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| <b>EXXON</b><br><br><b>EXXON<br/>ENGINEERING</b> | <b>WATER POLLUTION CONTROL<br/>MEDIA FILTRATION</b><br><br><b>PROPRIETARY INFORMATION - For Authorized Company Use Only</b> | <b>DESIGN PRACTICES</b>       |                        |
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## Revision Memo

|              |                                                                                                                                                                                         |
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| <b>12/98</b> | Editorial changes.<br>Included potential benefit of converting from gravity feed backwash to pumped backwash.<br>Included potential matching feedwater particle sizes with media sizes. |
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## SCOPE

This section presents process design procedures and mechanical design considerations for facilities to separate free (undissolved) oil and suspended solids from water, wastewater, and produced water by filtering the water through a bed of granular media such as sand, anthracite coal, garnet, or nutshells. In mono-, dual-, and tri-media filtration, combinations of media types (other than nutshells) can be used. Dual-media, downflow filtration is covered most extensively because this is the type of filtration most commonly used within Exxon. Features of the entire filtration system including filter bed cleaning are covered. Coalescing filters are not covered in this section, since many do not use granular media.

This section considers both the filtration of oil and/or suspended solids from gravity-separator and flotation unit effluents and the filtration of suspended solids - including biological solids - from the effluents of biological treatment plants, cooling towers, wastewater lagoons, and stabilization ponds.

## REFERENCES

### DESIGN PRACTICES

- Section II, Design Temperature, Design Pressure, and Flange Rating
- Section V, Drums
- Section VII, Fixed-Bed Reactors
- Section XIX-A, Guidelines for Selecting Wastewater Treatment Systems
- Section XIX-A2, Flotation Units
- Section XIX-A9, Chemicals/Chemical Feeders for Wastewater Treatment
- Section XXVI-A, Boiler Feedwater Treating Systems

### MANUALS

- Refining Construction Materials Manual, ER&E Report No. EETD 028, December, 1996.
- Chemical Construction Materials Manual, ER&E Report No. CED 009, July, 1997.

## DEFINITIONS

### Deep-Bed Filter

A deep-bed filter is a filter with more than 5 ft (1.5 m) of media. Deep-bed filters are typically used for potable water treatment, however, a multi-media filter with media deeper than 5 ft might be used for wastewater treatment.

### Depth Filtration

Depth filtration occurs when contaminants are removed throughout the entire bed.

### Effective Filtration Area

The effective filtration area is the cross-sectional area of the bed which is effective during filtration and which can be appropriately cleaned during backwash. With both vertical vessels and horizontal vessels, the cross-sectional area of the bed at the interface between the bottom layer of filter media and the false bottom or gravel under the media is normally used as the effective filtration area for design purposes.

### Effective Media Size

The effective size of the media is the diameter of the media particle just too large to pass through a sieve on which 90 percent of the material is retained. This is termed d<sub>90</sub> (see Uniformity Coefficient).

### Freeboard

Freeboard is the distance between the top of the media and the top of the backwash effluent nozzle.

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## DEFINITIONS (Cont)

### Graded Sand Filter

A graded sand filter contains layers of different-sized sand.

### Granular-Media Filter

- Granular-media filter is the general term for the most common type of filter used in wastewater treating. This type of filter typically consists of a supported bed of granular material such as sand, through which a liquid is passed to remove extraneous, non-dissolved material from the liquid. Granular-media filters remove both suspended oil and suspended solids from water. Removal mechanisms in these filters include straining through the filter bed, sedimentation between the media particles, and impingement and adsorption upon them. The filters are periodically taken out of service and backwashed to remove the deposited material and reduce pressure drop.

### Gravity Filter

A gravity filter relies upon the height of the water above the bed to provide the driving force for flow through the bed.

### Hydraulic Loading

The flowrate through a unit area of filter media, e.g., gpm/ft<sup>2</sup> (m/h or m<sup>3</sup>/h/m<sup>2</sup>).

### Influent Flow Splitting

Influent flow splitting is a procedure to divide the flow evenly among all of the filters in the system.

### Mono-Media Filter

A mono-media filter is a granular-media filter which contains a single type of media, for example, sand.

### Mudballs

"Mudballs" is a term used to describe sludgy material sometimes formed in a filter by oil and solids combining with media. Operation of a filter over some period of time with inadequate backwashing can lead to mudball formation.

### Multi-Media Filter

Multi-media filters are granular-media filters that contain more than one type of media. Dual-media filters contain two types of media - usually sand and anthracite or garnet and anthracite; tri-media filters contain three types of media - usually sand, anthracite, and garnet.

### NTU

Nephelometric turbidity unit. The unit of measurement for turbidity.

### Nutshell Filter

A deep-bed pressure filter that uses nutshells as the filter media.

### Porosity

Porosity is the ratio of the volume of void space within the granular-media bed to the total volume of the bed. Porosity increases with uniformity coefficient.

### Pressure Filter

A pressure filter uses a pressure driving force greater than that provided by gravity to force the liquid through the bed.

### Produced Water

Water produced with the crude oil or gas. May be natural or a result of water flood or steam stimulation hydrocarbon recovery operations.

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## DEFINITIONS (Cont)

### Shallow-Bed Filter

A shallow-bed filter operates with a total depth of filter media less than five ft (1.5 m).

### Sphericity

The sphericity of a particle is the ratio of the surface area of a sphere having a volume equal to that of the particle to the surface area of the particle. The sphericity of any particle that is not spherical is always less than unity.

### Uniformity Coefficient

Uniformity coefficient is a measure of the uniformity of the sizes of the media particles. Uniformity coefficient is defined as:

$$U = \frac{d_{40}}{d_{90}} \quad \text{Eq. (1)}$$

**where:** U = Uniformity coefficient, dimensionless.

$d_{40}$  = Diameter of the particle just too large to pass through a sieve on which 40 percent of the material is retained.

$d_{90}$  = Diameter of the particle just too large to pass through a sieve on which 90 percent of the material is retained.

### Wastewater

A generic description for water, regardless of origin containing suspended solids and/or dissolved/undissolved oil.

## DESCRIPTION

♦ A granular-media filter is a supported bed of granular material (usually sand, anthracite, garnet, or a combination of these or nutshells) through which a liquid is passed to remove an extraneous, non-dissolved material from the liquid stream. These filters effectively remove undissolved oil and solid suspended material from many wastewaters. It may be necessary to add a flocculent to the wastewater prior to granular-media filtration, to enhance removal of free oil and suspended solids. **Figure 1** shows a granular-media filtration system with chemicals addition.

♦ As impurities are removed, bed pressure drop will increase, and the filter removal efficiency will also increase due to the coating of the bed by suspended solids. The filter removal efficiency and pressure drop will continue to increase until the filter is either backwashed or breaks through, pushing solids and oil into the effluent. The filters are periodically taken out of service and cleaned by backwashing to remove the filtered material in order to reduce pressure drop. Backwashing is usually accomplished by first injecting air to break up the bed, expanding or fluidizing the bed with water (normally filter effluent) at a relatively high flow rate with simultaneous air injection to scour the particles, and then flushing with water alone. Gas can be substituted for air. Occasionally, a detergent wash or steaming may be employed to more thoroughly clean the bed. The nutshell filters do not require air or gas to enhance the cleaning process as they use media scrubbers for this purpose.

Granular-media filters can be of different designs. These are differentiated in several ways - mode of operation: downflow or upflow; driving force for flow: pressure or gravity; number of media materials in the bed: mono-media, dual-media, or tri-media; material of media: nutshells, sand, anthracite, ilmenite, or garnet; depth of bed: shallow-bed or deep-bed; and depth of penetration of the contaminants: depth filtration or surface filtration. Seven different types of filters are depicted in **Figure 2**.

In mixed-media filters, which are always operated downflow, the particle sizes of the different media are selected so that the media of largest particle size occupies the top layer and the media of smallest particle size occupies the bottom layer. This arrangement results in a large pore size at the inlet-end of the filter to capture and retain a relatively large amount of material from the water without excessive pressure drop buildup, and a small pore size at the effluent-end of the filter for further clean up of the small particles in the wastewater. The different media selected must have appropriate particle densities as well as proper particle sizes: the top layer must be the lightest media material and the bottom layer the heaviest. These differences in densities result in the different media becoming reclassified after backwashing and settling back into layers in their original proper positions.

Gravity filters have not been used as extensively as have pressure filters within Exxon for wastewater treating.

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## FILTER TYPES

Granular-media filtration is, in most cases, an effective advanced primary treatment for API separator and air/gas flotation unit effluents and an effective polishing step to remove biological solids, including algae, from the effluent from biological wastewater treating units.

The type of granular-media filter selected for any particular wastewater application will normally belong to one of the following five categories:

- Downflow, pressure filters
- Downflow, gravity filters
- Upflow sand filters
- Downflow, nutshell pressure filters
- Special proprietary filters

Most of Exxon's wastewater filters are of the downflow, pressure type, but the nutshell filters are now widely used, especially for oil removal from produced waters. Downflow filters, whether pressure or gravity, have two advantages over upflow sand filters: they do not fluidize at high flowrates, and they offer a more positive protection against breakthrough.

**Downflow, Pressure Filters (Figures 2A, 2B, 2C, 2F, and 2G)** can be mono-media, dual-media, or tri-media, but to date, the use of tri-media nutshell filters has not been reported.

Mono-media filters (**Figure 2C**) contain a deep-bed [ $> 5$  ft ( $> 1.5$  m)] of sand that is relatively coarse and relatively uniform in size. These filters approach the depth filtration, filtrate quality, and solids retention capacity achieved with the coarse-to-fine filtration of shallow-bed, mono-media filters.

In Exxon's wastewater applications, multi-media filters are generally shallow-bed. Because the filtration in multi-media filters occurs through media that varies from coarse to fine, the pressure drop does not build up as rapidly in them as it does in mono-media filters, and this results in longer cycle times. Dual-media filters (**Figure 2A**) typically contain coarse anthracite on top of fine sand. Tri-media filters (**Figure 2B**) typically contain a top layer of coarse anthracite, a middle layer of sand that is finer than the anthracite, and a bottom layer of garnet that is still finer.

**Gravity Filters (Figure 2E)** - Gravity filters are generally open-top vessels, of either concrete or steel construction and usually contain the single media, sand. Since the driving force is less than that in pressure filters, gravity filters should be used only when the concentrations of suspended solids and oil in the influent stream are low. High concentrations of these materials will foul the bed too quickly and prevent an adequate flow rate.

**Upflow Sand Filters (Figure 2D)** - Upflow sand filters are deep-bed filters containing graded sand over graded gravel, with two different sizes of each. The media are arranged so that the size progressively decreases in the direction from bottom to top. This arrangement of media sizes provides a relatively large void volume and void size at the inlet-end of the bed, which allows capture and retention of a relatively large amount of contaminants. Large particles are captured without excessive pressure drop. The media sizes provide a small void volume and size at the outlet end for retention of fine particles for final polishing. Depth filtration is achieved.

A hold-down grid is located near the top of the bed to prevent fluidization during filtration. The hold-down grid has openings larger than the sand grains, so it is not an absolute restraint against fluidization at all flow rates, but it normally does prevent fluidization at the flow rates used during filtration, as a result of the sand "bridging" across the grid openings.

Hydraulic overloads can upset upflow filters. Also, since the flowrate to these filters is limited by fluidization of the bed, they may not be operable at rates sufficiently high for optimum filtration economics.

**Nutshell Filters (Figure 2F)** are used primarily to remove oil from wastewater and produced water streams, but there is no reason why they cannot be used for suspended solids removal. Experience with these types of filters for solids removal is limited.

- ♦ The main difference between the nutshell filters and the more conventional filter designs is the media cleaning system. Media cleaning is achieved by fluidizing the nutshells via a conventional backwash and then directing the nutshells through a scrubber. Various scrubber designs exist, but all are based on using a section of wedge wire screen. These screens are formed by winding metal bar of trapezoidal cross section in a continuous manner around a support cage made up of rectangular cross section metal bars of the same material so that a gap is formed between adjacent windings. The gap size can be adjusted to retain any size of filter media, but the standard gap width is 0.01 in. (0.25 mm). A wide range of materials can be used to make the wellscreen, with stainless steel being the standard.

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### FILTER TYPES (Cont)

The early nutshell filter design incorporates a scrubber which is external to the filter vessel. The scrubber design consists of a section of wellscreen housed inside a section of larger diameter pipe such that an annular space exists between the wellscreen and the inner pipe wall. During the media cleaning cycle, a slurry recirculation pump fluidizes the nutshell bed from the filter bottom and lifts the media to the top of the vessel where it exits and enters the top of the scrubber. The water and media slurry moves down through the scrubber, back through the slurry pump and into the bottom of the filter. During passage through the scrubber, the nutshell media pieces contact both the wellscreen and each other to create a scouring action similar to that obtained during the backwash/scour stage of a conventional filter clean. The oil and dirt released from the media passes through the wellscreen and is removed from the bottom of the scrubber for further treatment.

The continuous recirculation of the media through the filter and scrubber creates a very effective cleaning cycle, considered to be superior to that obtained from a conventional backwash/scour.

An alternate design has the slurry pump mounted on top of the filter vessel with the scrubber (which operates as previously described) mounted inside the vessel. This design saves on floor space, but extra headroom is required for removal of the slurry pump and/or scrubber.

A current available design (**Figure 2F**) does not have a slurry pump. Media cleaning is achieved by using a rotating scrubber instead of pumping media around a stationary scrubber. In the new design, a motor mounted on top of the vessel rotates a three-blade mixer. The scrubber assembly is also connected to the shaft and located directly above the mixer. During the cleaning cycle, the combined action of the mixer blades and backwash directs the media up to the rotating scrubber. The unit backwash outlet valve is open at this time, and the pressure of the incoming backwash water creates a small pressure differential across the scrubber such that the media migrates to the outside of the scrubber where media scouring takes place. The released oil and/or solids migrate through the scrubber and into four collection pipes which transfer the dirty water to the top of the unit where it exits via the backwash outlet valve.

The volumes of dirty backwash water discharged from the nutshell filters during media cleaning are significantly lower than from a conventional filter backwash. The nutshell filters typically use 1 to 2 percent of the service throughput for cleaning compared to 6 to 8 percent for the conventional filters. Also, the influent water to the nutshell filters can be used during the cleaning cycle, and this removes the need to store filtered water for backwash or withdraw the water from the effluent header of the in-service filters.

The rate of withdrawal of backwash water from the nutshell filter scrubbers is an important design parameter. The ratio of flowrate of water past the scrubber compared with the dirty backwash water withdrawal rate varies from 3:1 to 8:1 for various manufacturers. The higher ratios are preferred (one company is adamant that the ratio should never be below 8:1) for at the lower ratio levels, the situation can arise where if too much water is drawn off in comparison to the amount of water passing the scrubber, the media will be drawn into the wellscreen and "blind" it so that the flow through and contact with the screen is severely restricted.

The vigorous scouring action occurring at the scrubbers, combined with that in the slurry pump (if used), necessitates the use of a media that can withstand these operating conditions. Nutshells provide the requisite characteristics. They are resilient and pliable and when used for oil removal, are preferentially water wetted and thus readily adsorb and desorb the oil. The nutshells are crushed and graded like any other media. Black walnut shells are widely used and some companies prefer mixtures of nutshells. One mixture contains pecan and walnut shells in a 4:1 ratio. Pecan shells when crushed and sieved produce splinter-like pieces, and if used alone, would pack closely together and create high-pressure drops. The walnut shells are included to provide "voidage" for the pecan shells. This particular mixture is claimed to be able to filter out smaller particles than walnut shells alone.

**Special Proprietary Designs** - A number of filter manufacturers have their own proprietary designs for granular-media filters with unique features. These include but are not limited to the Hydro Clear Filter manufactured by U.S. Filter/Zimpro in Rothschild, WI; the DynaSand filter manufactured by Parkson Corporation in Fort Lauderdale, Florida; and the Automatic Backwash Filter manufactured by Inflico Degremont in Richmond, Virginia. Each of these proprietary designs has special features that are of interest.

The Hydro Clear Filter is a downflow, shallow-bed, gravity, mono-media filter, typically containing about 12 in. (305 mm) of sand. Filtration takes place at the top of the bed, so depth filtration is not achieved. The unique feature of this filter is periodic pulsing of the bed to mix the media and thereby deposit the collected particles deeper in the bed to reduce pressure drop. The filter operates with a vented air space below the media, and the air pulse is effected automatically by temporarily stopping filter feed and allowing the level of water under the bed to rise and push the entrapped air into and up through the media. This takes about 30 seconds. Compartments are provided above the air space below the media to distribute the air pulse uniformly across the bed. The filter is also provided with a low-pressure air scour at the surface of the bed. When pulsing of the bed no longer reduces head loss sufficiently, the bed is backwashed.

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### FILTER TYPES (Cont)

Hydro Clear filters typically operate at 1.5 to 5 gpm/ft<sup>2</sup> (4 to 12 m<sup>3</sup>/h/m<sup>2</sup>), start out with no head loss and are backwashed when the head loss above the top of the media is about 42 in. (10 kPa) of water.

Since filtration is by surface straining, the size of the sand, which can be selected to fit the needs of the application, determines the size of the particles removed. The standard sand size is 0.45 mm with a uniformity coefficient of 1.7, but the vendor reports that sand with an effective size of 0.35 mm is sometimes used for algae removal and that the smallest sand they have used has an effective size of 0.17 mm.

The DynaSand filter is a shallow-bed, upflow sand filter that continuously backwashes the media during filtration. This filter contains a moving bed of sand about 40 in. (1 m) deep and provides depth filtration. Sand from the bottom of the bed is continuously lifted with air to a chamber above the bed. Some particles separate from the sand which drops into a backwash chamber where it is automatically and continuously washed in several stages with filtrate. The washed sand is deposited on the top of the bed. The result is a bed that continuously moves downward, counter-current to the water being filtered, with the cleanest water in contact with the cleanest media and vice versa. The rate of sand movement can be varied by adjusting the quantity of air fed to the air lift if compensation for changes in the concentration of suspended solids in the feed is desired. Typically, the turnaround time for the sand in the bed is 3 to 12 hours.

The vendor claims that this filter can tolerate feed with a high concentration of suspended solids (up to 800 ppm) and with a low pressure drop (< 2 ft [< 6 kPa]). Other advantages claimed are low operator attention, no backwash water storage tank or pump, no internal screens, grids or underdrains, and no splitter boxes.

Units are available in a range of sizes with treatment capacities up to 500 gpm (114 m<sup>3</sup>/h). The vendor reports that these filters are suitable for algae removal, removal of metal hydroxides, and for treating oily wastewater.

The Automatic Backwash Filter is both compartmented, shallow-bed, gravity filters in a rectangular vessel equipped with a traveling bridge that allows sequential small portions of the bed under the bridge to be backwashed as the bridge travels along the length of the filter. Normally, a high head loss initiates movement of the bridge. The bridge travels continuously along the entire length of the bed backwashing the bed under it as it moves along. If head loss is still too high, the process will repeat. A backwash pump in the effluent channel provides the backwash water, which is admitted through sectionalized underdrains. A hood attached to the traveling bridge collects the dirty backwash from the top of those compartments that are being backwashed, and a washwater pump, also attached, removes the dirty backwash water from under the hood.

The vendor of the Automatic Backwash Filter offers the following additional information:

- The bridge travels at about 22 in. (560 mm) per minute.
- A floating oil skimmer can be provided in the filter, if required.
- The media in these filters can be sand, dual-media, or carbon (for removal of trace organic material).
- A sand bed is 11 in. (280 mm) deep, a dual-media bed is deeper
- These filters are used for tertiary treatment and have been used for oil removal in post-API separator service.
- In the treatment of API separator effluent, the hydraulic loading is typically about 2.5 gpm/ft<sup>2</sup> (6.1 m<sup>3</sup>/h) with 11 in. (280 mm) of sand having an effective size of 0.55 to 0.65 mm.
- Backwash volume is typically 2 to 3 percent of feed.

### FILTER SELECTION

The main item for consideration when selecting a filter type is whether the major contaminant is oil or solids. The filter types described above will all filter free oil and/or suspended solids with some degree of efficiency and although overlap does exist, each type tends to be suited to a set of process conditions.

Gravity filters are used primarily to filter waters with low suspended solids concentrations, e.g., waters with a turbidity of < 10 NTU. They can be used to filter water with low oil concentrations < 10 ppm, but other filter designs are better suited for this service.

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### FILTER SELECTION (Cont)

Downflow pressure filters and upflow sand filters are suitable for the removal of solids and/or oil at concentrations in excess of 10 NTU turbidity and 10 ppm oil. In order to prevent bed fluidization, the flowrate through the upflow units must not be allowed to exceed a maximum value (refer to table in section on **FILTER SIZING**) and should not be used where surges in hydraulic loading are expected unless a flow control system is in place. The downflow pressure filters have no such restrictions.

The nutshell filters are used mainly for oil removal and are ideal for the filtration of wastewaters and produced waters with high oil concentrations and low suspended solids concentrations. They have the ability to quickly recover their filtration efficiency after receiving an oil slug. This is not the case with the conventional filters which rely on a backwash and air or gas scour for cleaning. The passage of a slug of oil through these units often results in the need for repetitive cleanings to restore the filtration efficiency to an acceptable level, and in serious cases, solvent or steam cleaning or even media replacement may be necessary.

For a wastewater, the pressure filters can operate at about twice the hydraulic loading of a gravity filter, and the smaller pressure vessels are usually more cost effective than the larger gravity filters. This is especially true for the nutshell filters which can operate at hydraulic loadings up to 16 gpm/ft<sup>2</sup> (39 m<sup>3</sup>/h/m<sup>2</sup>).

Filter selection should be based on pilot-plant filtration tests with the same wastewater that will be filtered in the full-scale plant. These pilot-plant tests should include different filter types and an evaluation of media sizes of a wide range - for example, effective sizes from 0.4 mm to 2.0 mm, and for some applications, even larger sizes. Also, the tests should cover a range of filtration rates from 4 gpm/ft<sup>2</sup> to 15 gpm/ft<sup>2</sup> (9.8 m<sup>3</sup>/h/m<sup>2</sup> to 36.8 m<sup>3</sup>/h/m<sup>2</sup>), evaluate the effect of adding flocculating chemicals, and evaluate several bed depths.

These pilot tests are important. They are necessary for the selection of the optimum filter type and to determine the following design parameters:

- Filtrate quality
- Hydraulic loading
- Pressure drop, cycle time, and backwash requirements

Where there is no opportunity for pilot studies, design parameters have to be estimated from experience. Typical values of effluent quality are given below:

| DESIGN PARAMETER           | API SEPARATOR EFFLUENT     | FLOTATION UNIT EFFLUENT                    | BIOLOGICAL TREATMENT EFFLUENT    |
|----------------------------|----------------------------|--------------------------------------------|----------------------------------|
| Residual Oil Concentration | 25-200 ppm <sup>(1)</sup>  | 15-25 ppm <sup>(1)</sup>                   | 3 ppm free oil <sup>(2)</sup>    |
| Suspended Solids           | 80 percent average removal | 80 to 90 percent removal                   | 80 percent average removal       |
| 5-Day BOD Removal          | 30 percent <sup>(3)</sup>  | Negligible - only 20-minute residence time | Only related to suspended solids |

#### Notes:

- (1) See [Section XIX-A](#), p. 28 and [Section XIX-A2](#), p.28 for more detail.
- (2) When the oil content of the feed is less than 20 ppm.
- (3) Based on the removal of insoluble BOD when the filter is used as an advanced primary treatment process, this BOD reduction should not be expected when the filter is used for polishing. Granular-media filters do not remove soluble BOD or any other dissolved constituent.

### FILTER SIZING

In sizing filters, the most important design parameter is the hydraulic loading. The hydraulic loading on an individual filter should be based on design flow rate with one unit out of service for backwashing. The recommended values based on Exxon operating experience are as follows: