PRE-CLEANING MEASURES: FILTRATION

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Contents

Summary

The filtration process as pretreatment for desalination plants, especially for reverse osmosis systems, depends on various influences.

In this chapter basic principles and different characterizations are summarized. For the design of filtration plants, all the important points (as described above), should receive attention. This is necessary for optimal operation performance of filtration plants.

1. General

Filtration is essentially classified according to filtering by means of support layers or deep filtration by means of a filter bed consisting of one or more layers. The selection of the various methods or systems depends on different criteria such as:

- Qualities of the liquid, its impurity and time variation;
- Desired quality of the filtrate and its tolerances;
- Installation conditions;
- Cleaning possibilities;
- Economic conditions.

The different solutions vary according to investment and operating costs which are influenced by the filtering demands on the water, the filter-cleaning technology, and the automation level. As pretreatment for seawater desalination, particularly when using the reverse osmosis process, filtration through layers of granular material has proved successful. Filtration of polluted water plays a central part in the water treatment process. In principle water filtration involves the separation of the solid and liquid phase as well as interaction between the water components and filter media. These processes lead to variations in the concentration.

In the last few years a series of technical improvements related to process engineering and operation have been studied and successfully put into practice. The development of these techniques began with surface filtration using a deep sand bed. Later a technique using deep bed filtration was adopted with the aim of optimizing the exploitation of the entire volume of the filter bed.

In practice, however, not only the filtration of suspended particles is of relevance. The technique in which flocculation-oxidizing or biological processes also occur in the filter is consciously carried out to an even greater extent.

In the following sections filtration using granular material will be dealt with showing how it is predominantly used as pretreatment for desalination plants. The subject matter will cover aspects of process engineering as well as practical experience with the operation of such plants, permitting an advantageous and economic application of the deep bed filtration process.

2. Basic Principles of Filtration

Filtering is a process in which a liquid, containing solid or suspended substances, flows through a layer of granular material where filterable materials are retained. If the dimensions of the materials to be removed are larger than those of the existing pores in the liquid, then they are retained on the surface. This is called surface or cake filtration, or filtration using support layers. If materials are retained inside the filter layer this is referred to as deep or bed filtration. In both cases the flow processes of water in a layer of granular material comply with Darcy's law. This states that the pressure loss is in proportion to the filtration velocity. The proportionality factor depends on the dynamic viscosity of the water and on the resistance in the filter layer.

On examining the existing practice of application techniques as well as the literature in the field of filtration, it has been established that the construction of large-scale filter plants is only based on empirical values and semi-technical tests. In practice filter theories are almost never used to determine the plant size, although a series of publications on filter theories is available. Special reference can be made to the works of Ives et al. (1960), Herzig et al. (1970), and Kawamura (1975). The cause lies mainly in the following factors.

1. Filtration of turbid water by means of a filter made of granular materials entails transport processes, agglomeration mechanisms, and the breakaway effect caused by shearing stress. The particles to be removed must first be conveyed to the filter

grains where they can be retained by agglomeration processes. Even after deposition on the filter grain, there is still some possibility that particles become suspended by shearing stress.

2. The mathematical description of the processes in a filter is complicated even further by the fact that very different individual transport processes play a determining part. In addition, the agglomeration mechanisms are by no means homogeneous.

Below is a summary of the possible mechanisms:

Transport processes	agglomeration mechanisms
Diffusion	van der Waalssche forces
Sedimentation	electrical forces
Interception	adsorption processes
Hydrodynamic effects	chemical processes

Since it is exceptional to find homogeneous particles in natural water, more than one transport mechanism is expected to have a determining influence on the filtering tasks used in practice. An analogy can be drawn of conditions with regard to the various agglomeration mechanisms. In this case one must always expect to find several simultaneous processes and in turn their probable or possible mutual interference. One must not overlook the fact that knowledge of the limiting quantities in respect of filtration can be of great significance to the planning of an expedient and optimum filter plant. For example, the mutual influence of the various mechanisms such as filter height, grain size, velocity of flow, filter media, and also materials to be removed.

Besides the filtering technique presented so far, there are other techniques to accomplish filtration. Particularly noteworthy are the membrane processes such as nano or ultra filtration. However, in respect of pretreatment for desalination, no great importance is attached to these processes for essentially economic reasons. Nevertheless, in the case of small-scale plants, this technology is applied successfully.

3. Particle Transport and Agglomeration Mechanism

When natural water, rendered turbid by solid matter, flows through a bed of granular filter media, the water will pass the filter layer with a more or less reduced solids content. On examining the filter, it will be established that the solid matter has settled on the grains in the interspaces of the filter layer. Natural impurities of seawater are as a rule very minor and are caused, for example, by remains of organisms, algae, and minerals, which exist in various geometrical forms. Subsequently, studies of the transport processes are based on particle diameters of 0.1 to 100 μm. Chemical pretreatment of water can cause substantial variation in the particle size. On the assumption that the filter media has a diameter of 1.0 mm and porosity of 0.4, the ratio of the particle diameters with 25 μm particles is approx. $1\ 20^{-1}$. Hence the particles are very small in proportion to the channels. This means that a screening effect can be ruled out. However, since the particles settle on the gravel, they must have been transported there by certain mechanisms. Since the range of Waals and electrostatic forces are too small for effective sedimentation, they can be eliminated as a cause of transport through the liquid. The only transport mechanisms which remain are:

- Motion of the water when flowing through the bed;
- Proper motion of the particles, as in the case of sedimentation or diffusion.

The following is a brief summary showing which of the influences prevails, e.g. whether particles flow through the stream channels without obstruction or whether the stream is so slow, in proportion to the sinking velocity, that the particles can deposit sediment without hindrance.

3.1. Sedimentation

A comparison of the sinking velocity of a particle to the average velocity of flow through a filter layer with 0.4 porosity results in a ratio of sedimentation velocity to velocity of flow between $1\ 3^{-1}$ and $1\ 5^{-1}$. In every stream, boundary layers develop on solid walls and reduce the speed to zero. Therefore, the transport effect of sedimentation must also be taken into account. The particle, however, flows through different stream layers and thus exerts influence on the sedimentation paths. It is assumed that upon descent of a particle to the grain surface, part of the speed remains in the direction of flow and part is lateral to the direction of flow. Given that the part of speed in the direction of flow is negligible in proportion to the velocity of flow, the part lateral to the direction of flow toward the grain is the sole determining factor in transportation through sedimentation. This applies in most cases of filtration through granular material.

3.2. Diffusion

The description of the agglomeration process through sedimentation applies in particular to specific heavy particles, which are not too small. However, it should also be taken into consideration that there are also very small particles with diameters of less than 2 μm, which could possibly be diffusive. In addition to the transport mechanisms due to material qualities of the particles, the flow processes in the bed of the filter media should also be taken into account. As a rule the flow in the filter is laminar and the pressure loss is proportional to the velocity of flow. However, any adjustment to the concentration in a filter is due to a process similar to the mixture, which occurs while passing through the bed. In this case the liquid streams are separated and form new stream channels with the aid of partial streams from different pore channels. This causes particles, previously located in the center of flow, to reach the boundary zones of the stream channels and thus become agglomerative. When a floating particle passes a pore it will generally move towards the surface of a grain where it then settles. This transportation process can be carried out according to several mathematical interrelationships whose different effects depend upon material quality of the particles, the geometry of the bed, the direction of flow, and the stream behavior of the water. In order to represent these transport and agglomeration mechanisms mathematically, calculation models have been drawn up by different authors. Herzig et al. (1970), Saffman (1965), Ives (1966), Gregory (1966) and Rolke (1971).

These mathematical models will not receive detailed consideration at this stage. However, the knowledge drawn from these models is examined in the description of the transport and agglomeration mechanisms. The calculation models for filtration and the design of filter plants have not yet found widespread use in practice and are only consulted to verify results of pilot tests.

4. Filter Systems and Selection

Water polluted by turbid matter and dissolved or undissolved organic impurities requires cleaning treatment in which various filter systems are used. In this chapter, however, only those filter systems used in the pretreatment for seawater desalination plants will be examined. In these types of filters water is passed through granular masses as pretreatment. The operation of these filters is usually effected from the top toward the bottom. There are also specially designed filters in which the filtration process is effected from the bottom toward the top. The latter are seldom used and are reserved for special cases, e.g. for filtration with biological reactions, the backwashing is effected from the top toward the bottom.

Membrane filter systems, recently used under certain conditions, are described in section 6 (See: Microfiltration and Ultrafiltration) and will therefore not be studied here. This also applies to filters, which operate by means of a precoat filter such as cartridge or plate filters.

4.1. Filtering Through a Bed of Granular Material

This technology is applied when the quantity of material to be retained is larger but the particle size relatively small. In order to achieve effective filtration, the impurities must penetrate deep into the filter bed without clogging its surface. For this purpose, the filter media must be carefully selected with regard to grain size and layer height in order to ensure the desired quality of the filtrate. To attain good filtrate quality the filter must fulfil a series of conditions. There is no universal filter, but at best filters which are more or less suitable for the various tasks. With regard to filtration of water using granular material, a distinction is made between low-rate filtration and rapid filtration.

4.2. Low-rate Filters

Low-rate filters are practically never used for the treatment of seawater since the occupied space, filtrate quality, and handling do not meet the requirements and are not economical. The filtration velocity for this type of filter varies as a rule from 0.05 to 0.4 m h^{-1}. In addition, these filters are not suitable for backwashing.

4.3. Rapid Filters

Rapid filtration means that the water to be filtered flows through the filter bed at a speed of 4 to 30 m h^{-1}. Rapid filters are designed for backwashing. They are classified according to:

- System:
  - Direct filtration in which no reagents are added to the water to be filtered;
  - Flocculation filtration with coagulation both on top of and inside the filter layer;

  - Filtering of flocculated water from which turbid matter has been largely removed.
- Design

4.4. Open filters

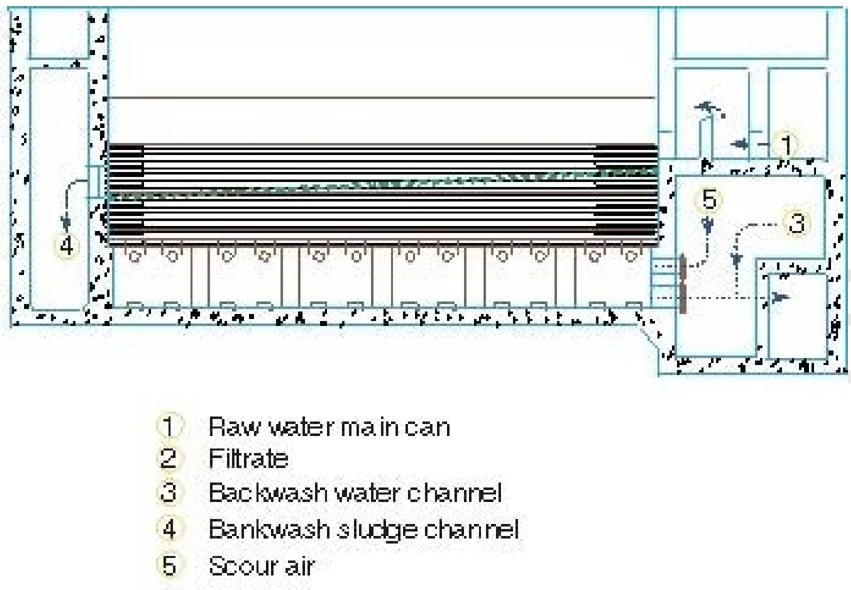

Figure 1. Open gravity filter.

The flow through these filters is effected by force of gravity. They are mainly made of concrete. The filtration velocity is up to 15 m h^{-1} and is limited by the pressure loss in the filter layer. The pressure drops until the existing level of freeboard is exhausted.

4.5. Closed Vertical Pressure Filters

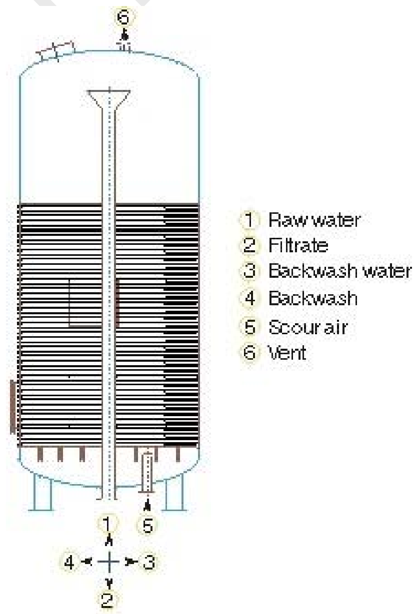

Figure 2. Pressure filter vertical.

These filters are as a rule produced of steel with a suitable corrosion-resistant lining. The diameter is limited to approx. 6.00 m for economic reasons. In addition, concrete pressure filters can also be used.

4.6. Closed Horizontal Filters

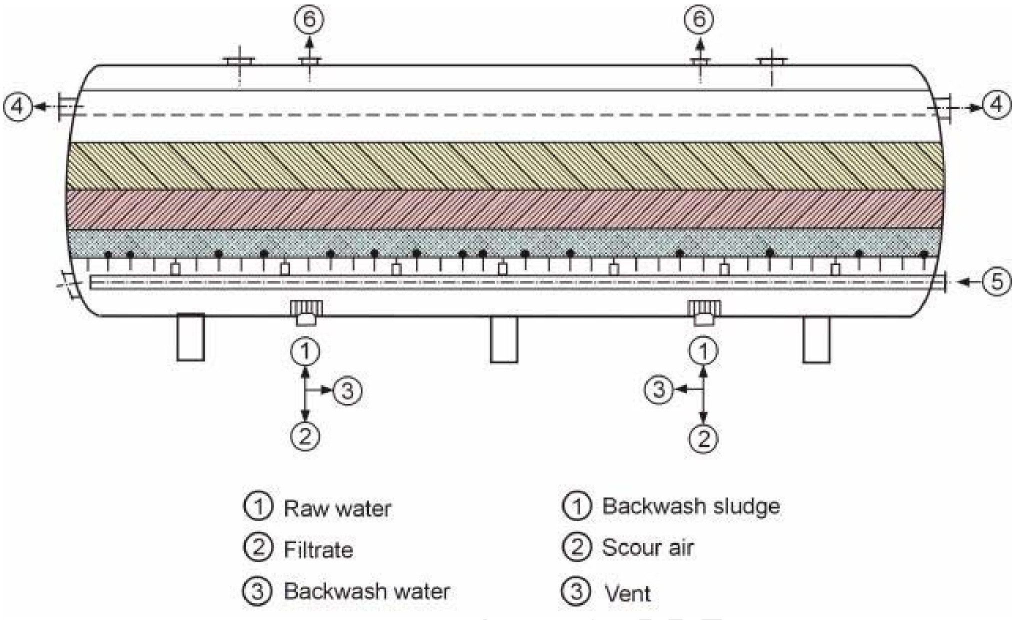

Figure 3. Pressure horizontal vertical.

This filter design is used in the case of higher output per filter unit. The filters operate at low excess pressure or as gravity filters. These filters, compared to vertical filters, are usually built with a large diameter and an extension to the filter length can produce a considerably larger filter area. Production costs can therefore also be reduced. The method of operation of these filters is identical to that of the vertical filters. Owing to this design the layer height of filter media is lower and the filtering velocity is limited to values of up to 15 m h^{-1}.

- Method of operation:

- Single-layer filter, i.e. Homogeneous filter block with regard to material and grain size;
- Multichamber filter, i.e. Two or more filter vessels or two or more filter chambers with a parallel connection in a central vessel;
- Multilayer filter, i.e. Various types of filter media with a range of grain sizes and variable gross density of grain. These filters can be manufactured in an open or a closed design.

In addition, there are still some special designs which have never been used in the pretreatment of seawater. They are essentially counterflow filters, self-cleaning automatic filters, and flocculation filters with a refiltration system.

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