Conceptual/experience-based design of suspended solids removal systems

The Importance of Suspended Solids Removal

The importance and impact of suspended solids is more than it appears. “Suspended solids” is a collective name for different materials in water which have a common feature, which is that they are in the “solid phase”. The suspended solids in water could be composed of different material, which could be organic or inorganic. Therefore, if the material of a specific suspended solid is organic, by removing that suspended solid, the organic content of the water will decrease. On the other hand, if the suspended solids are solid particles of $Fe(OH)_3$, then by removing that, the total iron content of the water will decrease.

The impact of high suspended solids in water depends not only on their concentration and particle sizes, but also on the nature of the suspended solids. For example, if the suspended solids are in the form of sand, then a stream of this water would be abrasive, while a stream containing suspended solids in the form of magnesium hydroxide, which is a gelatinous suspended solid, would not be abrasive and could even decrease the abrasiveness of other suspended solids (e.g. sand) by “embracing” them. Organic suspended solids make a stream a “time sensitive” stream; it could quickly become septic and pungent. It could also be problematic if the stream is to be directed to heat transfer equipment. It is not unusual to see a fraction of organic suspended solids being converted to gas (as a VOC/volatile organic compound) and decreasing the heat transfer rate by attaching bubbles to heat transfer areas.

The main problems of suspended solids are:

1. Solid settlement and reduced capacity of equipment and pipes, or interference with their operation. The degree of particle settlement depends on the density of particles but is usually problematic when the particle sizes are larger than 200 μm (for naturally occurring sand and clay particles). A high concentration of the solids worsens this problem.

2. Plugging and clogging of mechanical systems: If a piece of equipment has a clearance (a narrow passageway), usually particles of a size greater than the clearance - and even down to two thirds of the size of the clearance - could cause plugging in the system.

Generally speaking, when the size of the particles goes beyond 1 to 4 mm, non-conventional centrifugal pumps should be considered. A high concentration of solids worsens this problem.
On the other hand, positive displacement pumps are more sensitive to suspended solids. That is why permanent suction strainers are more popular for them than for centrifugal pumps.

3. Erosion: The suspended solids concentration and the size and material type of the suspended solids can make a slurry either more or less abrasive. There could be cases where even a 10% slurry isn’t

considered as an abrasive slurry because the suspended solids are not very hard, but rather are in the form of a gelatinous solid.

4. Wasted chemicals: If there is a chemical injection point before the suspended solids removal operation, a portion of the chemical will inevitably be wasted through the removed suspended solids. One famous example of this is the chlorination of water for the purpose of disinfection. Chlorination in the presence of suspended solids is never complete because chlorine cannot be very effective on the microorganisms which are hidden in the particles.

Reporting Suspended Solids in Water

In general, there are three aspects of suspended solids which could be reported:
1. Suspended solids concentration
2. Suspended solids size and size distribution
3. Suspended solids material

-Suspended solids concentration

Usually particles in the "normal" range are reported in weight per volume of water: for example, mg/l or ppm.
In very dirty applications and in the case of very large suspended solids (more than a few centimetres) it makes more sense to report the solids content of water in volume of solids per unit volume of liquid; for example, the solids content of non-urban storm water could be 0.1 m^3 of solids per m^3 of water.
However, reporting in volume per volume has advantages for equipment selection too. Generally, the suspended solids tolerance of equipment such as centrifugal pumps is reported in volume/volume units, since the "volume" is what a piece of equipment can "see", and part of it is "occupied" by the suspended solids.
In very high quality water applications like the pharmaceutical or microchip manufacturing industries, in which TSS (total suspended solids) needs to be very low, it is reported as the number of particles per unit volume of water. For example, the water quality specification in the pharmaceutical industry could be 2 particles per 100 ml of ultra-pure water.

-Suspended solids size

Although a water sample with a single particle size can be made in the lab, in reality a "range" of particle sizes are found in natural or industrial waters. This size distribution generally follows a bell-shaped curve (possibly skewed), with one peak. A bell-shaped curve with two peaks can sometimes be interpreted as a stream which was generated by two or more recently mixed streams.

-Suspended solids material

The suspended solids material is not usually of importance. This is because the removal methods for suspended solids are generally non-material-specific. Possibly the only important material characteristic of suspended solids is whether they are organic or inorganic.

Table – 1 shows different characteristics of organic vs. inorganic suspended solids in water.

Table – 1: The features of organic and inorganic suspended solids

Inorganic Suspended Solids	Organic Suspended Solids
• Gravity separation is mainly via sedimentation • Easier to trap in filters because there are more solids • The removed suspended solids can be of beneficial use for building material	• Gravity separation could be via sedimentation or flotation • The removed suspended solids can be used for land applications • The removed suspended solids can quickly become septic (odorous, etc.)

TSS Concentration vs. Particle Size

In the lab, one can make water samples with different concentrations of suspended solids and different particle sizes. But in natural systems, usually particle size and suspended solids concentration have some correlation. Roughly speaking, the larger the concentration of suspended solids (in weight per volume), the larger the particle size.

Suspended Solids Removal

Theoretically, to remove particles with a wide range of sizes in order to produce a liquid stream free of any particles, it is enough to install one strainer sheet with a pore size smaller than smallest particle size. Actually, depending on the Solidity of particles, the pore size could be larger than the smallest particle size up to 50 or 60%.

However, this recommendation is not the best solution from a technical or economic standpoint. By implementing this, we would have a system which would need frequent cleaning and, consequently, a great deal of attention.

A better solution is to arrange a series of strainers with different pore sizes; starting from the biggest pore size and gradually decreasing to the smallest pore size (Figure -1).

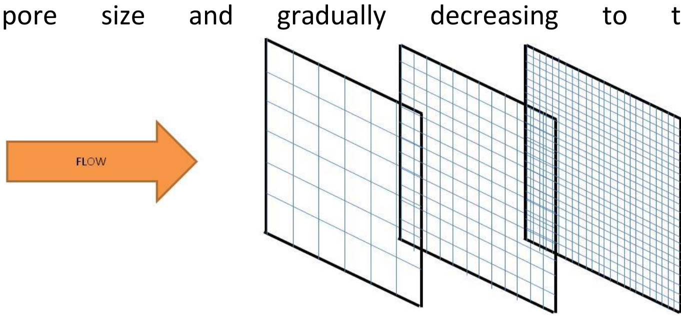


Figure – 1: Theoretical Removal of total suspended solids

This concept can be implemented in the following preliminary design to optimise it to a more practical design:

1. One variation of this arrangement is to replace the last few strainers with a depth filter.

As is to be expected, a strainer is a surface filter which removes all particles larger than its pore size. While, a depth filter removes particles bigger than its "pore size" and, surprisingly, all other smaller particles down to a certain size! In other words, a depth filter is NOT a 3D version of a surface filter (or strainer) from an application viewpoint. Their duties are completely different and they are actually complementary to strainers. In practice, a depth filter is placed at the end (or near the end) of a "suspend solids removal string". This means that upstream of the depth filter, there could be one or more "strainers".

In theory, only one depth filter could be installed to remove all of the particles (bigger and smaller than its "pore size") down to e.g. 2 micrometers; however, because of this unique capability of being able to remove particle sizes even smaller than its pore size, in practice, particles that are bigger than the pore size of the depth filter are removed by strainers as much as possible upstream of the depth filter. This is in order to offload the big particles from the depth filter using less sophisticated systems (strainers), as large particles decrease the operation cycle of depth filters.
Usually a depth filter removes particles in the range of 2 to 50 micrometers.

In the above discussion, whenever a depth filter was mentioned, "pore size" was used loosely because pore size is well-defined for strainers and fixed media filters, but not for loose media filters. This is mainly because of the complication of defining pore size for loose media depth filters. In such cases, media size is used instead to specify a depth filter.

2. For particle sizes larger than 100 µm, with concentrations of more than 1%, and if the flow rate is high (say, more than 200 m^3/h), a more attractive option than a "strainer" is sedimentation.

Sedimentation is not popular for particles smaller than 50 µm because it takes a long time. Although there is no theoretical limit, but the largest particles which can practically be removed in a sedimentation basin are around 5000 µm (5 mm). This is because the particles removed end up in the sludge on the bottom of the sedimentation basin, and if they are larger than 5 mm, they cannot be handled/ conveyed easily by conventional centrifugal pumps. Technically, a sedimentation basin can be used even for particles larger than 5 mm, but this is not economically very attractive.

3. Although up to this point the discussion has claimed that a depth filter can remove particles of a given size and lower, in reality depth filters with conventional designs cannot effectively remove particles smaller than 2 µm. If this residual suspended solids content is still problematic, it should be removed via surface filtration.

Based the above concepts, a generic string for suspended solids removal starts with one or more surface filters (strainers), then a depth filter, and occasionally one or more surface filters at the end(Figure – 2).

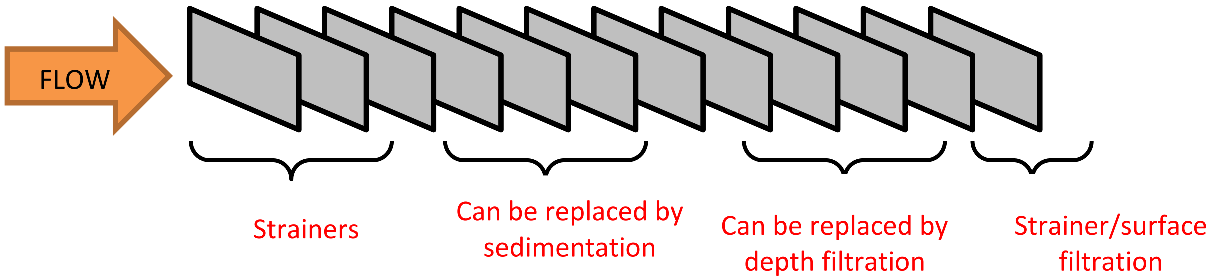


Figure – 2: A practical approach for removing total suspended solids

In the following examples, the use of the above concept is shown:

Example 1: Obtaining water suitable for an RO (Reverse Osmosis) system from a groundwater source: The use of a multimedia sand filter followed by a cartridge filter is popular. This is because the TSS of groundwater is usually less than 50 mg/l and a multimedia sand filter will remove all the TSS down to 10 micrometers. Because the RO membrane is sensitive to particle sizes of about 10 micrometers, another filter - a surface-type cartridge filter, which works based on the mechanism of straining - is used at the end.

Example 2: Obtaining water suitable for a biological treatment system from raw municipal wastewater: Municipal wastewater can have suspended solids of up to 15 cm in size. Therefore, at the beginning of the string, one or more sets of strainers should be installed. If the particle size distribution shows that one set of strainers (fine screen type) can handle the particle content suitably, one set is enough. However, if the installation of one set of strainer leads to too frequent cleaning (in manual cleaning types, more than once per 8 hours) or mechanical cleaning that is too complicated (in the case of mechanically cleaned strainers), two sets of strainers - one coarse strainer (bar rack) and the other fine (fine screen) - should be installed.

After that, once the size of the remaining particles in the wastewater is less than roughly 5 millimetres, sedimentation is used (the equipment for this is called a primary clarifier). Water from this clarifier has less than a few hundred ppm of TSS and is ready to go the next step, which is a bioreactor. Suspended culture bioreactors can tolerate up to a few hundreds of ppm of TSS, so no further upstream TSS removal is needed.

Example 3: Obtaining ultrapure water from groundwater: Again, here we can start with a multimedia filter to drop the suspended solids particle size to less than 2 micrometers and then, because the intention is to generate ultrapure water with an almost zero particle count, two cartridge filters with pore sizes of 0.45 micrometers and 0.2 micrometers can be used in series.

Filtration Mechanisms

The filtration operations - depth filtration and sieving – can be accomplished via different mechanisms (Table – 2). While all the mechanisms are available for depth filtration, not all of them are applicable in a straining operation. The only mechanism that works during straining is “sieving”.
Sieving is a mechanism through which a particle is removed by trapping in the pores of a given media. Inertial impaction is when a particle collides with, and resides on the surface of filter media, and is thereby removed from the stream. When a particle is grasped by the surface of a filter media, the mechanism is called “interception”. In sedimentation, particles are sedimented on the surface of the filter media due to gravitational force. Diffusion occurs when a particle is so small that Brownian motion causes it to strike the surface of filter media.

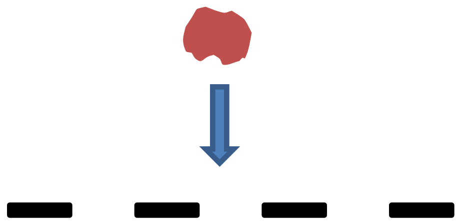
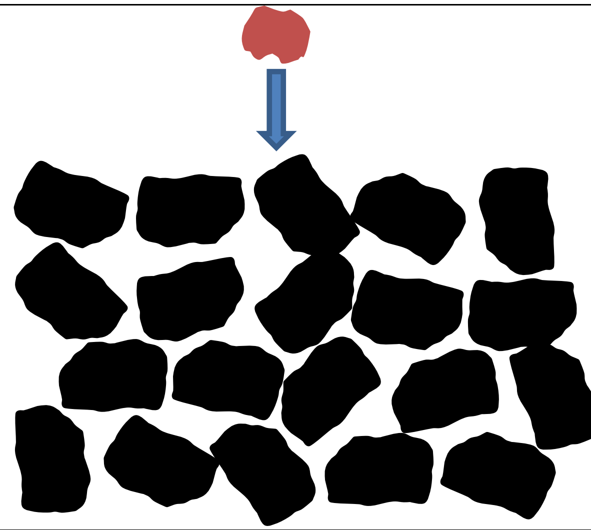
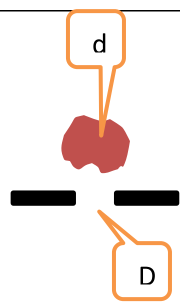
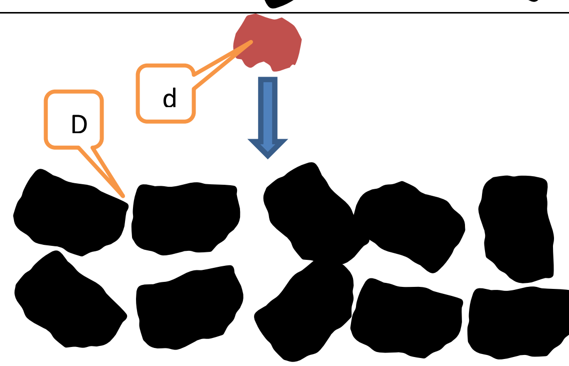
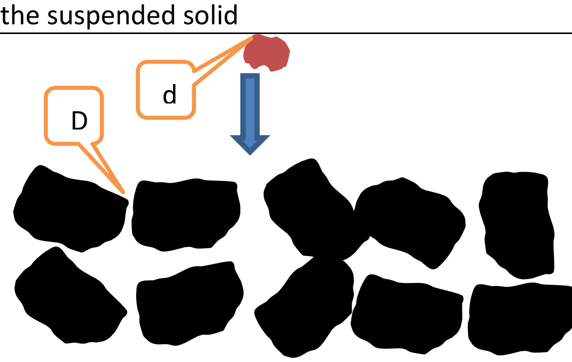
In liquid filtration with a low liquid velocity, inertial impaction can be considered as a negligible mechanism with regards to particle removal.

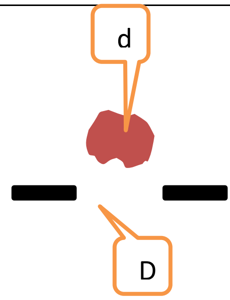
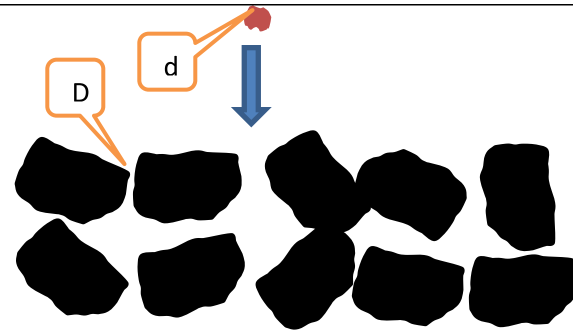
Table – 2: Different suspended solids removal mechanisms	Straining	Depth Filtration
Sieving	✓	✓
Inertial impaction	Not important in liquid filtration	
Interception	X	✓
Sedimentation	X	✓
Diffusion	X	✓

From a simplistic point of view, when particles approach a strainer or filter, one of three things can happen: trapping on the surface of strainer/filter, trapping inside the filter media, and escape. These three events are shown in the Table – 3 with some rules of thumb which predict their behaviour.

All numbers in the table are approximate and can be changed for different filtration rates. They are stated here only to give a general understanding of filtration.

Table – 3: Behaviour a typical suspended solids in straining and filtration operation

	Straining	**Filtration**
Schematic		
Trapping on surface	 d > (1.0 to 1.5) D depending on the solidity of the suspended solid	 d > (0.1 to 1.5) D depending on the solidity of the suspended solid
Trapping in depth	Not applicable	 (0.05 to 0.15) D <d < (0.3 to 1.5) D depending on the solidity of the suspended solid

Escape	 d < (1.0 to 1.5) D depending on the solidity of the suspended solid	 d < (0.05 to 0.15) D depending on the solidity of the suspended solid and flux; d < 1-2 micrometer => 100% escape
Removal mechanism	Straining	Inertia, Sedimentation, Diffusion

Some Aspects of Filtration Equipment

Number of filter vessels

One important parameter in filtration systems is the number of filters. In depth filtration, by choosing a bigger vessel (with a larger volume of media), we can have fewer vessels and less piping and valves (lower capital cost), but more frequent backwashing is needed, which means a lower on-stream factor for the filter. On the other hand, by increasing the number of filter vessels, the capital investment (the expense of fabrication and installation) will be higher but the operating cost will be lower. Therefore, an economically optimal point for the number of filters can be found.

Kawamura[1] stated that the number of filters in potable water treatment systems is (after unit conversion):

$N = Q^{0.5} / 10.46$ Equation - 1

Where:

Q : feed flow to filters in m^3/h

N : number of filters

However, the author believes that in industrial facilities, the number of pressure filters is better calculated with this formula:

$N = Q^{0.5} / K$ Equation - 2

Where:

Q: feed flow to filters in m^3/h

K: ranges between 10 to 26 and is typically around 20

N: number of filters

Surface Filtration or Cake Filtration?

Theoretically, cake filtration can be done using the same equipment as a surface filter by providing more space for trapped solids. This is because in both cases the pore size is smaller than the particle sizes and the particles will be trapped on the surface of the filter. However, cake filtration is usually done using specific equipment designed for this purpose.

In this equipment, trapped suspended solids are present in such high quantities that they build up a thick layer of particles (cake) on the surface of the surface filter; this built-up cake has a good porosity to work as secondary filter, and, when it is time, the cake can be removed from the filter easily. If the cake which is generated does not have good porosity and detachment properties, adding a “filtration aid” as body feed and/or pre-coat to the stream can help.

Having said that, usually cake filtration is not used in water and wastewater treatment because the concentrations of suspended solids in those streams are so low that cake filtration is not necessary. However, cake filtration can be used in process industries or for waste streams from suspended solids removal operations, which have higher suspended solids concentration. Additionally, cake filtration has the advantage that the removed solids from cake filtration are in the form of a wet cake, whereas from filtration and sedimentation this is a watery stream with less than 30% suspended solids content.

There are many different systems for suspended solids removal in industry but here a conceptual approach is used to describe the applications of the workhorses of the industry, which are strainers, (depth) filters and clarifiers.

(1) Kawamura S., 2000. “Integrated design and of water treatment facilities” 2nd ed. New York: John Wiley & Sons.

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