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Determination of the Filtration Performance of Industrial Filter Cartridges as Defined by Beta Ratio

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Abstract

A new procedure has been developed to accurately rate filter cartridges over a wide range of particle sizes from 5µm to 110µm. The new procedure uses hard spherical contaminants that can provide particle sizes in the challenge solution larger than 20µm. Beta Ratios were calculated to determine the Absolute Rating of the tested filter cartridges. This new procedure is the first published procedure that provides the user with an aqueous based test method to accurately determine the Absolute Ratings of the more open grades of filter cartridges (>20µm).

Of all the cartridges tested, **only** *the rigid, resin bonded Beta-Klean cartridges provide consistent filtration efficiency performance such that these cartridges can be assigned absolute ratings that do not change over the life of the cartridge. The CUNO Beta-Klean cartridges demonstrate both* **consistent absolute filtration performance** *and* **longer** *cartridge life than their major competitive filter cartridges.*

All of the Competitive cartridges tested showed either **inconsistent** *filtration performance or* **loss** *of filtration performance over the life of the cartridge.*

The performance demonstrated by the melt blown cartridges tested is typical of a compressible cartridge where the media moves when subjected to differential pressure causing the previously retained contaminant to be released downstream (unloading). The physical structure of the cartridge changes under differential pressure and this change permits contaminant to pass through the cartridge that would have been retained (by-pass). These characteristics are demonstrated by a decrease in Beta Ratio as the differential pressure increases.

The performance of the competitive nominally rated, resin bonded cartridges is marked by poor initial removal efficiency as demonstrated by a Beta Ratio less than 1000. The Beta Ratio increases as the test progresses but does not reach a $\beta_x = 1000$ *until a contaminant cake is formed on the cartridge surface. The cartridges are typically more open than their nominal ratings would indicate.*

The performance of nominally rated string wound cartridges typically shows poor filtration performance over the life of the cartridge. The media moves under pressure causing unloading and/or by-pass. No $\beta_x = 1000$ *is achieved initially and no* $\beta_x = 1000$ *is reached even after contaminant cake formation.*

Many of the more open (>30µm) Competitive cartridges tested did not show the distinct particle size cut-off required to assign an absolute rating.

1. Introduction

There are a number of commonly used terms to define the contaminant removal performance of a filter cartridge. These include:

- Nominal Filter Rating
- Absolute Filter Rating
- Gravimetric Efficiency
- Contaminant Capacity
- Dirt Holding Capacity
- Turbidimetric Efficiency

Many of the approaches used to determine these contaminant removal performance characteristics are measured at a single point in time during the test. We took the approach that a clear picture of the contaminant removal performance over the **life** of the cartridge was needed, not the contaminant removal performance at a single point in time.

Many of these approaches also ignore the fact that the cartridge is challenged by particles over a wide size range and not at a fixed, single particle size. Single valued performance evaluations also ignore the fact that the filtration performance changes over the life of the cartridge.

We developed a test method to accurately determine the filtration performance of filter cartridges rated at <20µm and >20µm. We modified an existing published test procedure developed by Ostreicher (1) and used it to evaluate the performance of Industrial filter cartridges: "Performance Evaluation of Industrial Filter Cartridges", ASTM Special Technical Publication 975. As stated in the Introduction to ASTM STP 975, "this procedure reduces the complexity of the filter performance comparison and it provides the user with a clear and comprehensive picture of the actual performance." We call our new approach: Multiple Parameter Characterization or **MPC**.

We select hard-particle contaminants that provide the necessary counts in the particle size ranges of interest. The specific contaminant used for each test is chosen based on the published rating or the anticipated rating of the filter to be tested. The contaminant selected must be able to provide a minimum of 1000 particle counts in the influent at and above the size range of interest so that the $\beta_x = 1000$ (where x = the micron size) can be calculated. Commercially available test dusts do not provide a sufficient number of particles greater than 20 µm to accurately rate open filter cartridges. Therefore, we use five different rigid contaminants to cover the range of 0.5µm to 110µm. The contaminants were selected based on their particle size distributions over the ranges of interest and the fact that they remain suspended in the challenge solution for the duration of the test. The identification of these new contaminants that provide particle counts which meet our new, stricter criteria and our development of improved particle counting techniques give us the ability to absolute rate filter cartridges above 20μm.

To conduct this comprehensive test protocol, we selected contaminants with wide particle size distributions and measured the removal performance of the contaminant over the life of the cartridge, **not** at a single time point. We selected hard-particle contaminants that provide the necessary counts in the particle size ranges of interest.

Cartridge life can be defined in many ways. We have decided to define it in terms of "contaminant capacity". Contaminant capacity is defined as the amount of contaminant per 10" equivalent that is required to reach a differential pressure across the cartridge that would be indicative of cartridge plugging. The test can be used to predict the relative contaminant capacity of each of the filter cartridges tested. The test cannot be used to determine the exact cartridge life that would be obtained under actual use conditions.

In this report, we will describe our basic approach to determine the absolute rating of a filter cartridge and its contaminant removal performance as determined by our new test procedure, Multiple Parameter Characterization (**MPC**). We are currently using this test procedure to not only evaluate our cartridges versus our Competitors' cartridges, but also as an internal tool to guide filter cartridge development efforts.

2. Beta Ratio

The concept of Beta Ratio was developed in the early 1970's by E. C. Fitch (2) at Oklahoma State University as a means of defining the performance of hydraulic filters. The Beta Ratio is defined in terms of cumulative particle size/particle count data as follows:

$$\beta_x = \frac{\text{Cumulative Number of Particles Larger than X in the Influent Challenge}}{\text{Cumulative Number of Particles Larger than X in the Effluent}}$$

CUNO defines Absolute Rating as "the particle size (x) providing an initial Beta Ratio (β_x) = 1000". At this Beta Ratio, the removal efficiency is = 99.9%

Hong and Fitch (3) state " ...Based on this great quantity of test data, it became obvious that Beta Ratios varied during the course of the test. In other words, the Beta Ratio is not a static parameter but a dynamic parameter, and its value depends on the dirt loading process. Hence the use of a single value Beta Ratio (for example, the minimum Beta Ratio) is not sufficient to reflect the entire service spectrum of filter performance." Therefore, we decided to determine the Absolute Rating of our filter cartridges based on Beta Ratio but determine the overall performance of the filter cartridge based on a test that accurately measures the filter performance over the entire life of the filter.

We demand that the Beta Ratio/removal efficiency does not deteriorate during the life of the cartridge. Non-rigid, compressible cartridges cannot meet this criteria because unloading caused by media movement induced by pressure will occur as the pressure drop across the media increases.

3. Procedure

A new procedure was needed to accurately rate filter cartridges over a wide range of absolute ratings from 5μm to 110μm. Since the publication of ASTM STP 975, particle counting techniques have significantly improved. Therefore, a modified version of ASTM STP 975 was required for this study.

The CUNO Absolute Rating of a cartridge is determined from data collected with our Multiple Parameter Characterization (MPC) test procedure. The cartridge is challenged with the appropriate contaminant at a constant flow rate. The challenge makes one pass through the filter medium (that is, the filtrate is not recirculated into the contaminant feed tank). The filtration performance is monitored over the life of the cartridge. The influent and effluent streams are sampled during the test and the particle size distribution of each sample is obtained. The data from the particle counter is fed into a computer program that calculates the particle removal efficiency over the particle size range. A graph of Beta Ratio vs. Differential Pressure across the cartridge is prepared and evaluated. From the removal efficiency data we calculate Beta Ratios over the life of the cartridge. From the Beta Ratio data collected by our MPC Test Procedure, we calculate the Absolute Rating of the cartridge. To be considered a valid rating, we require that no deterioration in Beta Ratio/removal efficiency occurs over the duration of the test as the pressure drop across the cartridge increases.

Performance curves and graphs are created for each cartridge tested for data presentation. The Beta Ratio data as a function of Differential Pressure during the test are plotted to evaluate the filtration performance of the cartridge over its life. Excellent performance is demonstrated if the cartridge initially reaches a β_x = 1000 and the Beta Ratio at the selected rating does not deteriorate or it increases during the test. Examples of poor performance would be a decrease in the Beta Ratio at the selected rating as the test progresses or if a β_x = 1000 is not reached during the test.

The 10" cartridges are challenged at a constant flow rate of 3 gpm with an influent aqueous contaminant concentration of 0.13 to 5 grams/gallon, depending on the contaminant. On-line turbidity and differential pressure measurements are made during the test. The influent and effluent are sampled at four specific times during the test (initially, prior to a contaminant cake forming on the cartridge surface; and at 0.5 psid, at 1 psid and at 10 psid, respectively, above the clean pressure drop across the cartridge). We sample the influent and effluent streams and determine the particle counts in the samples off-line to provide more accurate particle counts. (See schematic of the Automated Test Stand, Figure 1). In-line particle counters typically have four to six channels to cover the particle size range of interest. Each channel can potentially cover a very wide particle size range when counting samples that contain a wide particle size distribution. A single channel covering a wide range leads to poor particle size resolution. In-line counters are typically based on light scattering techniques. Therefore, the contaminant concentration must be low enough to avoid saturation of the detector. We use a particle counter that has up to 256 channels and, as a result, each channel covers a narrow particle size range providing a more precise particle count than an in-line counter.

The test end point is defined as the time when a 20 psi pressure differential is reached over the initial clean pressure drop of the cartridge at the test flow rate of 3 gpm. The 20 psi differential pressure was selected because it is representative of a plugged cartridge and, in most applications, cartridge change-out typically takes place at a ΔP of 10 to 35 psid. Our work has shown that when 20 psid is reached, the pressure drop across the cartridge is rapidly increasing and no additional meaningful data will be obtained by continuing the test. This point is on the rapidly ascending portion of the curve of ΔP vs. grams of contaminant added.

All data are collected by computer. Performance curves and graphs for each cartridge are then created for data reduction. The data from four sampling points during the test are plotted as the particle removal efficiency vs. particle size for each sampling point. Differential pressure (ΔP) and Turbidimetric Efficiency (TBE) are plotted as a function of the grams of contaminant added during the challenge test. The ΔP and TBE vs. grams of contaminant added are also presented in tabular form. Graphs of Beta Ratio as a function of Differential Pressure are also prepared.

The relative life of each cartridge can be predicted from our contaminant capacity data. Our standard procedure is to calculate the cartridge contaminant capacity at 20 psid when challenging with ACCTD or ACFTD and 5 psid when challenging with other contaminants. The amount of contaminant can be determined from either the raw data or from a plot of differential pressure vs. grams of contaminant added.

All grades of Beta-Klean filter cartridges were tested versus all the major equivalent Competitive cartridges. This Report will focus on only two of grades tested. The CUNO Beta-Klean filter cartridges (BKZ8200, BKZ8700) can be absolute rated. They can be assigned absolute ratings of 20 and 70 microns, respectively, based upon CUNO's newly developed MPC procedure for determining the absolute rating (β_x = 1000) and filtration performance of filter cartridges.

A. <u>Materials</u>

SAE Course Test Dust (ACCTD), Powder Technology, Inc. (at contaminant challenge concentration of 1.0 gm/gal).

Standard cut, rigid, thick-walled, hollow, silica-alumina spheres (5.0 gm/gal).

0.2µm filtered city water, pH 7.2 - 7.4, with a Total Dissolved Solids (TDS) of approximately 180 ppm.

Filters used for this study are listed in the <u>Cartridges Tested</u> Table.

B. <u>Equipment</u>

Coulter Multisizer II E Particle Counter interfaced to an IBM compatible 486 PC

CUNO Automatic Cartridge Challenge Test Stand interfaced to an IBM compatible 386 PC (see Figure 1)

C. <u>Methods</u>

Modified version of ASTM, Special Technical Publication 975, "Performance Evaluation of Industrial Filter Cartridges", E.A. Ostreicher, Fluid Filtration: Liquid, Volume II, ASTM STP 975, American Society for Testing and Materials, P.R. Johnston and H.G. Schroeder, Eds. (1986).

Beta Ratio is defined in terms of cumulative particle size/particle count data as follows:

$$b_x = \frac{\text{Cumulative Number of Particles Larger than X in the Influent Challenge}}{\text{Cumulative Number of Particles Larger than X in the Effluent}}$$

The 10" cartridges were challenged at a 3 gpm flow rate of 0.2µm filtered city water using ACCTD as the contaminant at a concentration of 1.0 gm/gal or 5.0 gm/ml using the rigid spheres as the contaminant.

Cartridges Tested

Cartridge Designation	Cartridge Type	Manufacturer's Rating
CUNO BKZ8200	Resin bonded	20µm absolute
CUNO BKZ8700		70µm absolute
Competitive Melt Blown (200)	Melt blown polyolefin	20µm absolute
Competitive Melt Blown (700)		70µm absolute
Competitive Spun Bonded (05)	Spun bonded polyolefin	5µm
Competitive Melt Blown (20)	Melt blown polyolefin	20µm
Competitive Resin Bonded (25)	Resin bonded cellulose	25µm nominal
Competitive Resin Bonded (50)		50µm nominal
Competitive Cotton String Wound (C-10)	Generic string wound	10µm nominal
Competitive Cotton String Wound (C-25)		25µm nominal
Competitive Cotton String Wound (C-75)		75µm nominal

4. Results and Discussion

A. Filter Ratings

In this study, we determined the "Absolute Rating" of each filter cartridge. The results from this study confirmed that there are as many definitions of nominal rating of filter cartridges as there are filter cartridge manufacturers. Therefore, we are proposing a more rigorous cartridge rating procedure.

The results from our testing of the 20µm and 70µm rated cartridges are presented in Table I showing the nominal or absolute rating as stated by the Manufacturer for each cartridge tested, the measured "nominal" rating at a commonly selected nominal removal efficiency of 90% and the Beta Ratio at the manufacturer's published rating.

Table I

Nominal/Absolute Ratings vs. β_x at Manufacturer's Rating

Cartridge Designation	Nominal/ Absolute Rating by Manufacturer	Rating at 90% PRE (Nominal)	Rating at β_x = 1000 (Absolute)
CUNO BKZ8200	20µm absolute	10.9µm	β_{20}=5762 ACCTD
CUNO BKZ8700	70µm absolute	20.7µm	β_{70}= ¥ (rigid spheres)
Competitive Melt Blown (200)	20µm absolute	5.4µm	β_{20}=1084 (ACCTD)
Competitive Melt Blown (700)	70µm absolute	40.4µm	β_{70}= ¥ (rigid spheres)
Competitive Spun Bonded (05)	5µm	~14µm	β_5=1.6 (ACCTD)
Competitive Melt Blown (20)	20µm nominal	12.3µm	β_{20}=225 (rigid spheres)
Competitive Resin Bonded (25)	25µm nominal	>33.5µm	*NR (ACCTD) β_{25}=5 (rigid spheres)
Competitive Resin Bonded (50)	50µm nominal	>48µm	*NR (ACCTD) β_{50}=33.4 (rigid spheres)
Competitive Cotton String Wound (C-10)	10µm nominal	5.4µm	β_{10}=109.5 (rigid spheres)
Competitive Cotton String Wound (C-75	75µm nominal	~11µm	*NR

*NR = Not Ratable, due to the absence of a defined removal efficiency cut-off due to by-pass or unloading

B. Performance as a Function of Differential Pressure

A summary of the Absolute Ratings (β_X = 1000) as a function of Differential Pressure are presented in Table II and plotted in Graphs 1 and 2. As shown in the Graphs, Beta Ratio as a function of Differential Pressure(ΔP) can be used to evaluate the filtration performance of the cartridge over its life. Excellent performance is demonstrated if the cartridge initially reaches a β_X = 1000 and the Beta Ratio at the selected rating does not deteriorate or it increases during the test. Examples of poor performance would be a decrease in the Beta Ratio at the selected rating as the test progresses or if a β_X = 1000 is not reached during the test.

Table II

Beta Ratio versus Differential Pressure as a Function of Cartridge Life

Cartridge Designation	Initial	Beta Ratio at 0.5 psid	at 1.0 psid	at 10.0 psid
20mm Rated Cartridges				
CUNO BKZ8200	4625	3325	3623	4539
Competitive Melt Blown (200)	1084	734	766	22
Competitive String Wound (C-10)	255	236	283	80
Competitive Melt Blown (20)	299	69	301	203
70mm Rated Cartridges				
CUNO BKZ8700	1228	3188	1494	1769
Competitive Melt Blown (700)	1609	16	14	47
Competitive Resin Bonded (25)	336	217	635	733
Competitive String Wound (C-75)	10	10	10	5

As shown in both Graphs 1 and 2, the removal performance as a function of ΔP demonstrated by the melt blown cartridges tested is typical of a compressible cartridge where the media moves under pressure causing the previously retained contaminant to be released downstream (unloading). The physical structure of the cartridge has changed under pressure and this change permits contaminant to pass through the cartridge that would have been retained (by-pass). These characteristics are demonstrated by a decrease in Beta Ratio as the differential pressure increases.

As shown in Graph 2, the performance of the competitive nominally rated, resin bonded cartridges is marked by poor initial removal efficiency as demonstrated by a Beta Ratio <1000. The Beta Ratio increases as the test progresses but does not reach a $\beta_x = 1000$ until a contaminant cake is formed on the cartridge surface. These cartridges are typically more open than their nominal ratings would indicate.

The performance of nominally rated string wound cartridges typically shows poor filtration performance over the life of the cartridge, as seen in Graphs 1 and 2. The media moves under pressure causing unloading and/or by-pass. No $\beta_x = 1000$ is reached initially and no $\beta_x = 1000$ is reached even after contaminant cake formation.

C. Cartridge Life

The contaminant capacities are summarized in Table III.

Table III

Measured Contaminant Capacity

Cartridge Designation	Contaminant Capacity (grams)
CUNO BKZ8200	111.7 (ACCTD)
^	211.9 (rigid spheres)
CUNO BKZ8700	245.1 (ACCTD)
^	417.9 (rigid spheres)
Competitive Melt Blown (200)	40.4 (ACCTD)
Competitive Melt Blown (700)	230.5 (rigid spheres)
Competitive Spun Bonded (05)	45.6 (ACCTD)
Competitive Melt Blown (20)	146.2 (rigid spheres)
Competitive Resin Bonded (25)	119.2 (ACCTD)
^	251.8 (rigid spheres)
Competitive String Wound (C-10)	142.7 (rigid spheres)
Competitive String Wound (C-25)	148.3 (rigid spheres)
Competitive String Wound (C-75)	317.3 (rigid spheres)

Does one sacrifice cartridge life to obtain an absolute rated filter? The answer is an emphatic NO! As seen in the data presented in Tables I, II and III, the CUNO Beta-Klean cartridges provide the assurance of absolute ratings that do not deteriorate over the life of the cartridge and longer filter cartridge life. With the CUNO cartridges you get the best of both: **absolute ratings and long cartridge life.**

5. Conclusions

1. A new procedure has been developed that can be used to determine the absolute rating of Industrial filter cartridges, the Multiple Parameter Characterization (**MPC**). The MPC procedure can be used to determine the absolute rating of a filter cartridge over a wide micron size range (5µm to 110 µm) and evaluate the filtration performance of a filter cartridge over its useful and effective life.

2. The MPC procedure is a totally aqueous filtration performance test that can be used to determine the absolute ratings of the more open grades of filter cartridges, cartridges with ratings greater than 20µm. The contaminants used contain at least 1000 particles in the size range of interest.

3. Significant variability exists between the Manufacturer's selected nominal ratings and the actual measured filtration performance.

4. Absolute ratings based on a β_x= 1000 is a valid way to determine the actual filtration performance of a filter cartridge.

5. Of all the cartridges tested, **only** the rigid, resin bonded Beta-Klean cartridges provide consistent filtration efficiency performance such that these cartridges can be assigned absolute ratings that do not change over the life of the cartridge.

6. The CUNO Beta-Klean cartridges demonstrate both **consistent absolute filtration performance** and **longer** cartridge life than their major competitive filter cartridges.

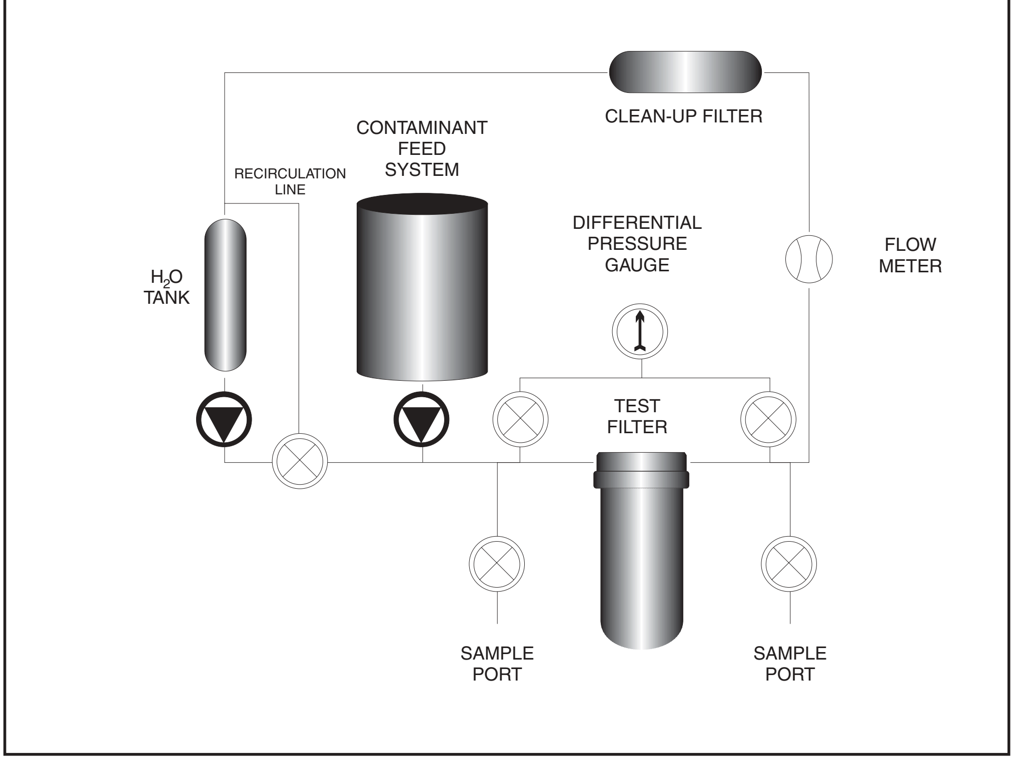
References

1. ASTM, Standard Technical Procedure 975, "Performance Evaluation of Industrial Filter Cartridges", E.A. Ostreicher, Fluid Filtration: Liquid, Volume II, ASTM STP 975, American Society for Testing and Materials, P.R. Johnston and H.G. Schroeder, Eds. (1986)

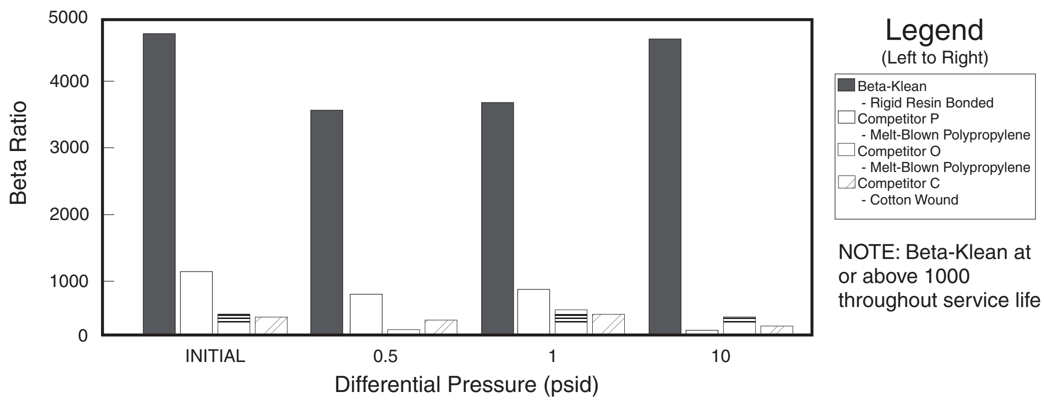
2. E. C. Fitch, "Encyclopedia of Fluid Contamination Control", Parts 4.30.1, 4.30.2, 4.35.1 and 4.35.2, Fluid Power Research Center, Oklahoma State University, Stillwater, OK, Hemisphere Publishing Company, Washington, D.C. (1977)

3. I.T. Hong and E. C. Fitch, "An Innovative Technique in Filter Rating", 1985 International Off-Highway & Power Plant Congress & Exposition, SAE Technical Paper #851590, (September 9-12, 1985)

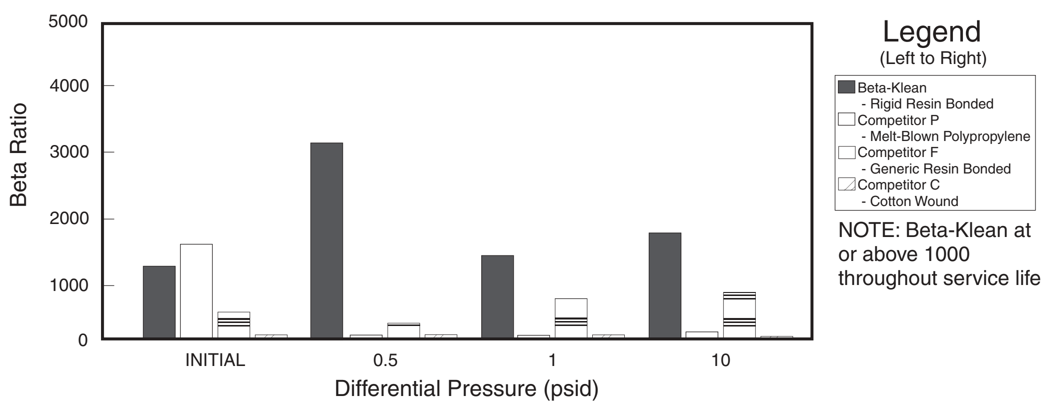
FIGURE 1. - TEST STAND SCHEMATIC



GRAPH 1. - BETA RATIO vs. DIFFERENTIAL PRESSURE COMPARISON OF FILTER CARTRIDGES RATED AT 20 MICRONS AS A FUNCTION OF CARTRIDGE LIFE



GRAPH 2. - BETA RATIO vs. DIFFERENTIAL PRESSURE COMPARISON OF FILTER CARTRIDGES RATED AT 70 MICRONS AS A FUNCTION OF CARTRIDGE LIFE



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