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Advanced Lightweight Ceramic Candle Filter Module

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Advanced Lightweight Ceramic Candle Filter Module

CONTRACT INFORMATION

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SUMMARY OF OBJECTIVES

Vacuum formed aluminosilicate fiber has often been post-treated to add strength and density. At high operating temperatures it's material strength rivals that of costly alloys. Using relatively inexpensive materials, service operating temperatures of up to 2730°F (1500°C) can be realized.

After wrestling with the engineering problems and the manufacturing costs of alloy tubesheets at elevated temperatures, Industrial Filter & Pump Mfg. Co. and Universal Porosics, Inc. reached an agreement for joint development of light weight, alternative (ceramic) structural materials. After several years, a family of products trademarked Fibro™, were developed from vacuum formed aluminosilicate fibers. The basic formed pieces are post treated for additional strength and density. The finished raw product is then fire cured to produce the Fibro family of structural ceramics. A combination of these Fibro materials has been in operation for 18 months in a 4000 ACFM filter at temperatures of up to 1830°F (1000°C) to verify the suitability of an "all ceramic" hot gas filter system.

BACKGROUND INFORMATION

A comparison of the material strength of two Fibro products with three alloy products at temperatures ranging from ambient to 2000°F (1100°C) is shown in Figure 1. Note that at low temperatures the alloys are much stronger, but at approximately 1700°F (930°C) the Fibro and the alloys have about equal strength, and beyond 1700°F only the Fibro material is suitable for service.

Using the strength data developed, tubesheet thicknesses and weights were calculated for three different filter vessel diameters at four different operating temperatures. In each case, a maximum pressure drop of 14.5 psi (1 bar) across the tubesheet was used in the calculations. For low temperature, 390°F (200°C) operation, the alloy tubesheets were not cooled. Beginning at 1400°F (760°C), the tubesheets were cooled with steam and the metal thickness necessary for cooling passages was included. Since Fibro is rated at 2600°F to 2800°F (1425°C

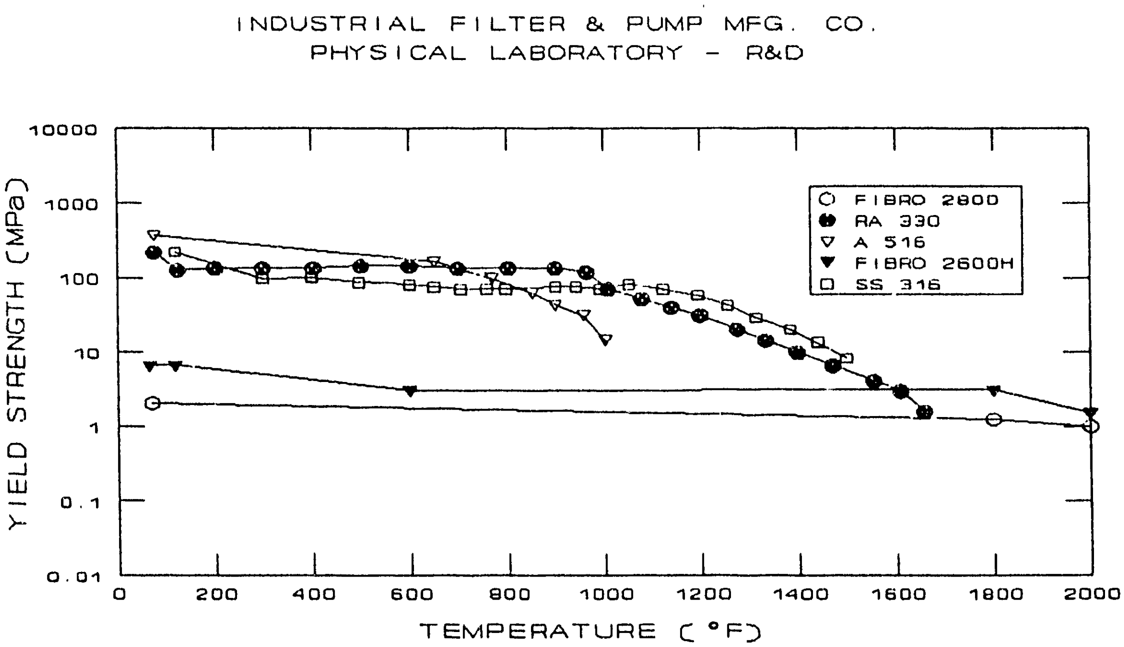

Figure 1. Material Strength Comparison Chart

Table 1. Tubesheet Thickness and Weight Comparison

VESSEL DIAMETER	OPERATING TEMP. (°C)	SB536 330 (ALLOY)			FIBRO 2800 (CERAMIC)	
		COOLING	THICKNESS*	WEIGHT	THICKNESS	WEIGHT
1060mm	200	N.C.	25 mm	279 Kg	--	--
	760	S	32 mm	362 Kg	50 mm	24 Kg
	870	S	52 mm	589 Kg	50 mm	24 Kg
	982	S	N/A	--	50 mm	24 Kg
1500mm	200	N.C.	32 mm	603 Kg	--	--
	760	S	47 mm	982 Kg	63 mm	30 Kg
	870	S	77 mm	1451 Kg	63 mm	30 Kg
	982	S	N/A	--	63 mm	30 Kg
1980mm	200	N.C.	36 mm	1382 Kg	--	--
	760	S	63 mm	2232 Kg	75 mm	36 Kg
	870	S	102 mm	3080 Kg	75 mm	36 Kg
	982	S	N/A	--	75 mm	36 Kg

* THICKNESS INCLUDES ALLOWANCE FOR COOLING PASSAGES
N/A = NOT ALLOWED BY A.S.M.E. CODE
S = STEAM COOLED
N.C. = NOT COOLED

to 1540°C), no cooling was necessary. Table 1 summarizes those calculations.

The weight ratios, alloy/Fibro, range from 15.08 for the 1060mm diameter tube-sheet at 1400°F (760°C) to 85.56 for the 1980mm diameter tube sheet at 1600°F (870°C). Note that ASME and other codes will not permit the use of alloy at the 1800°F (982°C) temperature used in the study, while Fibro is acceptable at 1800°F (982°C) and above.

In addition to the weight of the tubesheet itself, the weight of the load (candles) suspended from the tubesheet had to be included. Four different candle constructions were considered. Two were silicon carbide, and two were Fibro. The respective weights are summarized in Table 2. Notice that the weight ratio of SiC/Fibro can be as high as 11.

TUBESHEET DESIGN IMPLEMENTATION

A decision was made to build a 4000 ACFM filter to operate across the stack of a licensed incinerator on the IF&P premises. Although strength calculations showed that Fibro 2600H would have a safety factor of greater than 2.0 in the "worst case" using the heavier 15mm wall SiC candles, ceramic structural tubesheet supports were installed to increase the safety factor. Figure 2 illustrates the ceramic structural forms considered. Shape "C", constructed of alumina/mullite, was chosen and installed.

TEST FILTER STATION

A Fibro tubesheet, ceramic supports, and Fibro "S" candles were installed in the 4000 ACFM filter station, as illustrated in Figure 3, in March/April 1991 and have been in operation since. The incinerator is used to burn Class 1 waste. Although the incinerator is licensed with an afterburner temperature of 1400°F (760°C), the filter station was fitted with extra gas burners to increase operating temperatures to 1850°F (1010°C). The extra heat necessitated the installation of a quench system on the filtered gas line in order to protect the I.D. fan which was only rated at 600°F (315°C).

USE OF SORBENTS TO MODIFY PARTICLE SIZE DISTRIBUTION

The test filter installation was later fitted with a dust hopper, dry dust feeder, and dust accelerator, (see box in Figure 3). The purpose of installing the dry feed system was to prove the increased efficiency of modifying particle size distribution through dry feeding of sorbents, such as $Ca(OH)_2$. In this particular case, it was found that a sorbent accelerator jet was required for efficient operation. Figure 4 illustrates the precept of the system.

OPERATING CONDITIONS

Although the filter has the provision for installing 255 ft.^{2} (23.7m^2) of candle surface area (85 candles), only 45 ft.^{2} (4.2m^2) of candle surface area (15 candles) were installed. This reduction of filtration surface area allowed the exploration of high face velocities (FV). Gas flow varied from 450 ACFM (10 FPM-FV) to 1710 ACFM (38 FPM-FV). Gas temperature varied from 1100°F to 1650°F (590°C to 900°C). Dust loads varied from 300 ppm to 2000 ppm; (this number was higher while sorbents were being fed).

Jet pulse was triggered by time and/or pressure drop and the jet pulse frequency ranged from 10 to 30 mins. The candles were pulsed in 3 groups of 5 candles each at 8 liters of air per candle at 80-90 psig (5.5-6.2 bar). The 80-90 psig (5.5-6.2 bar) of air is measured in a pulse measuring tank (PMT) and dumped through a solenoid valve. The jet pulse system is rigged so that the "dump" solenoid valve is locked out until a "PMT

Table 2. Tubesheet Loadings Using 1500mm Long Filter Candles

VESSEL DIAMETER	CANDLE QUANTITY	DiaSchumalith *	LayCer 70/3 **	FIBRO 2800 L **	FIBRO 2800 S **
1060mm	65	384.5 Kg	257.4 Kg	37.7 Kg	33.7 Kg
1500mm	165	976 Kg	653.4 Kg	95.8 Kg	85.4 Kg
1980mm	313	1851.4 Kg	1239.4 Kg	181.6 Kg	162 Kg

* 15mm WALL
** 10mm WALL

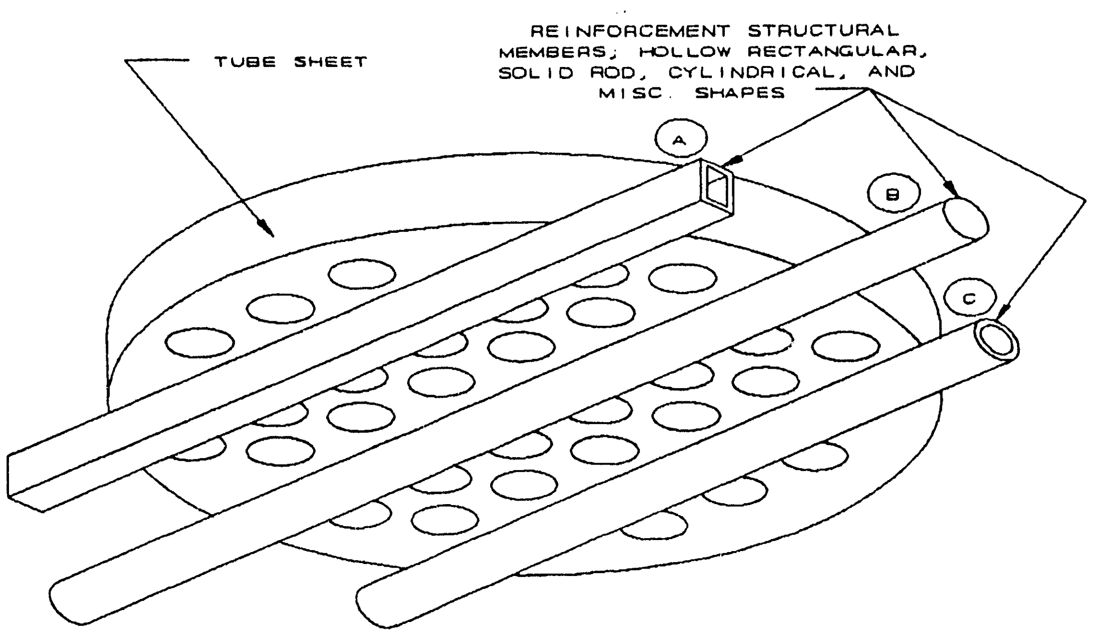

Figure 2. High Temperature Reinforced Ceramic Tubesheet

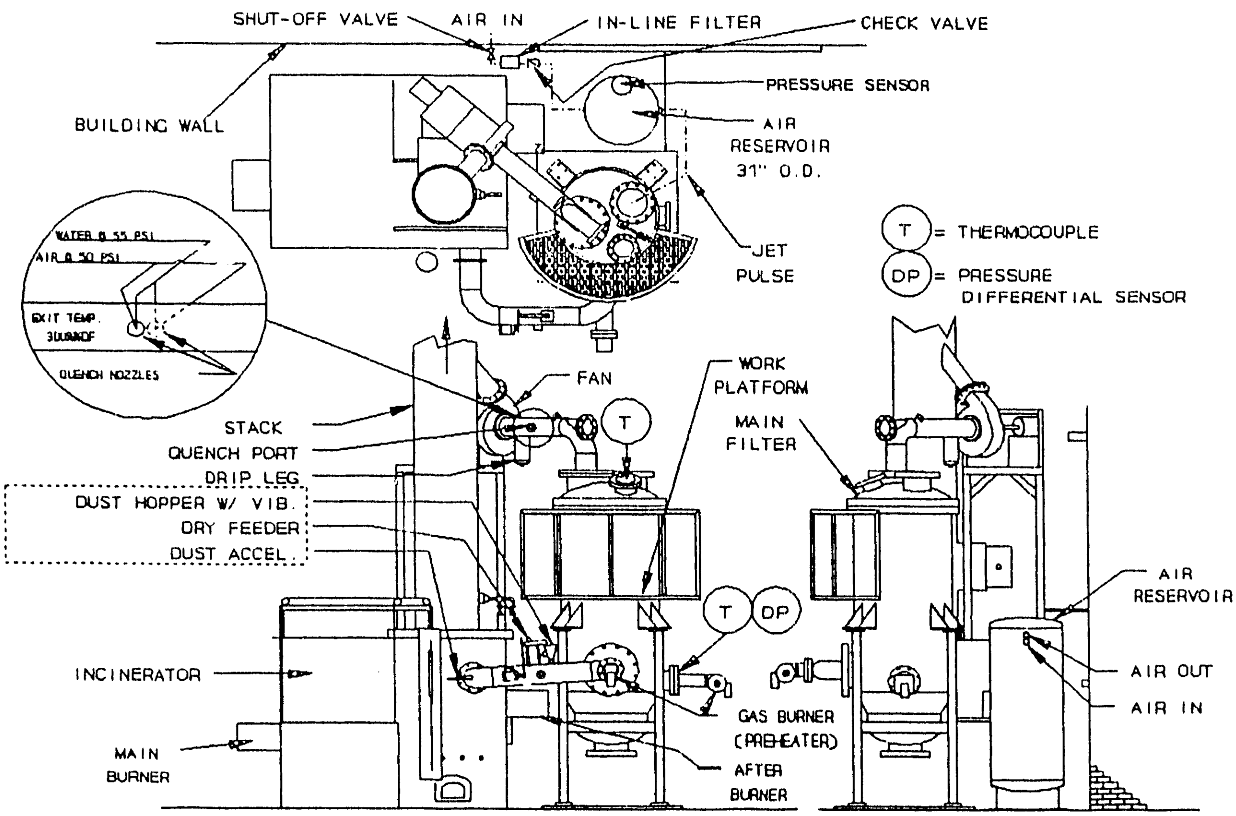

Figure 3. Incinerator Test Filter Station

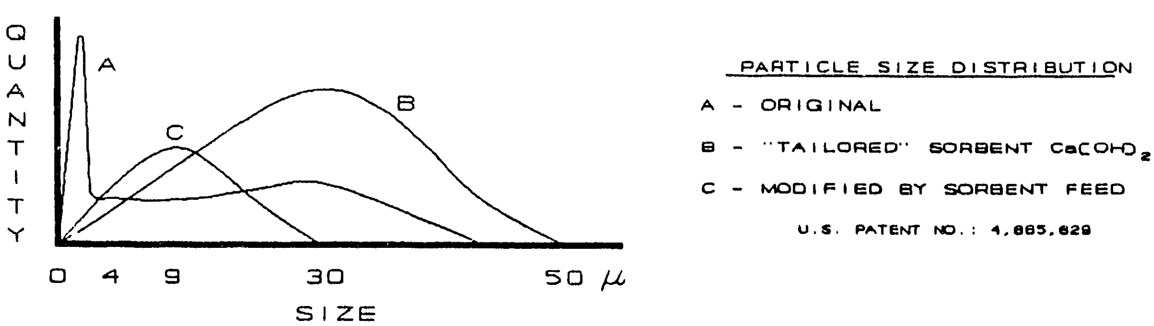

Figure 4. Modifying Particle Size Distribution with Sorbents

full" signal is registered at the controller. Effluent gas particulate averaged 2.17 x 10^{-4} gr./SCF. Figure 5 summarizes the operating conditions.

PLENUM CONCEPT

Experiences installing, and maintaining the original header/nozzle jet pulse delivery system led to the design of a much simpler and less expensive plenum system. Figure 6 illustrates the plenum system that was installed after about 1 year of operation. The original 15 candles were used in the new plenum.

The tubesheet portion of the plenum and the plenum chamber are fabricated of Fibro Plate™ 2600 H. The hold down is constructed of Fibro Plate 2600MH, a less dense material that is meant to be the sacrificial piece for lock-up.

All gaskets are Heet Lok™, a thermally expanding material comprised of approximately 50% vermiculite, 40% aluminosilicate fiber, and 10% binder. Filtered gas exits through a multi-aperatured flow control device called the Enhancer™, installed in the discharge conduit. The Enhancer (U.S. Patent 4,909,813) also introduces the jet pulse, and by design, minimizes the reflected (and subsequently lost) jet pulse cleaning gas. The hold down plate directly beneath the Enhancer is protected by a diverter cone which also aids cleaning gas distribution. The lower end of the Enhancer is equipped with a porous shield, the purpose of which is to prevent the passage of solids through the Enhancer in the event of a catastrophic candle failure. The plenum structure is cemented and then locked together with high purity alumina (ceramic) bolts.

"PIE CUT" SYSTEM

A plenum design for larger diameter filters has been devised called the "PIE CUT" system. Figure 7 illustrates the "PIE CUT" plenums which are fastened to the refractory in the top head of the filter. The plenums are further supported from the underside by a strongback and spokes of castable refractory. When the filter is sealed for service, the plenums are in compression between the top head and the chamber.

ECONOMIC EFFECT OF LIGHT WEIGHT CERAMICS

To determine the economic effect of light weight ceramics, several sizes of filters were cost estimated for operation at 217.5 psi (15 bar) based on the use of all light weight ceramics (Fibro/Fibro) vs. the use of cooled alloy (RA300) tubesheets and silicon carbide candles (Alloy/SiC). A jet pulse delivery system was included in both estimates. The Fibro/Fibro system was estimated with the plenum design while the Alloy/SiC system was based on header/nozzle design.

Battery limits were the filters and jet pulse delivery systems, Ex-works, with no main valves or dust removal systems. It was found that the cost of Fibro/Fibro components were consistently lower than the cost of the Alloy/SiC components; this comparison is illustrated in Figure 8.

TEMPERATURE	1100 to 1650 °F
CANDLE SURFACE (INSTALLED)	45 sq. ft.
CANDLE SURFACE (MAXIMUM)	255 sq. ft.
GAS FLOW	450 to 1710 A.C.F.M.
DUST LOAD	300 to 2000 P.P.M.
EFFLUENT GAS PARTICULATE	2.17×10^{-4} gr./SCF
JET PULSE FREQUENCY	10 to 30 min.
JET PULSE PRESSURE	85 to 90 P.S.I.G.
JET PULSE VOLUME/CANDLE	8 liters

Figure 5. Test Filter Operating Conditions

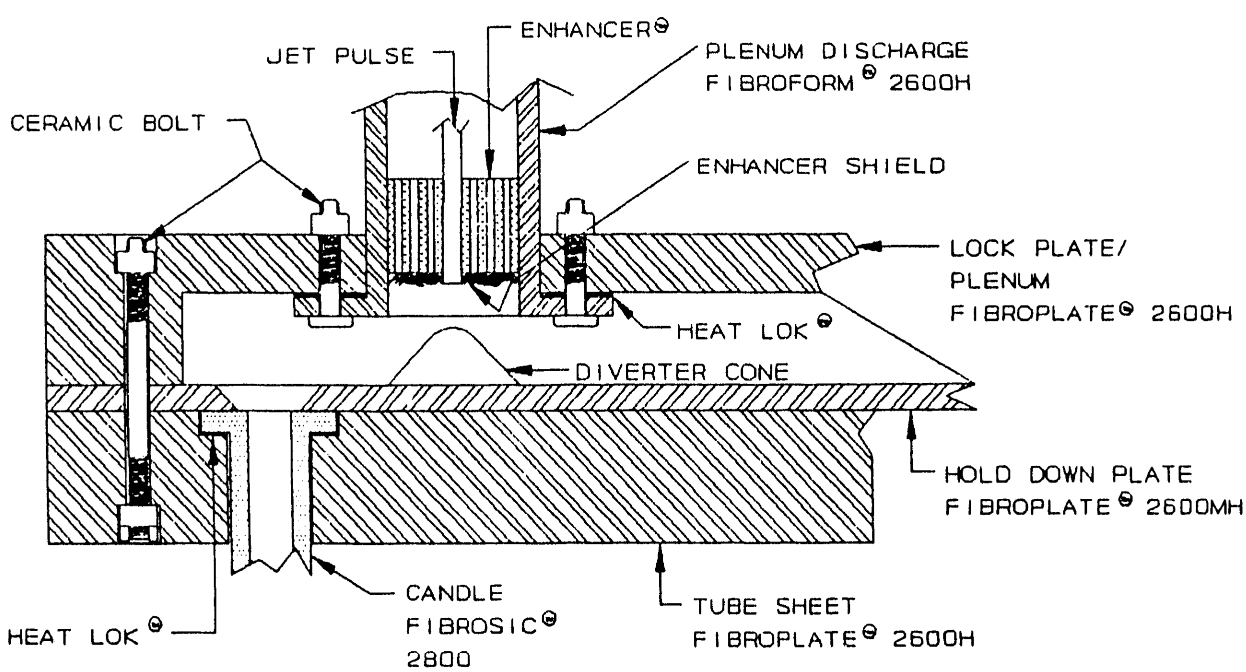

Figure 6. Ceramic Plenum Design

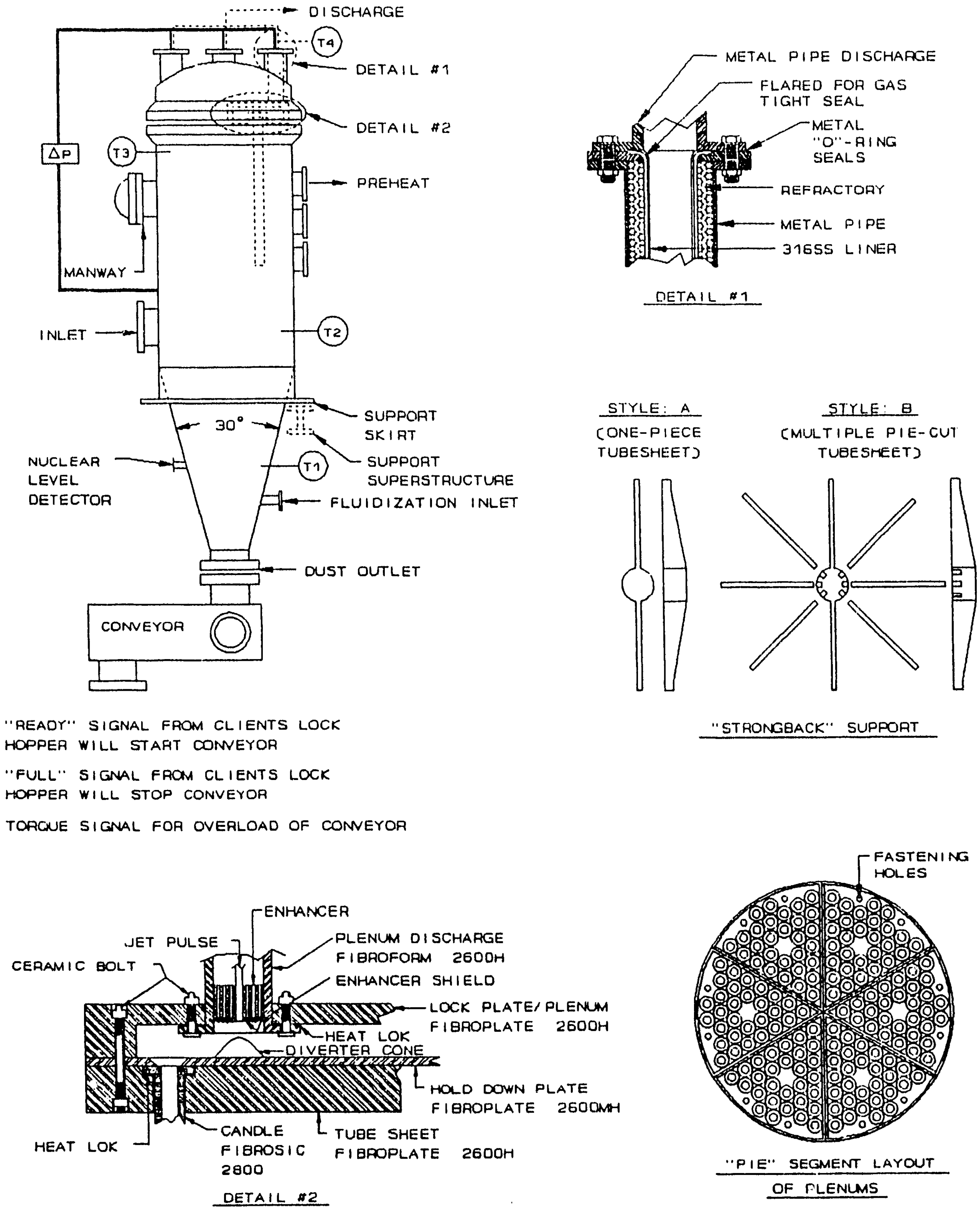

Figure 7. Large Filter Pie-Cut Plenum Design

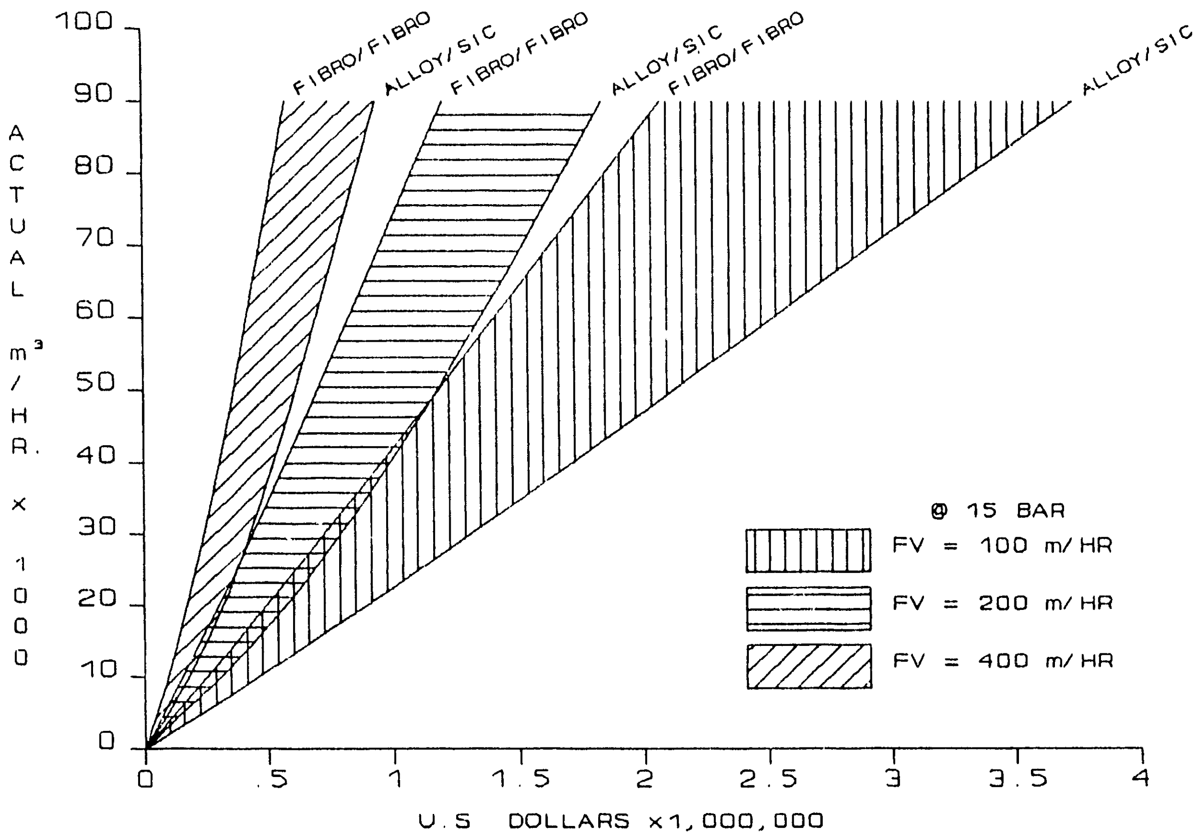

Figure 8. Filter Cost Comparisons with Varying Materials of Construction

CONCLUSION

In addition to the existing need for durable hot gas filters and components, there is a growing need for filters with higher temperature and thermal shock resistance capabilities that is being driven by process economics. "Traditional" materials used in hot gas filters, such as silicon carbide filter elements and alloy tubesheet and structural components, have been plagued by corrosion and erosion as well as thermal and mechanical design problems. As a result, the ever-present advances in ceramic material technology and novel ceramic filter components (especially vacuum-formed ceramics) have proven to be very promising candidates despite the harsh environments encountered.

Particularly promising are vacuum-formed aluminosilicate fiber components, which are low cost, easily manufactured, and possess outstanding thermal and chemical resistance. Densified versions of these fiber components show great promise as structural filter components in that their physical characteristics (e.g., tensile and compressive strengths) can be "tailored" to a given application. The end result is a filter with internal components that are made entirely of ceramics.

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