II. SELECTION OF FILTRATION SYSTEMS

The focus of this Engineering Technical Letter (ETL) is to provide information regarding technical and practical aspects of solids/liquid separation processes to remove particulate from a waste stream. Given a need to remove solids in a waste stream, the first step is to identify a filtration process which is compatible with the waste stream to be treated and which can meet the desired effluent quality. It should be noted that each waste stream has unique characteristics which can impact selection of the filtration alternative. This chapter will address key waste stream components which dictate selection of a filter. While there are many filter options available, only the following filtration systems and techniques will be addressed in the ETL:

- Granular Media Filtration
  - Pressure Filtration
  - Traveling Bridge Filtration
  - Continuous Backwash Filtration
  - Gravity Filtration
- Precoat Filtration
- Cartridge Filtration
- Bag Filtration

To aid the designer in selecting one of the above filtration alternatives for use at HTRW sites, a selection scheme has been developed based on the factors listed below. Where possible, tables and figures have been provided as general use guides. The designer is advised to contact manufacturers representatives, review published operational data and consult with experienced filtration design professionals. The factors considered are listed below.

- Particle Size
- Relative Costs
- Metals Removal
- Oily Slurries
- Space Limitations
- Settling Velocity
- Solids Output
- Precoat Filtration
- Solids Concentration
- Treatment Flow Rate
- Environmental Hazards
- Objective of Solids Separation
- Chemical Addition
- Expendable Media
- Continuous or Batch Operation

Particle Size

In general, media filters can remove particles in the 4-6 micron range and pressure filters can remove particles down to 10 microns. However, the efficiency of particle removal in these small micron ranges is very low compared to cartridge and bag filters and the efficiency likely will diminish over the length

of the filter run. Therefore if the intent of particle removal for a waste stream is to efficiently remove particles in the range of 4-6 microns bag or cartridge filtration will be needed. The designer should also recognize that for a bag or cartridge filter to operate efficiently they may require pretreatment by a media filter particularly where there is a significant amount of solids considerably larger than the desired effluent micron quality. However, a significant concentration of large particles is present, smaller micron particles may get trapped in the schmutzdecker which forms at the top of the filter. Hence, granular filtration may still warrant consideration. Figure A-l and Table A-2 are guides that can be used in selecting a filtration device based on particle size.

Relative Costs

Typically the capital cost for media filtration is higher than the cost of cartridge or bag filtration. For Operation and Maintenance (O&M), costs increase as the volume of waste to be treated increases. The long term cost for media filters would be less than the cost needed for membrane replacement in bag or cartridge filters or precoat filter media because of expendable media cost, and potentially hazardous waste disposal cost for the media.

Metals Removal

In many systems metals are removed by precipitation, sedimentation and filtration. For waste streams low in solids and metals to be removed, continuous backwash filters can enhance the metals removal by providing a constant stream of return solids to the sedimentation system and increasing solids contact, thereby improving sedimentation and reducing downstream filter loadings. One drawback with continuous backwash filters is that they typically remove only 95% of the influent solids suggesting that a downstream bag or cartridge filter may be necessary depending on effluent requirements. Where there are effluent/discharge requirements with low total metals concentration, multiple filtration process may be required to filter out fine floc often associated with metals precipitation.

Oily Slurries

Waste streams which contain oily slurries in most cases should have some pretreatment prior to filtration particularly if the oily material is in a separate phase. One exception to this rule may be the use of bag filters since bag filters are typically designed to remove solids from viscous oily or organic materials. In this case the oily material will pass through the filter. Bench or field testing should be considered.

Space Limitations

In space limiting situations bag and cartridge filters are good selections depending on waste stream characteristics. In some instances the designer may not be able to consider space saving filter options due to either high solids loadings, high cost of disposal of expendable cartridge and bag filter elements or high operating costs if frequent filter changes are required. Again the designer needs to consider if these filters will provide the ease of operation and effluent quality for a particular application.

Settling Velocity

Sedimentation velocity can help the designer determine if settling or filtration may be required for a given waste stream. Waste streams with high settling velocities (>0.5 cm/sec) are typically dependent on gravimetric or centrifugal type treatment processes prior to filtration to reduce the quantity of solids prior to filtration. Filtration in this case would be used to remove the solids remaining in suspension. Settling velocities can be determined in the laboratory. Test method "2701 E. Zone Settling Rate" of the 18th Edition of Standard Methods for the Examination of Water and Wastewater should be considered for determining settling velocities.

Solids Concentration

The feed solids concentration is the weight percent of dry solids in the waste stream to be treated. This can be obtained by filtering a known quantity of waste through a tared and previously weighed dry filter paper (see Standard Methods 18th Edition Method 2540 D. "Total Suspended Solids). Where solids concentration is high, the designer must consider the use gravimetric or centrifugal solids separation processes prior to filtration.

Treatment Flow Rate

Treatment flow rate is important in determining the degree of automation that can be economically allowed. In general, low flow rates require less operator attention thereby reducing 0 & M costs versus higher flow rates which may require frequent operator input. The tradeoff is that the lower flows typically have higher capital investments where the economy of scale decreases as the volume of waste treated increases. For HTRW sites the treatment flowrate is often determined during the remedial investigation/feasibility study (RI/FS) phase of work.

Environmental Hazards

If the waste stream to be treated is toxic, flammable or explosive it is best treated in an isolated environment. For this parameter those filtration devices which are closed vessels

i.e., pressure filters, are more suitable than open gravity, type systems. In the case of cartridge filters, operator contact during filter changes may impact selection of this type of filtration device.

Objective of Solids Separation

As the concentration of the solids increases, two treatment processes are typically required. The first should provide removal of the bulk of the solids, usually some sedimentation type device, followed by filtration to clarify or remove those solids not removed by gravimetric or centrifugal type systems. At lower solids concentrations only filtration may be required. Solids separation may also be used to capture and concentration the solids. In this case media filtration in combination with dewatering devices for the backwash stream or cartridge or bag filtration are possible treatment alternatives.

Chemical Addition

Chemical addition refers to the use of flocculants, coagulants or other chemicals that will enhance separation. For some processes, adding chemicals from an operational point of view may not be desirable. This is a concern when polymers and submicron cartridge filters are used together. The organic polymers may coat or blind the filter media causing premature failure. Electrolytes are often used to precipitate colloids or enhance filtration of particulate/colloids. To improve particulate removal electrolytes which have a charge opposite in sign to the particles are used. Table A-3 shows the relative coagulating power of several electrolytes, the higher the value the better the relative coagulating power. From this table it is clear why aluminum and iron salts are so often used as coagulant aids. Sawyer and McCarty, "Chemistry for Sanitary Engineers", gives a good general discussion on the use of coagulants.

Expendable Media

Expendable media refers mostly to filter cartridges, filter bags or precoat filter aids. For low volumes expendable media may be economical. As filter volumes increase, so do disposal costs associated with expendable media. Expendable media and either dry cake or hazardous slurries are frequently incompatible. Filter cartridges or filter aid usually retain significant amount of filtrate/solids. For hazardous wastes this can substantially increase disposal costs.

Solids Output

Solids are removed from the separation/filtration device as either a slurry from backwash of media type filters or a relatively dry cake as with cartridge filters. If the disposal of the solids is to be incineration then the driest possible cake is

desired. Where slurries may be landfilled mechanisms such as dewatering should be considered to reduce overall disposal volume and costs.

Continuous or Batch Operation

Continuous or batch operations usually depends on upstream or downstream processes. When using batch filtration with continuous upstream or downstream processes the designer must consider the size of intermediate holding tanks to be used as feed or effluent control of the waste stream flow. When using continuous filtration with upstream or downstream treatment processes the same is true.

Precoat Filtration

Unlike the other filtration systems discussed in this document precoat filtration relates to the a process technique, not a specific filter type. That is, many commercially available filtration/solids separation processes can be used as precoat filters. Some of these include rotary drum vacuum filters, vertical tube filters and recessed plate and frame filters. The designer must contact filter representatives regarding available data on the use of their filters for precoat applications. Generally precoat filters are used when there are high inert solids loadings at levels typically greater than 1,000 mg/L total suspended solids (TSS).

Ernst Solid Separation Scheme

A solid-liquid separation scheme has been developed by Ernst, M. et.al. and published in the July 1991 Chemical Engineering Process Journal. The Ernst scheme covers over 60 solids separation types of equipment, most of which are not covered in this ETL.

The Ernst selection criteria is based on a series of questions that a designer should ask when selecting a filter. These questions are then ranked in summary Table A-I. The rating scale in the table goes from +2 to -2 and #. The +2 indicates excellent performance of the filtration objective of the waste stream characteristic and the -2 represents poor performance. Zero indicates average performance and +1 and -l indicate above or below average performance. The # sign indicates that filtration alternative would not function well under that particular condition. For example, for question E, none of the filtration devices are recommended for waste streams having suspended solids concentrations greater than 4% by weight. This should be a signal to the designer that pretreatment of the waste stream

would be required to reduce solids loadings to any of the filtration devices listed.

The rating questionnaire covers the solids separation topics regarding definition of the waste stream and definition of the process. The definition of the waste stream refers to the physical and chemical characteristics of the waste to be treated while the definition of the process refers to the physical removal of solids by a filtration system or technique. The designer should consult references listed at the end of each filtration section to obtain design ranges and values for filtration equipment. The tables and figures provided at the end of this chapter can be used as guides.

DEFINITION OF THE WASTE STREAM

1. What is the settling velocity of the solids to be captured?
   > 0.5 cm/sec (1 ft/mm.) _____ A.
   0.1 - 0.5 cm/sec (0.2 to 1 ft/mm.) _____ B.
   0.02 - 0.1 cm/sec (0.04 to 0.2 ft/mm.) _____ C.
   <0.02 cm/sec (0.04 ft/mm) _____ D.

2. What is the feed solids concentration?
   > 4 wt% _____ E.
   0.1 to 4 wt% _____ F.
   1 to 1000 ppm by weight _____ G.

3. What is the feed liquid vapor pressure?
   < 20 kPa (3 psi) NA
   20 to 50 kPa (3 to 7 psi) _____ H.
   Over 50 kPa (7 psi) _____ I.

4. What is the scale of operation?
   > 1100 L/min. (300 gal/mm) _____ J.
   100 - 1100 L/min. (30 - 300 gal/mm.) _____ K.
   < 100 L/min. (<30 gal/mm.) _____ L.

5. Is the waste stream toxic, flammable or explosive? YES __ M.
   NO NA

6. Is emulsified oil present? NO NA
   See warning No. 5 YES

DEFINITION OF THE PROCESS

1. Is the primary objective of the solids liquid separation process to:

Clarify the liquid (remove solids from the wet stream)? _____ N.

Concentration or recovery of solids? _____ 0.

Note: If both N & 0 are checked the designer must consider using multiple filtration/solids liquid separation methods.

2. Can chemicals be added to enhance separation of the solids from the wet stream?

Yes _____ P.
No _____ Q.

3. Can expendable media be used? YES NA
NO _____ R.

4. Are the solids to be removed required to be:

A dry granular cake? _____ S.
A concentrated slurry? _____ T.

5. Is the wet stream recovery critical to the process?

YES____ U.

6. Is the feed flow rate steady on an hourly basis? YES NA
No_____ V.

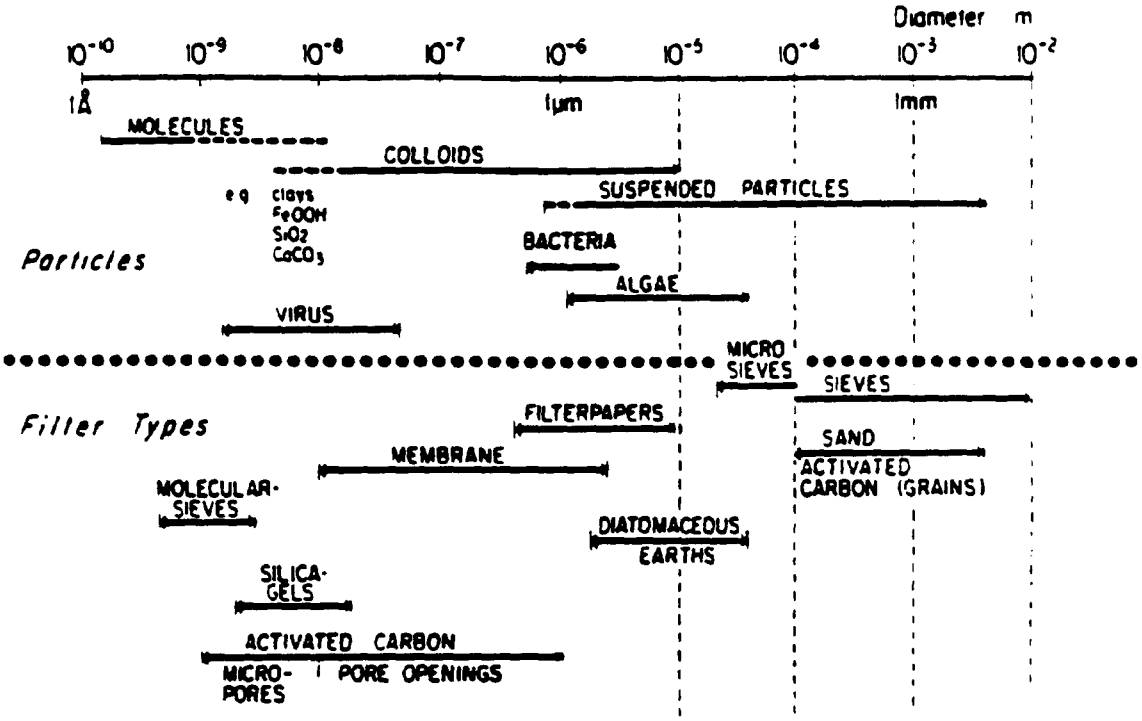
7. Does solids output have to be continuous? _____ W.
Is solids output a batch process? _____ X.
No preference NA

NA, indicates that no answer is required because no equipment would be eliminated by this answer.

TABLE A-1

SOLID-LIQUID SEPARATION SELECTION SCHEME

QUESTIONS / FILTRATION DEVICE	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X
PRESSURE FILTER	#	#	1	1	#	#	1	2	2	1	2	1	1	2	#	2	0	-2	-2	0	0	2	#	1
TRAVELING BRIDGE FILTER	#	1	1	1	#	#	1	1	2	2	1	#	-1	2	#	2	0	-2	-2	0	0	2	2	#
CONTINUOUS BACKWASH FILTER	#	1	1	1	#	#	1	1	2	1	2	1	0	2	#	2	0	-2	-2	1	0	2	2	#
GRAVITY FILTER	#	#	1	1	#	#	1	1	2	2	2	1	-1	2	#	2	0	-2	-2	0	0	1	#	#
PRECOAT FILTER	#	#	-1	1	#	-2	1	1	2	0	0	1	-2	1	#	0	0	2	-2	0	0	1	#	1
CARTRIDGE FILTER	#	0	1	1	#	#	1	1	2	#	-2	1	-1	2	#	1	0	2	-1	-2	-1	1	#	1
BAG FILTER	#	0	1	1	#	#	1	1	2	#	-2	1	-1	2	#	1	0	2	-1	-2	-1	1	#	1



Suspended particles in natural and wastewaters vary in diameter from 0.005 to about 100 μm (5×10^{-9} to 10^{-4} m). For particles smaller than 10 μm, terminal gravitational settling will be less than about 10^{-2} cm sec^{-1}. Filter pores of sand filters, on the other hand, are typically larger than 500 μm. The smaller particles (colloids) can become separated either by settling if they aggregate or by filtration if they attach to filter grains. Particle separation is of importance in the following processes: aggregation of suspended particles (clays, hydrous oxides, phytoplankton, biological debris) in natural waters; coagulation (and flocculation) in water supply and wastewater treatment; bioflocculation (aggregation of bacteria and other suspended solids) in biological treatment processes; sludge conditioning (dewatering, filtration); filtration, ground water infiltration, removal of precipitates. [From W. Stumm, *Environ. Sci. Technol.*, 11, 1066 (1977).]

FIGURE A-1. SIZE SPECTRUM OF WATERBORNE PARTICLES AND OF FILTER PORES

TABLE A-2
CHARACTERISTICS OF PARTICULATES REMOVED BY FILTRATION

TYPE	Size Range (μm)	Shape	Density (g/cm^3)	Zero Point of Charge (pH)	Floc Strength	Compaction (Percent Solids, Gravity Sedimentation)
Bacterial flocs	0.5–1000	Variable	~1.02	2–3	Medium	0.5–5.0
Algae	1–200	Variable	~1.05	2–3	Medium	1
"$Fe(OH)_3$ OR "$Al(OH)_3$"	0.1–1000	Variable	~1.01	5–9	Low	0.5–2
Fe_2O_3	0.1–50	Plates	5.2	9–10	Low	4–6
$CaCO_3$	0.1–50	Rounded	2.4	8–9	Low	4–6
Oil Droplets	10–100	Spherical	0.8	3–5	Medium	?

Reference: James M. Montgomery Consulting Engineers, Inc. Water Treatment Principles and Design. John Wiley & Sons, Inc., New York. 1985

TABLE A-3
RELATIVE COAGULATING POWER OF SEVERAL ELECTROLYTES

Electrolyte	Relative Power* of Coagulation	
	Positive Colloids	Negative Colloids
$NaCl$	1	1
Na_2SO_4	30	1
Na_3PO_4	1,000	1
$BaCl_2$	1	30
$MgSO_4$	30	30
$AlCl_3$	1	1,000
$Al_2(SO_4)_3$	30	>1,000
$FeCl_3$	1	1,000
$Fe_2(SO_4)_3$	30	>1,000

* Values given are approximate and are for solutions of equivalent ionic strength.

[1]Source: Chemistry for Sanitary Engineers, McGraw-Hill, Inc., 1967