John Hampton, Filtration Technology Corp, USA, and Guy Weismantel, Weismantel International, USA, consider the costs (both direct and indirect) associated with changing out cartridge filters used in hazardous applications, and discuss the contribution of these costs to the total cost of cartridge filter ownership and the benefits of using high capacity (HC) filters.

Examining the True Cost of Cartridge Filter Change-out

During a meeting of the American Filtration & Separations (AFS) Society several years ago, the top filtration engineer at Exxon pointedly stated: "One of our company goals is to totally eliminate filtration from all our process operations." He went on to explain that that goal was directly related to economics because:

(i) Filtration often indicates impurities – impurities that must be removed because of poor quality feedstocks, inadequate conversions, poor processing or contamination from various sources.

(ii) The filtration unit operation is one of the most expensive that takes place within a refinery or petrochemical plant, especially when the filter and the filter media are handling toxic or hazardous materials. This greatly exacerbates disposal costs.

In contrast, DuPont's filtration guru points out that 70% of the company's products are in a suspension form at some time during their processing, making filtration the most important of all unit operations utilized by this chemical giant.

It is little wonder then that more on-line time, extended mean time between change-out (MTBC), higher efficiency and higher dirt holding (or product holding capacity) are essential to reduce both operating and maintenance costs. For example, change-out costs skyrocket when a cartridge filter (or any filter) is handling toxic or hazardous wastes, such as in acid filtration, or when a filter (air/particulate filter or liquid/particulate filter) is handling toxic materials - particularly if personnel must 'suit up' with protective clothing to facilitate cartridge removal from housing vessels and ultimate disposal under Resource Conservation and Recovery Act (RCRA) requirements.

It is unsurprising that return on investment (ROI) is dramatically affected by filter selection and filtration costs, and yet this unit operation is virtually ignored by most companies and is seldom taught in chemical engineering curriculum. This article addresses the cost considerations related to change-out, but keeps in mind that there are other costs to be considered in the total cost of filter ownership.

Overview

Because filtration costs can be very high, it is no wonder that both the refinery and petrochemical businesses consider specific pros and cons of new filtration technology when it becomes available. This includes: self cleaning filters (especially for catalyst operations) and filters with high dirt holding capabilities and extended MTBC.

Catalyst recovery and/or catalyst conditioning receives special attention because many catalyst contain platinum or other nobel metals. If contaminants enter the reactor and poison the catalyst

Table 1: Comparing annualized costs of non-hazardous & hazardous/toxic filter replacement (basis: standard cartridge elements)

Item	Non-Hazardous Service		Hazardous-or-Toxic Service	
	Basic	Cartridge	Basic	Cartridge
Purchase price of filters	Same	Same	Same	Same
Disposal cost	US$50 per drum per change-out	$50	$500 per drum per change-out	$500
Change-out time (hours)	1 hour		1-8 hours	
Change-out labour cost per hour	1 man @ $25-30/h	$30	3 men @ $100/h*	$2400
Protective clothing & respiratory cost	None	None	$100/h	$800
Oxygen source & other equipment	None	None	$100/h	$800
Decontamination expense	None	None		$400
Total change-out cost		$80		$4900
If there are four change-outs over 12 months		$320		$19 600
One-time training expense	1 day @ $400/h	$3200	4 days @ $400/h	$12 800
Total cost		$3520		$32 400

**One man suited with protective clothing and oxygen breathing apparatus.*

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Table 2: Typical data for 20 micron absolute pleated polypropylene cartridge.

Cartridge type	Dirt holding capacity	Typical cost	Alpha factor
Standard (2.5" OD)	1.7 pounds	$33.25	19.6
HCF (6.25" OD)	17 pounds	$267.75	15.8
UHCF (12.75" OD)	85 pounds	$1015.00	11.9
UCF (20.0" OD)	255 pounds	$2250.00	8.8

or reduce its efficiency (due to particulates plugging pores), a unit's production can drop dramatically causing millions of dollars in lost revenue. Consequently, when selecting filter cartridges, it's important to consider both the initial purchase price and long-term costs. The extra efficiency and increased MTBC of a high capacity (HC) filter easily pays for itself over time. This is partially because you do not have to change them as often, saving both filter costs and maintenance time. This is particularly true when the service is toxic or hazardous.

A simplified comparison (Table 1) shows how much more expensive it is to change-out filters in the hazardous versus non-hazardous situation. It becomes very clear how overall cost decreases by using higher performance HC filters with improved dirt holding capacity and better on-line time. By comparison, the HC filter may be changed out only two to three times per year, while the standard low capacity filters may be changed out 18 or more times. On that basis, the savings to the customer could reach over $437 000 annually by using an HC unit, but more importantly, employees will not be exposed as often to the potential danger of change-out.

In that light one should consider the following questions when selecting a filter cartridge:

- Can HC filters be used in existing filter housings?
- How will the MTBC be affected with the use of HC cartridges?
- How will the dirt holding capacity and particulate removal efficiency be affected?
- Will process changes affect filter selection?
- What filtration efficiency must be met?
- Will an HC unit assist in meeting regulatory compliance or other standards?
- How often will the filter cartridges need to be replaced compared to standard string wound or single pleated cartridges?
- What is the true cost to change filters, including downtime, loss of production, frequency of change-out?
- What is the ROI if we select HC technology?
- How will overall capital, operating and maintenance costs be reduced?

Design engineers should recognize that a similar analysis takes place with air filtration, either in a process or power plant or in heating, ventilation and air conditioning systems (HVAC) on a control room (which if often fitted with an activated carbon filter for sulphur removal). In an HVAC system the annual cost is analyzed over the cost per ft^2 of (or volume of ft^3) serviced.

The total cost of ownership must include:

- Air purifiers and pre-filters
- Replacement costs of actual filters and pre-filters
- MTBC
- Head loss costs

If we continue to consider air filtration (such as world-scale sulphuric acid plants or power plants), the head loss of one inch of water can be as high as US$10 000 annually.

In respect to the above general analysis, whether a filter is used in liquid/particulate or in gas/particulate service, the hazardous and toxic filter replacement should include the cost of additional insurance cost and additional record keeping including transportation manifests. The 'paper trail' for filter disposal must be carefully kept and available to the enforcement agencies.

Also, for both gas or liquid filters handling hazardous or toxic materials differential pressure gages should be fitted. At the very least these instruments should give a visual indication of the pressure across the filter. Greater safety is provided by an instrument that also sounds an alarm when the pressure drop is excessive. A device that shuts the entire system down when filter pressure is abnormally high provides the most protection.

One final point that increases the cost of filter replacement of hazardous/flammable materials, is that the operator's equipment and clothing (e.g. shoes, gloves, etc) should not be made of materials that lead to the build-up of static electricity.

Given this general background information, we can now consider a general example dealing with processes that are found in all refineries, gas processing plants and petrochemical facilities.

Liquid Process Filters

When cartridge filters are used in refinery or petrochemical operations, there are several factors that affect both performance and operations. These are: chemical and temperature compatibility, flow rate, acceptable pressure drop, degree of filtration and overall filtration cost. Depending upon the size of the liquid process filter unit, an HC system will use one of the following cartridges that are approximately 40 inches in length:

- 6.25" OD – High capacity filter (HCF)
- 12.75" OD – Ultra high capacity filter (UHCF)
- Full housing (20" OD) – ultimate capacity filter (UCF)

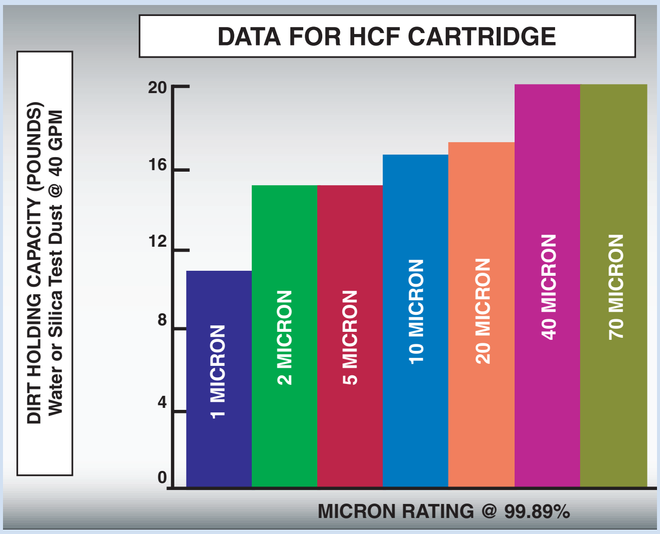

Figure 1: Dirt holding capacity of HCF cartridge filters.

HCF, UHCF and UCF cartridges are designed to provide high quality filtration, while maximizing dirt holding capacity in order to assure maximum time between change-out. Many process streams are hazardous, so producers try to keep the units on-line as long as possible to improve MTBC.

These cartridges utilize segregated flow channels and flow chambers to optimize the Alpha Factor (Å): a factor that is the key to determining total cost of filtration operations. Combining this design with the technique of pleating several different filter media together in a single pleat pack maximizes dirt holding capacity. This design permits the use of many different types of filter media. This is essential for a wide range of fluid and temperature applications.

As with all refinery and chemical operations, materials selection is very important in process filtration. Since streams vary in chemical composition, it is difficult to designate a filter medium that is ideal. Other complications can arise from the glues and seals used in filter construction. Commonly used media include: polyester, fibreglass, polypropylene and cellulose. However, operating temperature and presence of various chemicals in the system will affect filter choices.

Both filter housing and pump sizes are dictated by the desired flow rate, pressure drop limitations and required level of filtration. The recommended flow capacity of a filter element is used to determine the total number required for the desired flow rate. Housing size relates directly to the number of filter elements. Sufficient pump pressure must be provided to permit the desired flow rate through the filter element as it plugs so as to fully use the effective dirt holding capacity of the filter. It is imperative that daily testing of the process stream (using sample ports) be conducted. Testing is critical in identifying when upset conditions exist within most processes.

Calculating Filtration Costs

Filtration Cost Efficiency (E) is defined as the total costs (direct and indirect) that are associated with removing one pound of solids from a process stream. Direct cost is filter price and indirect costs include labour and disposal. A lower total cost results in a better efficiency rating. If we disregard equipment depreciation, we can express this relationship by the following formula:

$$E = \frac{P}{H} + \frac{L}{H} + \frac{D}{H}$$

where D = disposal cost/filter, H = dirt holding capacity in pounds, L = labour cost/filter and P = filter price.

Filter price and dirt holding capacity are the dominant components in operating cost. The relationship between these two items is defined by the following formula as the Alpha Factor (Å):

$$\text{Alpha factor (Å)} = \frac{\text{Filter price (P)}}{\text{Dirt holding capacity(H)}}$$

Combining the Alpha Factor formula with the Filtration Cost Efficiency formula provides an interesting result:

$$E = A + \frac{L}{H} + \frac{D}{H} \Rightarrow E = A + \frac{L + D}{H}$$

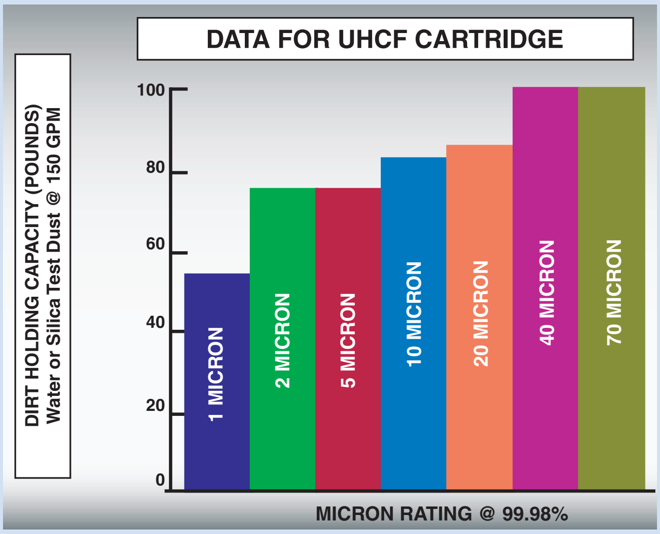

Figure 2: Dirt holding capacity of UHCF cartridge filters.

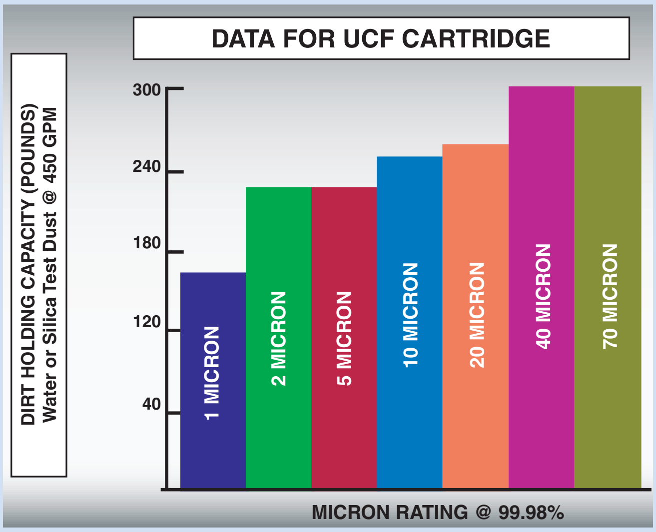

Figure 3: Dirt holding capacity of UCF cartridge filters.

The indirect costs shown in the equation are reduced as the dirt holding capacity of the filter increases. Therefore, the Alpha Factor becomes the dominant number in the equation. The lowest Alpha Factor results in the lowest filtration cost (Table 2).

Mean Time Between Change-out

A filter is changed out when it reaches its maximum dirt holding capacity. This can be defined as the total volume of fluid that passes through a filter before reaching the maximum operating differential pressure.

With a constant flow rate, the life of most absolute rated filters is significantly increased when their effective surface areas are increased. This property of filter life is a direct result of the relationship between flow density (gallons per minute per ft^2) and the resulting differential pressure across the filter area.

Under ideal conditions the maximum increase in filter life is equal to the square of the increase in effective surface area. Doubling the effective filter surface area can increase filter life up to four times.

Table 3: Monthly Operating Parameters (36" ID vessel, contaminate load 72 pounds/month).

Parameters	String wound (2½" OD)	Pleated filter (2½" OD)	HCF (6¼" OD)	UHCF (12¾" OD)
Depreciation	$400.00	$400.00	$400.00	$400.00
Filter cost	$1620.00	$1396.50	$1119.20	$862.75
Labour cost	$150.00	$35.00	$11.50	$4.25
Disposal cost	$720.00	$168.00	$104.50	$89.25
Total cost	$2890.00	$1999.50	$1635.20	$1356.25
Alpha factor (Å)	22.5	19.6	15.8	11.9

$$\text{Filter life increase} = \frac{Le}{Lo} = \frac{(Ae)^N}{Ao}$$

where Le - extended filter life, Lo = original filter life, Ae = expanded filter area, Ao = original filter area and $1 \leq N \leq 2$.

Given the above, our options are:

- Increasing the actual number of filters by increasing the size or number of housings.
- Changing to a HC filter, such as an HCF, UHCF or UCF. (Figures 1, 2 & 3)

In respect to cartridges with an HCF filter, the product is designed to replace up to 40 string wound or ten pleated 2.5" OD cartridges. The UHCF replaces 200 string wounds or 50 pleated elements. The UFC for a 24" OD housing is 20 inches in diameter and replaces 600 string wounds or 150 pleated elements. One can see that there is a quantum leap in dirt holding capacity when using a HC filter. Designed to fit most standard cartridge housings with minor, if any, hardware modifications, HC filters provide a very cost effective method of maximizing effective surface area in existing housings.

Change-out Economics

In addition to filter element costs and MTBC, design engineers must also consider housing/vessel costs. When one considers capital spending costs for new installations, the savings associated with filter housing costs is equally important. Many plant engineers design their filtration systems based on a maximum flow rate. If a 2.5" OD cartridge is used in the base flow rate calculations, a larger vessel will be required to meet the maximum flow requirements. Using an HC design will minimize the filter vessel size (and costs) required for specific flow rates and can result in significant cost reductions when high pressure filter vessels are required.

With an increasing demand for more cost effective filtration, new HCF and UHCF filter technology provides an excellent opportunity for reducing filtration costs in existing and future operations.

Tables 3 shows how cost savings can be realized by applying the basics of change-out costs to one's current operations.

Summary

In conclusion there are four important factors when selecting a filter and when considering the effect on MTBC:

- A filter element's Alpha Factor (Å) is easy to calculate. The lowest Alpha Factor results in the lowest filtration cost.
- An increase in effective surface area or a reduction in flow rate will result in a significant increase in filter life.
- HC filtration technology reduces filtration costs, both capital costs and maintenance costs (by improving MTBC), and is applicable to both retrofit and in new construction.
- Total filtration operating cost must include: equipment depreciation, filter element cost, labor cost for element change out, and element disposal cost.

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