PROCESS ENGINEERING HANDBOOK SERIES

Solids/Liquids Separation

PAUL N. CHEREMISINOFF

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PREFACE

Separation of solids from liquids is an operation that has extensive application in the chemical process, petroleum industries and in water/wastewater treatment. Such separation applied to liquid streams can be for the purposes of recovering valuable products or removing unwanted contaminants that may damage downstream process equipment or for product purification, or pollutant removal that may be harmful to the environment. This book is designed to be used as a continuing reference guide.

Because of the wide range of applications and properties of suspended solids encountered there is a large and diversified number of equipment and methods for solids/liquid separations. Presented here are the basics of such operations, so that the user of this book may grasp an understanding of a wide range of equipment available. Additionally, operations such as fluid mixing and coagulating chemicals are discussed because of their importance for this procedure in water/wastewater treatment. A special section is also devoted to separations by membranes, which has received increasing attention.

It is hoped that this basic reference will be a welcome addition to the process and environmental engineer's library.

PAUL N. CHEREMISINOFF

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CHAPTER 1

Industrial Filtration Equipment Overview

INTRODUCTION

A wide variety of liquid filtration equipment is commercially available, ranging from highly versatile units capable of handling different filtration applications to those restricted in use to specific fluids and process conditions. Proper selection must be based on detailed information of the slurry to be handled, cake properties, anticipated capacities, and process operating conditions. One may then select the preferred operational mode (batch, semibatch, or continuous) and choose a particular unit based on the preceding considerations and economic constraints.

Continuous filtration involves the use of several operations performed in series, namely solids separation and cake formation, cake washing, cake dewatering and drying, cake removal, and filter media washing. These operations are handled by two groups of equipment: stationary apparatus (which are the supporting devices such as the suspension vessel) and scraping mechanisms and movable devices (which can be the filter medium, depending on the design).

Either continuous or batch filters can be employed in cake filtration. In *filter-medium filtration*, however, where particulates are retained within the framework of the filter medium, only batch systems are applicable. Batch filters may be operated in any filtration regime, whereas continuous filters are most often operated at constant pressure.

Two general classification schemes are adopted to describe continuous operations in this chapter:

(1) Continuous filtration equipment is classified according to the method of generating pressure differential. This classification scheme is

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	Pressure Differential (N/m^2)
Hydrostatic pressure of the suspension layer to be separated	Usually no more than 5
Action of compressors	5–9
Action of pumps	Up to 50 and higher

(2) Classification is based on the relative directions between gravity force and the filtrate motion. Three possible orientations are countercurrent, co-current, and crossflow.

Operating principles and important features of major filtration equipment are described in this chapter.

APPLICATIONS IN INDUSTRIAL WATER CONSUMPTION

Although filtration is practiced in a variety of industrial applications and processes, it has become an even more critical unit operation because of large-scale efforts in the more effective use of plant water. Water use practice in the chemical process industries (CPI) has been undergoing dramatic changes over the past decade. While overall water use has been rising, plant water intake and discharges have been declining. The reason for this has been greater water reuse in plant operations. The major force behind this water reuse trend is environmental protection and conservation. Federal, state, and local laws backed by stiff penalties have established strict limits on the amount of effluents discharged by the CPI.

Governmental regulations are not the only reason the CPI are turning toward water reuse. As fresh water becomes a scarce commodity, its cost is becoming more expensive. Another contributing factor is the continually increasing cost of moving and heating fresh water, especially once-through water. The high cost of chemically treating fresh water cannot be overlooked either.

There is no doubt that a water reuse system can be an asset to the processor, as long as it is functionally efficient in design and operation. However, a serious problem must be reckoned with: recirculated water can have a much higher solids content. Although there is no clearcut solution to the problem of solids buildup, filtration and/or chemical treatment can normally achieve the desired result.

Deposit formation on waterside surfaces of heat exchangers has always concerned the cooling system and process operators. However, in the past, the problem was considered relatively minor because the equipment was usually operated only six months (seldom longer than twelve months) between cleanngs or turnarounds. This is no longer possible. Many industrialists, in an effort to reduce overall operating costs, are working toward less frequent turnarounds, higher throughput with the same equipment, and lower maintenance costs. This is accomplished by removing the solids that cause deposit formation. Examples of solids deposition problems in plant operations are as follows:

- In cooling tower operations, cascading water constantly "scrubs" airborne contaminants from the atmosphere and carries these particulates into the cooling system. Depending on geographic location and seasonal changes, these particulates can account for the highest concentration of suspended solids in the system. Other sources of fouling in cooling tower operations can be traced to makeup water, scale from system piping, solids from the process, and dissolved solids from the atmosphere (which must be controlled chemically).
- In the operation of heat exchange equipment, corrosion control is of prime concern. Deposition control deserves at least equal attention because both problems occur jointly or cause one another: as solids build up on the system surface, corrosion products begin forming, which, in turn, can produce a variety of undesirable operating conditions.
- reduced operating efficiency
- reduced or uneven heat transfer
- unexpected process equipment shutdown and associated maintenance
- shortened equipment life
- increased pumping costs

To avoid those solids-caused conditions, it is essential to remove the solids through filtration as soon as they enter the system.

In smaller systems with low flow rates, the filter can be placed directly on the tower outlet to handle the entire flow. However, full-stream filtration is not always necessary—or practical—for large cooling systems with moderate or high flow rates.

An economical side stream installation that continually filters a portion of the total system capacity will reduce tower blowdown and prevent loss of heat exchange efficiency. This can be accomplished by installing a loop off the tower basin. Incorporated in this loop is a filter, a pump pressurizing the filter feed line, and a discharge line leading to the tower basin. At some point in the discharge line, a restriction (usually a control valve or orifice plate) is necessary to maintain pressure on the outlet header. This permits backwashing with filtered water.

For sizing a side stream installation, recommendations will vary from user to user and even among filter manufacturers. Usually, manufacturer suggestions are based on a percentage of the system flow rates. However, because almost every system and application is different, it is virtually impossible to give a standard formula that would apply to all.

Filter sizing requires careful and detailed analysis of many factors, such as flow rate, pressure, system design. For example, if the makeup water is high in solids (from a river or lake), it may be necessary to install a separate filter in the makeup system. An alternative is a central filter designed to handle both the makeup water and a portion of the recirculated water.

Choosing the proper filter screen requires careful examination of the source of solids and nature particulates. Current operating systems on cooling towers are providing satisfactory performance with screen retention ranging from 150 mesh to 5–10 μm.

For new cooling systems, initial installation of finer filter screens is recommended based on the anticipated solids size. On existing systems that have operated without filtering, coarse screens are generally used to reduce the solids concentration. After the backwash frequency has been stabilized, screens can be installed.

Because backwash filters use tower water for backwash cleaning, the frequency of tower downs for removing the dissolved solids can be reduced. Also, savings are realized in the cost of chemicals used for treating makeup water.

Water for spray-type wet scrubbers can be recirculated with water from other processes. This water must be filtered as it is pumped to the scrubber. If not, solids can quickly clog small nozzle openings. This results in decreased scrubber efficiency; if the problem goes unchecked, the flow of water can eventually stop, and downtime may be necessary to correct the situation.

If recirculated water is used in a scrubber system, it is unlikely that cartridge filters will be the primary equipment for solids removal, because the water would form a sludge or slurry, which requires sophisticated clarification techniques for high solids removal. Generally, cartridge filters are used on the return line to the scrubber as a final filter for protecting spray nozzles.

Because of evaporation, scrubber systems using recirculated water still require some makeup water. Those systems are usually handled full-flow by cartridge filters. Filtering the makeup water ensures that further contamination is not introduced by this source. Automatic backwashing filters are best in that kind of application to prevent plugging of filter screens and restriction of water flow.

Boiler feed water can come from a variety of sources such as well water, city water, plant and process water, and condensate. In boiler feedwater systems, solids that can collect in boiler vessels and reduce boiler efficiencies must be removed. In this application, filtering the water down to 15–20 μm is common.

- *Food and package industry:* Container rinse water can be recirculated water or water from other processes. As a rinse water, recirculated water is more advantageous than makeup water because it requires less energy for heating. A major concern, especially to the food industry, is that no visible particles appear on the container surface. To prevent this, the rinse water can be clarified by filters with 250 mesh screens. Where smaller particulates such as dust and paper fibers are present, finer screens can be used.
- *Paper industry:* Throughout the paper industry, protection of machine showers is critical for product uniformity and consistency. Any filter installed to protect machine showers must satisfy three requirements:
  (1) It must have sufficient screen area to handle the required flow.
  (2) It must remove contaminants that may plug shower nozzles.
  (3) It must be easy to clean so that minimum operator attention is needed.

The desired operating pressure, location of the shower, and type of water used determines which filter will provide the best results.

Freshwater filters are normally equipped with a wire screen; the mesh size is determined by the size of the nozzle orifice. A particle retention rating of five to six times smaller than the orifice should prevent plugging.

Whitewater showers pass a relatively high percentage of well-dispersed individual fibers and fines. However, because nozzles will plug with fiber bundles, pipe scale, and other contaminants, a whitewater strainer is required. Pressure filters are widely used in the protection of these showers, normally after some type of primary clarification. This is generally accepted as the best method of assuring satisfactory operation of a shower system.

- *Steel industry:* The steel industry is one of the largest users of water, for cooling purposes. One typical application is in rolling and drawing mills, where recirculated water cools the equipment that farms the hot bars. As the water cascades over the rollers, it carries scale from the bars, airborne contaminants, and grease into a settling basin. At that point, most—but not all—contaminants and particulates settle in the bottom of the basin. Suspended solids that remain in the water must be removed before the water can be used.

If not, the small water lines in the rollers and drawers would quickly plug and cause extensive damage to the equipment; also, the cooling water distribution system would foul. Filters are usually installed immediately ahead of the rolling mills.

- *Other industries:* Many manufacturers use water to hydrostatically test their equipment. To prevent solids buildup in expensive testing equipment, the water is filtered between the collection sump and feed line to the test rack.

Another application of water reuse is for lubrication of pump seals. Again, this can be recirculated water or water from other processes. Most manufacturers of pump and seal equipment recommend filtration to 10 μm to remove sand or grit that can score the pump shaft or damage the sealing mechanism.

ROTARY-DRUM FILTERS

Rotary-drum filters constitute the countercurrent mode type and are either vacuum- or pressure-operated. They are most frequently operated as vacuum filters. Although operated under pressure, they are rarely subjected to excessive pumping pressures. The principal advantage of these filters is the continuity of their operation. Unfortunately, total filtration cycles are limited to narrow time intervals. As such, it is necessary to maintain nearly constant slurry properties. Changing slurry properties can lead to wide variations in the required times for completing individual operations of the filtration process.

For separating low-concentration, stratified suspensions, rotary-drum filters are normally specified a submergence rate of 50%. Such slurries require only mild mixing to prevent particle settling. These filters are less useful in handling polydispersions containing particles with wide size ranges. Fouling by small soilds is a frequent problem in these latter cases.

Drum vacuum filters with external filtering surfaces are characterized by the rate at which the drum is immersed in the suspension. These are perhaps the most widely employed countercurrent operated filters in industry, an example of which is shown in Figure 1.1. As shown, the design consists of a hollow drum (1) with a slotted face, the outer periphery of which contains shallow tray-shaped compartments (2). The filter cloth is supported by a grid or a heavy screen, which lies over these compartments. The drum rotates on a shaft with one end connected to the drive and the other to a hollow trunion adjoining to an automatic valve. The drum surface is partially immersed in the suspension contained in the vessel (6). The cake formed on the outer surface of the drum is removed by a scraper (7) as the drum rotates.

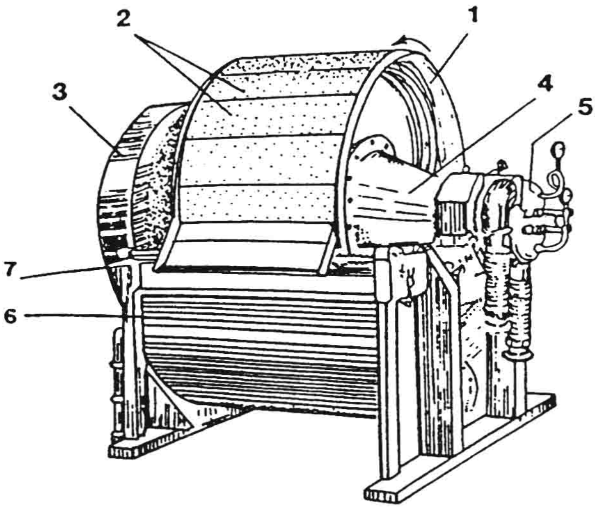

FIGURE 1.1. Rotary-drum vacuum filter with external filtration surface: (1) hollow drum, (2) filtration compartments, (3) drive, (4) hollow trunion, (5) automatic valve, (6) tank for suspension, and (7) knife for cake scraping.

Figure 1.2 shows a longitudinal view of the system. Each compartment (2) of the drum (1) is connected through a pipe (3) passing through the hollow trunion (4) of the shaft (5), with the automatic valve (6). A stirring device (7) is mounted under the drum to prevent particle settling.

A diagrammatic cross section of the filter is shown in Figure 1.3. As the drum rotates clockwise, each compartment is connected by the pipe (2) with different chambers of immobile parts of an automatic valve (4) and passes in series through the following operating zones: filtration, first dewatering washing, second dewatering, cake removal, and cloth regeneration.

In the filtration zone, the compartment contacts the suspension in the tank (11) and is connected to a pipe (10) hooked up to a vacuum source. The filtrate is discharged through the pipe and space in the collector, and the cake forms on the compartment's surface. In the first dewatering zone, the cake comes in contact with the atmosphere, and the compartment is connected to the same space (10). Because of the vacuum, the air is drawn through the cake, and, for maximum filtrate recovery, the compartment remains connected to a collection port on the automatic valve.

In the washing zone the cake is washed by nozzles [or wash headers (8)]. The compartment is connected through a port (6), which is also tied into a vacuum source. The wash liquor is removed in the other collector.

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