FILTRATION

Filtration is a physical or chemical separation process that separates solid matter and fluid from a mixture using a *filter medium* that has a complex structure through which only the fluid can pass. Solid particles that cannot pass through the filter medium are described as *oversize* and the fluid that passes through is called the *filtrate*. Oversize particles may form a filter cake on top of the filter and may also block the filter lattice, preventing the fluid phase from crossing the filter, known as *blinding*. The size of the largest particles that can successfully pass through a filter is called the effective *pore size* of that filter. The separation of solid and fluid is imperfect; solids will be contaminated with some fluid and filtrate will contain fine particles (depending on the pore size, filter thickness and biological activity). Filtration occurs both in nature and in engineered systems; there are biological, geological, and industrial forms. Filtration is also used to describe biological and physical systems that not only separate solids from a fluid stream, but also remove chemical species and biological organisms by entrainment, phagocytosis, adsorption and absorption. Examples include slow sand filters and trickling filters. It is also used a general term for microphagy in which organisms use a variety of means to filter small food particles from their environment. Examples range from the microscopic *Vorticella* up to the Basking shark one of the largest fishes, and the baleen whales, all of which are described as Filter feeders.

Physical processes

- Filtration is used to separate particles and fluid in a suspension, where the fluid can be a liquid, a gas or a supercritical fluid. Depending on the application, either one or both of the components may be isolated.
- Filtration, as a physical operation enables materials of different chemical composition to be separated. A solvent is chosen which dissolves one component, while not dissolving the other. By dissolving the mixture in the chosen solvent, one component will go into the solution and pass through the filter, while the other will be retained.
- Filtration is widely used in chemical engineering. It may be combined with other unit operations to process the feed stream, as in the biofilter, which is a combined filter and biological digestion device.
- Filtration differs from sieving, where separation occurs at a single perforated layer (a sieve). In sieving, particles that are too big to pass through the holes of the sieve are retained. In filtration, a multilayer lattice retains those particles that are unable to follow the tortuous channels of the filter. Oversize particles may form a cake layer on top of the filter and may also block the filter lattice, preventing the fluid phase from crossing the filter (blinding). Commercially, the term filter is applied to membranes where the separation lattice is so thin that the surface becomes the main zone of particle separation, even though these products might be described as sieves.
- Filtration differs from adsorption, where separation relies on surface charge. Some adsorption devices containing activated charcoal and ion-exchange resin are commercially called filters, although filtration is not their principal mechanical function.

- Filtration differs from removal of magnetic contaminants from fluids with magnets (typically lubrication oil, coolants and fuel oils), because there is no filter medium.
- In biological filters, oversize particulates are trapped and ingested and the resulting metabolites may be released. For example, in animals (including humans), renal filtration removes waste from the blood, and in water treatment and sewage treatment, undesirable constituents are removed by adsorption into a biological film grown on or in the filter medium, as in slow sand filtration.

Methods

There are many different methods of filtration; all aim to attain the separation of substances. Separation is achieved by some form of interaction between the substance or objects to be removed and the filter. The substance that is to pass through the filter must be a fluid, i.e. a liquid or gas. Methods of filtration vary depending on the location of the targeted material, i.e., whether it is dissolved in the fluid phase or suspended as a solid. There are several laboratory filtration techniques depending on the desired outcome namely, hot, cold and vacuum filtration. Some of the major purposes of getting the desired outcome are, for the removal of impurities from a mixture or, for the isolation of solids from a mixture.

Hot filtration method is mainly used to separate solids from a hot solution. This is done in order to prevent crystal formation in the filter funnel and other apparatuses that comes in contact with the solution. As a result, the apparatus and the solution used are heated in order to prevent the rapid decrease in temperature which in turn, would lead to the crystallization of the solids in the funnel and hinder the filtration process. One of the most important measures to prevent the formation of crystals in the funnel and to undergo effective hot filtration is the use stemless filter funnel. Due to the absence of a stem in the filter funnel, there is a decrease in the surface area of contact between the solution and the stem of the filter funnel, hence preventing re-crystallization of solid in the funnel, adversely affecting the filtration process.

Cold filtration method is the use of ice bath in order to rapidly cool down the solution to be crystallized rather than leaving it out to cool it down slowly in the room temperature. This technique results to the formation of very small crystals as opposed to getting large crystals by cooling the solution down at room temperature.

Vacuum filtration technique is mostly preferred for small batches of solution in order to quickly dry out small crystals. This method requires a Büchner funnel, filter paper of smaller diameter than the funnel, Büchner flask, and rubber tubing to connect to vacuum source.

Achieving flow through the filter

Fluids flow through a filter due to a difference in pressure—fluid flows from the high-pressure side to the low-pressure side of the filter. The simplest method to achieve this is by gravity. In the laboratory, pressure in the form of compressed air on the feed side (or vacuum on the filtrate side) may be applied to make the filtration process faster, though this may lead to clogging or the passage of fine particles. Alternatively, the liquid may flow through the filter by the force exerted by a pump, a method commonly used in industry when a reduced filtration time is important. In this case, the filter need not be mounted vertically.

Alternatives

Filtration is a more efficient method for the separation of mixtures than decantation, but is much more time-consuming. If very small amounts of solution are involved, most of the solution may be soaked up by the filter medium. An alternative to filtration is ***centrifugation***—instead of filtering the mixture of solid and liquid particles, the mixture is centrifuged to force the (usually) denser solid to the bottom, where it often forms a firm cake. The liquid above can then be decanted. This method is especially useful for separating solids which do not filter well, such as gelatinous or fine particles. These solids can clog or pass through the filter, respectively.

As seen above, filtration is the separation of solids from a fluid by passage of the fluid through a medium that restrains all or part of the solids. In a situation where the fluid is liquid, filtration tends to be used when the solids content in the liquid-solid slurry is relatively low. In most cases the liquid is the product of value and the removal of solids is done to improve the value and processability of the liquid. The filtration medium may be any one (or a combination) of woven screens or fabric, or non-woven fabric or paper, or a porous membrane. The configuration may locate the medium in a plate-and-frame apparatus, on horizontal plates, as circular or flat cartridges. as a belt, as a rotary drum, or as the wall of a centrifuge. Granular beds are also sometimes used for filtration.

There are three basic types of filtration.

1. ***Cake filtration***. The solids build up on the surface of the filter medium and form a cake of steadily increasing thickness. This cake actually becomes the filter. A filter aid (e.g., diatomaceous earth) may be added to enhance the filtration. However, it must be removed from time to time as the pressure drop becomes excessive.

2. ***Depth filtration***. The solid particles enter into the filter medium and are trapped between fibres. Gradually the medium becomes plugged or begins to pass solids out with the *filtrate* (the leaving liquid), so the filter requires periodic cleaning.

3. ***Cross-flow membrane filtration***. This more recently developed type of filtration is designed to separate out very small particles. Instead of flowing *through* the filter medium (in this case a porous membrane) the liquid-solid mixture moves across it. Some material passes through the membrane but the surface of the membrane is kept free of solids accumulation.

Other complex filtration types

These include

i. Micro-filtration
ii. Ultra-filtration
iii. Nano-filtration

Microfiltration is a type of filtration physical process where a contaminated fluid is passed through a special pore-sized membrane to separate microorganisms and suspended particles from process liquid. It is commonly used in conjunction with various other separation processes such as ultrafiltration and reverse osmosis to provide a product stream which is free of undesired contaminants.

General principles

Microfiltration usually serves as a pre-treatment for other separation processes such as ultrafiltration, and a post-treatment for granular media filtration. A pump is commonly fitted onto the processing equipment to allow the liquid to pass through the membrane filter. There are also two pump configurations, either pressure driven or vacuum. A differential or regular pressure gauge is commonly attached to measure the pressure drop between the outlet and inlet streams. The most abundant use of microfiltration membranes are in the water, beverage and bio-processing industries.

Range of applications

Water treatment

Perhaps the most prominent use of microfiltration membranes pertains to the treatment of potable water supplies. The membranes are a key step in the primary disinfection of the uptake water stream. Such a stream might contain pathogens such as the protozoa Cryptosporidium and Giardia lamblia which are responsible for numerous disease outbreaks. Both species show a gradual resistance to traditional disinfectants (i.e. chlorine). The use of MF membranes presents a physical means of separation (a barrier) as opposed to a chemical alternative. In that sense, both filtration and disinfection take place in a single step, negating the extra cost of chemical dosage and the corresponding equipment (needed for handling and storage).

Sterilization

Another crucial application of Micro filtration membranes lies in the cold sterilisation of beverages and pharmaceuticals. Historically, heat was used to sterilize refreshments such as juice, wine and beer in particular, however a palatable loss in flavour was clearly evident upon heating. Similarly, pharmaceuticals have been shown to lose their effectiveness upon heat addition. Micro filtration membranes are employed in these industries as a method to remove bacteria and other undesired suspensions from liquids, a procedure termed as 'cold sterilisation', which negate the use of heat.

Petroleum refining

Furthermore, microfiltration membranes are finding increasing use in areas such as petroleum refining, in which the removal of particulates from flue gases is of particular concern. The key challenges/requirements for this technology are the ability of the membrane modules to withstand high temperatures (i.e. maintain stability), but also the design must be such to provide a very thin sheeting to facilitate an increase of flux. In addition, the modules must have a low fouling profile and most importantly, be available at a low-cost for the system to be financially viable.

Dairy processing

Aside from the above applications, Micro filtration membranes have found dynamic use in major areas within the dairy industry, particularly for milk and whey processing. The Micro filtration membranes aid in the removal of bacteria and the associated spores from milk, by rejecting the harmful species from passing through. This is also a precursor for pasteurisation, allowing for an extended shelf-life of the product. However, the most promising technique for Micro filtration membranes in this field pertains to the separation of casein from whey proteins (i.e. serum milk proteins). This results in two product streams both of which are highly relied on by consumers; a casein-rich concentrate stream used for cheese making, and a whey/serum protein stream which is further processed (using ultrafiltration) to make whey protein concentrate. The whey protein stream undergoes further filtration to remove fat in order to achieve higher protein content in the final WPC (Whey Protein Concentrate) and WPI (Whey Protein Isolate) powders.

Microfiltration membranes can generally operate in one of two configurations.

Cross-flow filtration: where the fluid is passed through tangentially with respect to the membrane. Part of the feed stream containing the treated liquid is collected below the filter while parts of the water are passed through the membrane untreated. Cross flow filtration is understood to be a unit operation rather than a process.

Dead-end filtration; all of the process fluid flows and all particles larger than the pore sizes of the membrane are stopped at its surface. All of the feed water is treated at once subject to cake formation. This process is mostly used for batch or semicontinuous filtration of low concentrated solutions.

Ultrafiltration (UF) is a variety of membrane filtration in which forces like pressure or concentration gradients lead to a separation through a semipermeable membrane. Suspended solids and solutes of high molecular weight are retained in the so-called retentate, while water and low molecular weight solutes pass through the membrane in the permeate (filtrate). This separation process is used in industry and research for purifying and concentrating macromolecular solutions, especially protein solutions. Ultrafiltration is not fundamentally different from microfiltration. Both of these separate based on size exclusion or particle capture. It is fundamentally different from membrane gas separation, which separate based on different amounts of absorption and different rates of diffusion. Ultrafiltration membranes are defined by the molecular weight cut-off (MWCO) of the membrane used. Ultrafiltration is applied in cross-flow or dead-end mode.

Applications

Drinking water

Ultrafiltration can be used for the removal of particulates and macromolecules from raw water to produce potable water. It has been used to either replace existing secondary (coagulation, flocculation, sedimentation) and tertiary filtration (sand filtration and chlorination) systems employed in water treatment plants or as standalone systems in isolated regions with growing populations. When treating water with high suspended solids, ultra-filtration is often integrated into the process, utilising primary (screening, flotation, filtration) and some secondary treatments as pre-treatment stages. Ultra-filtration processes are currently preferred over traditional treatment methods for the following reasons:

- No chemicals required (aside from cleaning)
- Constant product quality regardless of feed quality
- Compact plant size
- Capable of exceeding regulatory standards of water quality, achieving 90–100% pathogen removal

Ultra-filtration processes are currently limited by the high cost incurred due to membrane fouling and replacement. Additional pre-treatment of feed water is required to prevent excessive damage to the membrane units. In many cases ultra-filtration is used for pre filtration in reverse osmosis (RO) plants to protect the RO membranes.

Protein concentration

Ultra-filtration is used extensively in the dairy industry; particularly in the processing of cheese whey to obtain whey protein concentrate (WPC) and lactose-rich permeate. In a single stage, an ultra-filtration process is able to concentrate the whey 10–30 times the feed.
The original alternative to membrane filtration of whey was using steam heating followed by drum drying or spray drying. The product of these methods had limited applications due to its granulated texture and insolubility. Existing methods also had inconsistent product composition, high capital and operating costs and due to the excessive heat used in drying would often denature some of the proteins. Compared to traditional methods, Ultra-filtration processes used for this application:

- Are more energy efficient
- Have consistent product quality, 35–80% protein product depending on operating conditions
- Do not denature proteins as they use moderate operating conditions

Other applications

- Filtration of effluent from paper pulp mill
- Cheese manufacture, see ultrafiltered milk
- Removal of some bacterias from milk
- Process and waste water treatment
- Enzyme recovery
- Fruit juice concentration and clarification
- Dialysis and other blood treatments
- Desalting and solvent-exchange of proteins (via diafiltration)
- Laboratory grade manufacturing
- Radiocarbon dating of bone collagen

Nanofiltration is a relatively recent membrane filtration process used most often with low total dissolved solids water such as surface water and fresh groundwater, with the purpose of softening and removal of disinfection by-product precursors such as natural organic matter and synthetic organic matter. Nanofiltration is a membrane filtration-based method that uses nanometer sized through-pores that pass through the membrane. Nanofiltration membranes have pore sizes from 1-10 nanometers, smaller than that used in microfiltration and ultrafiltration, but just larger than that in reverse osmosis. Membranes used are predominantly created from polymer thin films. Materials that are commonly used include polyethylene terephthalate or metals such as aluminum. Pore dimensions are controlled by pH, temperature and time during development with pore densities ranging from 1 to 106 pores per cm^2. Membranes made from polyethylene terephthalate and other similar materials, are referred to as "track-etch" membranes, named after the way the pores on the membranes are made. "Tracking" involves bombarding the polymer thin film with high energy particles. This results in making tracks that are chemically developed into the membrane, or "etched" into the membrane, which are the pores. Membranes created from metal such as alumina membranes, are made by electrochemically growing a thin layer of aluminum oxide from aluminum metal in an acidic medium.

Range of applications

Historically, nanofiltration and other membrane technology used for molecular separation was applied entirely on aqueous systems. The original uses for nanofiltration were water treatment and in particular water softening. Nanofilters can "soften" water by retaining scale-forming, hydrated divalent ions (e.g., Ca^{2+}, Mg^{2+}) while passing smaller hydrated monovalent ions. In recent years, the use of nanofiltration has been extended into other industries such as milk and juice production. Research and development in solvent-stable membranes has allowed the application for nanofiltration membranes to extend into new areas such as pharmaceuticals, fine chemicals, and flavour and fragrance industries.

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