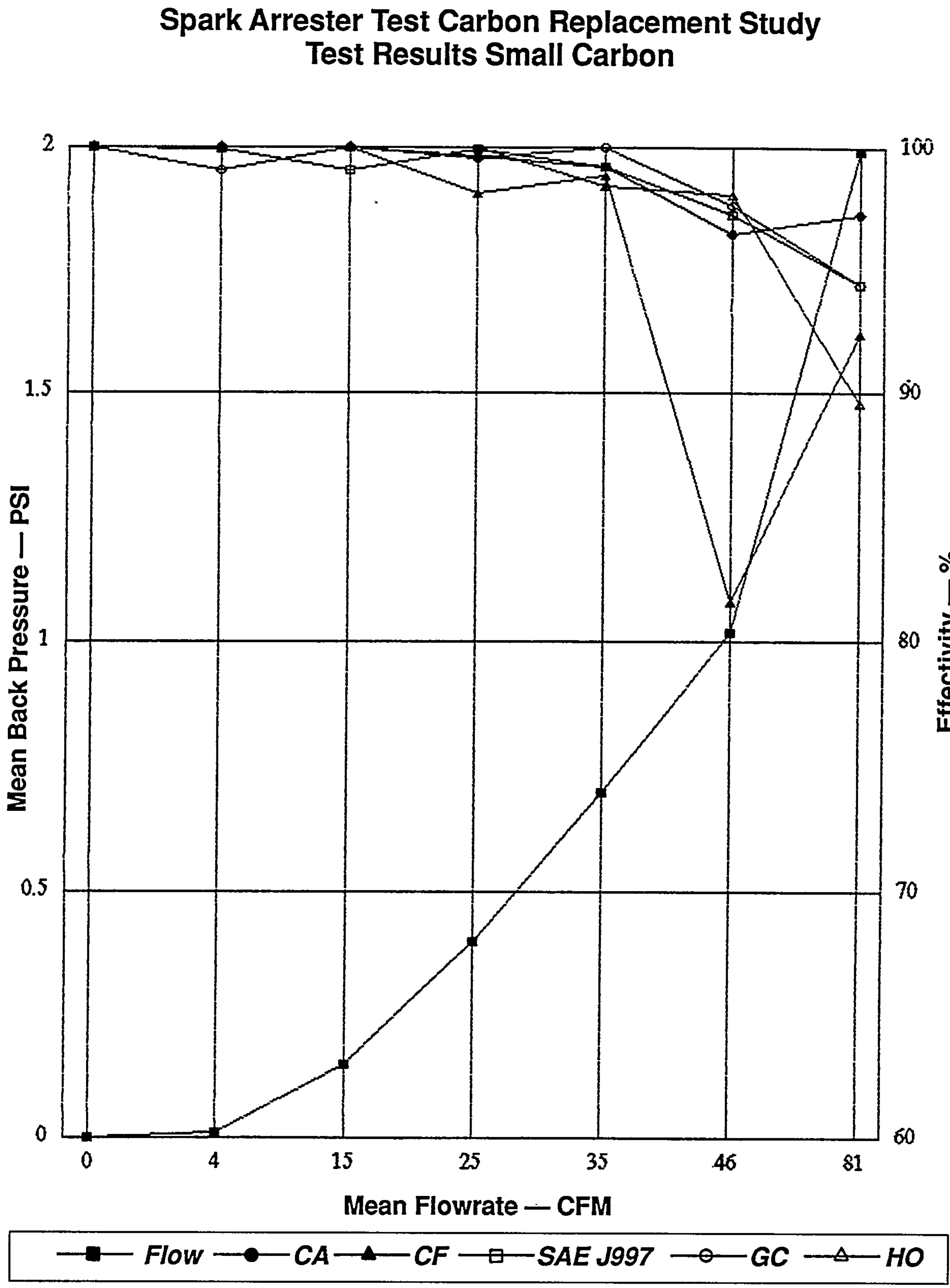


Figure 19.
Arrester C
Comparison of Effectivity Difference to SAE J997 Carbon

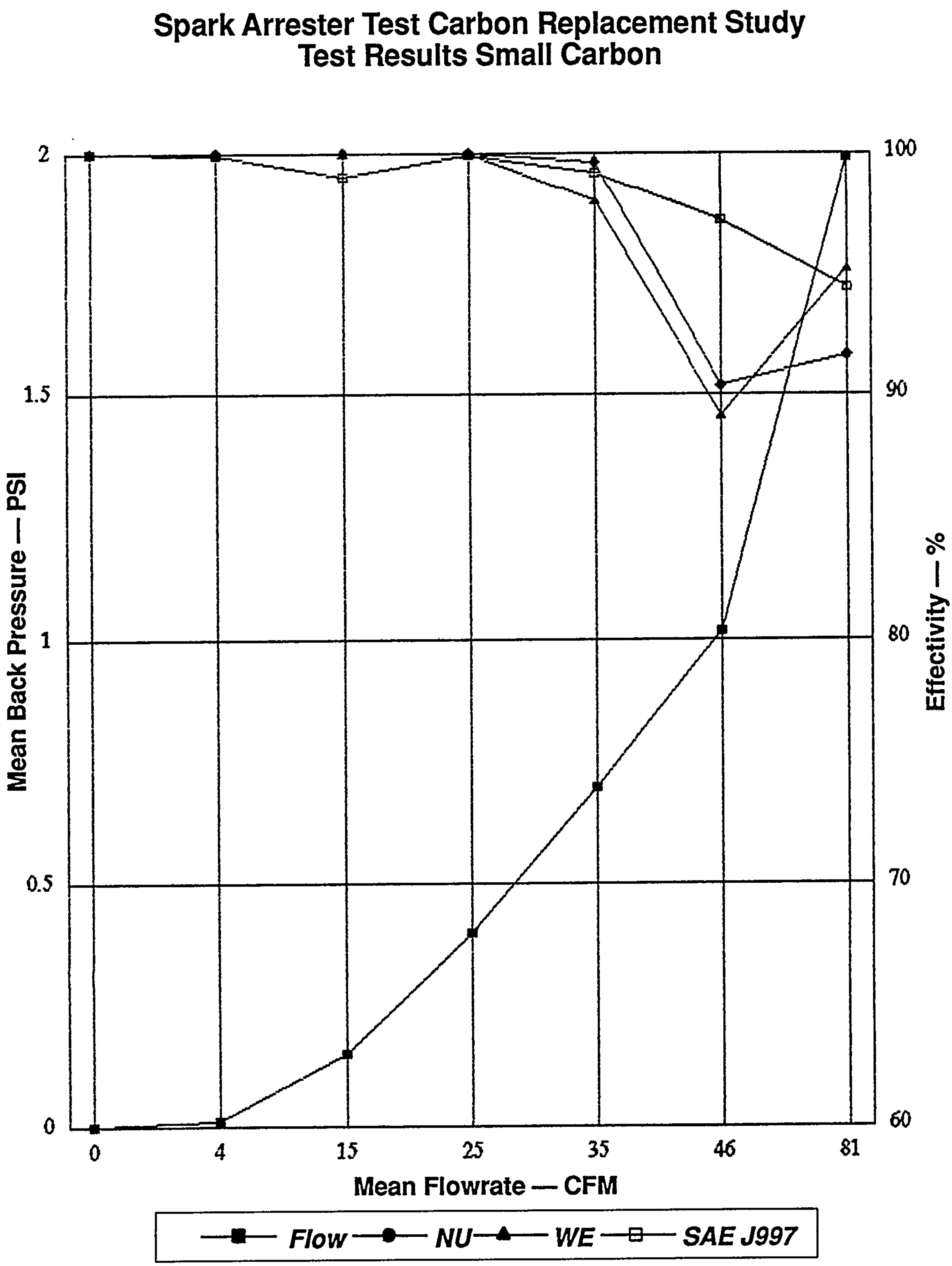


Figure 20.
Arrester C
Comparison of Effectivity Difference to SAE J997 Carbon

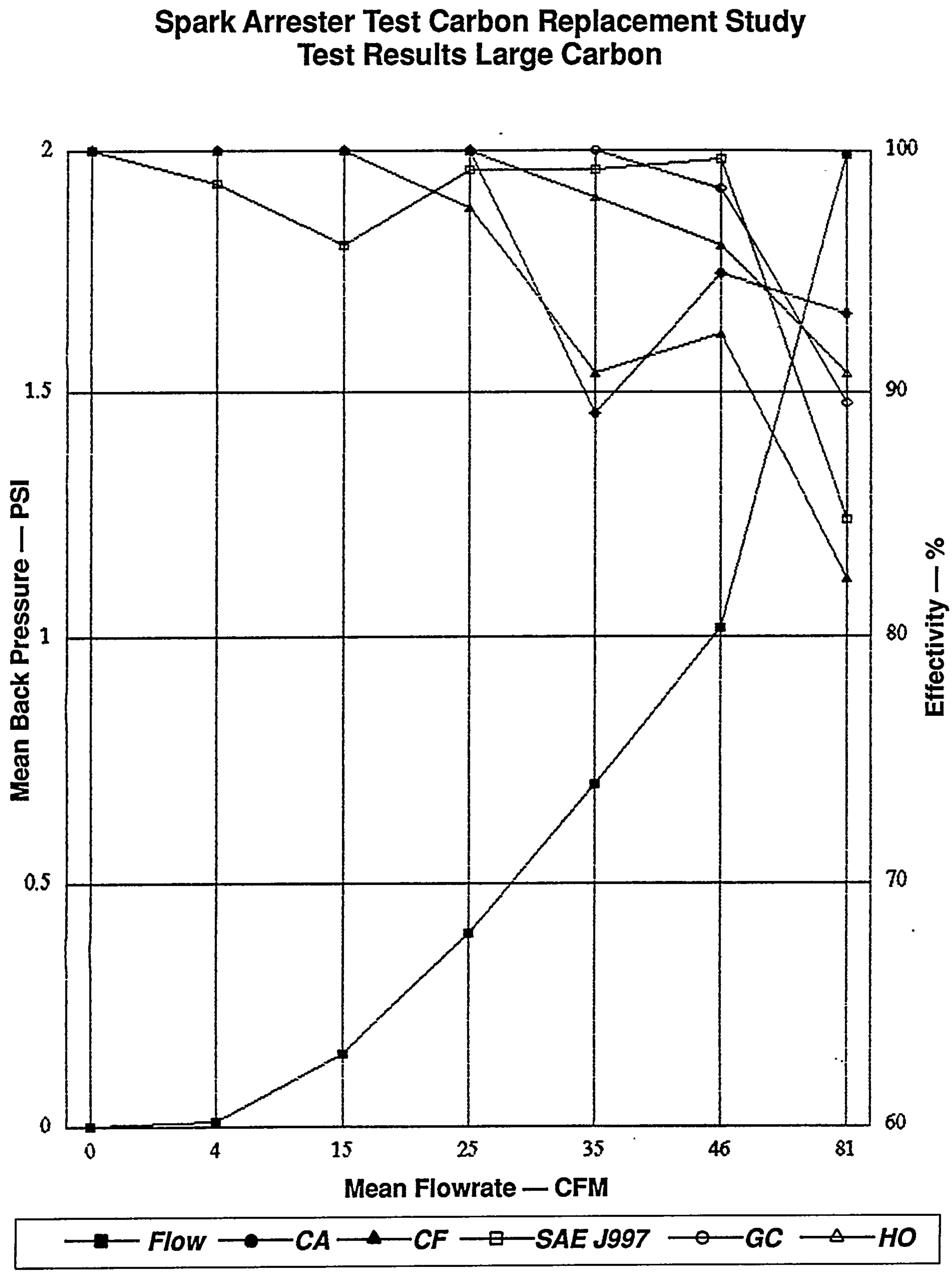


Figure 21.
Arrester C
Comparison of Effectivity Difference to SAE J997 Carbon

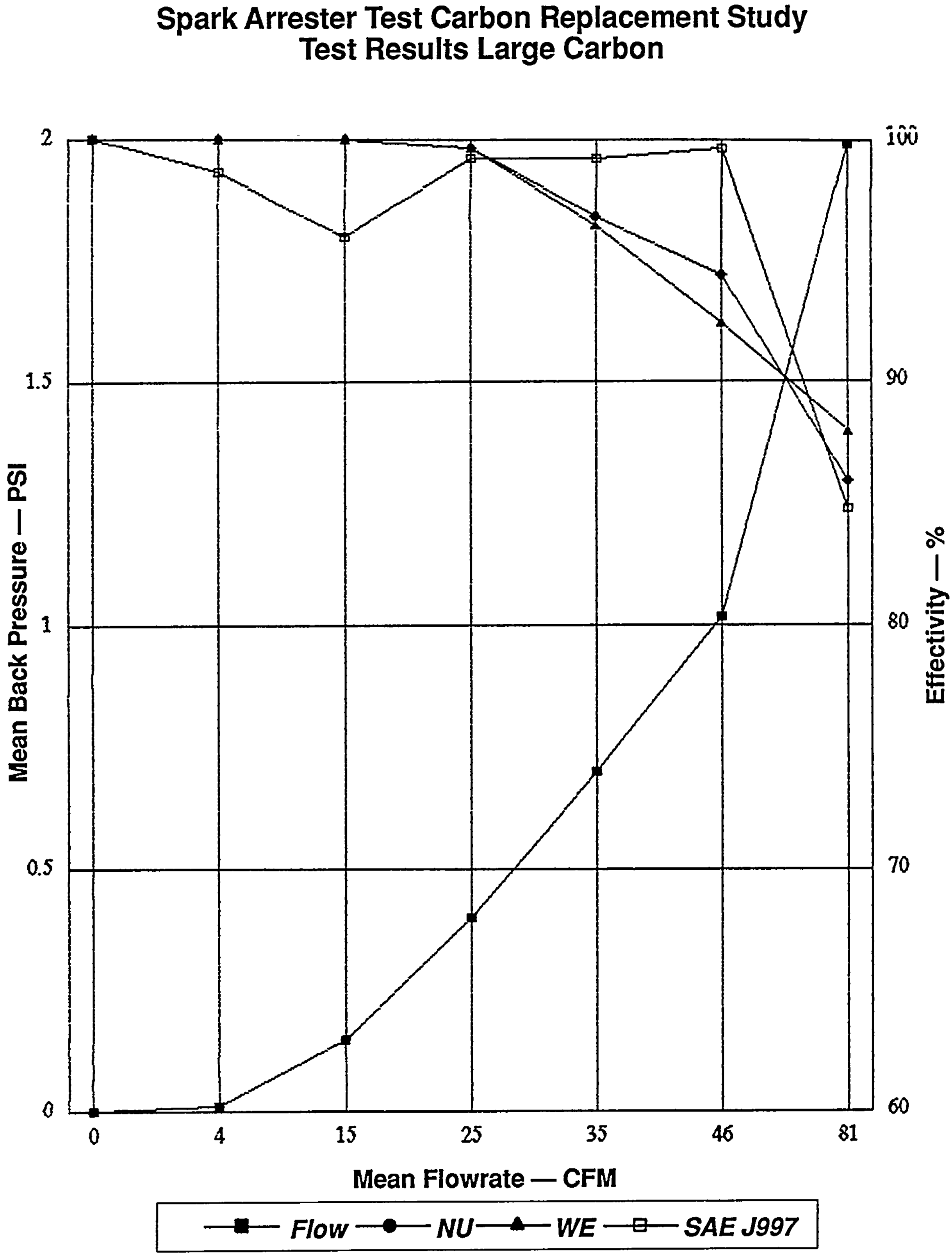


Figure 22.
Arrester C
Comparison of Effectivity Difference to SAE J997 Carbon

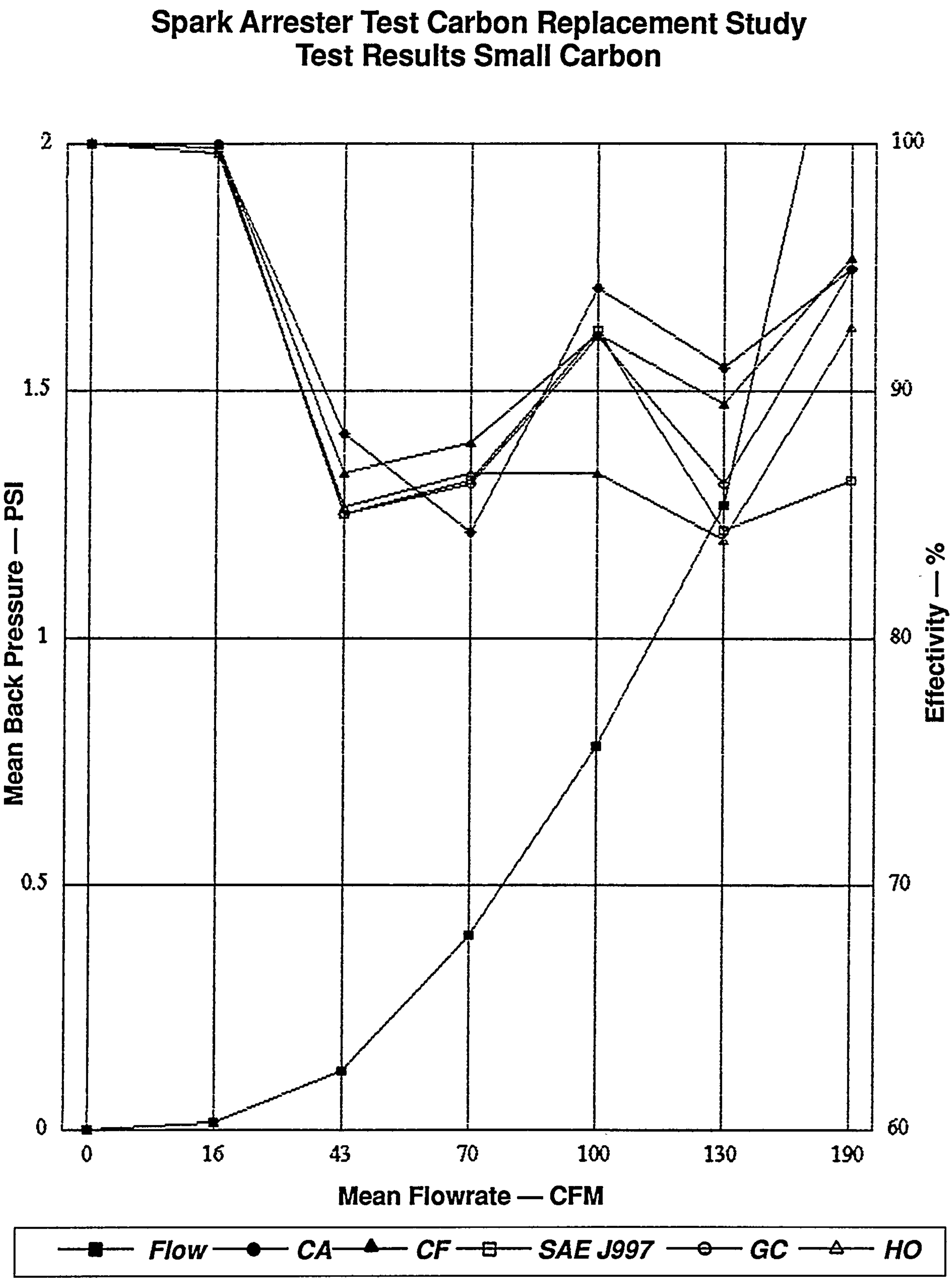


Figure 23.
Arrester D
Comparison of Effectivity Difference to SAE J997 Carbon

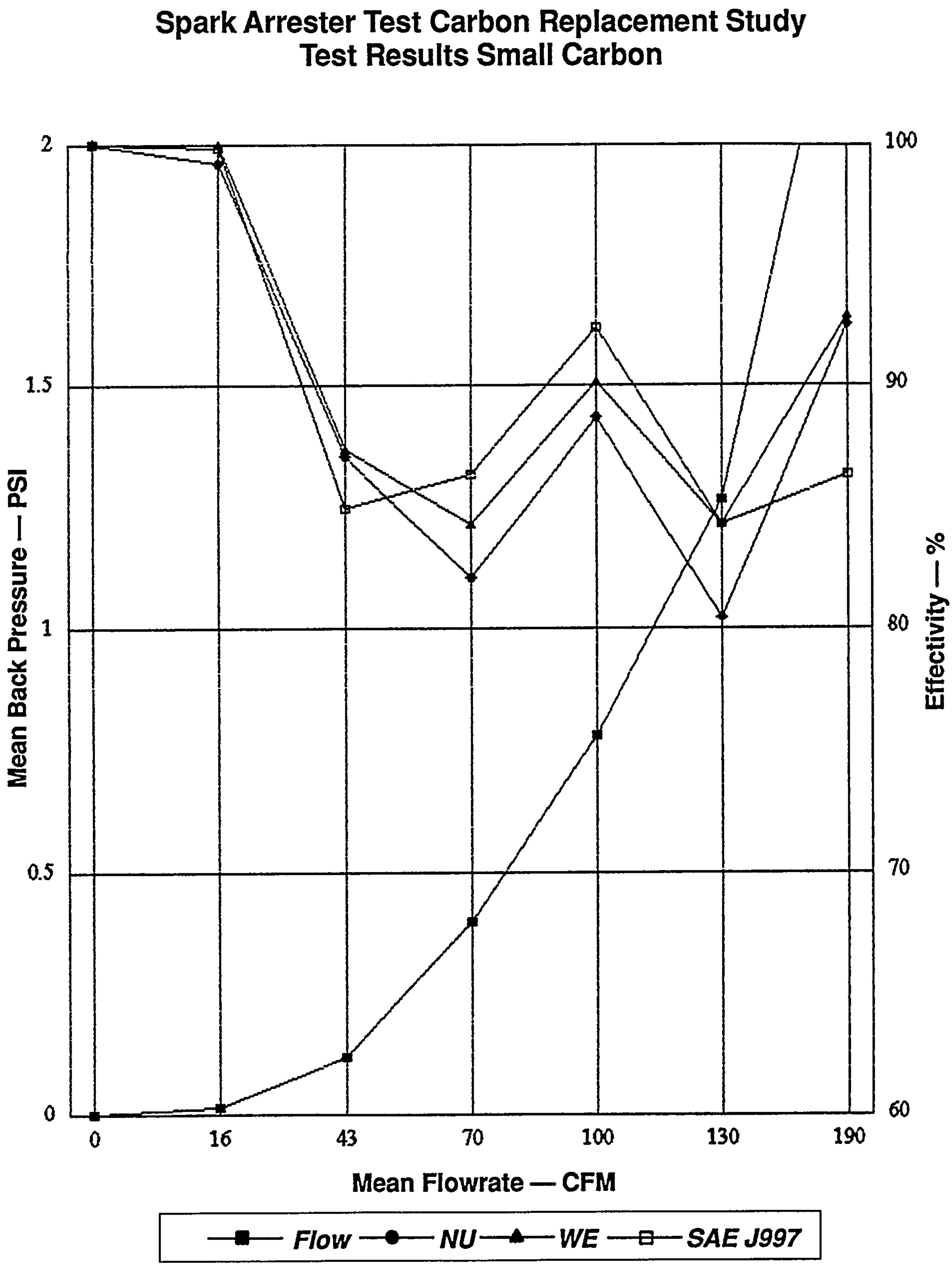


Figure 24.
Arrester D
Comparison of Effectivity Difference to SAE J997 Carbon

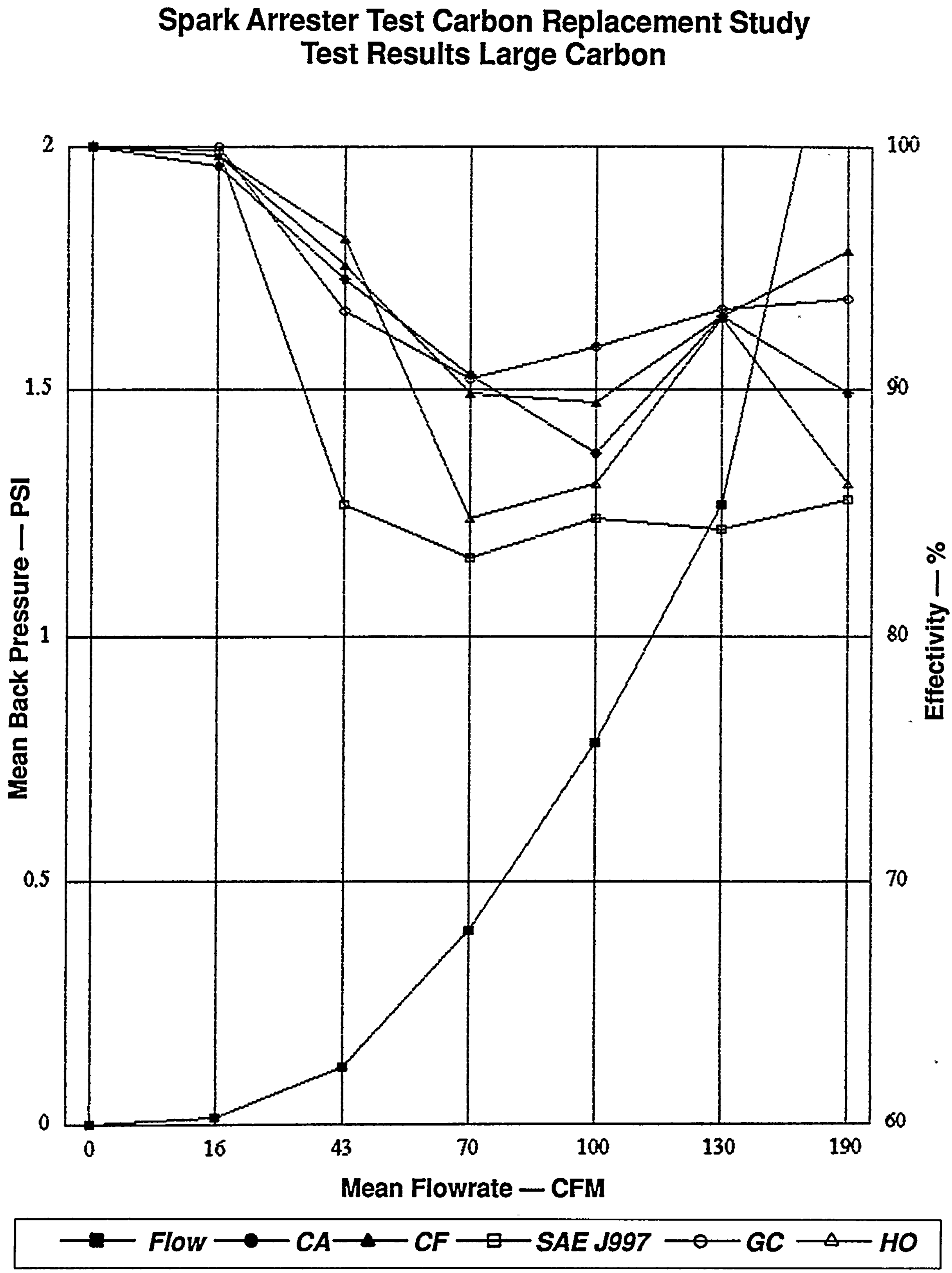


Figure 25.
Arrester D
Comparison of Effectivity Difference to SAE J997 Carbon

Spark Arrester Test Carbon Replacement Study
Test Results Large Carbon

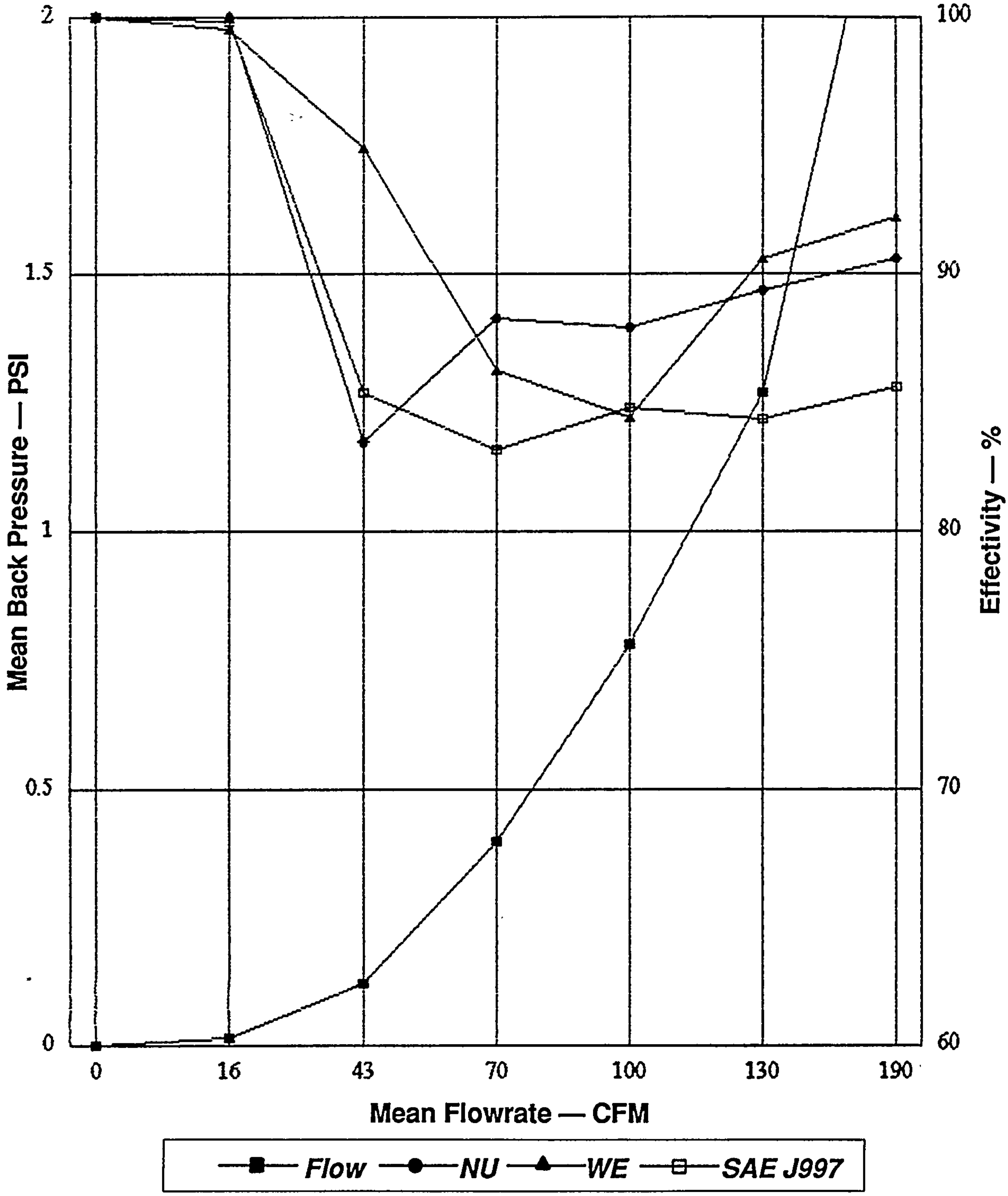


Figure 26.
Arrester D
Comparison of Effectivity Difference to SAE J997 Carbon

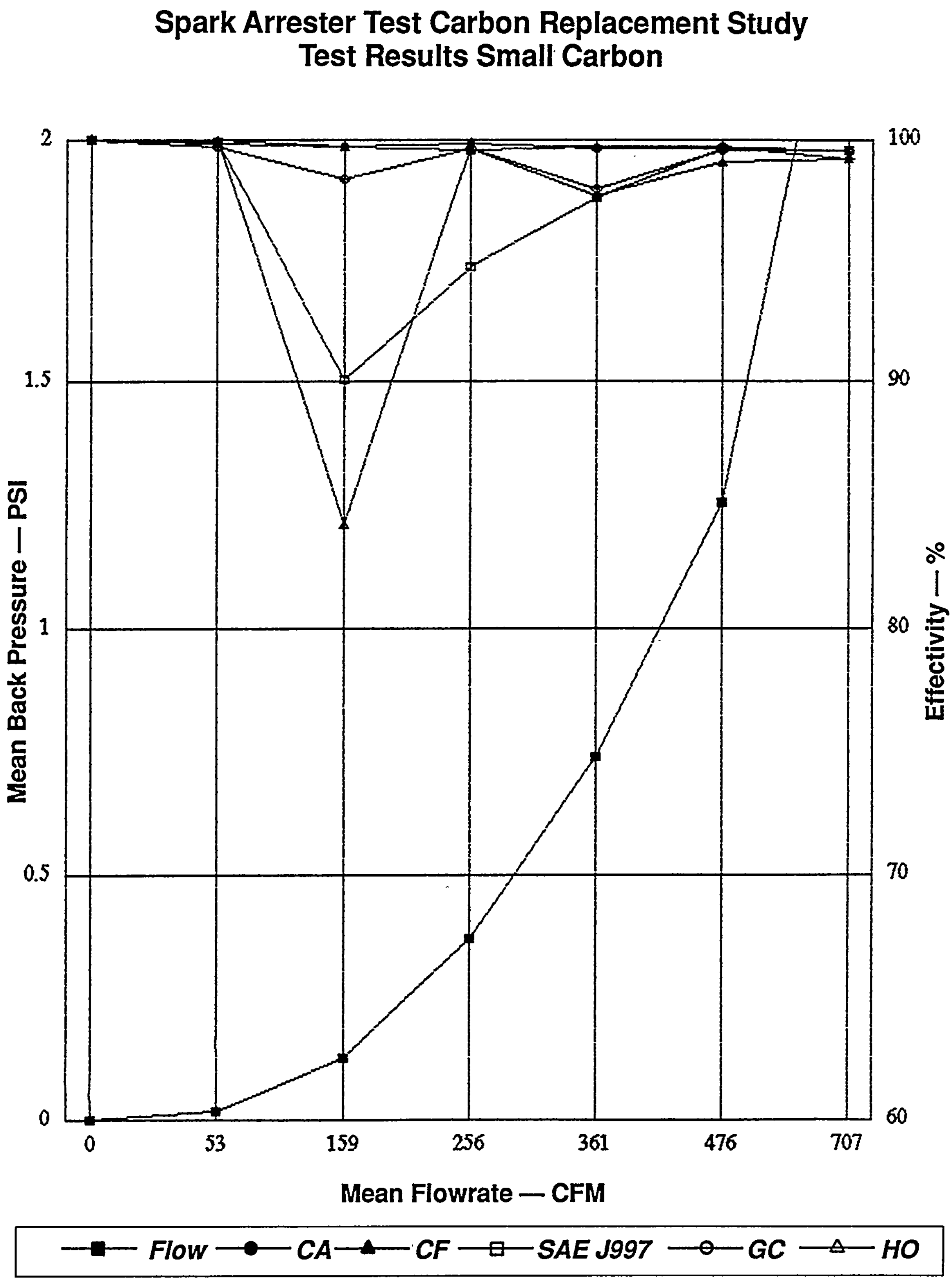


Figure 27.
ArresterE
Comparison of Effectivity Difference to SAE J997 Carbon

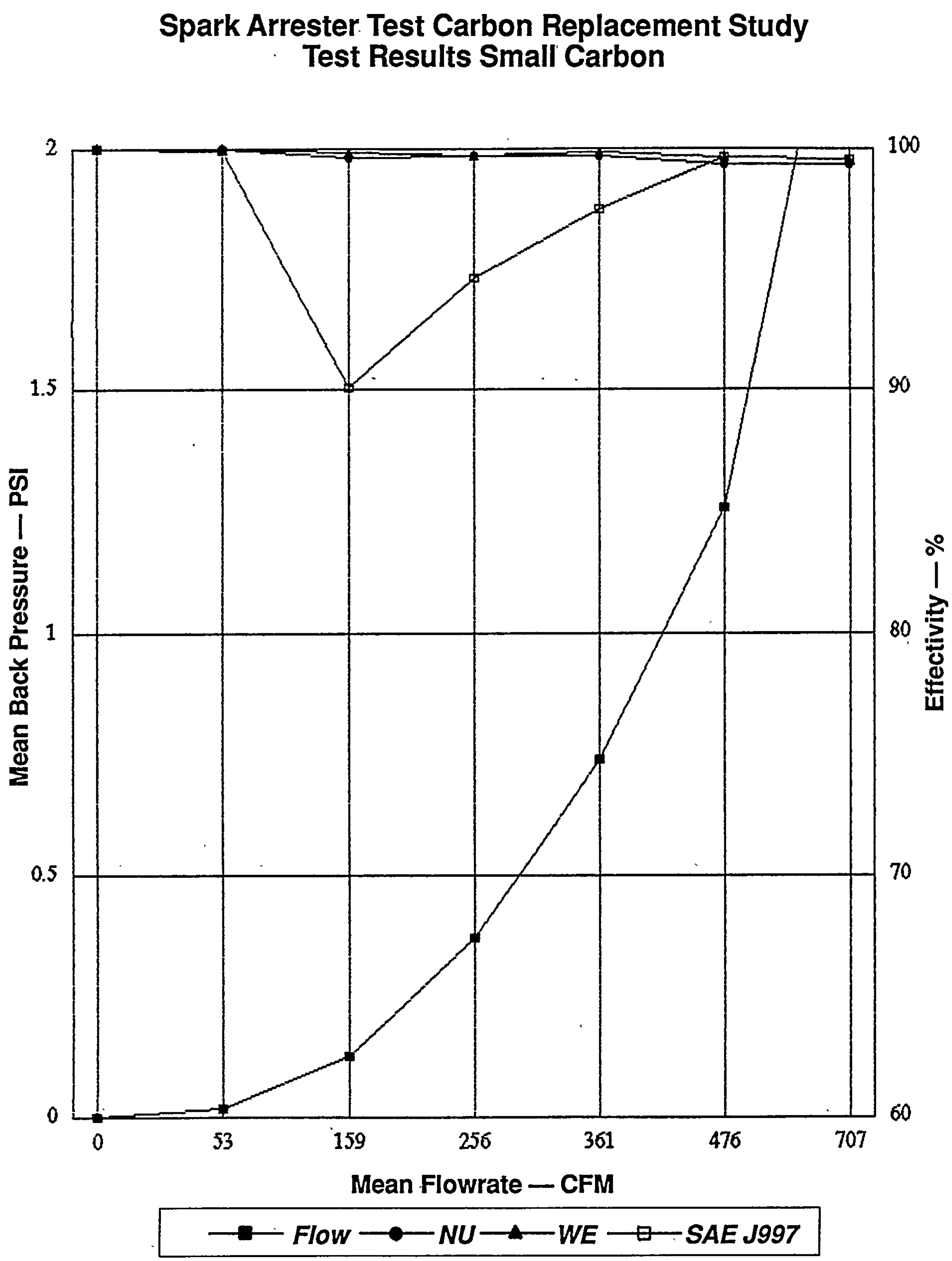


Figure 28.
Arrester E
Comparison of Effectivity Difference to SAE J997 Carbon

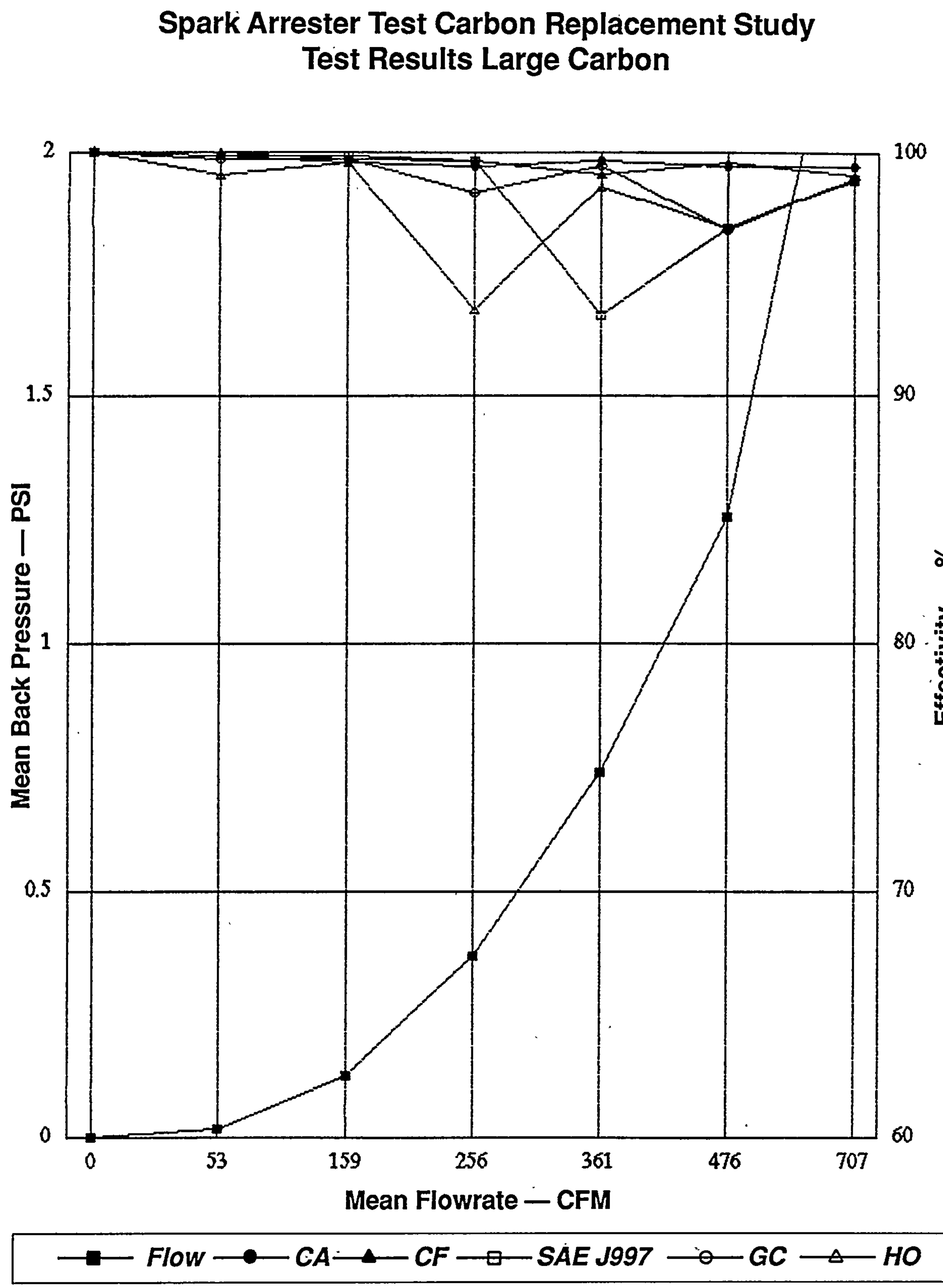


Figure 29.
Arrester E
Comparison of Effectivity Difference to SAE J997 Carbon

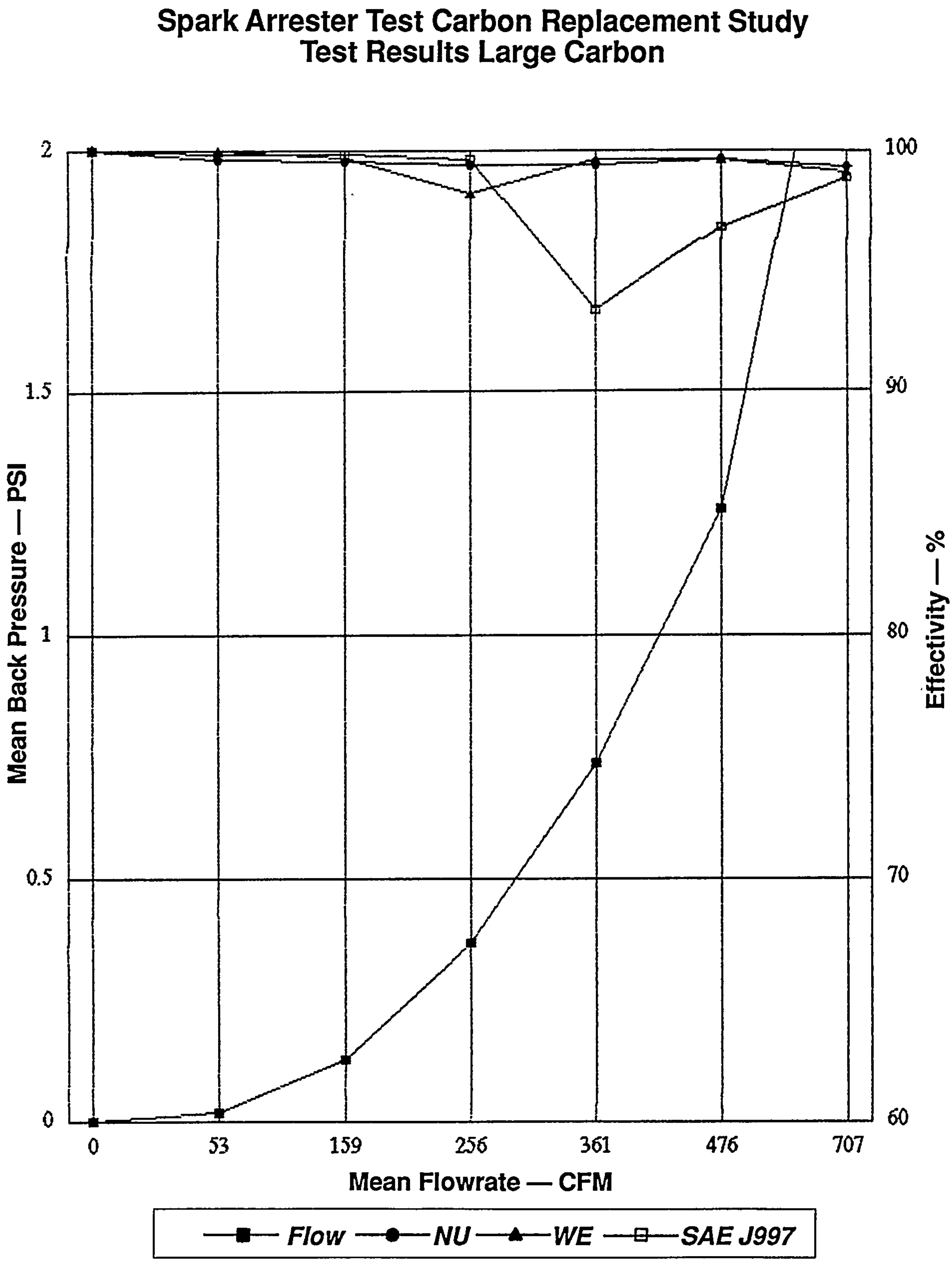


Figure 30.
Arrester E
Comparison of Effectivity Difference to SAE J997 Carbon

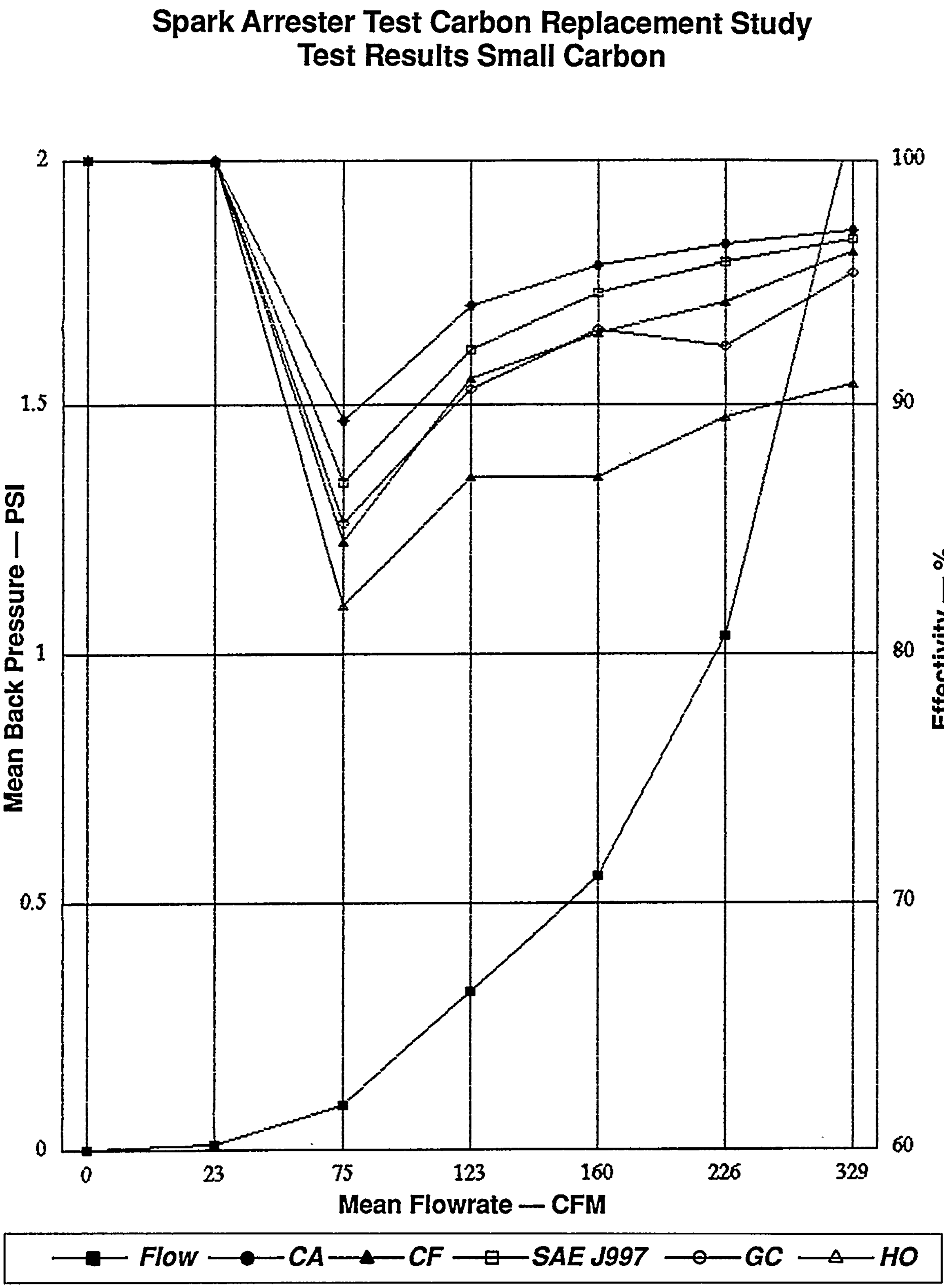


Figure 31.
Arrester F
Comparison of Effectivity Difference to SAE J997 Carbon

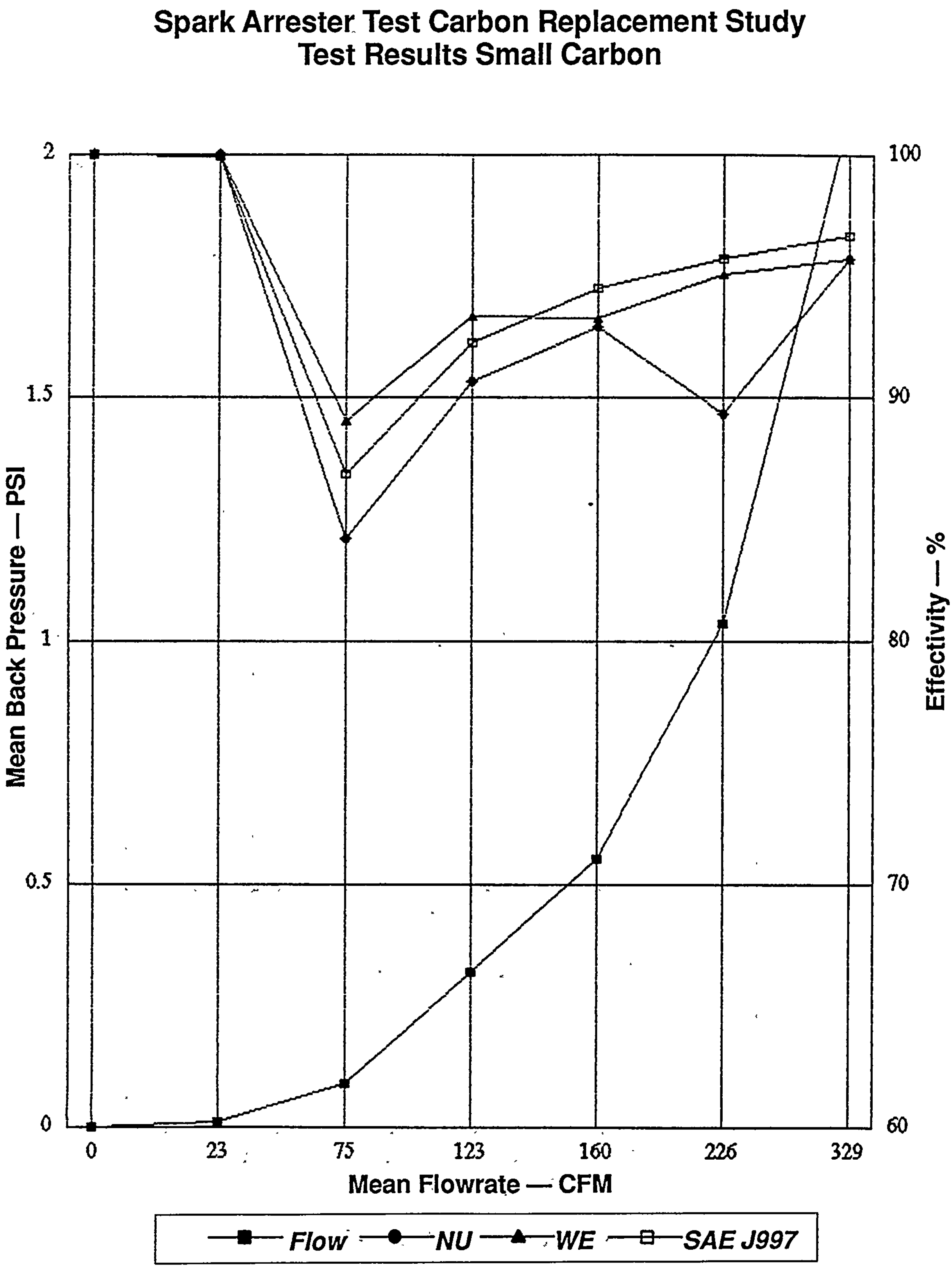


Figure 32.
Arrester F
Comparison of Effectivity Difference to SAE J997 Carbon

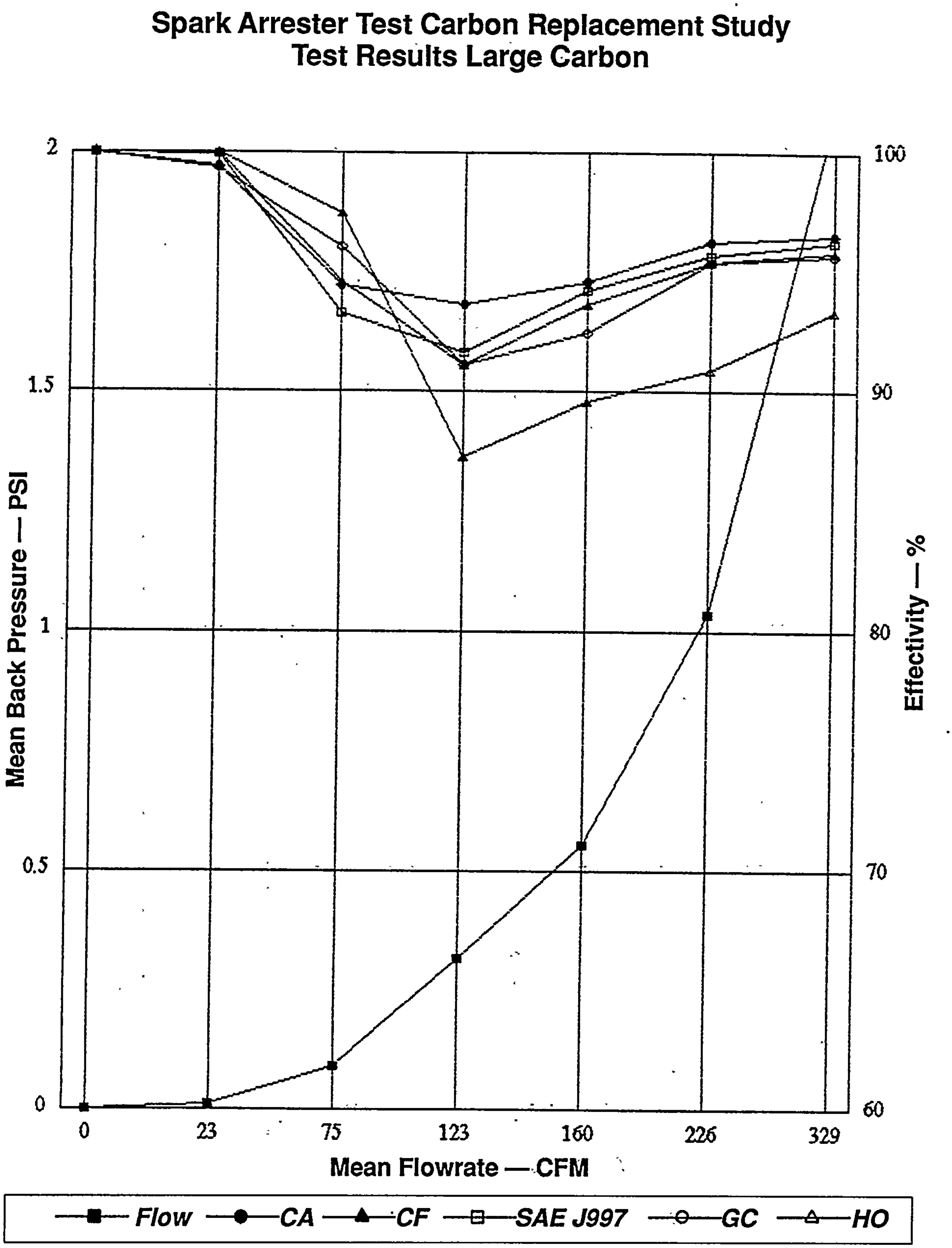


Figure 33.
Arrester F
Comparison of Effectivity Difference to SAE J997 Carbon

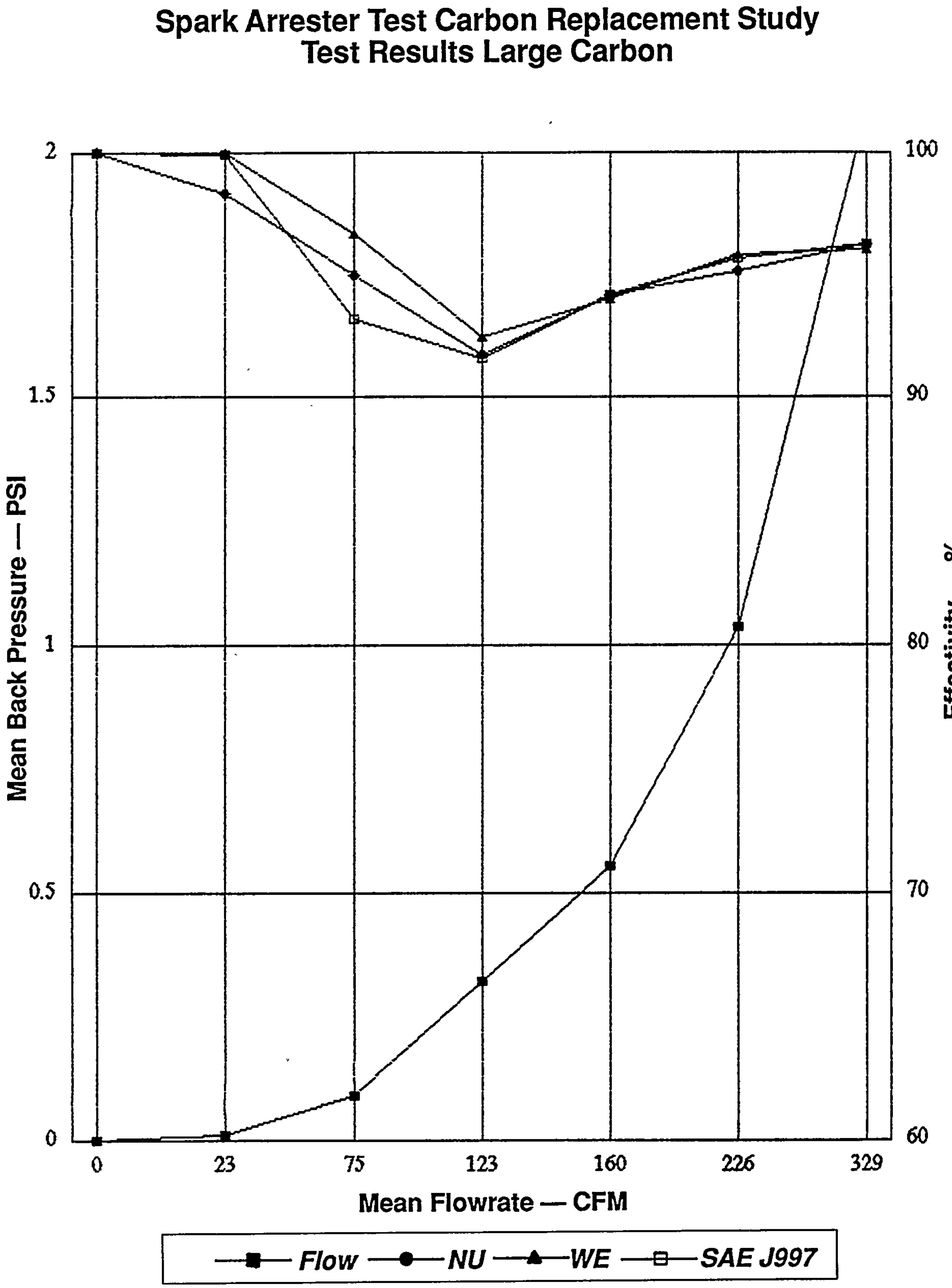


Figure 34.
Arrester F
Comparison of Effectivity Difference to SAE J997 Carbon

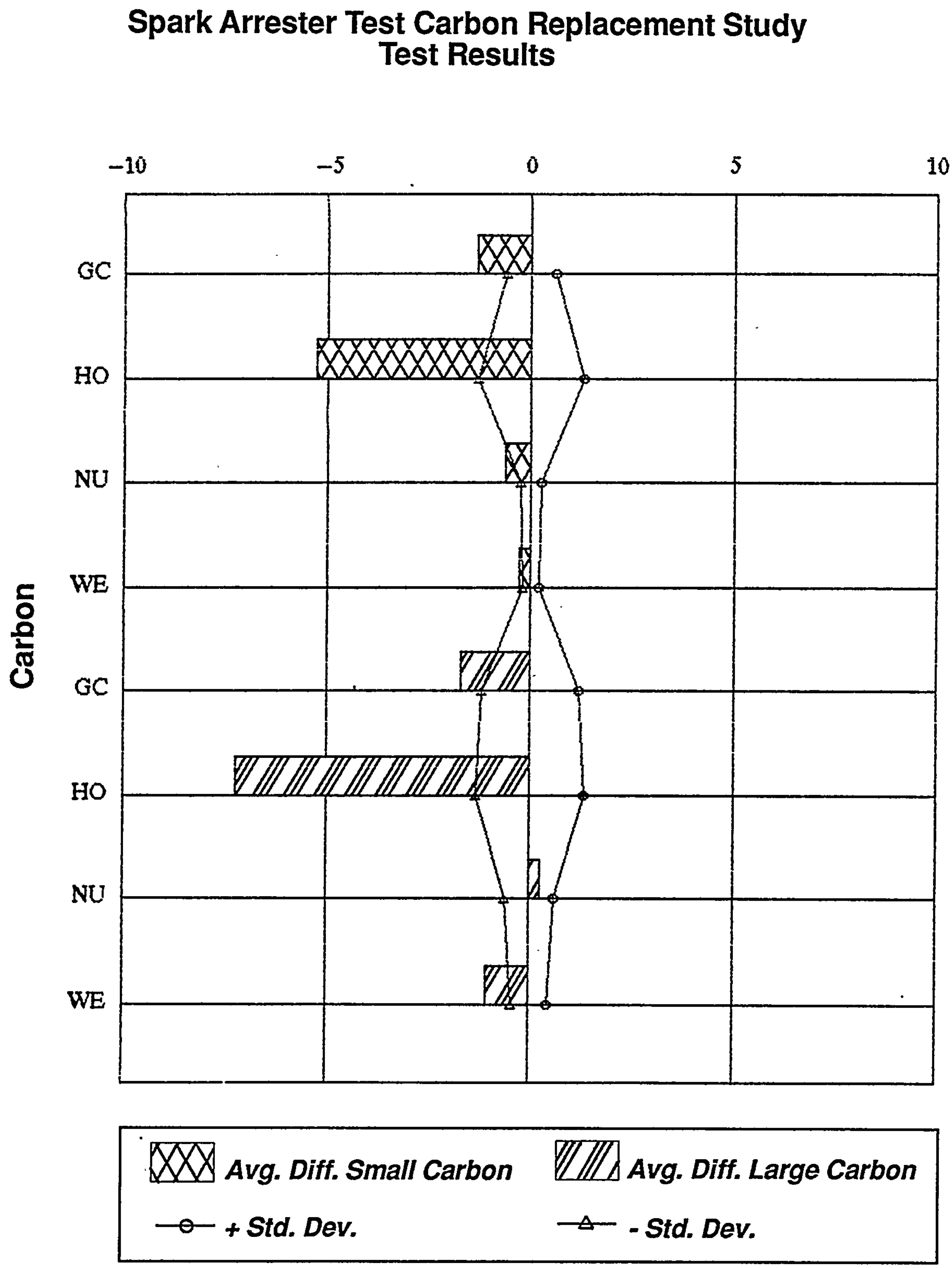


Figure 35.
Arrester A
Comparison of Average Effectivity Differences to SAE J997 Carbon

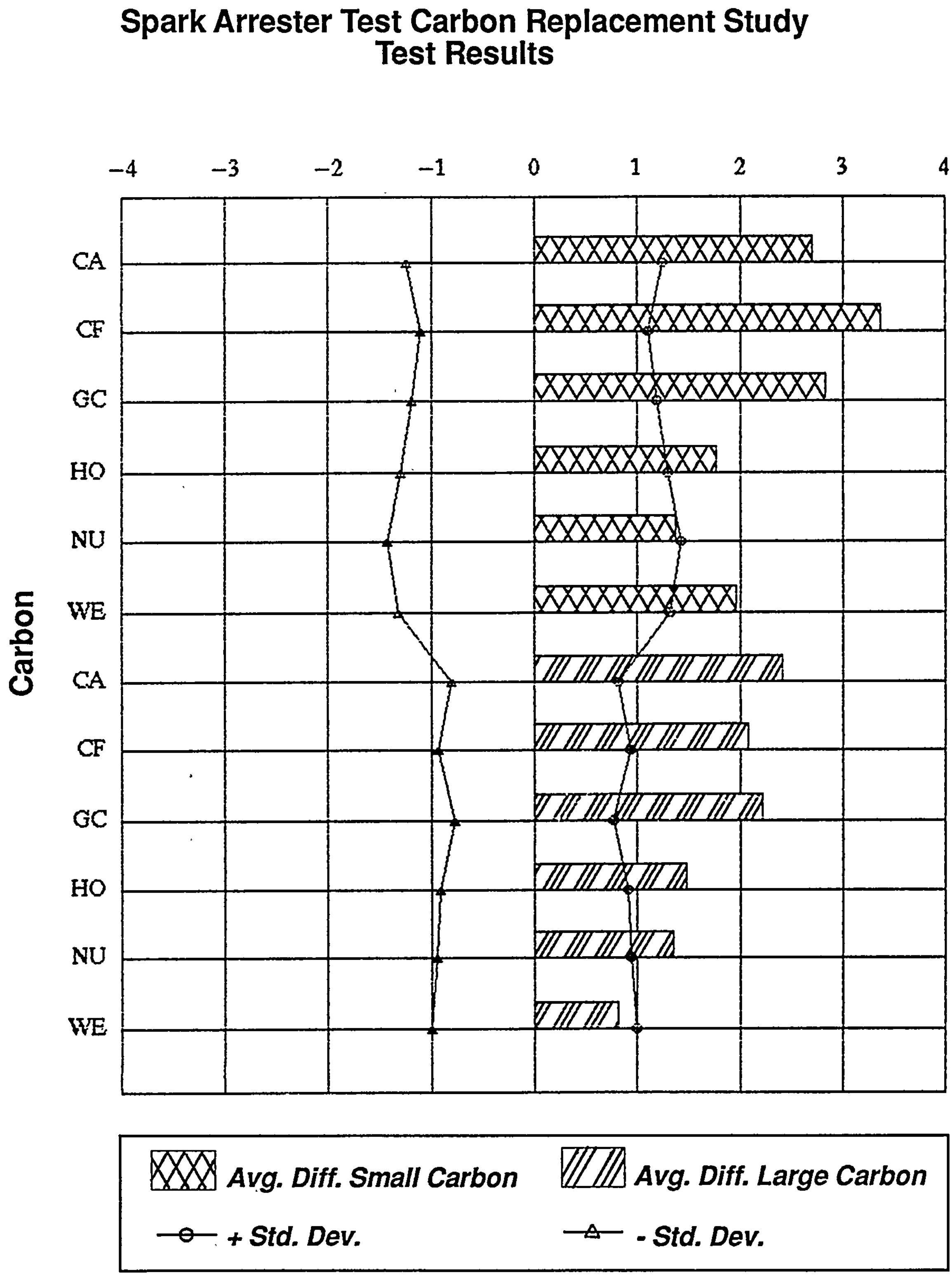


Figure 36.
Arrester B
Comparison of Average Effectivity Differences to SAE J997 Carbon

Spark Arrester Test Carbon Replacement Study
Test Results

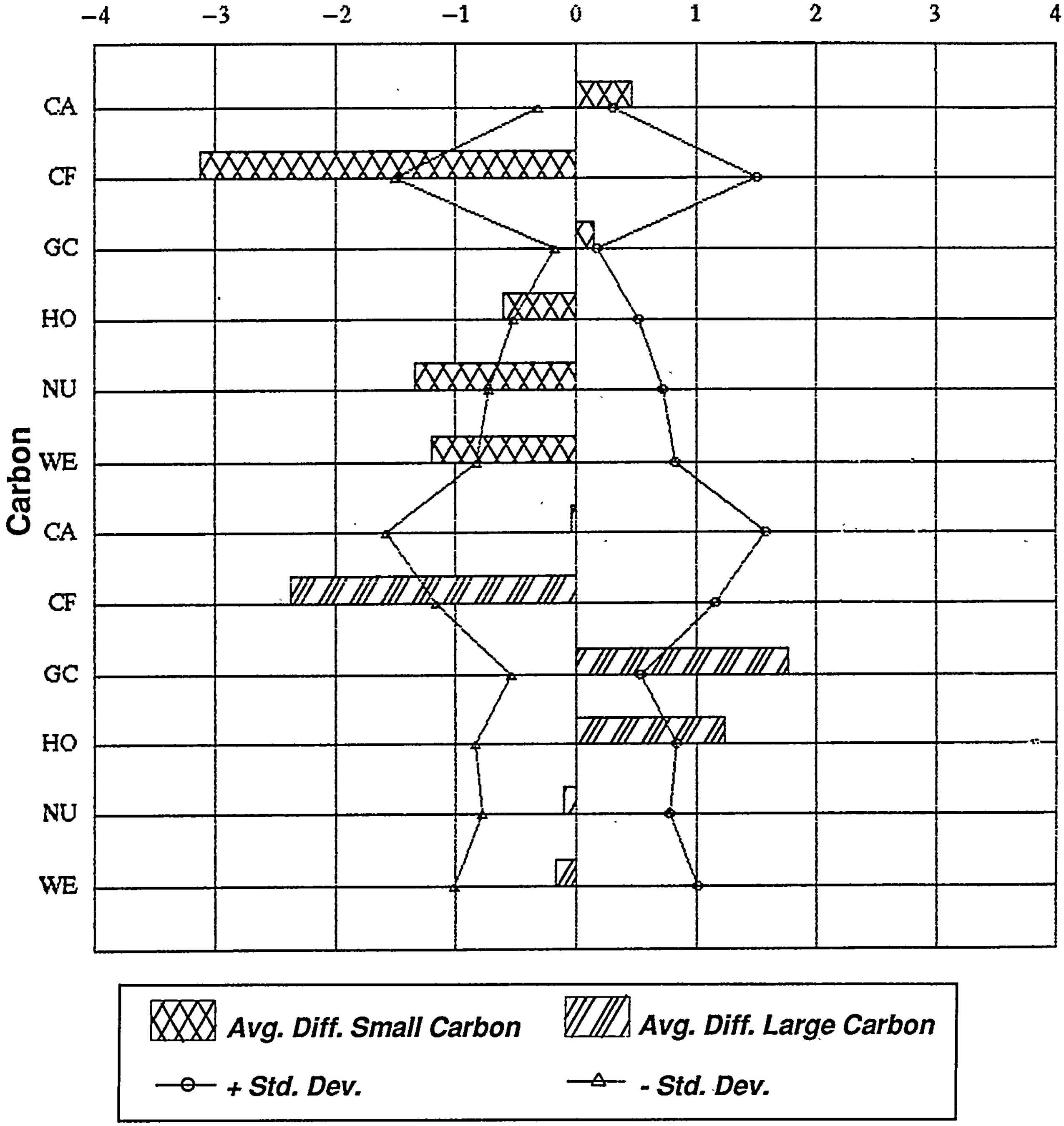


Figure 37.
Arrester C
Comparison of Average Effectivity Differences to SAE J997 Carbon

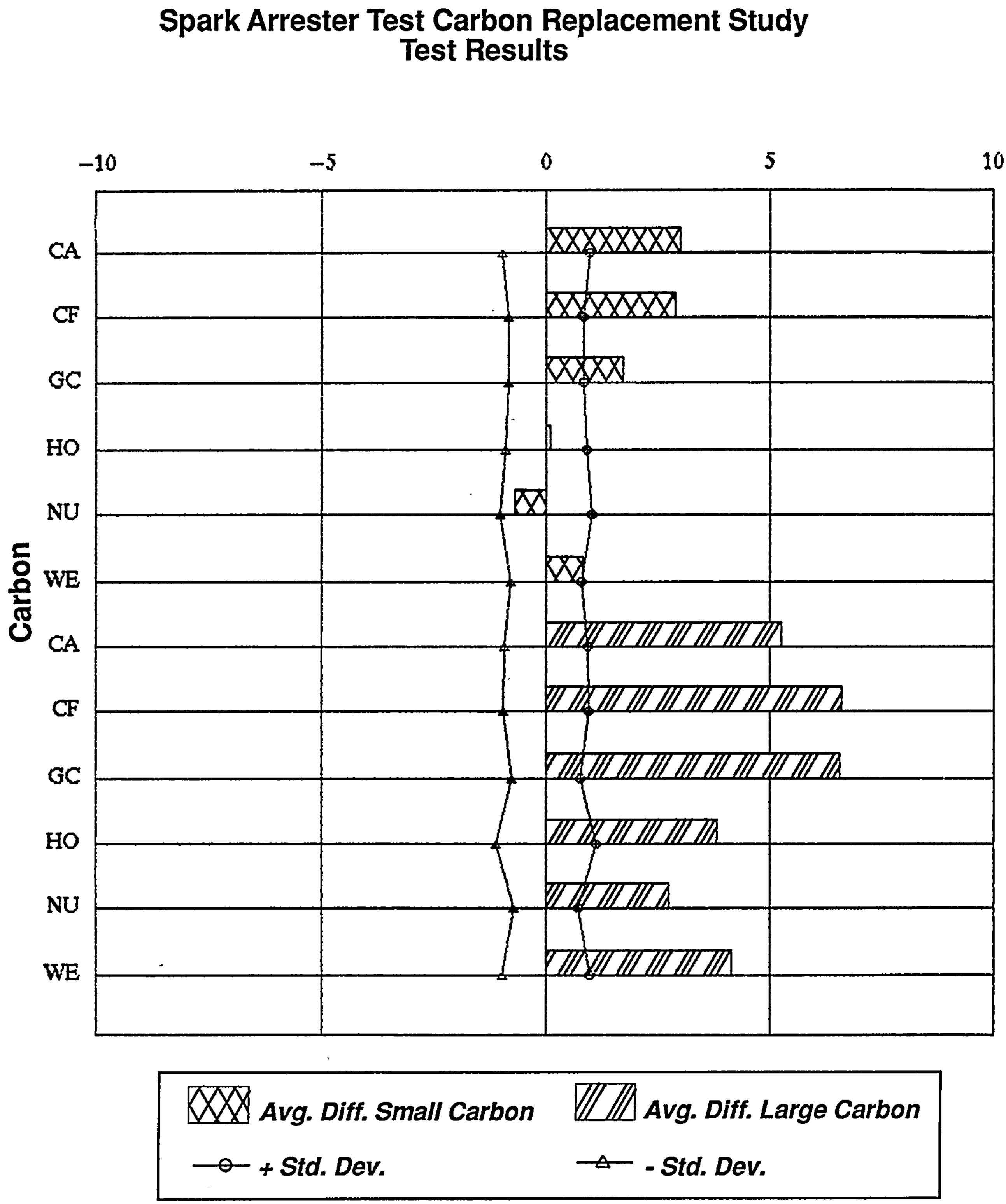


Figure 38.
Arrester D
Comparison of Average Effectivity Differences to SAE J997 Carbon

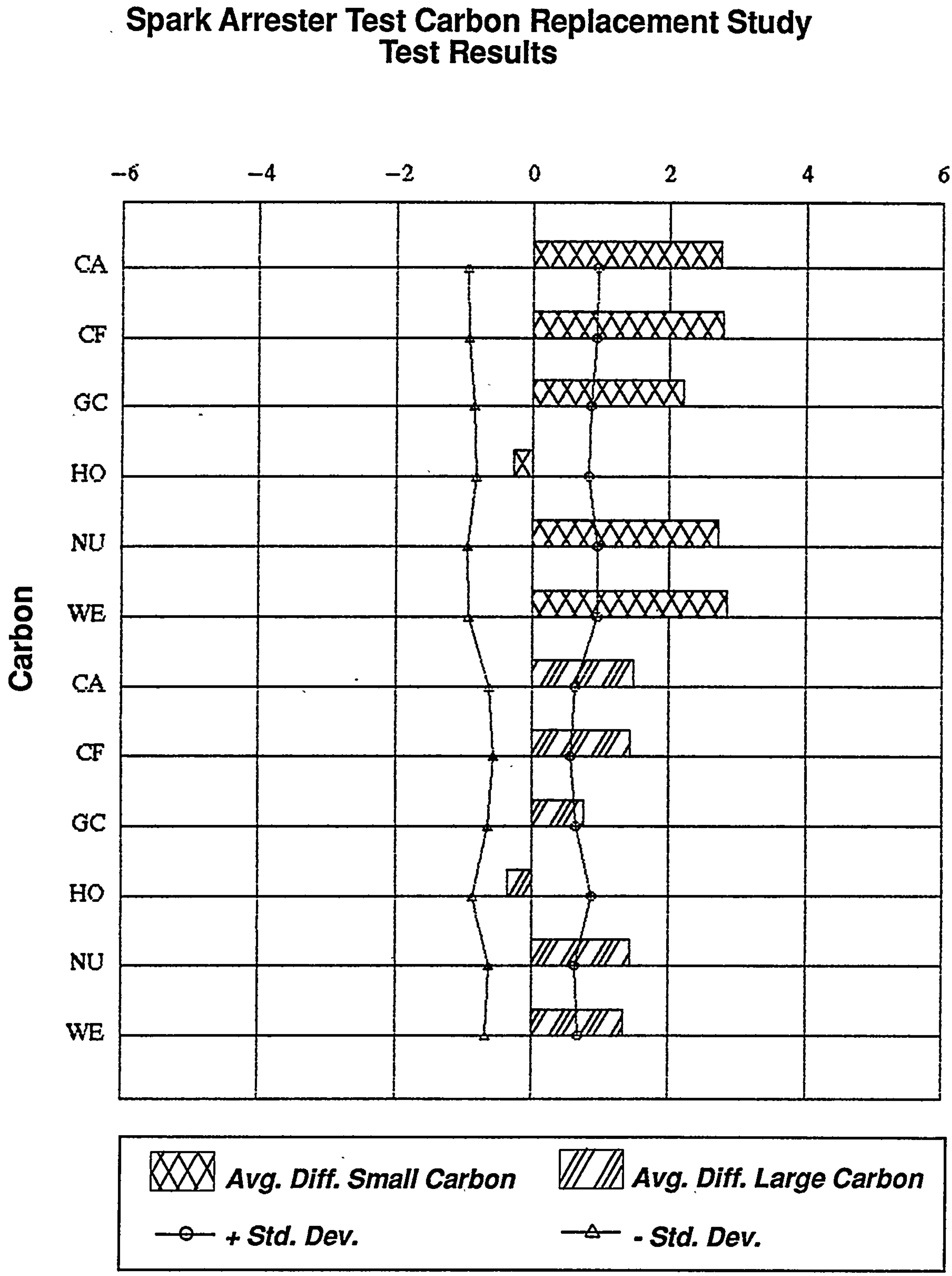


Figure 39.
Arrester E
Comparison of Average Effectivity Differences to SAE J997 Carbon

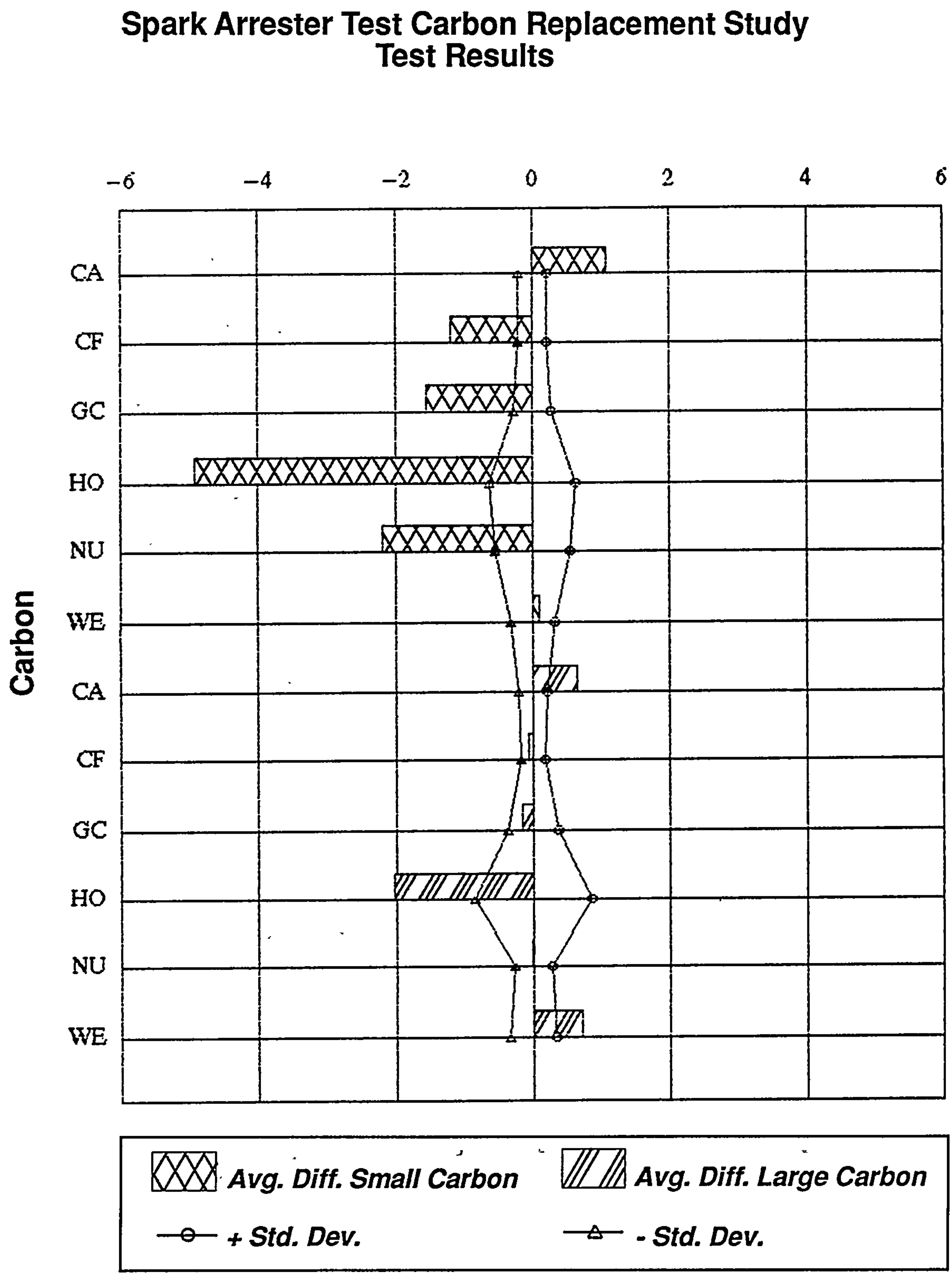


Figure 40.
Arrester F
Comparison of Average Effectivity Differences to SAE J997 Carbon

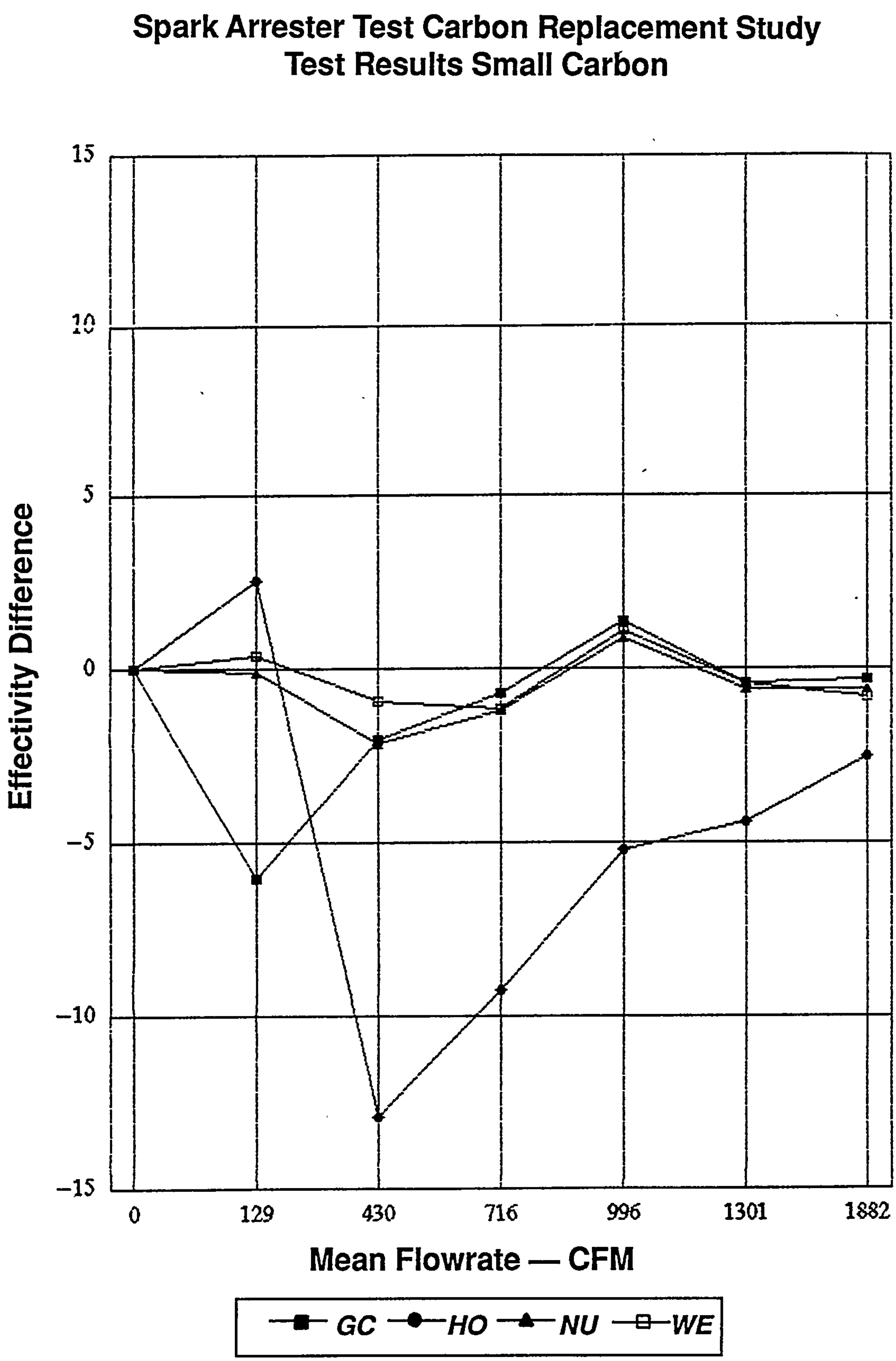


Figure 41.
Arrester A
Comparison of Discrete Effectivity Differences to SAE J997 Carbon

Spark Arrester Test Carbon Replacement Study
Test Results Large Carbon

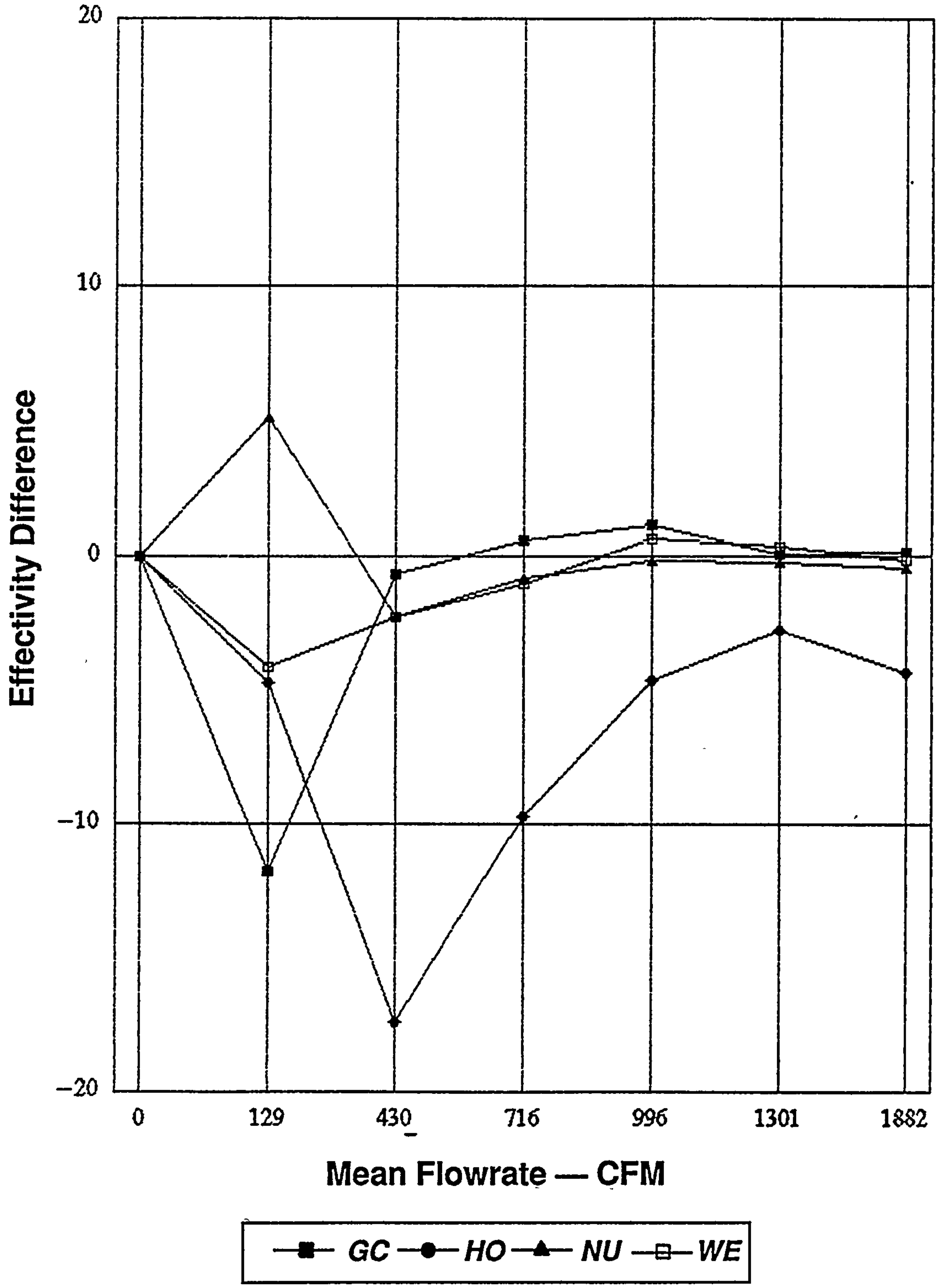


Figure 42.
Arrester A
Comparison of Discrete Effectivity Differences to SAE J997 Carbon

Spark Arrester Test Carbon Replacement Study
Test Results Small Carbon

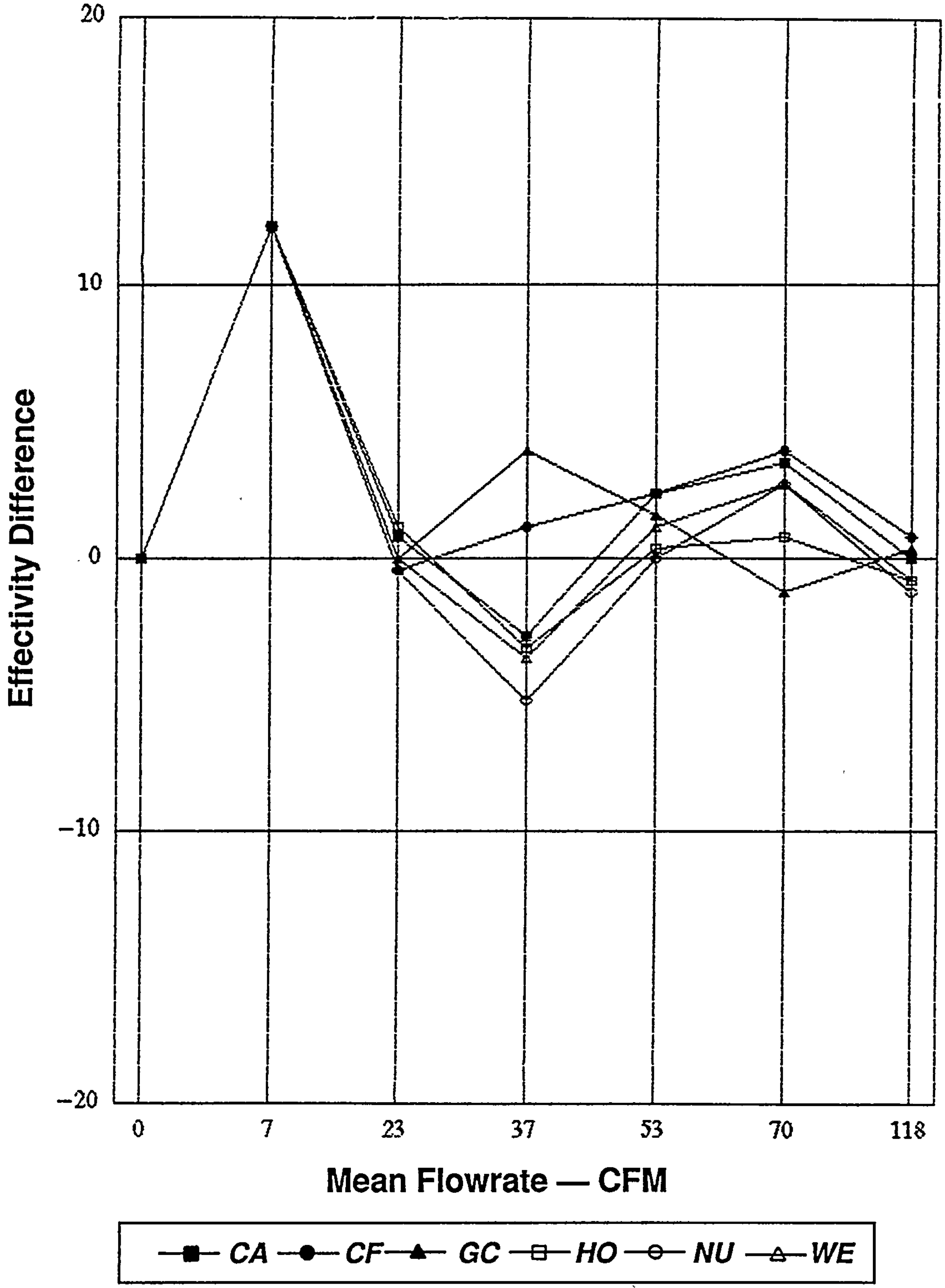


Figure 43.
Arrester B
Comparison of Discrete Effectivity Differences to SAE J997 Carbon

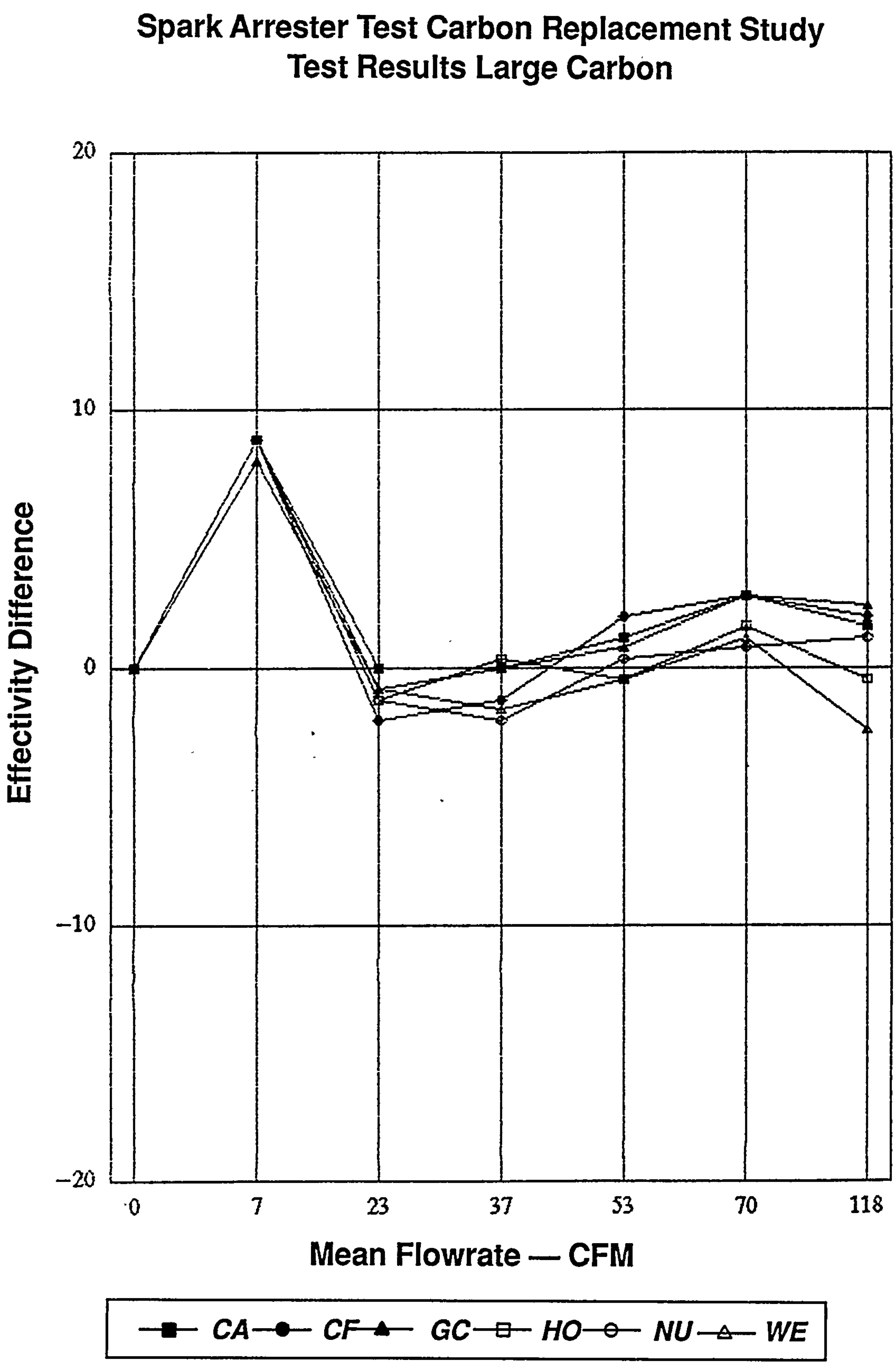


Figure 44.
Arrester B
Comparison of Discrete Effectivity Differences to SAE J997 Carbon

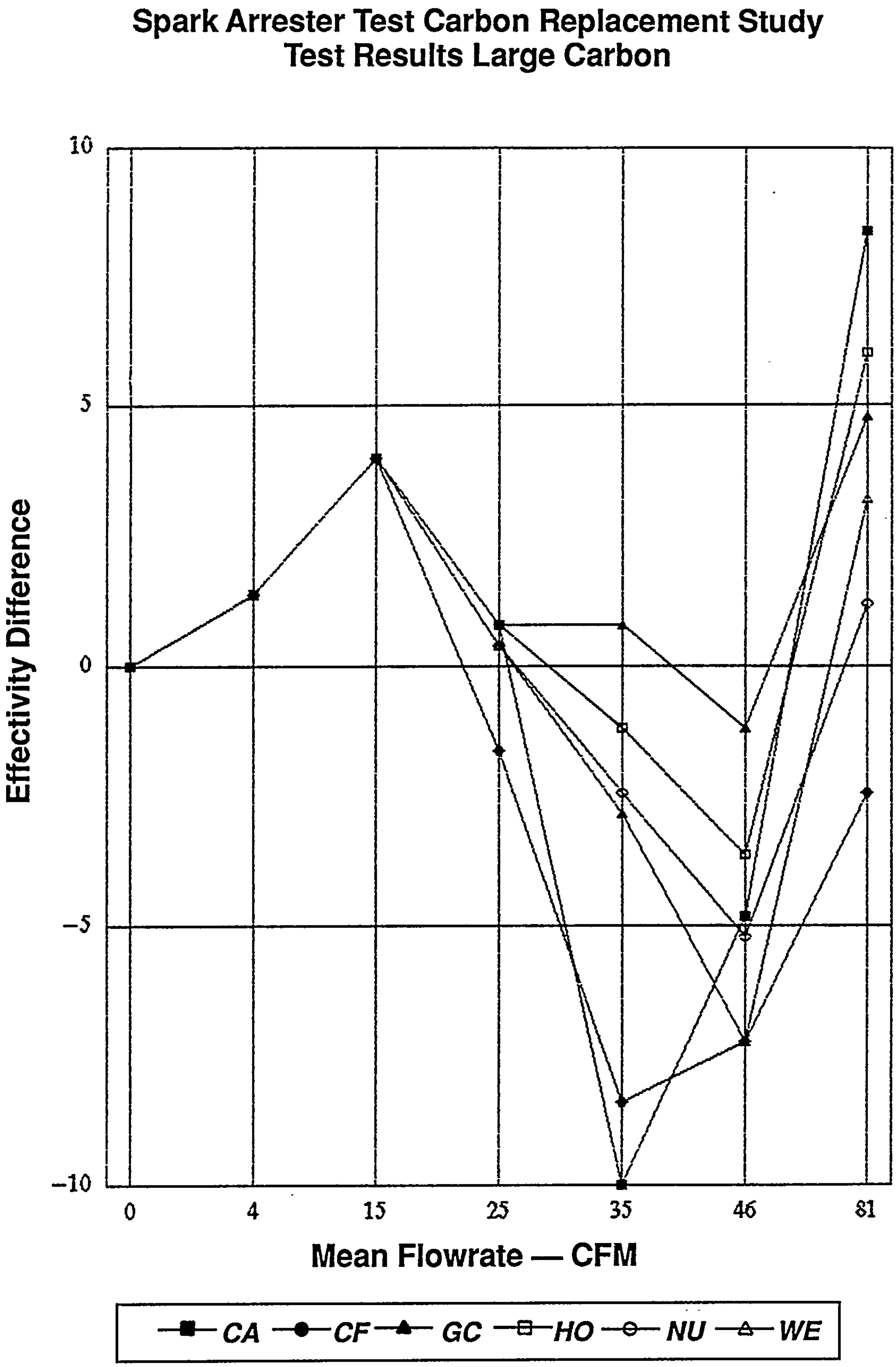


Figure 45.
Arrester C
Comparison of Discrete Effectivity Differences to SAE J997 Carbon

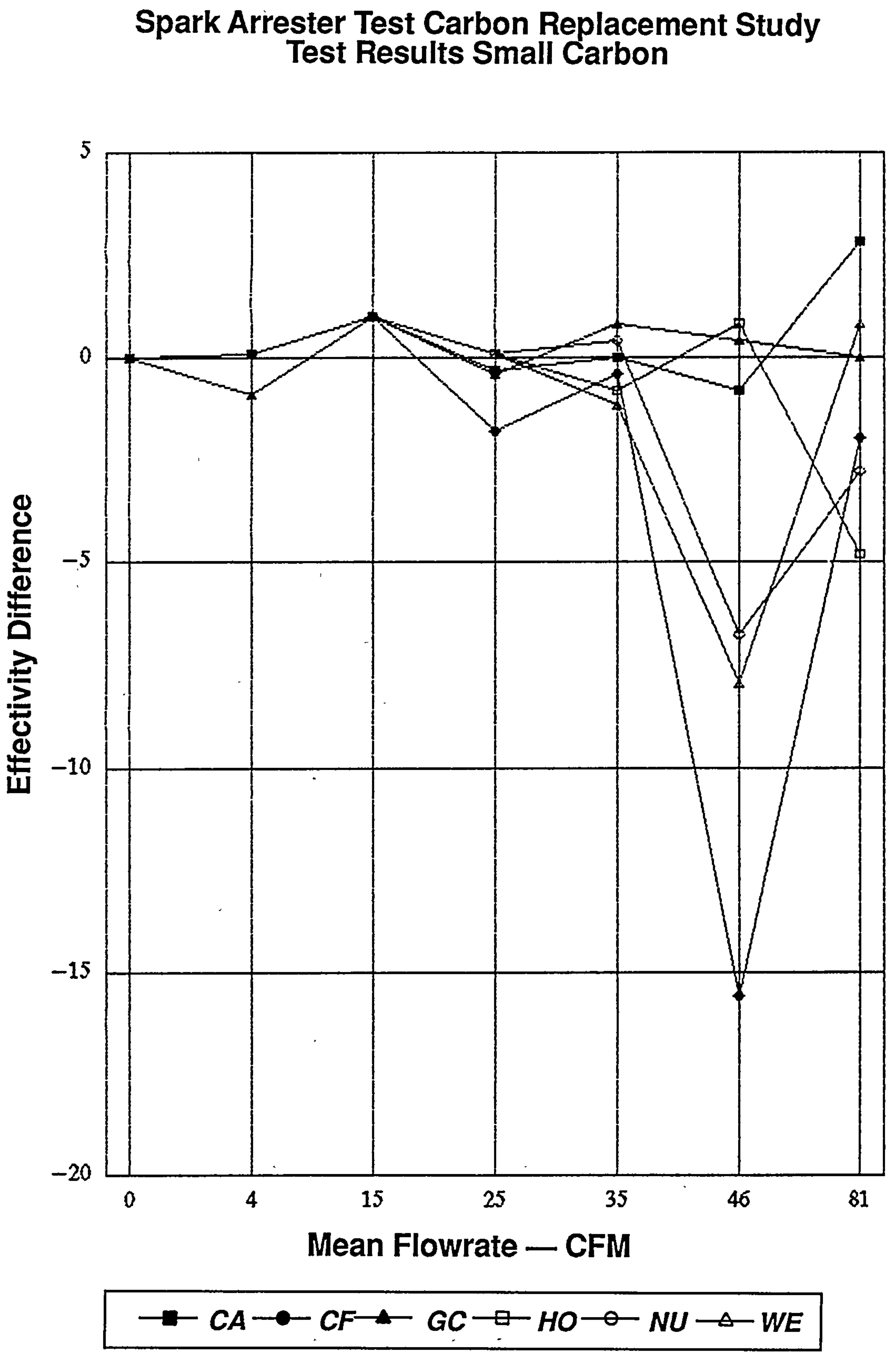


Figure 46.
Arrester C
Comparison of Discrete Effectivity Differences to SAE J997 Carbon

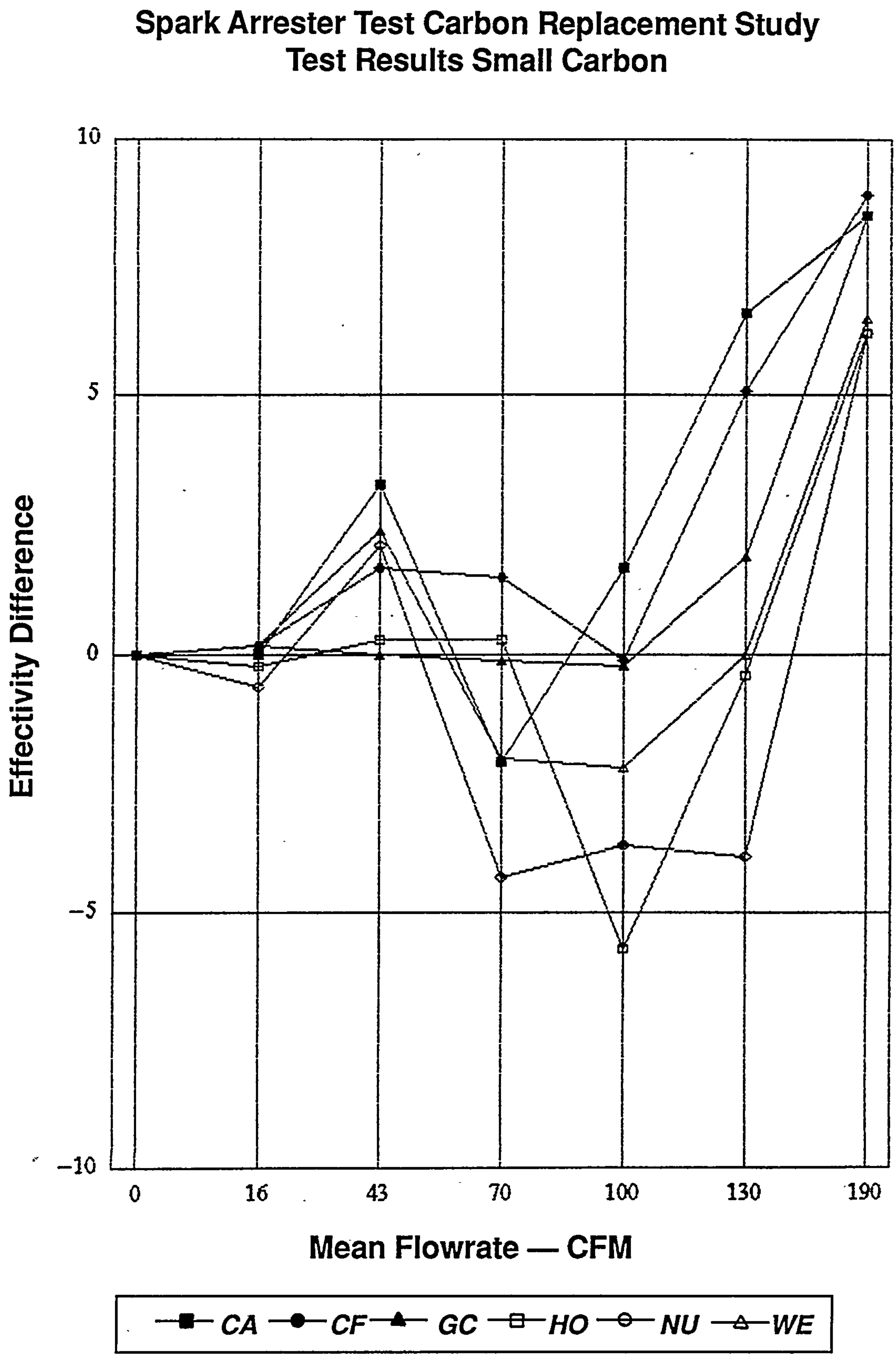


Figure 47.
Arrester D
Comparison of Discrete Effectivity Differences to SAE J997 Carbon

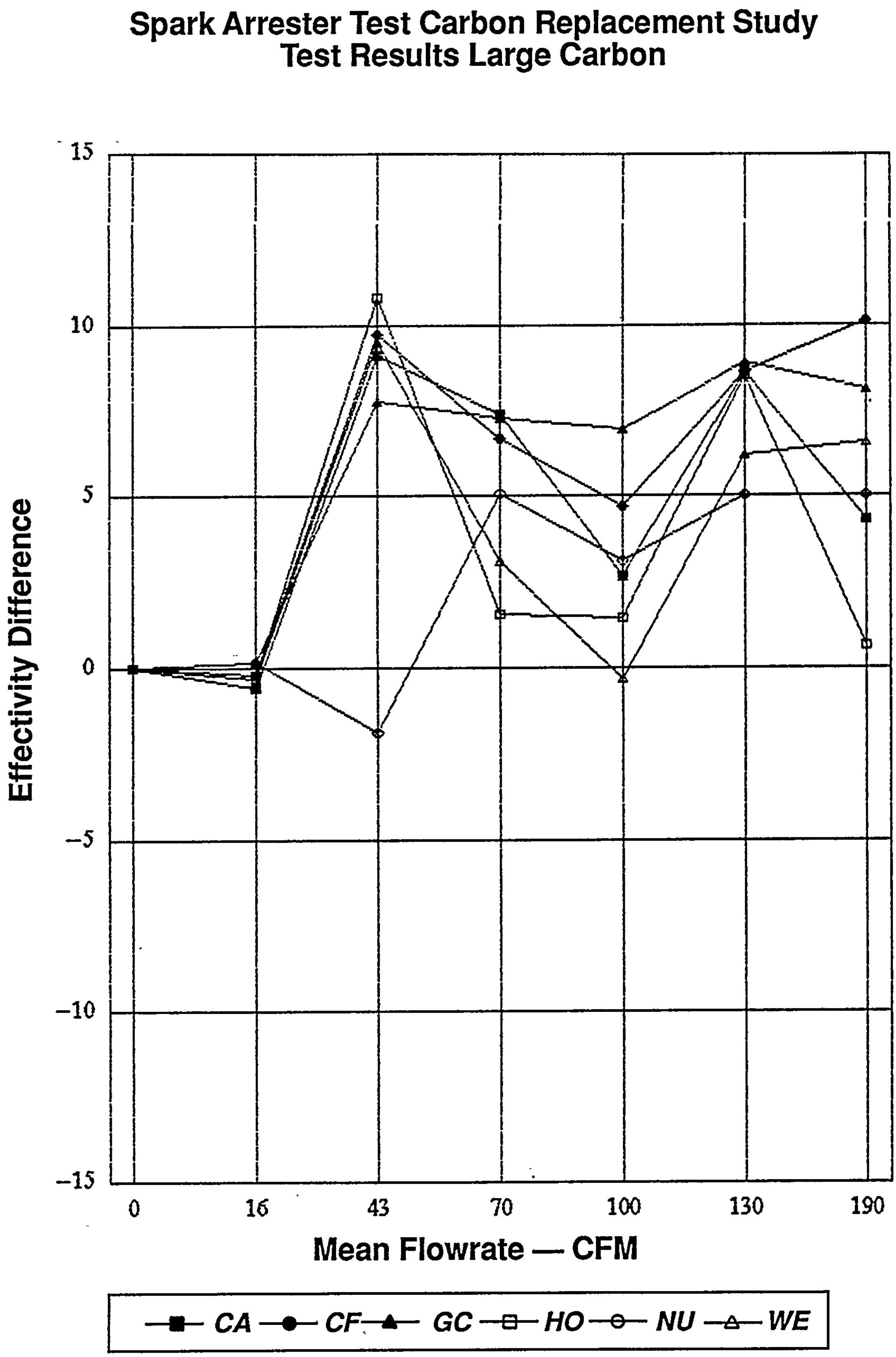


Figure 48.
Arrester D
Comparison of Discrete Effectivity Differences to SAE J997 Carbon

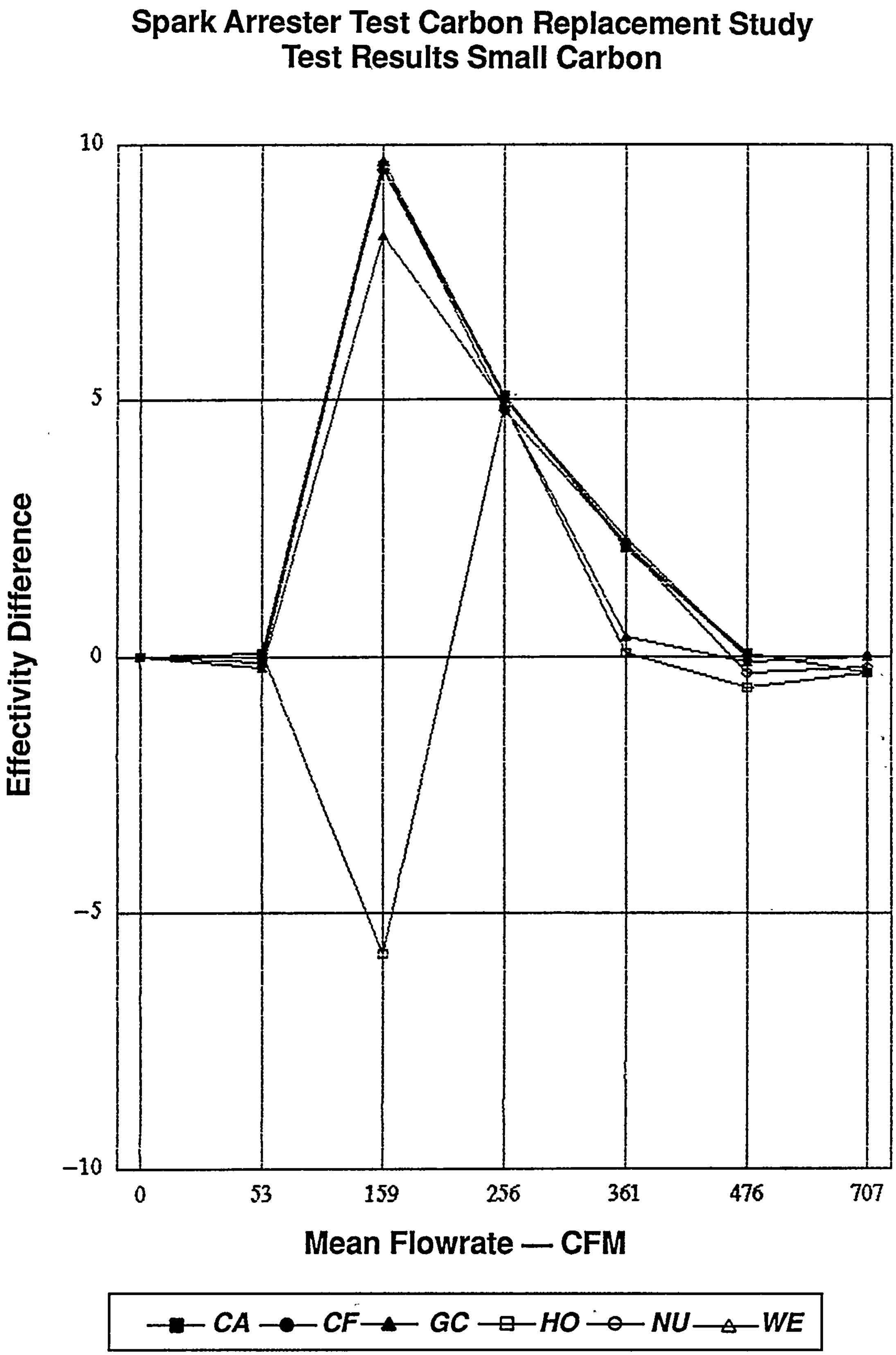


Figure 49.
ArresterE
Comparison of Discrete Effectivity Differences to SAE J997 Carbon

Spark Arrester Test Carbon Replacement Study
Test Results Large Carbon

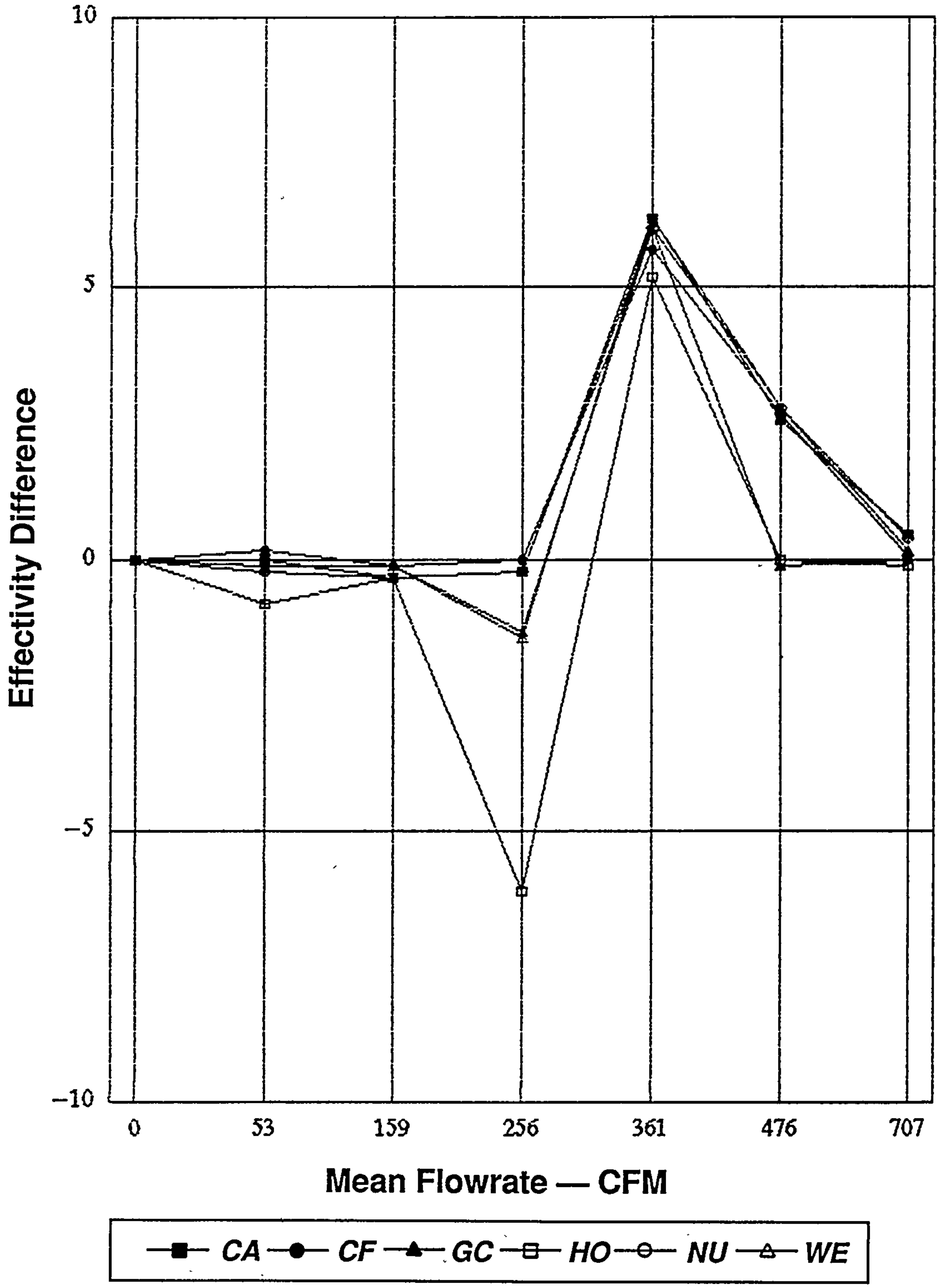


Figure 50.
ArresterE
Comparison of Discrete Effectivity Differences to SAE J997 Carbon

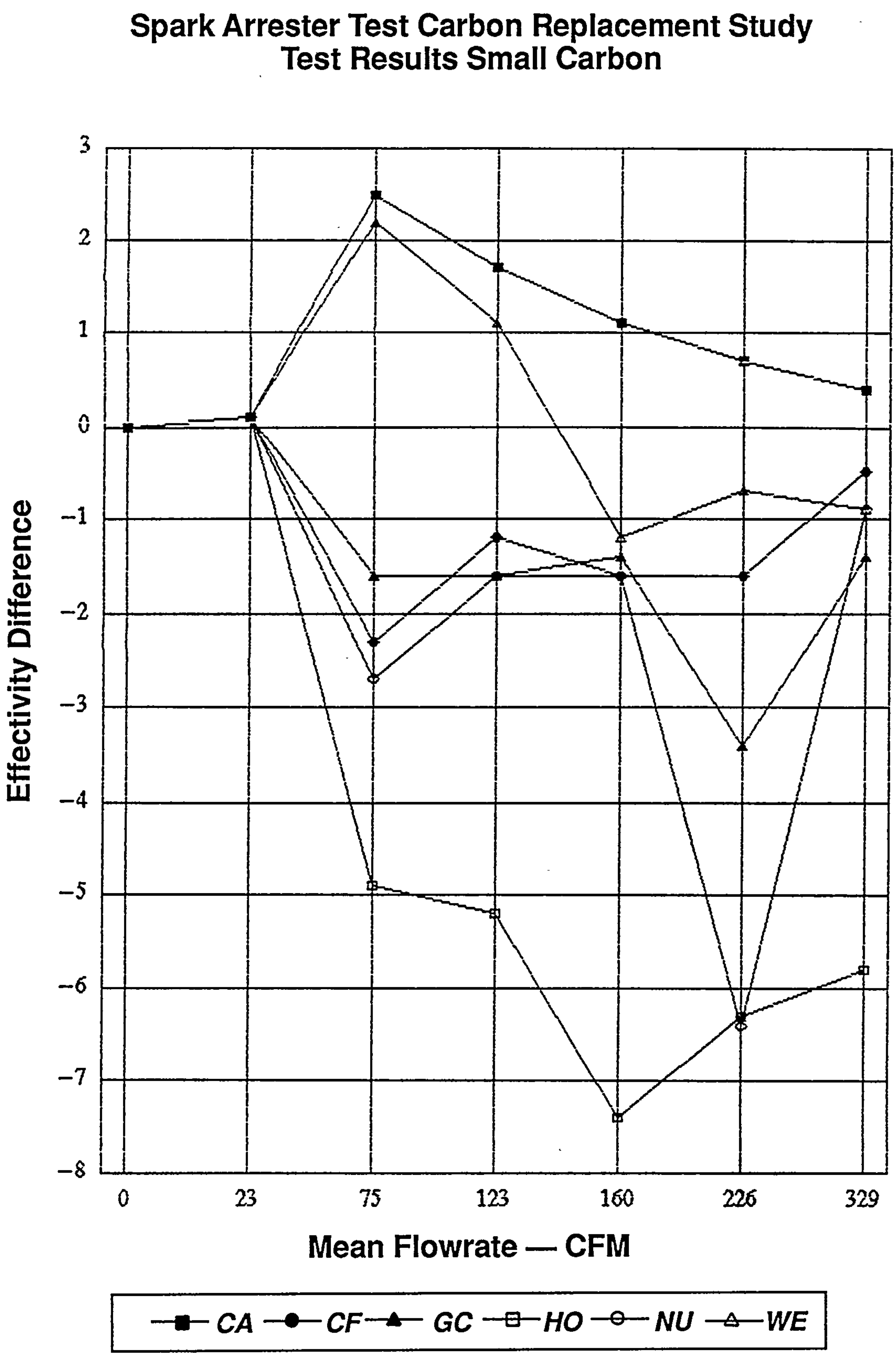


Figure 51.
Arrester F
Comparison of Discrete Effectivity Differences to SAE J997 Carbon

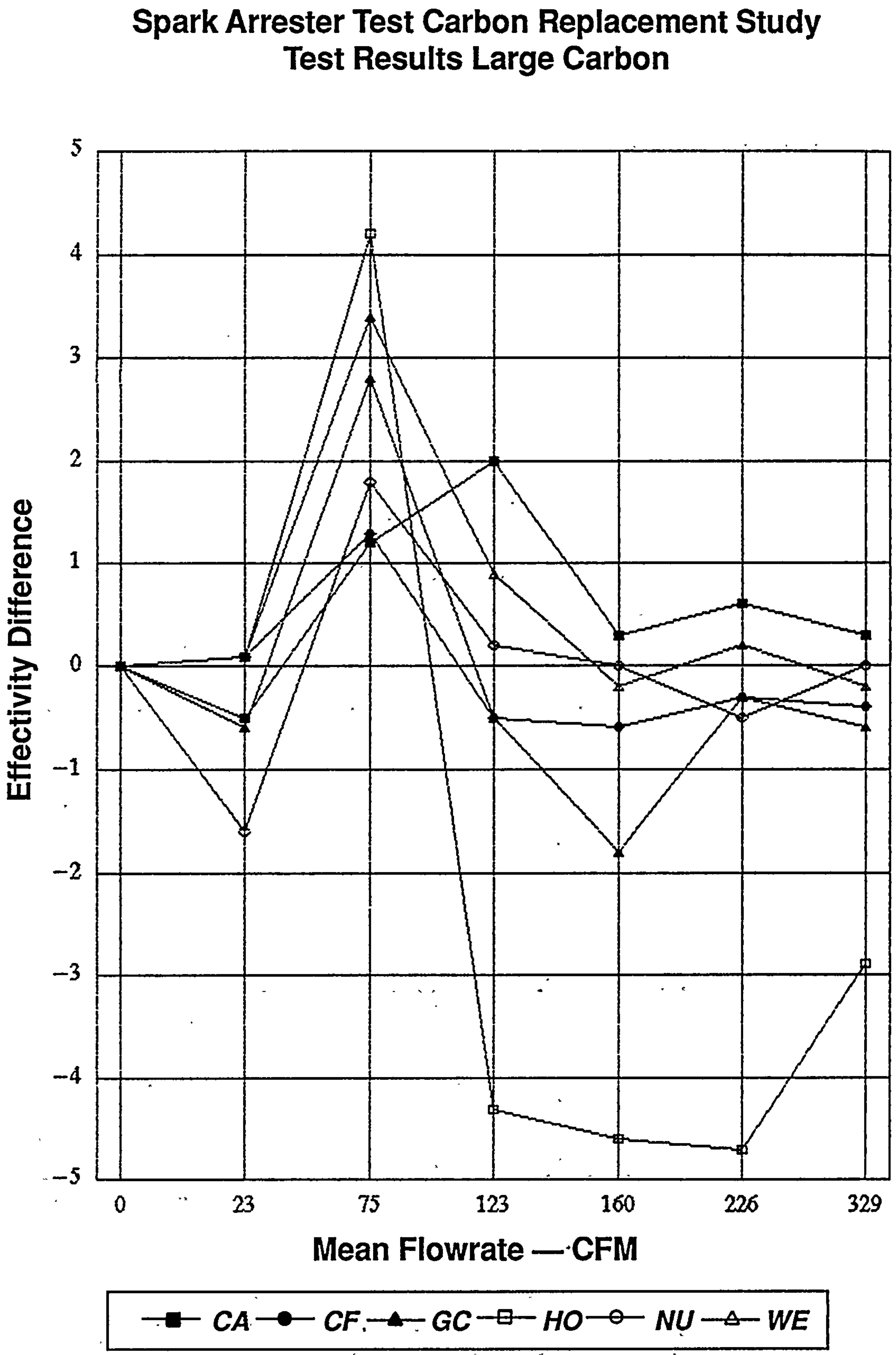


Figure 52.
ArresterF
Comparison of Discrete Effectivity Differences to SAE J997 Carbon

GPO 583-088/82038