Circular HEPA Filters for use in Nuclear Containment and Ventilation Systems

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Abstract

Circular or Radial High Efficiency Particulate Air filters represent a fundamental step change in the development of containment filters as used by the UK nuclear industry. The circular plug-in design provides many advantages compared to the classic 'square' filter, not only in terms of performance, with installations that allow higher airflow and lower pressure drops, but also with regard to installation, operation, maintenance and very importantly, disposal, as circular filters are readily disposed of by crushing.

1. Introduction

This paper discusses the circular filter design in comparison with the established generic square product. Although this form of HEPA filter has been used for many years it has not been without it's problems. Particular attention is focused on the design principles which resulted in the development of the filters in the UK nuclear industry. These principles are synonymous with some typical problems experienced by operators in the US. For example, over 70% of the acknowledged documented reasons for filter failure in the US during the period 1968 to 1986 can be eliminated by the use of circular technology.[1]

Details are given of the application and experience of BNFL in the use of circular filters in containment and ventilation systems particularly within the Sellafield fuel reprocessing facility. The source of information provided is based on over 300 filter installations with single or multiple stages of containment. Other information provided include details of operational performance and the practical aspects of system maintenance, and the methods used in disposal and decommissioning.

2. Current Practice using 'Square' Geometry Filters

The classic square filter design has been the mainstay HEPA filter used in many industrial applications for many years. In most applications these type of filters provide all necessary performance and safety requirements and consequently the design has changed only incrementally. It has been the case within the critical safety industries such as the nuclear industry where filter design has come under more scrutiny and filters have been extensively modified due to inherent constructional limitations. The main focus however has been concerned with the operational limitations of these designs. The UK industry in particular has been in the forefront of innovative redesign of filters and the original equipment used within the main nuclear facilities.

The principal constructional limitations of square filters are associated with geometry and gasket integrity in both manual and remote handling situations.
Where geometry is concerned, one of the major issues is that inherent sharp edges that can cause damage to changing bags in safe change situations, which when considering the applications where bag changes are necessary present an unacceptable hazard to the operators and the environment.

Gasket integrity has long been a problem in ensuring that the gasket provided a reliable seal after manual or remote installation. The early filters had flat faced gaskets made of layered glass fibre but had little or no resilience. Technology then allowed the move to neoprene and silicone seals, but again the long term behaviour was inconsistent. Knife edge seals were developed to provide positive location and compression. The means by which a seal could be shown to be effective was by the development of a seal test groove arrangement which allowed the interspace between two adjacent knife edges to be pressurised. The retention of pressure on the seal demonstrates seal effectiveness on installation and throughout the filter life time.

The problem throughout is that the filter requires correct orientation. This is a major factor with manually located filters, but presents enormous problems when handled remotely, because the filters require precise orientation and alignment with the seat on installation using power manipulators. Power manipulators have low availability and require considerable maintenance. It is almost impossible to ensure that the gasket provides an efficient seal even when the compressive loads involved are small. Some installations add weight to the filter element in an attempt to improve the seal.

An illustration of the problems associated with square geometry filters is shown by the survey carried out by ANSI which studied HEPA filter failures from 1968 to 1986. (2) (see Figure 1) This survey decided that there were three major causes of failure. These were; defective filter media, damaged gaskets and insufficient clamping. The criteria for 'failure' being defined as an inability to provide the decontamination factor (DF) required. The failure modes also included incorrect positioning and defective frames.

3. Circular Filter Technology

Circular filters were developed in the UK nuclear industry primarily to overcome the problems associated with orientation and handling in remote handling situations in highly contaminated environments but provide many advantages in other configurations. As stated in the introduction, over 70% of the acknowledged documented reasons for filter failure in the US between 1968 and 1986 are eliminated by the use of Circular filters.

Figure 2 shows a typical 3400 m^3/hr Circular filter element.(3)

The use of an internal lip seal (see Figure 3) represents the highest performance with the least force required. It is integral to the design and is extremely effective in negating alignment problems as it eliminates the restrictions of the square filters in terms of remote handling. Orientation is no longer a limitation and the placing system can be a simple wire rope hoist with a latching mechanism. This is a major improvement on the use of power manipulators as it increases availability and reduces maintenance.

The lip seal is primarily responsible for the elimination of the majority of the causes of failure with the traditional square filters. The principal benefits are:

- By pass and filter frames are no longer an issue.
- Clamping is not required.
- The gasket is less likely to be damaged in normal handling.
- Positioning and orientation are no longer required.
- The filter is entirely free of sharp edges and the sealing face integrity is highly reliable and repeatable.

Other important features are:
- The filter is normally used in to out so that the collected contaminant is on the inside. This allows the filter to be plugged after use to limit the loss of collected material.
- The outside surfaces are 'clean' thereby making handling as safe as is practicable.
- The construction is much more straightforward than the traditional square filter. It is less prone to handling damage as the media surface is protected.

In terms of performance the 3400 m^3/hr or 950 lps Circulars has a PD of 250 Pa at free discharge and 290 Pa installed at the rated flow rate. A comparison of Circular filter dust retention wih standard extended area deep pleat and minipleat filters against Carbon Black is shown by Figure 4 and illustrates the filtration characteristics of the Circular filter.

The Circular filter is available in a range of constructions. These include low temperature up to high temperature configurations. There is also a low temperature version which is fully incinerable to allow post incineration collection of fissionable materials etc.[4] The low temperature Circular filter range is shown by Figure 5.

The Circular geometry allows the use of external 'O' ring seals for push-through filter configurations for use in glove box applications [5] (see Figure 6).

The initial applications within the UK using circular filters were housings for remote handling at the THORP complex. These were followed by single manual change housings as it was determined that there were significant advantages compared to the standard square geometry. (See Figure 7 for examples of single element housings)

Following experience with single housings, banked multiple element housings were developed. (see Figure 8)

During the design of the second Encapsulation Plant at Sellafield a genuine multiple element housing was developed and patented by BNFL [6] with a single upstream and downstream plenum

with individual filter access. This housing design became known as the EP2 style which is now the most commonly installed variation due to the flexibility of inlet and outlet configurations afforded to the system designer.
(see Figure 9 for a typical 27000 m^3/hr EP2 housing and Figure 10 for a more conventional installation)

Circular filters are also used in single or multiple element mobile units for temporary or emergency ventilation requirements. (see Figure 11)

4. Operating Experience with Circular Filters

Circular filters have been used extensively throughout the nuclear industry in the UK since 1984. Table 1 shows the range of installations in the UK Nuclear industry. Other applications have been found in the commercial sector. It can be seen that the largest installations are on the BNFL sites at Springfields and Sellafield.

Table 1: Circular filter installations in the UK.

Operator	Number of Filters	Types and uses
BNFL Sellafield	2000+	Circular, EP2. (90% Manual, 10% Remote), Mobiles
BNFL Springfields	300+	Glove Boxes, Circular, EP2
Joint European Taurus	100+	Circular
AEA Dounraey	50+	Circular, Mobiles
AWE Aldermaston	50+	Circular, Mobiles
AEA Harwell	20+	Circular, Mobiles
Commercial	40+	Circular

In addition Nuclear Electric (now Magnox Electric) are refurbishing existing plant in their Power Stations using Circular technology.

It is fair to say that the UK Nuclear industry is now almost exclusively installing Circular containment systems for new or refurbished applications.

The largest installation of circular filters is the THORP plant, where there are 280 units with manual bag change arrangements and 30 units with remote change arrangements. The ventilation systems of the THORP plant have been previously presented to this conference [(7)], but since then there has been operational data generated on their performance.

The life of a filter in service can be determined by a number of criteria which include:
- Plant safety case requirements for pressure differential

- Cost of disposal
- Conditions for acceptance of waste (activity level, imposed life time limitations, ageing corrosive air streams etc.)
- System operating parameters

There has been much pressure in recent years to reduce energy consumption primarily at Sellafield, as the cost of electricity for running air movement plant was in excess of £20 million in the mid 1980's. The biggest effect on the energy consumption is the fan head, which is determined generally by the filter differential pressure. Lowering the change differential pressure can dramatically reduce the allowed fan head and hence the energy consumed over the life of a plant.

5. Experience with Circular Filters at THORP

THORP is the Thermal Oxide Reprocessing Plant at Sellafield, Cumbria, UK. The facility has been fully operational for five years and contains over 300 circular filter installations in a wide variety of applications. In that time the experience has shown that the original safety case estimates of time to filter change were pessimistic with the exceptions of the vessel ventilation and dissolver offgas systems which are associated with corrosive vapour streams. It was estimated that changes from shielded installations alone would reach 200/yr. This in fact is running at about 40 changes per year even allowing for the more frequent changes on the corrosive streams.

The vast majority of the installations have performed very well with in-situ measured decontamination factors in excess of 10^4 for a single stage of circular HEPA filter.

Another major finding is that the activity arisings on the various streams and hence the filters are not as high as were originally estimated.

Filter changing can be based on any of the criteria given previously but the cost of disposal is a major factor. There are three routes for the disposal of filters at Sellafield and each has an associated cost per circular filter;

Low Level Waste (LLW)	£164
Intermediate Level Waste (ILW)	£16447
Plutonium Contaminated Material (PCM)	£1750

There is therefore a great incentive to prevent filters being classified as LLW as long as the conditions for acceptance can be met. It has become clear during the five years of operational experience and the knowledge gained of the performance characteristics of the process that the majority of installed filters are able to be disposed of as ILW without any special considerations.

The criteria established for most filter changes is time. It has been decided that no filter will be left in service beyond the age of five years from the date of manufacture. This period is split as being two years storage life and no more than three years of installed service life. Most of the filters currently on line in THORP were installed in 1992/3 and hence the campaign of filter changes has been under way to comply with the 5 year rule. However, none of the currently installed filters have shown signs of fatigue or have failed an efficiency test.

The filters installed on the corrosive vapour streams are changed based on inspection via CCTV of the corrosion of the filter mild steel components. A programme is under way to replace these filters with those of a stainless steel construction and it is anticipated that the life to changeout will also become time based at 5 years from manufacture.

The glovebox extract system from the Plutonium finishing area has a push-through filter local to the glovebox and two stages of circular filter in the plant room. The local filters are disposed of as PCM, but the plant room filters are being disposed of as LLW. They are changed every two months to limit the potential for Alpha material on them and they are examined and monitored prior to sentencing as LLW.

6. Other Considerations

It is evident that if filters are prevented from reaching the ILW classification during normal operations, the costs can be reduced dramatically. Spent filters would therefore be cheaper to dispose of if they were simply changed more often. This method has been utilised on a number of plant at the Sellafield complex to reduce the operational costs.

More frequent changes have the added benefit of reducing the dirty filter differential pressure and hence the fan head required. In this way energy consumption is also reduced.

However, the result of more frequent filter changes is a greater volume for disposal. The cost saving made due to the change from ILW added to the reduced energy consumption may in some cases be offset by the increased volume in LLW using conventional geometry filters. Circular filters however provide additional benefits with regard to disposal.

The 950 lps circular filter has a volume of 130 litres and was designed to conveniently fit into a standard 200 litre disposal drum. Work carried out within BNFL [(2)] has shown that circular filters can be crushed in the axial direction to 20% of it's original length (see figure 12) whilst retaining the contaminant. This ability allows five filters to be disposed of in the same 200 litre drum, thus making significant overall savings.

Crushing of circular elements was not fully developed when THORP was designed and constructed and hence a crushing facility was not included. However more recent plant now under construction such as the Sellafield Drypac Plant have incorporated a crushing facility.

In principle, all spent filters can be crushed under controlled conditions within the facility from which they originate prior to being transported for storage or further processing. At Sellafield all LLW is passed through the Waste Management and Compaction plant prior to leaving the site for the land burial site at Drigg. As mentioned previously the vast majority of THORP's waste filters are classified as LLW and are therefore compacted before final disposal.

7. Future Development

Certain aspects of current AESS specifications for high temperature filters are considered excessive and will be superseded. One such condition is the requirement to withstand 500 C for 10 minutes. This value will be reduced to 350 C in the new BNFL specification currently being prepared. This change allows alternative sealing materials to be used instead of the mineral (ceramic) most commonly in use today. This development is another move to enhance the reliability of the filters used within BNFL facilities on the basis that a few filters have in the past been found to have sustained cracking of the mineral sealing material.

The feedback to the ventilation system designer based on the operation of the most recently completed plant at Sellafield has been that the typical dirty filter differential pressure of 1250 Pa can be reduced for most installations and future designs will take this into account in order to potentially save significantly on lifetime operating costs.

8. Summary

Circular or 'Radial' filters offer significant advantages to the designer and operator of containment systems in comparison with the classic 'square' format.

They represent a great advance in HEPA filter technology as used in the nuclear industry in the UK.

9. References

1) Radioactive Waste Management Handbook, Volume 2, 1990, page 413
2) Nuclear ventilation High Efficiency Particulate Air (HEPA) - Lessons learned, DOE, USA, 1998
3) AESS 30/95100, Specification for 950 lps Circular HEPA Plug In Inserts, 1990
4) Patent Application No. 9303491.6. Totally Combustible HEPA Filter. 1993
5) AESS 30/95200, Specification for 12.5-160 lps Circular HEPA Push Through Inserts, 1991.
6) Patent Application No. 9015136.6. Improved filter assemblies. 1990
7) Hudson P.I., Buckley C.P., Miller W.W., The development and design of the Off gas treatment systems for the Thermal Oxide Reprocessing Plant (THORP) at Sellafield, 24th DOE/NRC Conference 1996.
8) BNFL internal paper on high force compaction of filters, 1996

10. Figures

Figure 1: Results of ANSI HEPA Filter Survey (N510)
Figure 2: 3400 m^3/hr Circular HEPA filter
Figure 3: Circular Lip Seal
Figure 4 : Dust retention comparison of various filters at 3400 m^3/hr
Figure 5: Push Through Circular HEPA Filters

Results of ANSI HEPA Failure Survey

1968-86 (3160 tested, 351 failures)

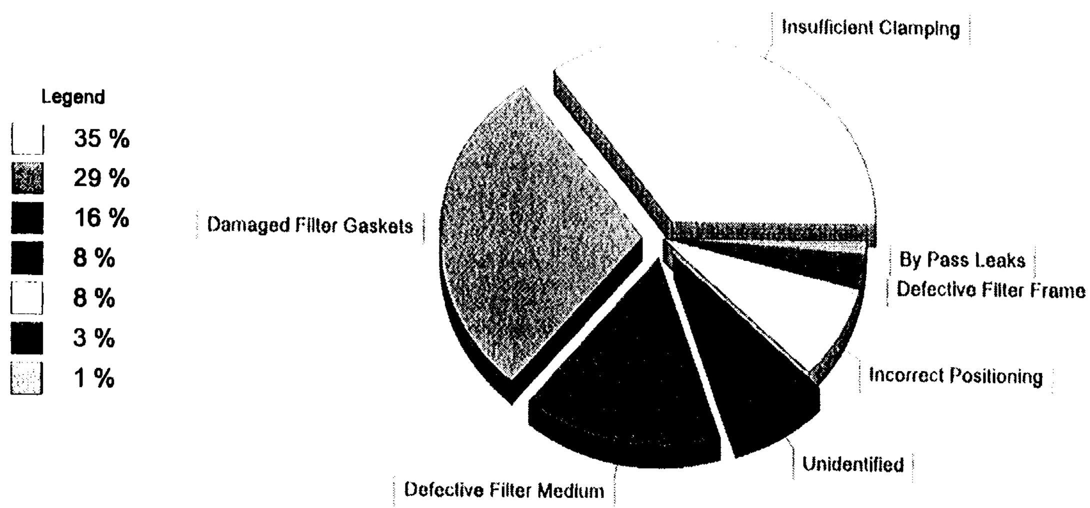

Figure 1: Results of ANSI HEPA Filter Survey (N510)

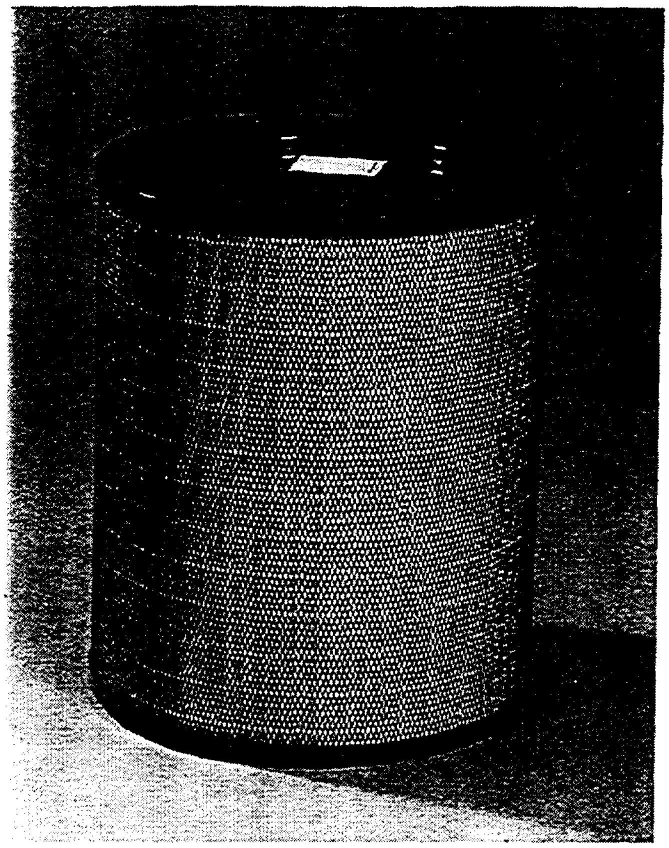

Figure 2: 3400 m^3/hr Circular HEPA filter

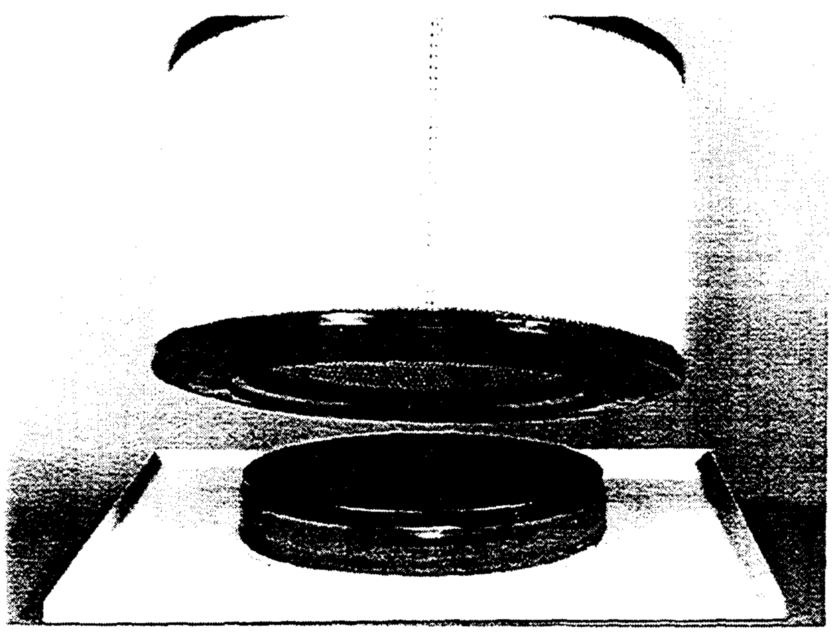

Figure 3: Circular Lip Seal

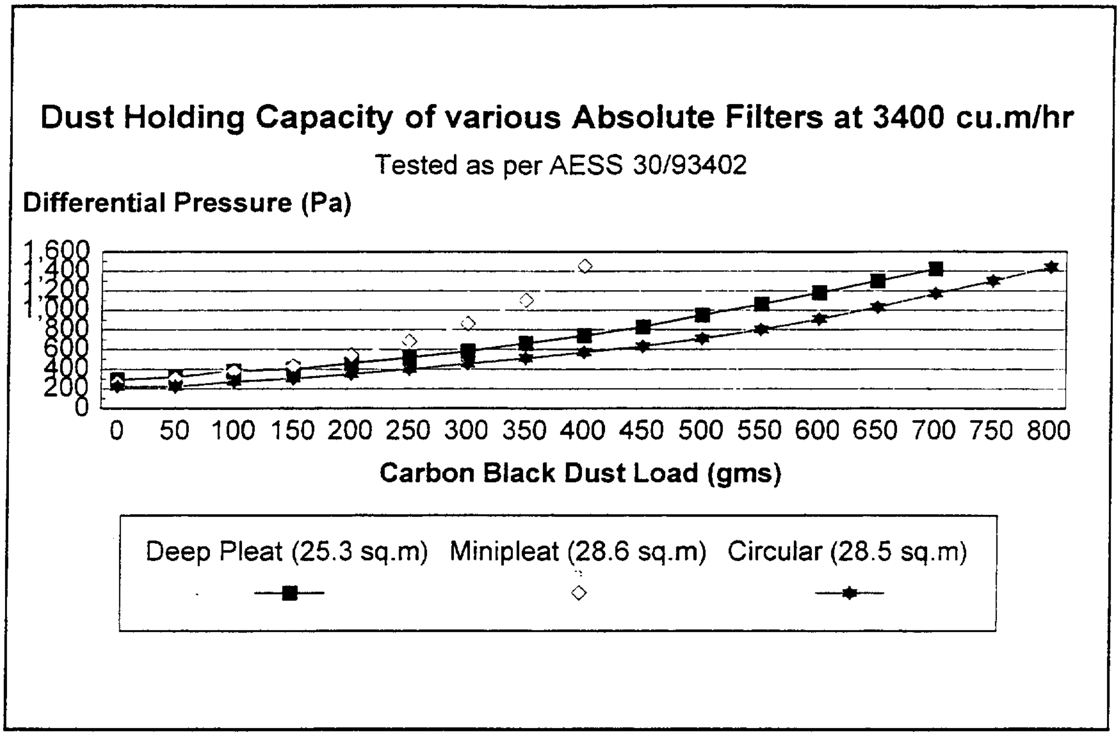

Figure 4 : Dust retention comparison of various filters at 3400 m^3/hr

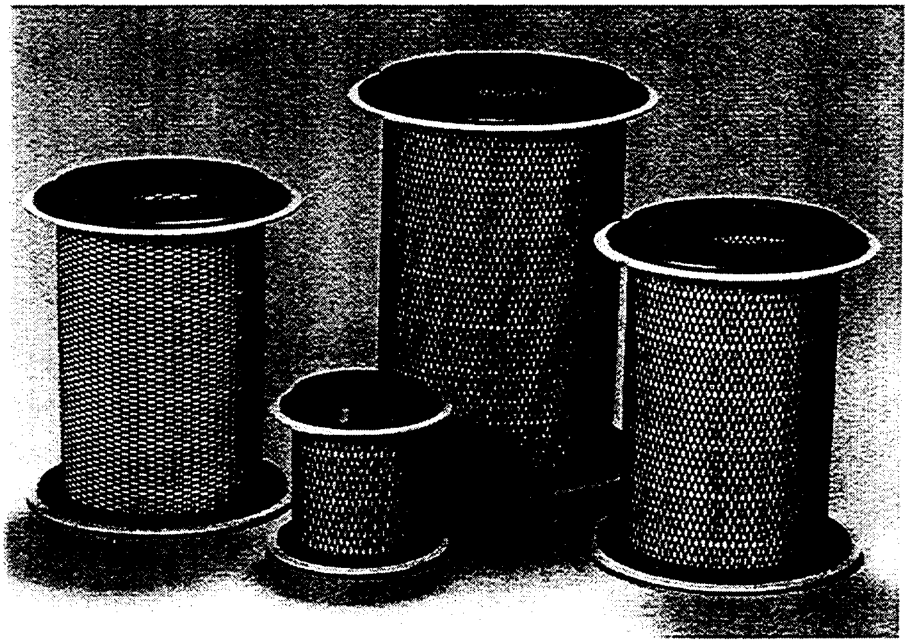

Figure 5: Push Through Circular HEPA Filters

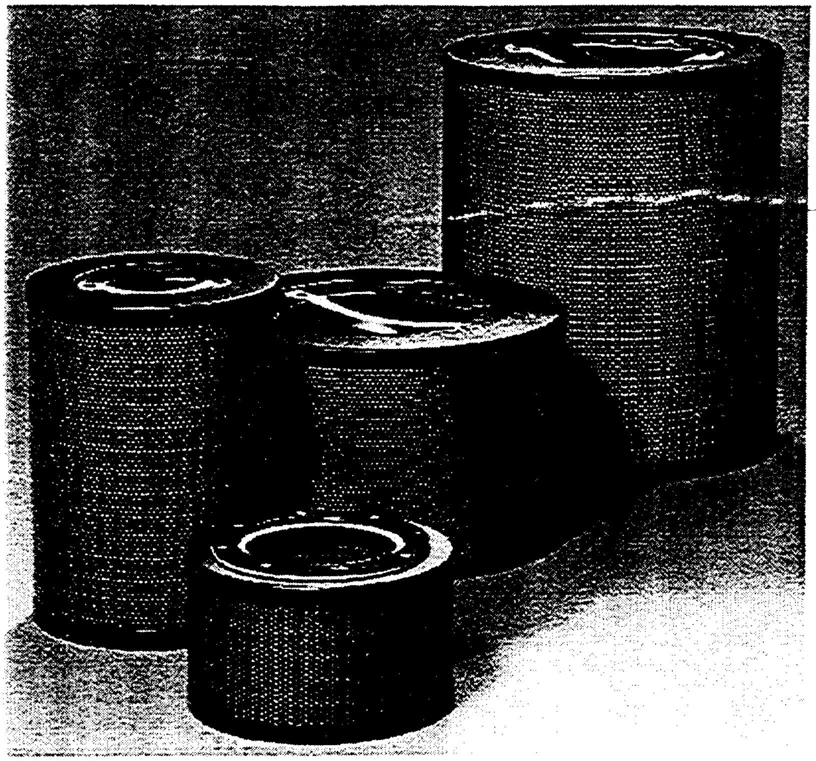

Figure 6: Range of Low Temperature Circular Filters

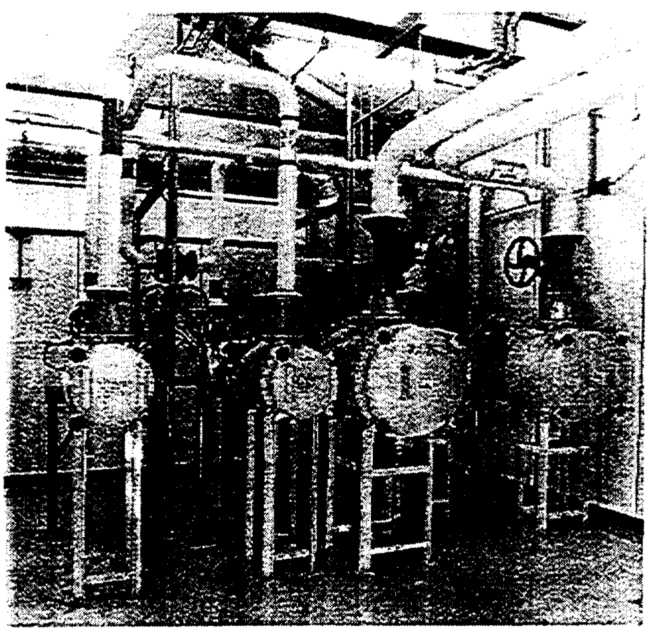

Figure 7: Single Circular Element Housings

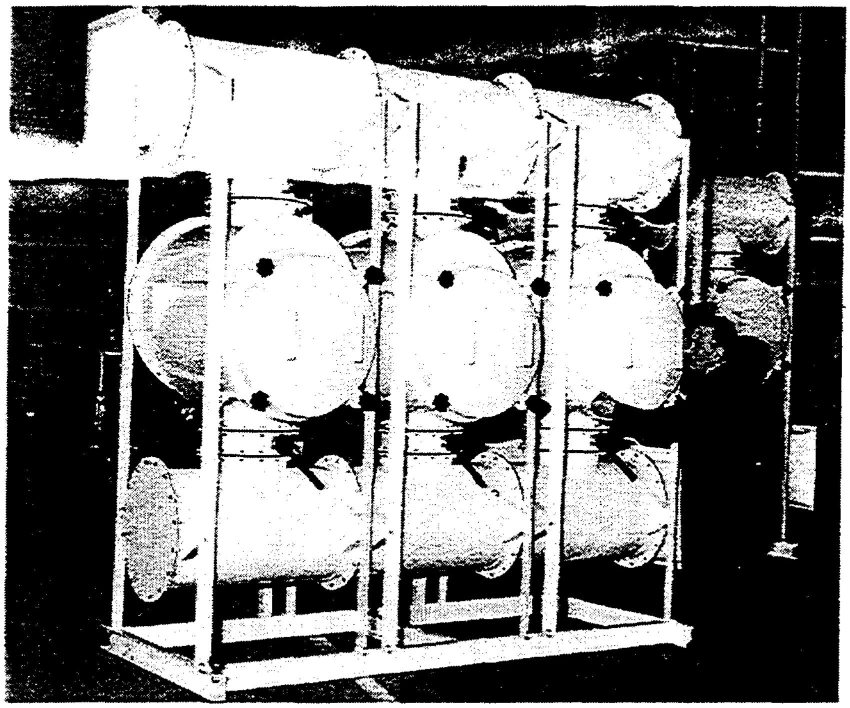

Figure 8: Banked Single Element Circular housing

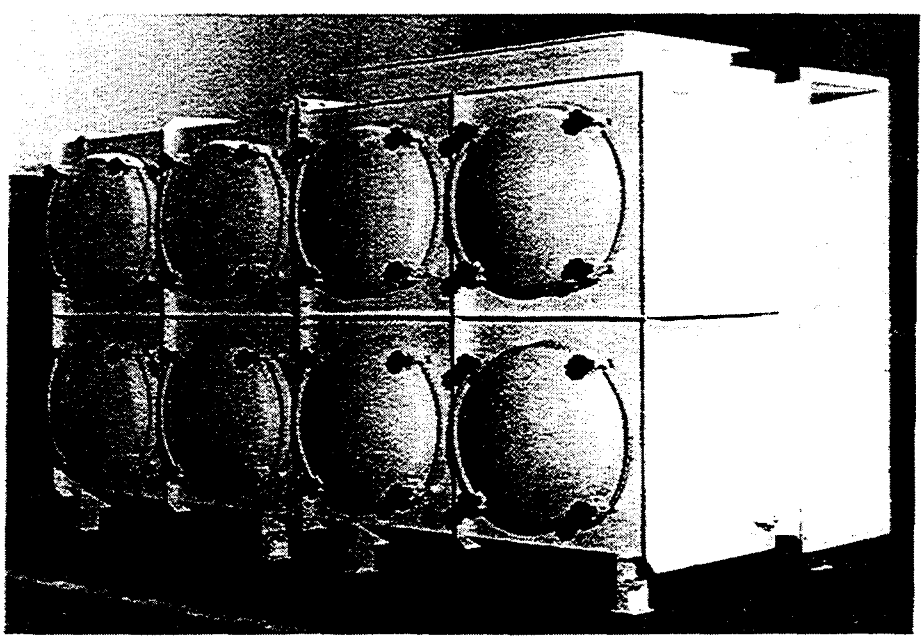

Figure 9: Multi element EP2 Style Housing

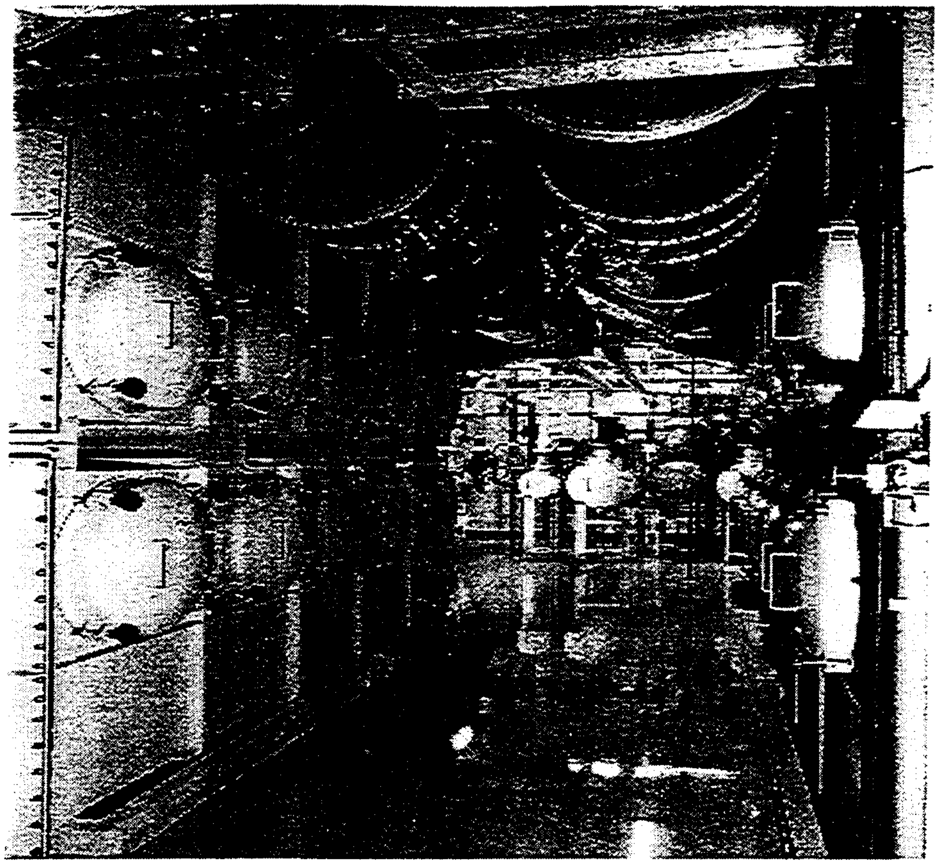

Figure 10: Installed Circular Multi Element EP2 and Single Element housings

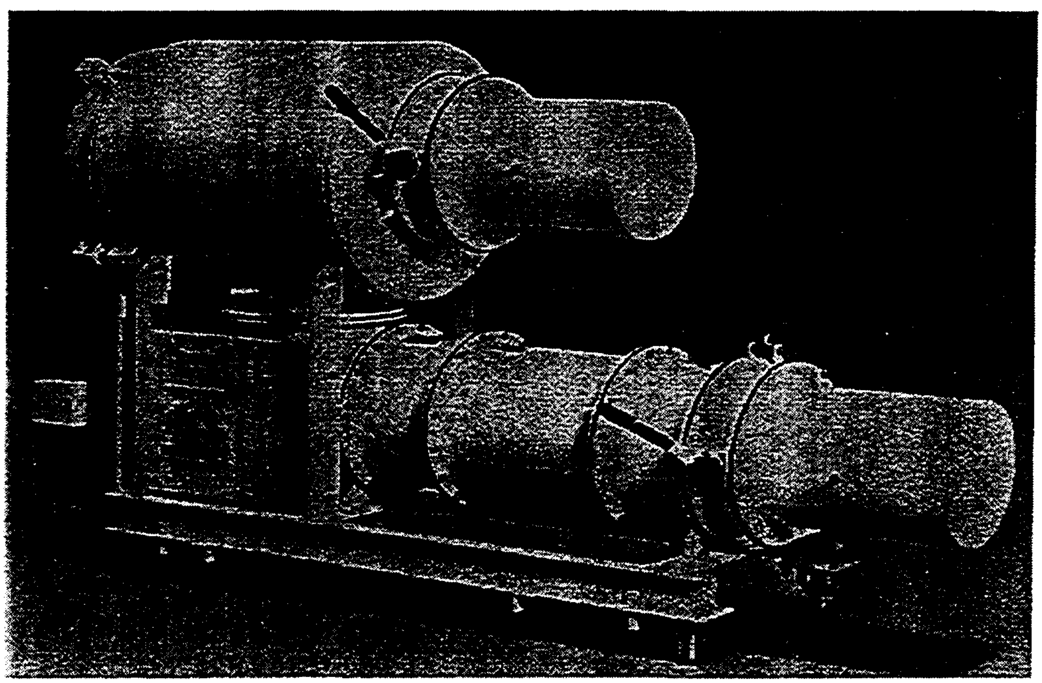

Figure 11: Circular Mobile Filter Unit

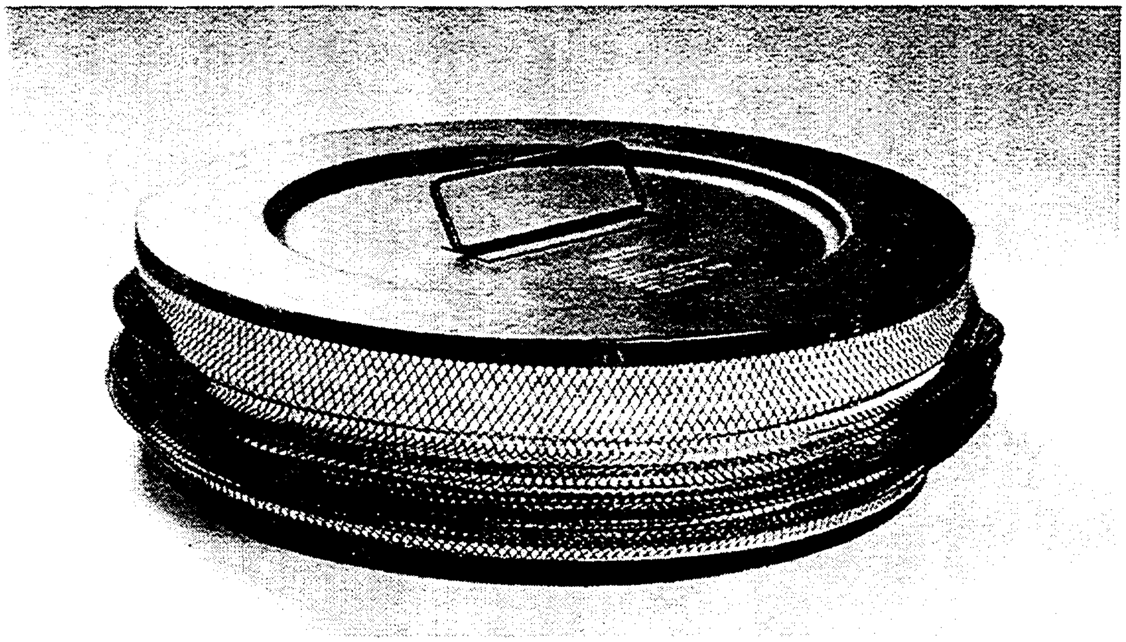

Figure 12: Crushed 3400 m^3/hr Circular Filter