FS-TER-001

TECHNOLOGY FACT SHEETS
FOR EFFLUENT TREATMENT PLANTS
OF TEXTILE INDUSTRY

HIGH RATE FILTRATION

SERIES: TERTIARY TREATMENTS

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INDITEX

HIGH RATE FILTRATION (FS-TER-001)

Date	September 2014		
Authors	Joaquín Suárez López Pablo Ures Rodríguez Alfredo Jácome Burgos		
Reviewed by			
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1.- INTRODUCTION

The main objective of the filtration is to remove or separate the suspended solids (SS) present in water, passing it through a filtering porous material.

Two types of filtration can be distinguished: surface filtration and granular media filtration.
Surface filtration is performed through membrane porous media. These membranes can be considered as microsieves with pore size between 10 and 100 μm. Plastic or metal microsieves can be commercially found. These units will remove suspended solids larger than the pore diameter of the filter. The accumulation of solids on the surface of the membrane commonly form a sludge cake, which also influences filtration.

Although there may also occur surface removal simultaneously, filtration through granular material, eg sand beds, is based on the capacity of the filter bed to retain solids on its volume. Two types of filtration are considered in granular media filtration:

- Slow Filtration
- High rate filtration

The efficiency of this kind of filters requires that the solids can penetrate deeply into the bed without clogging the bed surface. At the same time, it is necessary to select a filter material with an appropriate grain size and thickness to obtain the desired effluent quality.

Although the mechanism of filtration surface is relatively clear and simple, the granular filtration is not so.

Sieve retention is the main mechanism responsible for the removal of suspended solids in the filtration through granular bed:

- **Mechanical Sieving:** Particles larger than the pores of the filter medium are mechanically retained. Considering, for example, a filter material with a 0.150 mm diameter, the interstitial pore will be about 20μ . This pore size is acceptable to remove suspended solids present in either raw or settled water. As it happens on the sieve surface, the gaps located inside the granular bed become smaller as they are filled up with solids. There comes a moment when the solid particle flowing through the filter reaches a pore which it cannot pass and is retained.

However, there are other mechanisms that also influence, although its effects are minor and can be masked by sieving. These are the **transport** mechanisms of the particles to the surface of the filter and the **securing** mechanisms to its surface.

During **transport** of suspended solids through the bed the following mechanisms can interact:

a) **Sedimentation:** Filter beds can be considered as a set of tubes that may act as clarifiers. The same theory as in lamellar or tubular clarifiers could be applied. A filter bed may have a total surface area of about 15000 m^2/m^3. Assuming that the particles of the filter material were cubic, the specific settling surface would be approximately 1/6 (2500 m^2/m^3) but, in fact, a settling horizontal surface in the order of 1000 m^2/m^3 would be considered. Particles with diameters ≥ 4 μm could be removed.

a) **Centrifugal forces action:** Water flowing through the pipes follows curved paths. Inertial forces appear and the particles collide with each other forming flocs.
b) **Interception phenomena:** Particles clash with the filter material and can get trapped or attached to its surface.

c) **Diffusion phenomena:** The smallest particles have an erratic motion that can facilitate impact, promoting floc formation and attachment to the material of the filter bed.

The particles can stay attached to the filter material by different **fixing** phenomena:

a) **Physical adsorption phenomena:** Van der Waals and electrokinetic forces interfere. This phenomenon is critical when active carbon is used as filter media.
b) **Electrostatic interaction:** It depends on the ionic characteristics of the filter media and the contaminant to be removed.
c) **Chemical Adsorption:** Due to chemical interaction.

Biological growth within the filter will reduce the pore size and may enhance particles removal by any of the mechanisms described elimination (cases a-c).

The importance of the above phenomena depend on the type of water, the filter media, the type of coagulant previously used, etc.

The adhesion between particles is mainly a balance of forces. If circumstances change, resuspension of particles may occur. In a situation of constant filtration flow, process it is quite stable. If a flow reduction occurs, no major problems are expected. However, if the flow rate increases and the balance of retained forces is broken they can be dragged and washed away. This effect is called "**filter breakthrough**". In the process effluent water turbidity will increase loosing quality, being even higher than that of the filter inlet. Therefore, especial careful should be taken with treatment flow oscillations in filters operation.

2.- GENERAL PROCESS VARIABLES

In filtration process applications for suspended solids removal, the most important design variables are:

- Filter media characteristics.
- Inlet water characteristics and outlet quality requirements
- Filtration velocity

2.1. – Filter bed characterization

- **Material granular**: El más utilizado es arena silícea (ρ ~ 2.65 T/m^3). También se utiliza antracita (ρ ~ 1.35 a 1.75 T/m^3) y granate (ρ ~ 4 a 4.2 T/m^3). Se emplea también carbón activo aunque con otros objetivos además de medio filtrante.

The main elements that should be considered in filter beds characterization are:

- **Granular media:** The most common is silica sand (ρ ~ 2.65 T/m^3). Anthracite (ρ ~ 1.35 a 1.75 T/m^3) and garnet (ρ ~ 4 a 4.2 T/m^3) are also used. Considering additional objectives, activated carbon media is also used
- **Granulometry.** It is defined by two parameters: particle size and size uniformity. These features will determine the pore size between particles interstices. It is described as d_{10}, that is, the mesh size which allows to pass 10% of the solids present in the inlet by weight. The d_{10} is the effective size or diameter, and mainly determines the filtrate quality, since the pore diameter is normally around 1/7 of the effective diameter

The uniformity coefficient C_u gives an idea of the degree of sizes diversity. It is obtained by the relationship:

$$Cu = \frac{d_{60}}{d_{10}}$$

Where d_{60} is the mesh pore where only 60% of solids in weight pass through the filter material. A usual value in commercial sand is 1.5; maximum ratio should not exceeded 1.6 value and only in exceptional cases up to 1.8 values can be allowed. d_{10} and C_u are called Hazen parameters.

The effective size for sand varies between 0.50 and 2.50 mm.

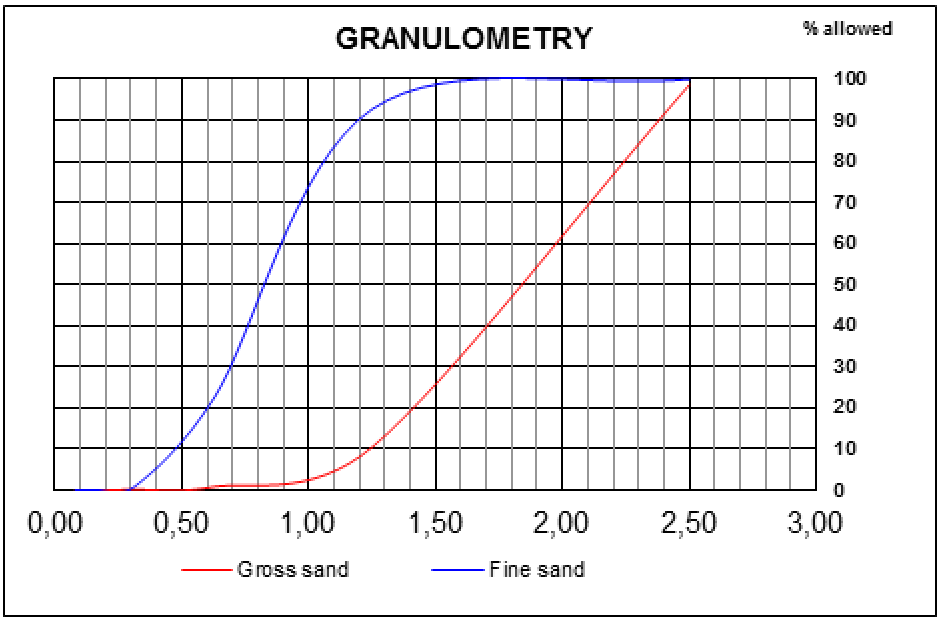


Figure 1. Particle size distribution of two types of sand (Vazquez F, 2000).

Material Shape: Granules can be angular (grinded) or rounded (river and sea sand); on the contrary of what can be thought, the first is less easily coupled to each other allowing more pores than the latter. Consequently, for a given particle size, the pressure drop increase is lower with angular grain than with rounded ones. Therefore, the effective diameter of angular granules will be lower than rounded ones for a certain effluent quality.

Robustness: Material can be degraded by the action of aggressive agents. Water acidity, as an example if there is CO_2 presence, can attack the material. Material robustness estimation is performed through the material immersion in a solution of 5% sulfuric acid during 24 hours, being subsequently dried and weighted. The weight change must be less than 2% in order to be an acceptable material (Degrémont, 1973). If 40% hydrochloric acid is used, the weight loss must be less than 5% after 24 hours (Steel and McGhee, 1981).

Friability: The sand to be used in the filters must be hard and robust. The formation of fine particles through attrition of the material should be minimized. Filters washing action can generate fine solids which lead to process clogging. The friability of a material is measured by determining the amount that remains usable, ie, verifying that it has the same effective size as the original sample, after being smashed under standardized conditions. In friability assessment two measures are carried out: after 15 min and 30 min of crushing. If the percentage of crushed material with less than the initial effective size is designated by X, friability or loss is estimated by:

$$\text{Loss\%} = \frac{10}{9}\left(X - 10\right)$$

Friability threshold reference values are (Degrémont, 1973):

Table 1. Threshold friability values

Characteristics	15 minutes	30 minutes
Very good	6 to 10 %	15 to 20 %
Good	10 to 15 %	20 to 25 %
Low	15 to 20 %	25 to 35 %
Bad	> 20 %	> 35 %

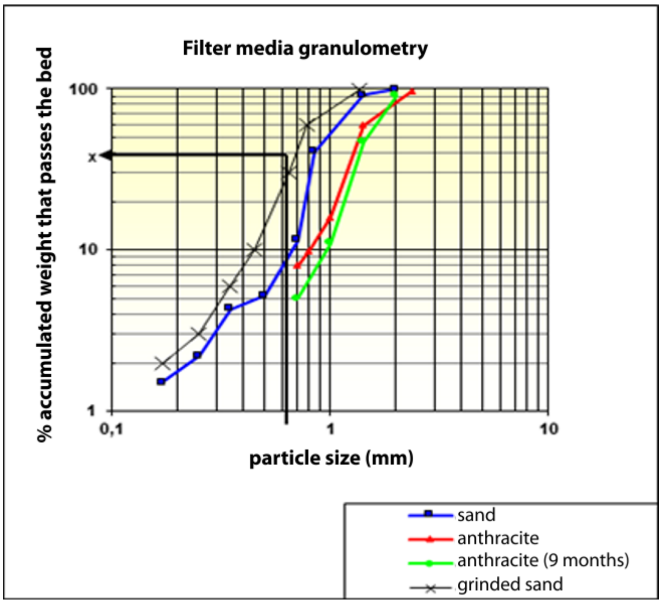


Figure 2. Particle size distribution of two types of sand (Vazquez F, 2000).

Bed geometry: The bed height and the filter surface are also important variables. It is shown experimentally that the height of a given grain size bed has a maximum value since filtrate quality does not improve at higher sizes. This height defines the minimum height to be used obtaining the best filtrate possible at clean filter conditions. To this height and the set velocity corresponds the minimal pressure drop.

2.2.- Process efficiency

Problem water composition is fundamental in the filter media behaviour and results to be obtained. The most important characteristics of the water to be filtered is the concentration of suspended solids, the size and distribution of particle sizes; and flocs consistency. Filters inlet water must not have solids concentration levels exceeding a certain limit because otherwise the functioning and operation of the filter would not be profitable. A coagulated, flocculated and settled water quality has a better quality to be filtered. The filter is then capable to retain flocs particles flowing out the clarifier.

When water has been previously coagulated and flocculated, the consistency of the flocs will be important. This property will depend on the characteristics of the original solids but also in the chemicals used and the operation of the processes.

The purpose of filtration is to remove suspended solids from the liquid. Process performance will be reflected in the decrease in turbidity of the effluent. Both the concentration of SS and effluent turbidity will be valid references when measuring the effectiveness of the process. Turbidity is easily measured directly and continuously, providing normally a suitable correlation with suspended solids concentration in a given water flow. Filter bed fouling occurs as water is being treated. There comes a time when the maximum turbidity threshold is exceeded and the process is no longer effective. Then a filter bed washing is needed.

Another way to know the process decrease in effectiveness is by measuring the hydraulic head loss. The more clogged the filter bed is, the higher resistance to the pass of water appears. Therefore, the water level on the bed increases. One control way consists on setting a water level maximum height over the filter surface and consider that washing operation is needed when this level is overpassed.

2.3. – Filtration velocity

In order to achieve an adequate performance, water flow rate has to be related with the available filter surface. Filtration velocity is used as basic design parameter, as the ratio between the inlet flow rate and the bed horizontal surface ($m^3/m^2/h$).

Filtration velocity will depend on the average size of the filter media and also on the flocs or solids consistency. Considering the same pore size in the bed, the more consistent a floc is, the higher can be the filtration velocity without breaking the floc, thus requiring lower filtration area.

3.- HIGH RATE FILTRATION

During a high rate filtration process, water can cross the filter bed at a velocity range between 4 and 50 m/h. At these velocities, the biological processes will be insignificant and, if any, there will try to eliminate them. Particles main removal mechanisms will be physical. The aim is the the full bed enters in operation.

Filtration can be carried out with or without water conditioning. Direct filtration, i.e. without preconditioning, is practiced when the objective consists on suspended solids and their associated turbidity removal; but it will not act on the color or the content of organic matter. Otherwise, for optimal clarification it would be necessary to condition water by addition of reagents with or without clarification.

As the filter retains solids, it gets clogged and has to be washed when the filtrate quality becomes unsatisfactory. The period of time between two filter washings is called filter run. Washing should restore the original characteristics of the filter, otherwise the bed would deteriorate and the material would need to be regenerated or replaced at a certain moment.
A proper filter operation depens on a good share of the inlet water, washing water or even the air used to wash. Then, the filtrate collector, inlet distribution or the bed support system become important.

The bed may be formed of a single homogeneous material, monolayer, or may consist of several layers of homogeneous materials in each layer. It may even be a mixture of heterogeneous materials, stratified or not.

A filter effectiveness strongly depends on the regulation of the inlet flow, which should be protected from both general flow rate increasing periods and washing processes of some of the filtration units.

3.1.- High rate filtration operation

If turbidity and pressure drop are plotted versus time in a process at constant flow and filtration velocity; the following curves are obtained:

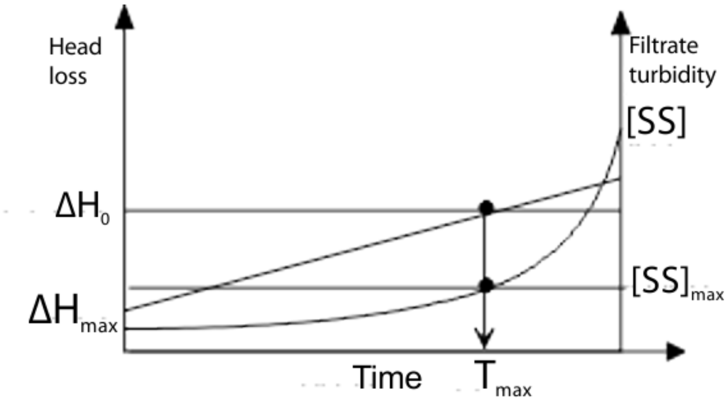


Figure 3. Graphical representation of optimum operating point and filter run threshold.

The optimal operation setup is established as the time period where the maximum head loss matches the maximum turbidity. Therefore, the filter run is properly delimited.

In order the filter clogging period were acceptable, it is necessary to increase the maximum bed height as the time during which the filtrate stays clear is proportional to it.
The bed height proper efficiency requires to set a maximum head loss considering time as lower than time necessary to reach the maximum clogging state. This maximum head loss represents the threshold above which the filter breakthrough occurs. The thinner is the bed filling media, the higher will be this threshold.

To maximize the thickness should set a maximum pressure drop such that the time tb required to reach a little less than ta time required for the maximum binding occurs. This value represents the load loss threshold above which filter breakage will occur. This limit value is much higher, the finer the sand.

These observations are better understood graphically. As an example, a filter whose maximum design pressure drop is 1.50 meters in water column is shown in the figure below indicating the evolution of the pressure drop versus time. The maximum level is reached after a t_b period

The lower graph represents the evolution of turbidity. Turbidity begins to decrease during a period called filter "maturation" and then remain stable for some time, before increasing with the filter break. If a maximum turbidity "x" is set, and it is reached after $t_a<t_b$, means that the filter is not properly designed and it will be necessary to increase the filter bed thickness.

Factors influencing the times t_a and t_b are:

- The quality and quantity of suspended solids contained in the treatment water.
- The granulometry of the filter bed material defined by its effective diameter.
- The filtration rate.
- The filtering layer height.
- Pressure drop variation

Theoretically, the ideal filter complies with ta = tb. In practice, a safety margin is considered in operation, with $t_a <t_b$.

3.2.- Effective material size in high rate monolayer filters.

The particle size of the filter material depends on the application field. The selection should be made taking into account the bed height and the filtration rate. This depends on the nature of the water to be filtered: raw water direct filtration, settled water filtration, secondary or tertiary biological effluent refining, etc. The uniformity coefficient is set from 1.2 to 1.8. According to Degrémont the usual practice is as follows:

- Effective size of 0.3 to 0.5 mm for high rate filtration, with pressure input, up to 25 m/h and even 50 m/h in pool water. That means, filtration of water with low levels of impurities. The pressure loss can reach several atmospheres. Washing is performed with enough water to expand the filter bed.
- Effective size 0.6 to 0.8mm: filtration of clarified water, at limited rate (7 m/h) in open filters and faster in closed filters, which can support a higher pressure drop.
- Effective size of 0.9 to 1.2 mm is used in homogeneous layer filters with settled water or low turbid waters with coagulation on the filter. It fits to filters washable with water and air, and can reach HLRs of 15 to 20 m/h, depending on the desired effluent quality.
- Effective size of 1.3 to 1.5 mm: Filtration of coagulated and settled water, with a pressure loss not exceeding 0.15 bar. It is used as support material layer for a 0.4 to 0.8 mm layer. It is effective as roughing in direct filtration or in systems with coagulation on the filter, as wastewater tertiary treatment.
- Effective size of 1.5 to 2.5 mm: classic raw water screening for industrial use (without coagulation).
- Size of 3 to 25 mm: almost exclusive use as a support layer.

3.3.- Structure

A conventional quick filter is composed by:

- A concrete-made open deposit of 6-100 m^2 area.
- A concrete, ceramic or plastic material false bottom, wherein the nozzles or drainage holes and washing air and water injectors are situated.
- A filter bed, located over the false botton.
- One or more raw water inlet channels, equipped with weirs or gates, which provide a homogeneous water distribution over the filter bed.
- One or more washwater collection channels.
- Raw water, wash water and filtered water characteristics.
- Pumps and flow and security valves.
- If washing is automated, monitoring and control panels are required.
- Diverse monitoring and control devices, in order to follow flow rate, water height and pressure drop levels.

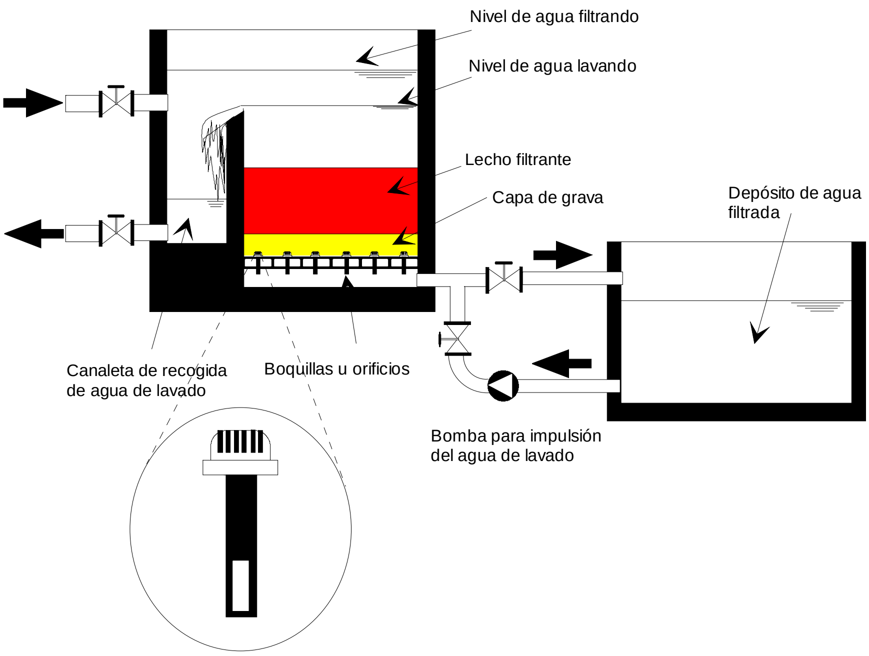


Figure 4.- Downflow gravity filter structure scheme.

In wastewater treatment plants, sevral filtration units are installed. A distribution channel allows raw water entry to the filter. Washing process periods enter alternatively in the filters, optimizing work operations.

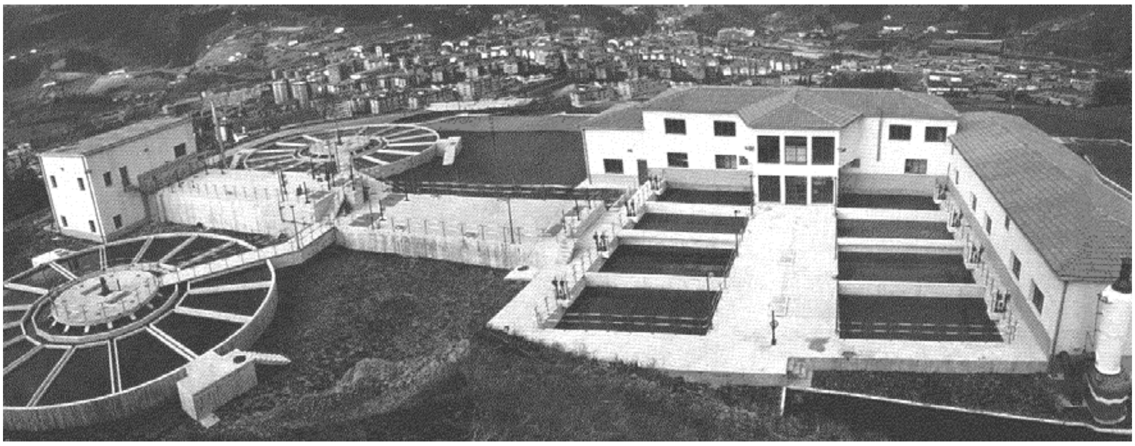


Figure 5.- Filters set in a water purification plant.

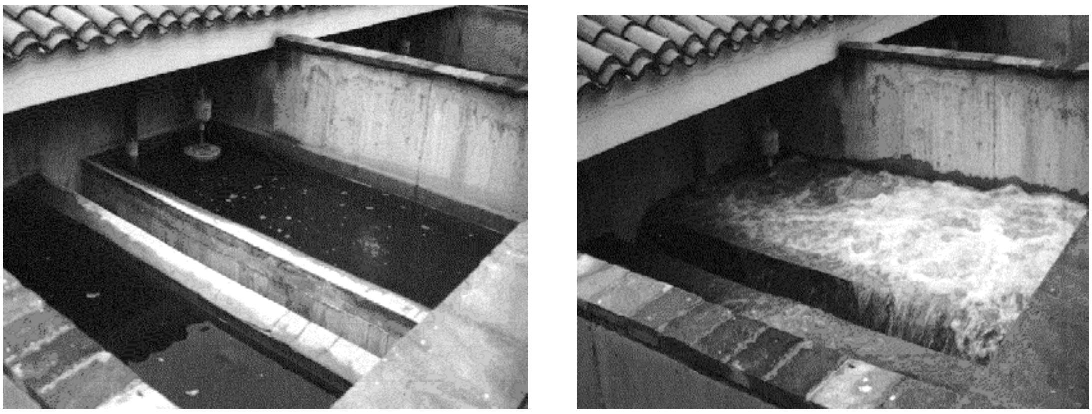


Figure 10.- Gravity open filter in filtering (left) and washing (right) operations.

3.4.- High rate filters typologies

Depending on the criterion used, some high rate filters classifications can be made:

According to the water driving force through the filter:
a) gravity filters
b) pressure filters

According to the structure:
a) open: the water is at atmospheric pressure, usually made of concrete, in some cases they can be covered
b) closed: usually pressurized, metallic materials are used on their construction.

According to the operation:
They can be classified into continuous and semi-continuous. Semi-continuous filters remain in operation until when they need washing. In continuous filters, filtration and washing processes are carried out simultaneously.

Depending on the bed composition:
a) Monolayer Bed: a single material, almost always silica sand, is used. Below the material layer, over the false bottom, it is usually placed a gravel underlayer.

Multilayer filter: Filters incorporating different materials in layers. There are several possibilities depending on the objective. If the target is a homogeneous filter clogging, layers with different efficient sizes should be placed, where higher effective sizes are situated on the upper layers and minor effective layers on the following layers. The bigger suspended solids will be retained on the surface, but the rest of the bed will be probably filled homogeneously with the remaining solids. Te filter gets globally clogged and the filter run is longer.
The problem arises when the filter has to be washed. In order to drag all materials, the flow needs to be enough to move the larger size materials. When the flow stops, heavy materials will settle firstly, being placed on the lower layers. It becomes necessary to select materials with different densities so that the filter can be properly rebuilt. Anthracite, sand and garnet are typical materials used on this kind of beds. Smaller materials should be those of higher density.

Depending on the flow:
a) downflow: the most common type
b) upflow: This mode has the advantage that a multilayer filter can be generated with a single material as larger particles will be situated at the bottom of the filter, which is the water inlet location.

According to washing methodology:
a) Water wash, for both upstream and downstream filters;
b) Water and air wash, in upflow or downflow systems. Air produces great turbulence and shear forces to allow dirt detachment. Air input can be carried out first, or both fluids can be jointly inserted in the washing process.
c) Surface wash: washing can be more intense in surface, where most dirt can be accumulated, by washing water ejectors. Generally, surface washing completes the other processes and it is only performed with water in order to break superficial crusts.

Washings will be discussed in a later section.

3.5.- Process control

The goal of process control is to optimize the operation of the filter. Esentially, filter breakthrough should be avoided, because it would result in the resuspension of particles that have to be retained. Great fluctuations in flow, and filtration loading rate may cause this phenomenon.
If filtering rate increases during the operation cycle, retained particles begin to be dragged, even dislodging the bed media. If the loading rate remains constant, process proceeds in balance. If the filtering rate decreases the process treatment capacity is lower, although the results can be better. Therefore it is recommendable to install monitoring and control systems in the filter unit.

3.6.- Filters washing

The filters should be washed when reaching a pressure drop of 2 to 3 m, or when the operator considers it appropriate. If the filter does not work continuously, washing may be performed at the end of the cycle, regardless of the pressure drop. However, washing need is not only manifested by pressure drop, but by flocs presence in the filtered water. Turbidity may appear with a pressure drop as low as 1.20 m.

Water washing

A water flow enough to expand the filter bed is used. The expansion required varies following different authors. In Degrémont (1973) a minimum 15% is proposed, while according to Steel and McGhee (1981) it should be from 28 to 40%.

Sludge detaches from sand particles surface as they move within the water flow colliding each other.

With this type of washing, the production of sludge aggregates is common, due to the superficial crusts dragged by advection currents towards the bottom of the filter during the process. This effect is partially faced through a surface washing operation with rotating or fixed pressured water ejectors. This operation requires many precautions. Its biggest drawback is the generation of particle size classification, where fine solids are situated at bed surface, which is unfavorable for downsflow filtration.

During washing, the filter behavior is controlled by the d_{60} and not by the d_{10}, that means, larger particles are more difficult to move in order to expand the filter.
Washing velocity should be sufficient to remove the sludge but not too high to displace the granular material. The maximum value depends on the material, being at 20 ° C:

- Sand ($\rho = 2.65$): $V_t = 10\ d_{60}$ (m/min)
- Anthracite ($\rho = 1.55$): $V_t = 4.7\ d_{60}$ (m/min)

There is also a minimum washing velocity, related to the force needed to begin bed fluidization, as indicated below:

$$V_{fl} = V_t \cdot f^{4,5}$$

In the case of a sand bed with 0.55 mm effective size and a uniformity coefficient of 1.5, a specific gravity of 2.65, and porosity of 0.45, the critical velocities are:

$$V_t = 10 \text{ x } (1.50 \text{ x } 0.55) = 8.25 \text{ m/min}$$
$$V_{fl} = 8.25 \text{ x } 0.45^{4.5} = 0.23 \text{ m/min}$$

That is, at 8.25 m/min sand will be drawn, and with 0.23 m/min, it will fluidize without expansion.

The material wash is a result of hydrodynamic shear and abrasion between particles forces. The maximum abrasion occurs when the bed expansion 10% (100% would drag out the sand), when:

$$V_b = 0.1\ V_t$$

For sand beds this means $V_b = d_{60}$ and with anthracite $V_b=0.47\ d_{60}$. These velocities are established at 20°C, for other temperatures:

$$V_{b(T)} = V_{b(20)} \text{ x } \mu_T^{-1/3}$$

Where μ_T is fluid viscosity in centipoise at T temperature.

In water washing design not only the size and density of the filter medium should be taken into account, but also the type and arrangement of the collection system; drains number, size and location; the required hydraulic load even supplied by pumping or by gravity from a water deposit; the system control and the type and capacity auxiliary surface wash.

Required washing wáter volume varies from 1 to 5% of the treated flow. Water washing period usually lasts five minutes, so once known the washing flow, it is easy to calculate the required volume.

Water and air washing

It consists in the use of a small amount of backwash water, which does not expand the sand bed. At the same time, the bed is stirred by a compressed air injection. It does not produce sludge aggregates as there is no bed expansion and because the surface crusts are crumbled with the air.

During air injection, washing water flow can be varied within a very wide range, always above 5 $m^3/h/m^2$. According to Degrémont (1973), it is advisable to apply air and water simultaneously.

Air agitation can help to restore the stratification of dual layer filters, and ti is particularly useful to clean the separation surface between anthracite and sand.

When dirt accumulates on the water surface without reaching draining channels, a rinsing operation should be done by:

a) Maintain the backwash water flow until drained water is clear. The higher the water flow (always higher than 12 m/h) and minor the water height over the filter surface, the lower the time spent on this operation.
b) Increase the water flow during rinsing, at least up to 15 m/h.
c) Sweep the filter surface with a horizontal raw water flow or water flow combined with settled outlet water backflow.
d) Drain the muddy water above the sand bed and sweep the surface as in c.

Washing flow rate

Flow rates used in washing depend on water depth over the bed. In filters with low water depth (approximately 0.50 m), hydraulic load ranges from 18 to 20 m/h for backwash water and 50 to 60 m/h for air. The power required in washing (compressor pump) is about 1.5 kW/m^2. Washing takes about 15 minutes, regardless of timeout period. Water consumption varies between 1 and 2% of the filtrate volume.

In filters with big water depth over bed (approximately 1.20 m) and with a bed height of 1.50 m or more, hydraulic load is in the range from 13 to 15 m/h for washing water and it is set from 50 to 60 m/h for air. These filters can perform surface washing using unfiltered water, so that no excess flow has to be used on the filters which are not being washed. The washing lasts 10 to 12 minutes.

The nozzles for water and air washing are usually configured as a long tube. The following figure represents the cross section of a long nozzle embedded in a false bottom, during washing with water + air operation. This nozzle consists on a head provided with slots and a tube with a hole at the top and a slot at the bottom. The air injected creates an air cushion under the false bottom which feeds the holes and slots of the nozzles, therefore ensuring a good mixture of air + water is distributed evenly across the surface. A minimum of **50 nozzles per square meter** should normally be provided. Countercurrent air flows are in the order of 1 m^3/h per nozzle.

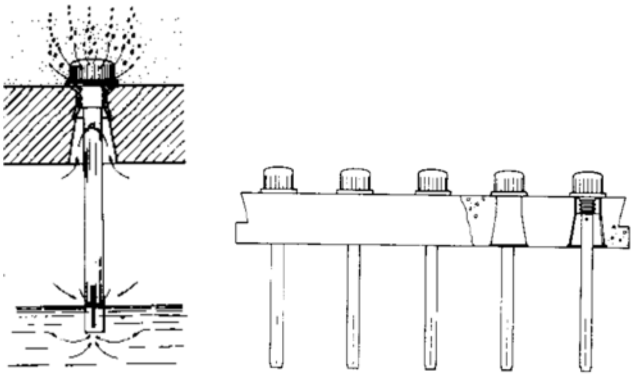


Figure 6.- Nozzle during washing with water and air (left) and assembly (right) (extracted from Degrémont, 1979; Steel and McGhee,1981).

Collecting wash water channels

Washing water, once crossed the bed is conducted through gutters, which are horizontal and are all arranged at the same height, generally at a distance equal to the ascension rate per minute, i.e., about 600-900 mm above the bed surface.

In the European practice, washing water is usually discharged on the vessel sides and not to channels arranged above the filters. This filter designs result in narrower filters, but decrease the possibility of unwanted filter material drag.

In America, channels arrangement depend on the size of the unit; in small units water from gutters is discharged into a channel disposed on one side of the filter, while large plants discharge into a central channel that divides the whole unit into two sections.

Since the wash water should not go laterally more than 1 m, the gutters are never installed at distances greater than 2 m from each other. They are made of concrete, fiberglass or steel, and their cross sections are of different sizes. Concrete gutters have vertical walls and V-shaped bottom and should be built with enough capacity to function as freefall weir for washing water. Gutter bottoms can be sloped to drains, but they are generally horizontal. Header space can be prevented with 50 to 100 mm height.

Washing frequency

The frequency of washing depends on the nature of the treatment water. In practice the basis is the maximum pressure drop, when it is reached, washing operation begins.

If the facility has a highly variable flow, the best solution consist on fixing the washing period after the filtration of a certain amount of water, determined according to the quality obtained at the end of the filter run.

Washing water consumption

Washing water consumption increases when:

- Water height over the bed is higher.
- There is low backwash flow.
- The separation between collection gutters is larger.
- There is more sludge amount to evacuate.
- There is higher mud cohesion and density

A 1 m height bed washed with water and air, will have a washing water consumption in the order of 3 to 4 m^3/m^2 of filter surface.

Under the same conditions, washing with water consumption ranges from 4 to 6 m^3/m^2.

3.7.- Pressured filters

Rapid pressure filters are generally metallic. There are two differenced typologies regarding washing operation: with water or with water and air. Pressured filters tanks are cylindrical and vertical shafted, although those with water and air washing are also horizontal.

Water washed pressured filters

They are equipped with filtering materials whose size and density is chosen by backwashing water rate, considered for bed expansion. The filter layer rests on successive bed layers with increasing size and water outlet is installed as a strained branched collector, embedded in the layer of higher granulometry.

In most cases, the bed is homogeneous, filled with sand or anthracite. Although they may be heterogeneous combining materials like anthracite and sand.

According to the granulometry of the filter bed, the filtration rate can vary from 5 to 50 m/h. The maximum pressure drop reached at the end of the filter run may vary from 2 to 20 mwc, being essentially a function of the filter layer thickness and the filtration rate.

Washing speed is also related to the particle size and should be sufficient to produce an expansion of the height of the filter bed 15 to 25%. The following table corresponding speeds are given a bed of sand:

Table 2. Effective sizes accordint to washing velocities

Washing velocity	Effective size
25 - 35 m/h	0.35 mm
40 - 50 m/h	0.55 mm
55 - 70 m/h	0.75 mm
70 - 90 m/h	0.95 mm

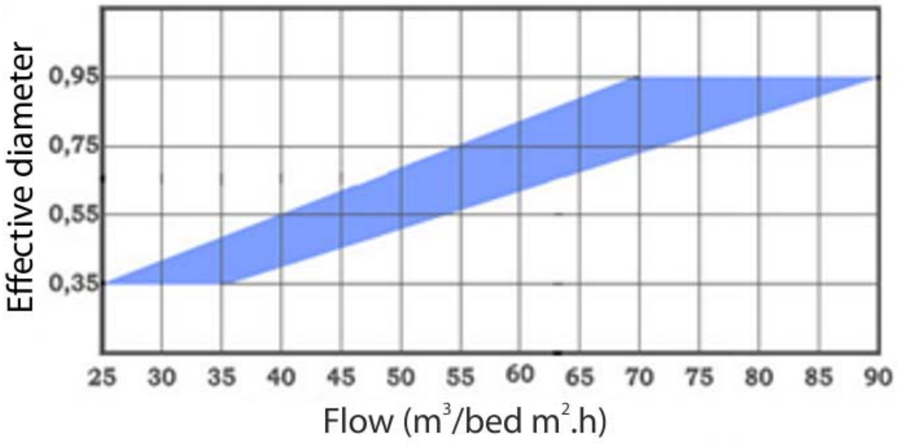


Figure 7.- Recommended washing flow range by bed m^2 for different effective sand diameters.

Washing period varies between 5 and 8 minutes, depending on the bed height sand and retained materials.

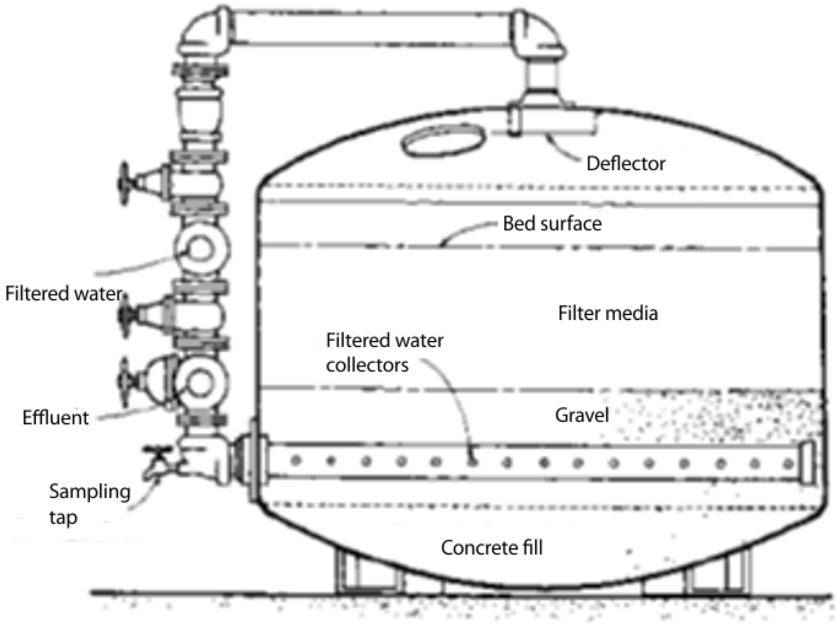


Figure 8. Typical cross section of a pressured filter (Ref. Metcalf & Eddy, 1995).

Air and water washed pressured filter

The homogeneous bed rests on the metallic false bottom where metal or plastic nozzles are located depending on the nature and temperature of the treatment water.

The general characteristics of this type of filter are as follows:

Table 3. General characteristics of pressured filters

Effective size	0.7 to 1.5 mm
Airflow	50 m/h
Water flow during air injection	5 to 7 m/h
Washing water flow	15 to 20 m/h
Pressure drop at the end of the cycle	100 to 400 mbar

The bed height must be adjusted to the filtration rate and solids load on the filter.

Filtration rates vary from 4 to 20 m/h. These filters are well suited for use in battery. It offers great advantages:

- Simplicity of operation
- Total operation safety
- Low wash water flow

3.8.- Design parameters

It is worthwhile reviewing lines or general applications of filtration systems. Depending on the type treatment water associated with other complementary processes:

- Natural water: SS < 15 ppm.
  Possible slow filtration.
  Possible direct high rate filtration **(1)**.

- Natural water: SS < 15 - 40 ppm.
  Possible coagulation plus high rate filtration **(1)**.
  ("coagulation over filter").

- Natural water: SS > 40 - 200 ppm.
  Possible coagul.+ floccul. + settling + monolayer high rate filter **(1)**.
  Possible coagul.+ floccul. + settling + monolayer high rate filter **(2)**.

- Swimming pool wáter:: Possible High rate filter.
  Possible pressured filter **(3)**,
  (Continuous recirculation processes)

The following table shows bed characteristics and process parameters that must be met in a specific filter. Bold numbering in brackets conduct to the references used above.

Table 4.Bed characteristics and required parameters.

BED CHARACTERISTICS	FILTER (1) (monolayer)	FILTER (2) (dual layer)
MATERIAL	Silica sand	Anthracite Silica sand
THICKNESS (m)	0.7 (0.5-1.0)*	0.6 (0.45 - 0.70) 1.0 (0.85 - 1.30)
EFFECTIVE SIZE (mm)	0.8 - 1.0 (0.6-1.2)	1.3 (1.25 - 2.50) 0.6 (0.50 - 0.80)
UNIFORMITY COEFF.	1.5 - 1.8 (<2)	1.5 - 1.8 (<2)
HYDRAULIC LOAD (m/h)	< 7.5 wash (4-15)	< 10 wash (10 - 15)
MAXIMUM PRESSURE DROP (MWC)	1.5	1.5

* Values in brackets refer to variation ranges

Washing the design parameters are:

Table 5. Washing design parameters.

METHOD	WASHING VELOCITY (m/h)	WASHING PERIOD (min)
WATER	60 (50 - 70)	15 - 20
WATER + AIR	WATER> 20 (12 - 30)	10 - 12
	AIR 50 (40 - 80)	1 - 5

When the filter is washed with water and air, significant water savings is appreciated.

Other aspects and parameters to consider are:

Table 6. Design parameters additional considerations

Bed expansión during washing: Sand...............................< 50% Anthracite.......................... < 100%
Maximum horizontal length of washing wáter to gutters....... 0.9 m
Washing wáter losses: with coagulation-flocculation + prior settling unit............< 1.5% Without coagulation-flocculation + prior settling unit............< 3.0%
Filter run........................ 24 h (12 h - 72 h)
Filters number .... $N = a \cdot \sqrt{Q\left(m^3/d\right)}$ where ***a*** varies between 0.044 y 0.051 ....$N \geq 2$
Unit surface .... S_h between 20 y 50 m^2 .... < 130 m^2

4.- SAND FILTRATION OPERATION

Operation should be visually controlled, verifying the absence of fissures in the filter vessel and water leaking.

Amount of sand

It should be checked that sand height inside the filter is correct, according to the manufacturer's instructions. In any case, it should be considered that the sand bed should never fill completely the filter because it would prevent the correct expansion of filtering material during backwashing. If, however, the amount of sand is insufficient. The filtering operation would be less effective, and filter fouling would be faster. The verification should be done twice per season, always ensuring before opening the filter, that water pressure has been evacuated and a reversal flow capable to expel sand out of the unit cannot be produced.

A water test of the drain water during backwashing allows to know if there is sand drag out from the filter.

Sand cleaning

If after backwash a normal pressure difference is not observed, a second backwash out of cycle is performed, with a longer period, ensuring that the water pressure exceeds 30 meters (well above standard 15 meters). If not yet returned to differential pressure level, filters should be opened (always complying with security measures) and visually check the sand, as it may be saturated or highly fouled with organic waste.

In some cases the deposits of micro- and macro-organisms are deposited on top of the sand filters forming an impermeable layer which reduces the filtering function. When this problem occurs, the water flows through galleries in which walls new deposits are formed until the full sand bed is clogged. To face this issue, a bath consisting on 15-20 mL/L of Sodium Hypochlorite (100 g/L) is added during 24 h, being washed afterwards with abundant water.

It should be checked that the sand has been properly cleaned. Otherwise filling sand should be extracted from the filter in order to be cleaned externally.

In other cases, sand gets clogged with calcium carbonate adquiring waterproofing characteristics. If acid cleaning is considered, the problem should be studied as it can suppose a higher cost than replacing the filling media.

It is possible that the pressure difference between the inlet and outlet of the water could become lower than normal. In this case, it should be necessary to verify that the sand has not been dragged out, leaving filter almost empty (usually this trouble can be avoided by installing a limiting flow valve set by the manufacturer at the backwash outlet pipe) or mainstream pathways have been formed through te filter bed, avoiding a proper filtration. This second cause can be corrected by injecting pressurized water from the top and stirring the bed media.

Threads lubrication

All screw threads of these filters should be kept protected by a thin film of grease to prevent oxidation and ensure their handling whenever necessary.

Sand replacing

Considering the quantity and quality of the filtered water, the injection of chlorine through the filters and the amount of residue retained by the sand, it is recommended to change bed media at constant periods. The sand filters should be changed when gravel grain agglomerates persist without getting separated through an intense cleaning. The filter has to be opened annually to check sand state. It is normally necessary to change filling media each 3-5 years. If the filter has been in correct operation ranges, the replacing sand should have the same characteristics than the former.

Coating

This verification leads to an early corrosion points detection, which should be corrected with a wire brush and a protection coating to enlarge equipment life.

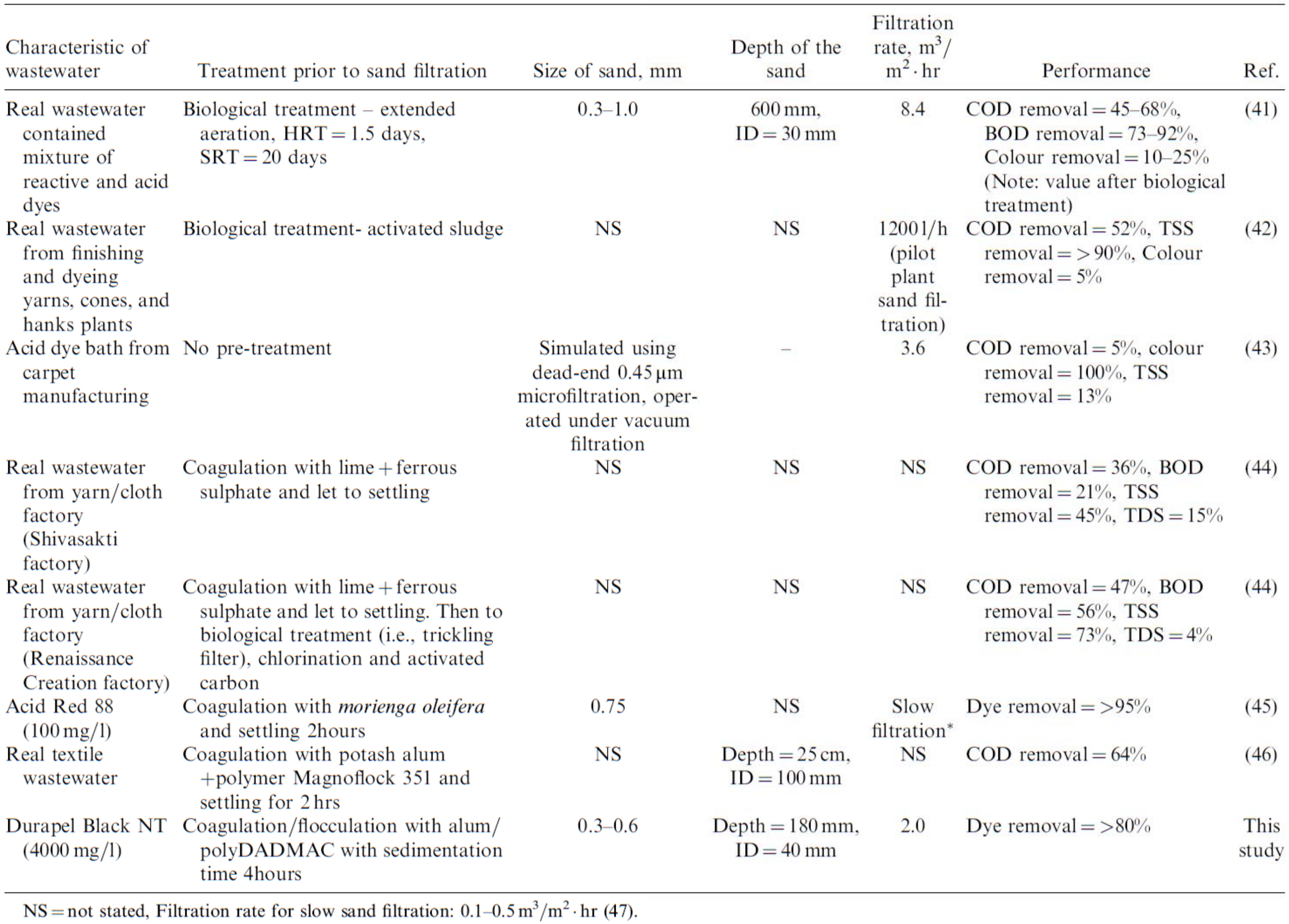
Drain system:
In all filtration systems, and especially in sand filters headers, which are washed by the effect of backwashing, it is very important to ensure the operation of the drain valve. This verification can be carried out by manual activation of the washing process, checking the change of valve position, or directly acting on the small three-way valve of each filter.
Drain collectors connected to these valves must be short and open to the atmosphere, without backpressure. If backpressure occurs, it only serves to n the contrary, only serve to provide additional cushion to turbulence intensity, therefore reducing washing efficiency.

5.- TEXTILE INDUSTRY EFFLUENT TREATMENT SPECIFICATIONS

Removal of Highly Concentrated Industrial Grade Leather Dye: Study on Several Flocculation and Sand Filtration Parameters A. Y. Zahrim, C. Tizaoui a & N. Hilal. *Separation Science and Technology*

The following table shows various studies of dye removal performances analyzed after sand filtration. The result concludes that dye/color and COD removal rates vary within a wide range of 5-100% and 5-68%, respectively.

Table 7. Performance of sand filtration in dyeing water



Characteristic of wastewater	Treatment prior to sand filtration	Size of sand, mm	Depth of the sand	Filtration rate, $m^3/m^2 \cdot hr$	Performance	Ref.
Real wastewater contained mixture of reactive and acid dyes	Biological treatment – extended aeration, HRT = 1.5 days, SRT = 20 days	0.3–1.0	600 mm, ID = 30 mm	8.4	COD removal = 45–68%, BOD removal = 73–92%, Colour removal = 10–25% (Note: value after biological treatment)	(41)
Real wastewater from finishing and dyeing yarns, cones, and hanks plants	Biological treatment- activated sludge	NS	NS	1200l/h (pilot plant sand filtration)	COD removal = 52%, TSS removal = >90%, Colour removal = 5%	(42)
Acid dye bath from carpet manufacturing	No pre-treatment	Simulated using dead-end 0.45 µm microfiltration, operated under vacuum filtration	–	3.6	COD removal = 5%, colour removal = 100%, TSS removal = 13%	(43)
Real wastewater from yarn/cloth factory (Shivasakti factory)	Coagulation with lime + ferrous sulphate and let to settling	NS	NS	NS	COD removal = 36%, BOD removal = 21%, TSS removal = 45%, TDS = 15%	(44)
Real wastewater from yarn/cloth factory (Renaissance Creation factory)	Coagulation with lime + ferrous sulphate and let to settling. Then to biological treatment (i.e., trickling filter), chlorination and activated carbon	NS	NS	NS	COD removal = 47%, BOD removal = 56%, TSS removal = 73%, TDS = 4%	(44)
Acid Red 88 (100 mg/l)	Coagulation with *morienga oleifera* and settling 2hours	0.75	NS	Slow filtration*	Dye removal = >95%	(45)
Real textile wastewater	Coagulation with potash alum +polymer Magnoflock 351 and settling for 2 hrs	NS	Depth = 25 cm, ID = 100 mm	NS	COD removal = 64%	(46)
Durapel Black NT (4000 mg/l)	Coagulation/flocculation with alum/polyDADMAC with sedimentation time 4hours	0.3–0.6	Depth = 180 mm, ID = 40 mm	2.0	Dye removal = >80%	This study

NS = not stated, Filtration rate for slow sand filtration: 0.1–0.5 $m^3/m^2 \cdot hr$ (47).

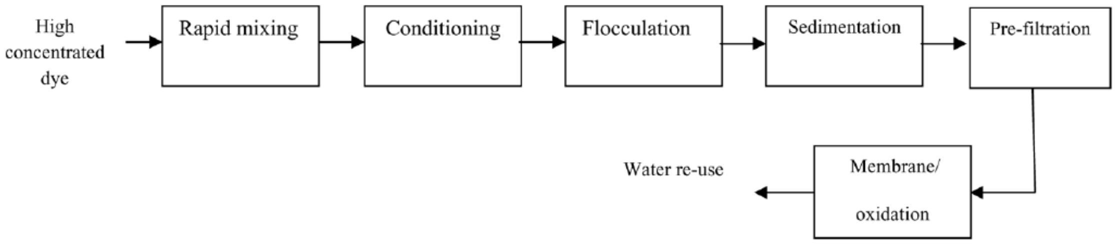


Figure 9.Treatment of highly concentrated dye solution by coagulation/flocculation–sand filtration and nanofiltration (A.Y. Zahrim, N. Hilal. Water Resources and Industry)

Study of coagulation-flocculation followed by sand filtration.

For the study of direct sand filtration, an effective size of 0.3-0.6, and a bed height of 350 mm were set. At this operation conditions, design filtering rate expected was 1.0 m^3/m^2.h.
As coagulant and flocculant, aluminum sulphate and low-medium molecular mass poly-diallyl-dimethyl ammonium chloride (polyDADMAC) were used. The filtration rate in operation was 0.6 m^3/m^2.h.

The best operating conditions were achieved with rates from 0.1 to 0.24 m^3/m^2.h (slow filtration).

6.- OPERATION TROUBLESHOOTING

Experience in working with sand filters determine that the fundamental problems are associated with difficulties in backwashing mechanisms or with unproper backwash operation.

An indication that the washing cycles are correct is observed when the interval between washing periods stays constant, which can also be verified if the pressure downstream of the filter recovers totally after each backwash. On the contrary, A consecutive sequence of washinge cycles should be carried out until achieving the common clean filter pressure.

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ANNEX 1
REQUIRED SURFACE ESTIMATION

SAND HIGH RATE FILTERS				
Range	**Filtration rate m/h**		**Diameter (m) 2**	
	5	**10**	**5**	**10**
Flow (m^3/h)	**Required surface (m^2) Functional surface**		**Minimum units**	
5	1,0	0,5	0,3	0,2
10	2,0	1,0	0,6	0,3
20	4,0	2,0	1,3	0,6
30	6,0	3,0	1,9	1,0
40	8,0	4,0	2,5	1,3
50	10,0	5,0	3,2	1,6
60	12,0	6,0	3,8	1,9
70	14,0	7,0	4,5	2,2
80	16,0	8,0	5,1	2,5
90	18,0	9,0	5,7	2,9
100	20,0	10,0	6,4	3,2

ANNEX 2
GRAPHICAL DESCRIPTION OF UNIT PROCESSES

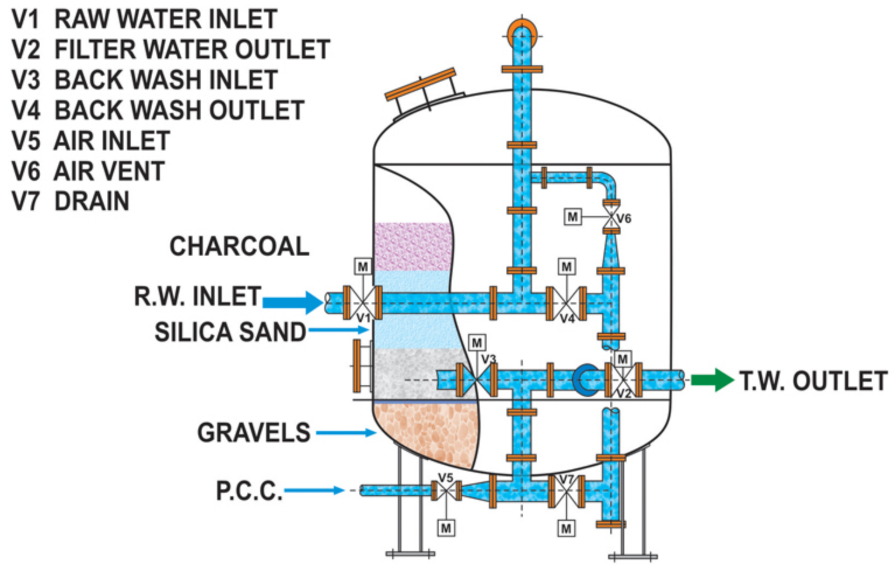

Figure 1
Basic scheme of a multilayer filtration system.

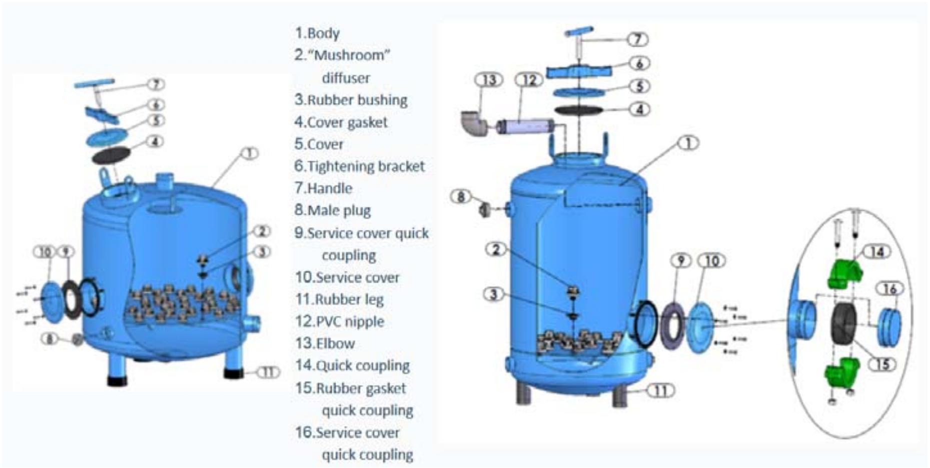

Figure 2. Basic scheme of a sand filtration system.
http://www.yamit-f.com

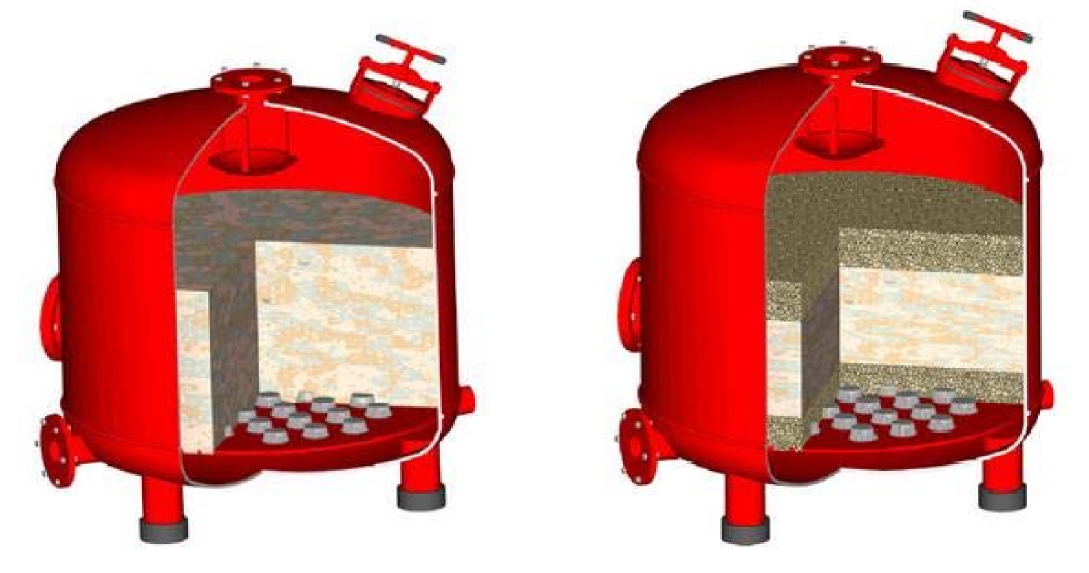

Figure 3. Basic scheme of a monolayer and multilayer filter.
http://galeon.com

Figure 4. Plastic collectors and nozzle.
http://galeon.com

Figure 5. Overview of a pressure filter set.
http://tecmoncade.com

Figure 6. Overview of a filttration system.

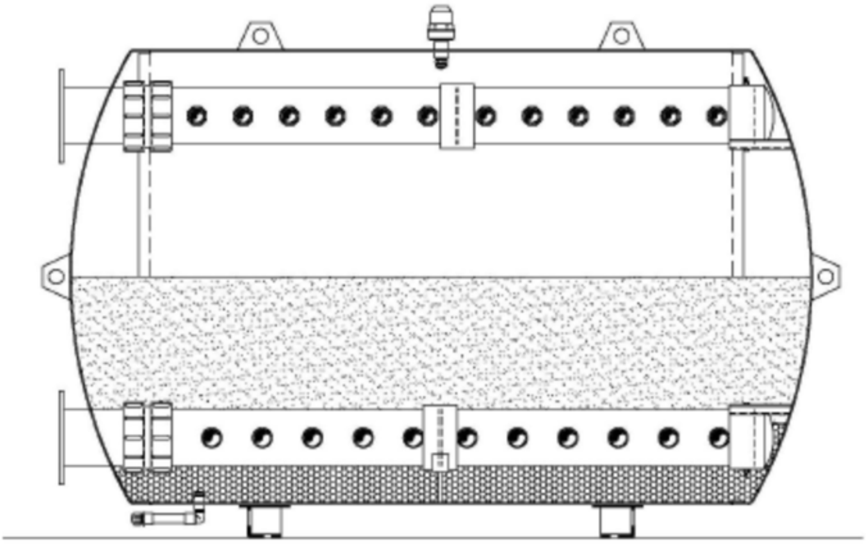

Figure 7. Horizontal pressured filter scheme.
http://www.paddockindustries.com

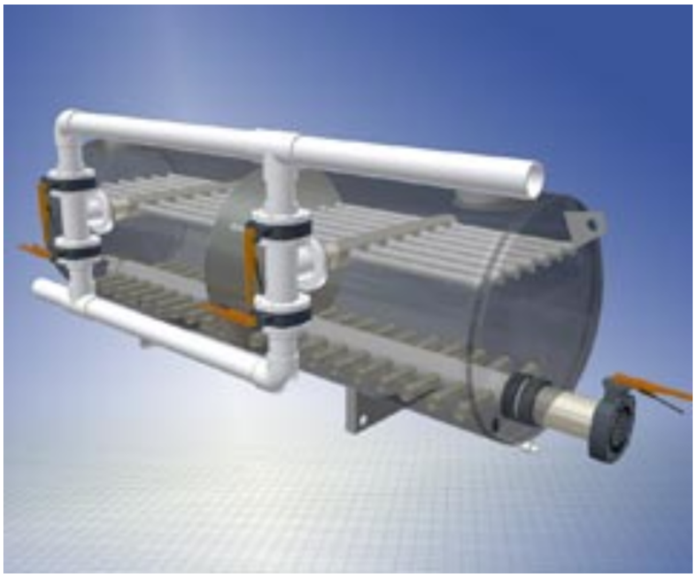

Figura 8. Stainless Steel Horizontal Pressure Sand Filters
www.paddockindustries.com

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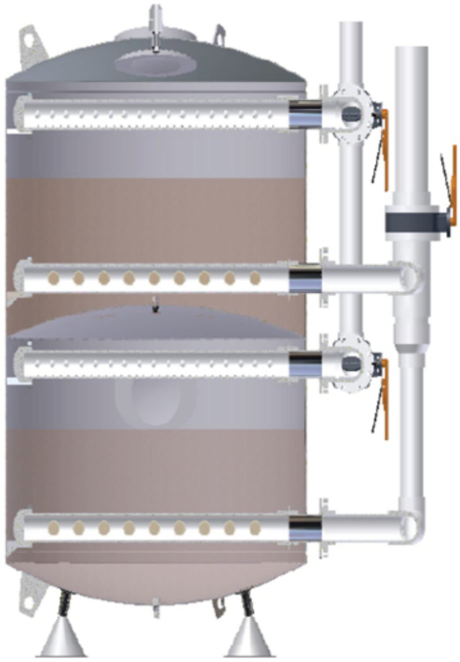

Figura 9. Double cell filtration system.
www.paddockindustries.com

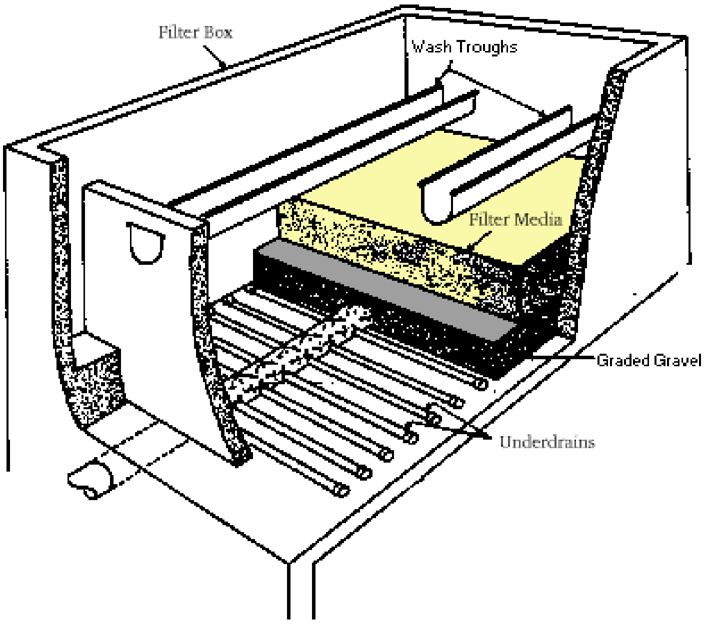

Figure 11. General sheme of a open gravity filter.

Figure 12. Multiple filtration system.
Hydro-Flo Technologies HydroCell™

Figure 14. Washing operation of an open filter.