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FEDERAL ENERGY MANAGEMENT PROGRAM

Side Stream Filtration for Cooling Towers

Prepared for the U.S. Department of Energy
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Cover photo: Cooling Towers. *Photo from Pacific Northwest National Laboratory*

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Abbreviations and Acronyms

ASHRAE	American Society of Heating, Refrigerating, and Air Conditioning Engineers
BLCC	Building Life Cycle Cost
FEMP	Federal Energy Management Program
gpm	gallons per minute
kW	kilowatt
kWh	kilowatt hour
LCC	life-cycle cost
L	liter
mm	millimeter
ORNL	Oak Ridge National Laboratory
ROI	return on investment
SNS	Spallation Neutron Source
TSS	total suspended solid

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Executive Summary

This technology evaluation assesses side stream filtration options for cooling towers, with an objective to assess key attributes that optimize energy and water savings along with providing information on specific technology and implementation options. This information can be used to assist Federal sites to determine which options may be most appropriate for their applications. This evaluation provides an overview of the characterization of side stream filtration technology, describes typical applications, and details specific types of filtration technology.

Cooling towers are an integral component of many cooling systems that provide comfort or process cooling. Cooling tower systems operation is most efficient when their heat transfer surfaces are clean. However, due to variations in the water source and their operating in an open environment, cooling towers are subject to four major water treatment concerns: corrosion, scaling, fouling and microbiological activity. These factors can significantly reduce the efficiency of the cooling towers. Side stream filtration systems can be a cost effective method to address these water concerns through filtering suspended solids out of the cooling water.

Side stream filtration systems continuously filter a portion of the cooling water to remove suspended solids, organics, and silt particles, reducing the likelihood of fouling and biological growth, which in turn helps to control other issues in the system such as scaling and corrosion. This results in both water and energy efficiency gains due to a reduction in the amount of water discharged from the cooling system and a decrease of scale formation on the heat transfer surfaces. The filter types examined in the technology evaluation are centrifugal separators, automatic screen filters, plastic disc filters, and sand filters. An overview of their main characteristics is summarized in Table ES.1 and more detailed information on each system type is presented in the main body of the report.

Table ES.1. Side Stream Filtration System Characteristics.

Filter Type	Particle Removal Level	Basic Filtering Mechanism	Applications	Notes
Centrifugal Separators	40-75 microns, fine to coarse inorganics with a specific gravity (1.62) or greater	High velocity water is fed in a circular pattern that moves heavier particles down and out of the system	Best for removal of large, heavy particles	Minimal maintenance is required
Automatic Screen Filter	Down to 10 microns	Water moves through a rigid screen, where large particles are trapped and sucked out of the system	Best for systems that cannot be interrupted such as industrial processes and hospitals	Self cleaning mechanism allows for no interruption in operation
Plastic Disc Filter	Down to 10 microns	Grooved, stacked plates trap particles as water moves through the discs	Appropriate where removal of both solids and organics are required	Self cleaning mechanism is automatic and requires little down time of the system
Sand Filters	Down to 10 microns for pressure sand filters; Down to 0.45 microns for high efficiency sand filters	Layers of granulated sand, trap particles as water moves through the sand layers	Best for applications that require the removal of fine and low density particles	Supplemental chlorine may be needed because sand filters can promote biological growth

A life-cycle cost analysis was performed on a hypothetical example of a pressure sand filter side stream filtration system as part of the technology evaluation. The system characteristics were based on a typical system for a 400 ton chiller with a total installation cost of $45,000 (see Section 3 on System Economics for more details on the example system). The results of the life-cycle cost analysis shows an annual cost savings of $8,800, 8 year simple pay back, and a savings to investment ratio of 2.3.

When considering a side stream filtration system, there are several key parameters that are important to weigh including the level of particle removal, filtration sizing, installation methods, economic analysis, and savings potential. Careful examination of these features will help to properly specify the side stream filtration system for the appropriate application.

1 Technology Review and Evaluation

This technology evaluation was performed by Pacific Northwest National Laboratory on behalf of the Federal Energy Management Program (FEMP). The technology evaluation assesses side stream filtration for cooling towers. The evaluation provides a characterization of side stream filtration technology, describes typical applications, and details specific types of filtration technology. System economics are also discussed, providing an example project with life-cycle cost analysis results to show the potential savings of a typical application. A Federal case study at Oak Ridge National Laboratory (ORNL) is also provided to showcase a success story of a side stream filtration application.

The evaluation's overall objective is to provide information on key impacts related to energy, water, and cost savings of side stream filtration as well as key attributes on specific technology options and component specifications so that Federal energy and facility managers can make informed decisions on which options may be most appropriate for their site.

1.1 Background

Cooling towers are an integral component of many cooling systems that provide comfort or process cooling. They are commonly used in industrial applications and in large commercial buildings to release waste heat extracted from a process or building system through evaporation of water. They receive the heated water, and evaporate a portion of the water to cool the remaining water so that it can re-used to again extract heat from the cooling system.

Cooling tower systems operation is most efficient when their heat transfer surfaces are clean. However, these are dynamic systems, due to variations in the water source and their operating in the open environment. Surface water sources such as lakes, rivers, and streams have seasonal variations in water quality and can carry high levels of suspended silt and debris. Groundwater sources don't have the seasonal variations, but can have high levels of dissolved minerals depending on the geology of the region.

Since cooling towers operate outside they are susceptible to dirt and debris carried by the wind. Birds and insects like to live in and around cooling towers due to the warm, wet environment. The combination of process and environmental factors can contribute to four primary treatment concerns encountered in most open-recirculating cooling systems: corrosion, scaling, fouling, and microbiological activity. As shown in Figure 1.1, these treatment concerns are inter-related such that reducing one can have an impact on the severity of the other three.

- ***Corrosion***: Corrosion is an electrochemical or chemical process that may lead to the premature failure of system metallurgy. The process of corrosion can be intensified by elevated levels of dissolved mineral content in the water and the presence of oxygen, both of which are typical of most cooling tower systems.

- ***Scaling***: Scaling is the precipitation of dissolved mineral components that have become saturated in solution, which can lower efficiency of the system. Factors that contribute to scaling tendencies include water quality, pH, and temperature. Scale formation inhibits heat exchangers because of the insulating properties of scale. Scale buildup will make the entire system work harder to meet the cooling demand.

- ***Fouling***: Fouling occurs when suspended particles or biologic growth forms an insulating film on heat transfer surfaces. Common foulants include organic matter, process oils, and silt, which can also lower system performance. Factors that cause fouling include corrosion and process leaks. Much like scale, fouling deposits create an insulating barrier on the heat exchanger surfaces that can significantly affect the energy performance of the cooling system.

- ***Microbiological Activity***: Microbiological activity refers to microorganisms that live and grow in the cooling system that can contribute to fouling and corrosion. Cooling towers are a perfect environment for biological activity due to the warm, moist environment. There are two distinct categories of biological activity in a tower system: planktonic and sessile biogrowth. Planktonic is a bioactivity that is suspended or floating in solution. Sessile biogrowth is a bioactivity that sticks to surfaces, such as biofilms or biofouling. Biofilms are problematic for several reasons. They have strong insulating properties that increase energy requirements, they contribute to fouling and corrosion, and they create byproducts that further increase microbiological activity. Sessile biogrowth can generally be found in and around the tower structure, in chiller bundles, on heat exchange surfaces, and in the system piping. Biofilms and algae mats can also be difficult to eradicate.

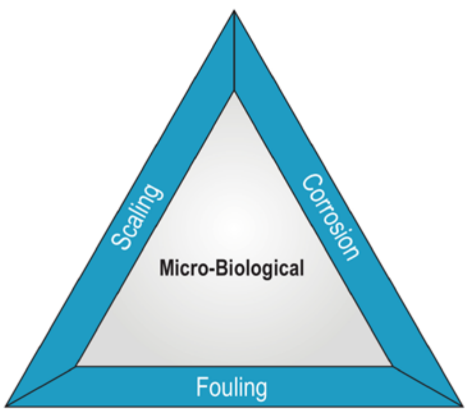

Figure 1.1. Cooling Tower Primary Treatment Concerns.

Side stream filtration systems reduce suspended solids and debris in the system cooling water, which leads to less fouling in the system. Decreasing suspended solids can also help reduce biological growth in the system because suspended solids are a good source of food for microbiological organisms. Decreasing biological growth in turn helps to reduce microbiologically influenced corrosion. In addition, scaling can be reduced from side stream filtration by limiting fouling and corrosion by-products, which can also contribute to scale formation on the heat exchange surfaces. Effectively managing these conditions through filtration can optimize system performance, often resulting in moderate to significant energy and water savings.

Each of the treatment concerns can decrease cooling tower performance, increase the use of water treatment chemicals as well as reduce cycles of concentration. “Cycles of concentration” is an industry term used to describe the relationship between the amount of system feed water flow and the amount of flow sent down the drain as blowdown. Low cycles of concentration (high amount of blowdown in relation to the system feed) correlate to inefficient use of water in a system to satisfy cooling needs.

Full flow and side stream filtration are the two most common methods used to filter the water that is pumped into the circulation systems. Full flow filtration uses a filter installed after the cooling tower on the discharge side of the pump. This filter continuously filters all of the recirculating system water in the system. Inherently, the filter must be sized to handle the system’s design recirculation rate. Side stream filtration, on the other hand, continuously filters a percentage of the flow instead of the entire flow. It can be a cost-effective alternative to full flow filtration that can easily improve the water quality to reduce water consumption and ensure efficiency of the cooling systems. And unlike full flow filtration, side stream filtration systems can be cleaned while the cooling systems are online, avoiding the need for planned downtime (BAC 2012).

1.2 Technology Characterization

Side stream filtration systems continuously filter a portion of the cooling water to remove debris and particles and return filtered to the cooling tower basin (called the sump). Figure 1.2 below shows a simplified cooling tower schematic, including the two example locations where side stream filtration can typically be installed. These systems remove suspended solids, organics, and silt particles for a portion of the water system on a continuous basis, reducing the likelihood of fouling and biogrowth, which helps to control other issues in the system such as scaling and corrosion. This improves system efficiency and often reduces the amount of water blown down. There are a variety of filter types, which generally fall into four basic categories: screen filters, centrifugal filters, sand filters, and multi-media filters. (WPCP, 2012)

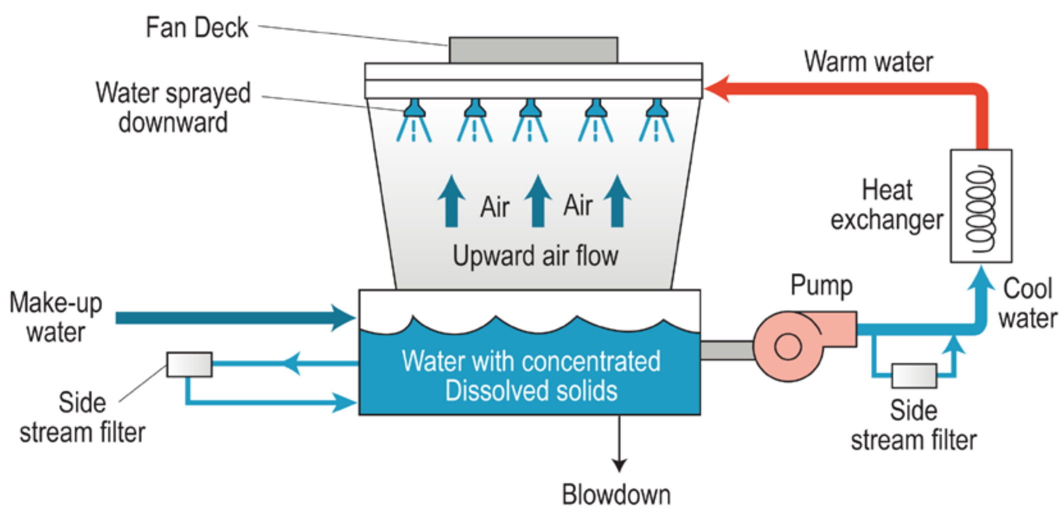

Figure 1.2. Cooling Tower with Side Stream Filtration Examples.

Side stream filtration requires a minimum supply pressure to account for the inherent differential pressure drop across the filter medium. This typically ranges from 20 to 30 psi. All side stream filters have a maximum working pressure; sand filters have a threshold of 80 psi, while mechanical filters, such as screen filters, can operate up to 150 psi. If adequate pressure is not available from the system, an additional pump may be required to pressurize the system. Backwashing of filters is required for side stream filtration systems to remove debris and particles that are collected during the filtration process.. Backwashing is typically activated when there is a pressure difference across the filter that indicates the filter is clogged, or by a simple timer that activates backwashing on a regular schedule.

Filters are rated by the size of particles that can be removed, measured in microns. Suspended solids in cooling towers typically range in size from 1 to 50 microns as shown in Table 1.1. In general, 90% of the particles in cooling towers are smaller than 10 microns (Bobby et al. 2001). However, for mechanical filtration the smaller numbers of larger particles are of more concern than the large number of smaller particles which are often bacteria removed by disinfection rather than filtration (BAC 2012), or micron and sub-micron sized suspended solids which can be treated and removed by chemical treatment. (See an example of particle removal in Table 4.1.) Side stream filtration systems are generally sized to filter from 3 to 10% (up to 20%) of the overall system flow. Filters are selected based on the percent of flow that the side stream filtration system is designed to handle. For example, in a cooling system with a recirculation rate of 1500 gpm, a filtration system sized to handle 10% of the recirculation rate would be sized to handle 150 gpm.

Table 1.1. Relative Size of Common Cooling Water Contaminants (McDonald 2009).

Particle	Microns
Sand	100 to 2,000
Pollens	10 to 1,000
Mold Spores	10 to 30
Bacteria	3

Side stream filtration increases water and energy efficiency and reduces cost, as described below (Latzer 2012; BAC 2012).

- **Reduction in water consumption**: Demand for makeup water in cooling towers is decreased with an increase in the system's cycles of concentration. Essentially, higher cycles of concentration mean that water is being recirculated through the system longer before blowdown is required. Less blowdown reduces the amount of makeup water required in the system, resulting in water savings.

- **Reduction in energy consumption**: Side stream filtration reduces the likelihood of scale and fouling on the heat exchangers. Even the smallest layer of scale or fouling on heat exchange surfaces can reduce the rate of heat exchange, forcing the system to work harder to achieve the desired cooling and in turn increases energy costs.

- **Reduction in chemical use**: Chemicals are used to bind suspended particles in the water stream and prevent scaling and corrosion. Dirty water requires more chemicals than clean water because a buildup of solid contaminants provides a buffer that reduces the effects of treatment chemicals. A side stream filtration system can remove suspended particles, reducing the need for additional chemical treatments such as dispersants and biocides.

- **Lower maintenance cost**: Traditionally, cooling towers are cleaned by draining the tower and having the sediment removed mechanically or manually from the sump. Costs associated with the cleaning process include downtime, labor, lost water, and additional chemicals. Cooling systems that are cleaned via side stream filtration routinely provide longer periods of continuous operation before being taken off-line for required maintenance.

- **Improvement in productivity and reduction in downtime**: When a cooling system is fouled or has scale buildup, production may be slowed due to inefficient heat exchange equipment. In some cases, the cooling system and heat exchange equipment may need to be taken offline for repairs, decreasing production.

- **Control of biological growth**: Biological growth control and reduction can mitigate potential health problems, such as those caused by *Legionella*. ASHRAE Guideline 12-2000 has basic treatment recommendations for control and prevention, stating that the key to success is system cleanliness. *Legionella* thrives where there are nutrients to aid its growth and surfaces on which to live. Use of side stream filtration can minimize habitat surfaces and nutrients by maintaining lower particle levels in the water stream.

1.3 Technology Applications

The following are applications where the addition of a side stream filtration system can improve the water and energy efficiency of the system.

- Systems for which the primary source of makeup water is a surface or other an unclarified source. Unclarified water sources, such as rivers or streams, can contain contaminants too small to be filtered out in a large grate protecting inlet piping. These contaminants can be both biological and environmental, and fluctuate based on season.

- Systems with difficult biological problems, even with the presence of a good biocide program. A good biocide program often increases the number of dead organisms in the water stream (Lingen, 2009). These organisms can be removed with a side stream filtration system.

- Systems that are susceptible to fouling due to either the nature of the application or the environment in which they operate. This is especially true if fouling is a problem even with the implementation of a good anti-foulant program. In some instances, a cooling system becomes contaminated on the process side of the heat exchanger, causing additional fouling with each cycle (Venkat).

- Systems where scaling deposits cause a loss of heat transfer. Scaling can be reduced from side stream filtration by limiting fouling and corrosion by-products, which can also contribute to scale formation on heat transfer surfaces.

- Systems with high levels of solids buildup in the sump due to dirt and debris deposited by windy conditions. Solids buildup in the sump can contaminate the cooling supply system from outside the makeup water supply. Operators cannot control the direction the wind blows, but the addition of a side stream filtration system can remove contaminants deposited by the wind.

- Systems in which the heat exchangers require frequent mechanical cleaning. Side stream filtration filters a portion of the cooling system continuously. Depending on the sizing of the system, the entire cooling capacity can be cleaned in a relatively short period. With the right chemical and biological treatment in addition to the side stream filtration, mechanical cleaning of the heat exchangers can be reduced and efficiency increased (Wymore, 2003).

2 Side Stream Filtration System Options

There are generally four system options for side stream filtration; centrifugal separators, screen filters, disc filters, and sand filters. For all of these options, the key performance elements to consider in the filter system are the particle removal level, self-cleaning function, ease of operation and water loss from back wash. These characteristics were assessed for the four basic types of side stream filtration systems. An overview of their performance characters is summarized in Table 2.1 and more detailed information on each system type is presented in the following sections.

Table 2.1. Side Stream Filtration System Characteristics.

Filter Type	Particle Removal Level	Self-Cleaning Features	Maintenance and Parts Replacement	Water Loss From Back Wash
Centrifugal Separators	40-75 microns, fine to coarse inorganics with a specific gravity (1.62) or greater	Purge collected solids from the collection chamber	Purge components only – periodic inspection servicing	None to minimal
Automatic Screen Filter	Down to 10 microns	Automatic backwash by using an rotating suction scanner assembly	Contain moving parts that enabling automatic backwash may require constant maintenance however compartments don't generally require frequent replacement	Requires much less water than other self-cleaning filters that utilize backwash cycles
Plastic Disc Filter	Down to 10 microns	Automatic backwash through releasing grooved discs and reversing water flow to wash collected solids off the discs	Consumable discs can require frequent replacement	Requires much less water than other self-cleaning filters that utilize backwash cycles.
Pressure Sand Filter	Down to 10 microns	Automatic backwash, once a day or on pressure drop as needed.	Periodic inspection; sand media and electromechanical parts; periodical sand media replacement	Requires a lot of water for backwashing
High Efficiency Sand Filter	Down to 0.45 microns. Best for fine light particles avoid heavy coarse particle applications	Automatic backwash features, requires less time and water than other sand filters.	Sand media must be monitored and periodically disposed and replaced.	Requires more backwash water than centrifugal separators, automatic screen, and disc filters; but about eight times less water than other sand filters

2.1 Centrifugal Separators

Centrifugal separators remove solids from water by the centrifugal force developed as water passes through the device. The technology is simple in design. Separators are fed high-velocity raw water to develop the circular flow pattern that produces the centrifugal action. This centrifugal action causes heavy solids that are suspended in the water to migrate toward the separator's sidewalls and downward, into a solids holding chamber. Cleansed water rises through the vortex and is returned to the system through an outlet at the top of the separator. Solids collected in the holding chamber are either periodically or continuously purged from the collection chamber (Figure 2.1).

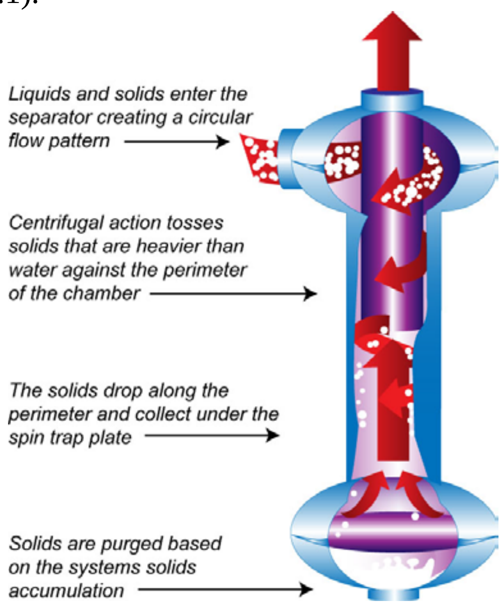

Figure 2.1. Centrifugal Separator Schematic.

The capacity for solids removal capacity is a function of particle density, size, and shape, and device design. Centrifugal separators are best used for and most efficient at separating large, heavy particles. A centrifugal separator requires little maintenance and infrequent replacement because it does not trap particles that clog or damage its system. Therefore, centrifugal separators tend to be more economical than other filtering systems with the same filtration efficiency, but are just as effective at removing suspended solids. (Griswold Filtration, 2008)

2.2 Automatic Screen Filters

An automatic screen filter, also known as a self-cleaning screen filter, is a type filtering system that uses system pressure to clean itself. Cooling water enters the filter through an inlet, then passes through a rigid cylindrical screen from the inside out, causing particles larger than the openings of the screen to accumulate on the inside surface and form a filter cake. Filtered water leaves the filter body through the outlet. The buildup of the filter cake in the upstream side of the screen causes a difference in pressure between the inlet and outlet of the filter. A controller monitors the pressure in the filter and opens a flush valve when it senses a differential pressure threshold has been exceeded. When the flush valve opens to atmosphere, the difference between the higher pressure of water inside the filter and the atmosphere outside the filter body causes high suction forces at the openings of each of the suction scanner nozzles. The suction force causes water to flow backward through the screen in a small area at very high velocity at each nozzle, pulling the filter cake off the screen and forcing it into the suction scanner and out the exhaust valve to waste (Figure 2.2).

The driving mechanism of the filter rotates the suction scanner assembly at a slow, fixed rotation while simultaneously moving the scanner linearly at a fixed speed. The combination of the rotation and the linear movement gives each suction scanner nozzle a spiral path along the inside surface of the filter screen, which allows the nozzles to remove the filter cake from every square inch of the filter screen. The cleaning cycle usually takes less than 1 minute. The total volume of water used for cleaning is small, usually less than 1% of the total flow.

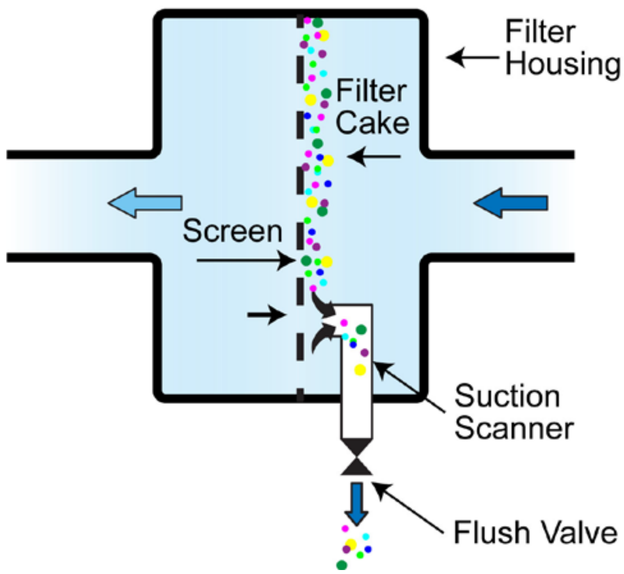

Figure 2.2. Automatic Screen Filter Schematic.

Automatic screen filters are unique in that the self-cleaning cycle does not require the entire system flow to stop and reverse. Therefore, unlike many other types of filters, the self-cleaning cycle of these filters does not interrupt system flow during the rinse cycle. In addition, automatic screen filters provide a two-dimensional, discrete opening that positively removes particles that are larger than the pore size of the screen based on size alone, regardless of other characteristics such as particle density, shape, or particle material. Self-cleaning screen filters are used in a variety of applications where continuous water flow is crucial, including industrial equipment protection, irrigation nozzle protection, and municipal water treatment. This technology is relatively inexpensive for the high flow rates it offers (BAC 2012).

2.3 Plastic Disc Filters

This technology uses plastic discs made of polypropylene that are stacked together under pressure and grooved to filter particles of specific micron sizes. Each disc has etched grooves in a slightly different pattern array between the top and bottom of the disc. When multiple discs are stacked and centered around a skeletal cylindrical structure, called a “spine,” the discs form a hollow cylinder with the ends of the grooves exposed to both the inside and the outside surfaces of the cylinder (Figure 2.3). The different groove patterns of the stacked discs create intersections of different sizes to trap particles when cooling water passes from the outside to the inside of the hollow cylinder. As particles are captured within the depth of the disc stack, a pressure differential is created. Backwash is initiated when the preset pressure differential is achieved. The stack pressure is relieved and the filtered water is forced through the disc stack in reverse through several nozzles within the disc stack spine. These nozzles create a tremendous amount of turbulence that cleans the discs very effectively in 10 to 20 seconds (Prochaska 2002).

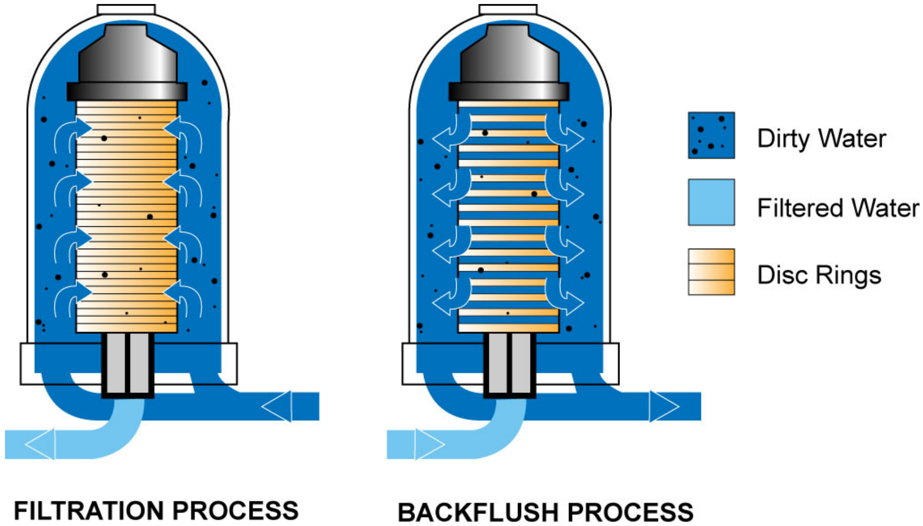

Figure 2.3. Plastic Disc Filters.

Disc filters can remove both solids and organic particles effectively. These filters also use much less water than other types of self-cleaning filters for backwash cycles, and tend to have relatively lower installation and operating costs compared to other filters with equivalent filtration rates. Disc filters can backflush multiple filters sequentially, and because the backflush cycle is sequential the filtration process is seldom interrupted. Triggered by differential pressures or timing intervals, or a combination of both, the self-cleaning process is fully automatic, requiring little maintenance.

2.4 Sand Filters

Sand filters are a common type of side stream filtration system. Sand filters direct fluid into the top of their tank(s) and onto the surface of a bed of specified sand and/or other media. As the cooling water flows through the bed of sand media, suspended solids and other particles are captured within the upper layer of media. The water moves downward, passing into a drain at the bottom of the filter tank and discharging through an outlet pipe. Sand filters are usually very efficient at removing the extremely fine and low density particles that cooling towers scrub from the air. Therefore, they generally have very high filtration rates. However, sand filters work less effectively with high density sand-like materials because these materials cannot be properly removed by backwashing. Furthermore, sand filters tend to be more expensive and larger than other types side stream filtration systems with equivalent filtration rates (Melancon 2004). There are typically three types of sand filters, pressure sand filters, high efficiency sand filters and gravity sand filters. However, gravity sand filters are rarely used for cooling tower systems; they are therefore not discussed in the research paper.

A feature of sand filter design that should be considered is the capability of supplemental chlorination during backwash or routine maintenance. The filter medium in many types of sand filters coupled with the increased temperature of the recirculating cooling water can support biological activity. Supplemental chlorination is an effective strategy to reduce increased bio-growth in the filter medium, and therefore in the cooling water as well.

In short, sand filters provide excellent removal of suspended solids, but size, expense, and maintenance concerns are considerations when selecting this technology. The following sections describe two main types of sand filters: pressure sand filters, and high efficiency sand filters.

2.4.1 Pressure Sand Filters

Pressure sand filters are one of the most common side stream filtration systems and are used in many facilities. A pressure sand filter consists of a pressure vessel and several layers of multi-media filters. A coarser filter media is located on the top layer, with layers of decreasingly granulated material down to the fine media at the bottom. A layer of gravel is included on the bottom layer to prevent finer sand media material from migrating through the drain (Figure 2.4). Typically, these systems are effective at filtering particles of sizes between 15 and 20 microns.

For pressure sand filters, the backwash requirement is relatively high and an external source of backwash water is needed. Clean, treated city water or clarified, chlorinated water are the preferred water source for backwash, which typically takes 10 to 15 minutes per backwash. Backwash is initiated by either a pressure differential switch measuring the incoming and outgoing pressures or an adjustable timer. A backwash with a clean, chlorinated source is recommended at least once per day to maintain media efficiency and to prevent microbiological activity.

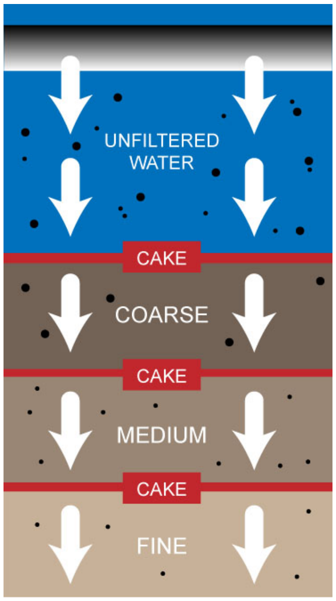

Figure 2.4. Pressure Sand Filter Schematic.

2.4.2 High Efficiency Sand Filters

This type of filter is similar to the pressure sand filter in that sand is used as the filtration media. However, the media layer order is reversed, with extra fine sand as the top layer and layers of gradually coarser sand down to the bottom layer (Figure 2.5). Raw water is introduced to the pressure vessel, with an angled inlet creating a turbulent and spinning flow across the media bed, called a "vortex." The particles in the vortex collide with the fine sand barrier and with the vessel wall. The collision causes the particulates to fall out tangentially and coat the media bed and vessel with a filter "cake."

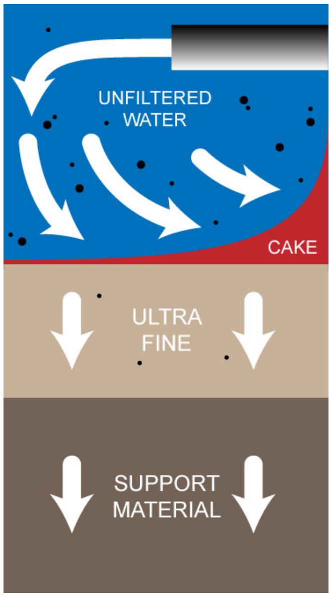

Figure 2.5. High Efficiency Sand Filter Schematic.

This technology, therefore, is differentiated from conventional pressure filters because particles are captured on the surface of the filter instead of penetrating the filter media. This provides two advantages: (1) filtration can be achieved down to 0.45 micron even on a clean media bed because of the use of the extra fine sand media and (2) backwash requirements are low because particles are not captured deep inside the filter media. Only approximately 50% of the designed forward flow through the high efficiency filter is required for a backwash that takes between 5 and 8 minutes compared to 150% of the design flow requiring 15 to 20 minutes for pressure sand filters.

These filters operate efficiently in a smaller installation footprint. High efficiency filters can filter 18 gallons of water per square foot of media surface, compared with 8 to10 gallons per square foot of conventional pressure filters. This filter footprint difference can be very important for selecting equipment in mechanical rooms.

3 System Economics

This section discusses the economics of a side stream filtration system, using a hypothetical example of life-cycle cost analysis for a side stream filtration system using pressure sand filters.

To calculate the potential savings associated with a filtering system, the analysis presented here is based on the following cooling tower specifications:

- System uses a 400 ton chiller.
- System operates 3720 hours a year.
- Typical load of the system is 70%.
- Operating efficiency is 65%.
- Cycles of concentration is 3
- Cooling tower consumes $1,500 worth of water treatment chemicals per year.
- Cooling tower is cleaned three times per year; each cleaning requires two people for 24 hours at a total estimated cost of $4,320.

The supply water contains particles with a minimum size of 20 microns. These particles take up 90% of the total particle volume and have the potential to form a layer of foul measuring approximately 0.001 inch thick. Each 0.001 increase in fouling results in a 10 % increase in power (ASHRAE Standard 550-98). In addition, this amount of particles can cause a 20% increase in the costs of water treatment chemicals (Dearmont et al. 1998).

The current energy cost of this cooling tower is estimated to be $47,393 per year, based on the following formula:

A\C ton × kW/ton × load factor × hours of operation/yr × cost/kWh = energy costs/year

400 ton A\C × 0.65 kW/ton × 0.7 load factor × 3,720 operating hours × $0.07/kWh = $47,393

In this example, a side stream filtration system is installed that filters 10% of the entire flow rate to remove the identified particles, with a minimum size of 20 microns. With this system installed, it is estimated that the cooling tower would consume 10% less energy (PEP, 2010), which translates to $4,739 of energy savings per year. Cycles of concentration would increase from three cycles to four in the system and create a water savings of 228,000 gallons of water annually (PNNL 2012). At a combined water cost of $7 per thousand gallons, this will save $1,596 annually. In addition, the filtration system is projected to reduce water treatment cost by 20% saving $300 per year. Finally, it is estimated that the maintenance requirement for the cooling tower could be cut in half (LAKOS, 2012), generating an annual maintenance saving of $2,160. In total, the side stream filtration system would save $8,795 per year.

A life-cycle cost (LCC) analysis was performed on this hypothetical example for a pressure sand filter. Pressure sand filters generally have the highest estimated cost of equipment and installation. It was concluded then, if the pressure sand filtration system had favorable economics, then all other systems would likewise be favorable. The savings estimates were based on a few manufactures' return on investment (ROI) Excel spreadsheet calculator tools (LAKOS 2012; PEP, 2010) and LCC calculations were performed using the Department of Energy's Building Life Cycle Cost (BLCC) (v5.3-11) software.

Table 3.1. Life-Cycle Analysis for Pressure Sand Filtration Systems.*

Filtration Type	Total Investment	Annual O&M Cost	Total Savings per Year	Payback Period	Savings to Investment Ratio
Pressure Sand Filtration	(A) Equipment cost: $35,000 (B) Installation cost: $10,000 (C) Total investment: 45,000	Annual O&M cost = $1,440 (labor) + $500 (sand renewal + $1166 (sand replacement) = $3106	$8,795	8 Years	2.31

* The cost and saving estimates of this life-cycle cost analysis is based on Pacific Northwest National Laboratory industrial survey data and the prices are as of June 2012.

4 Evaluate Field Application of Technologies

The Spallation Neutron Source (SNS) cooling tower at Oak Ridge National Laboratory (ORNL) is a four-cell, cross-flow tower that is divided into two two-cell operating systems. Half of the system meets the comfort cooling load of the research facilities in the SNS area, while the other half provides process cooling for the accelerator. Both sides of the tower are operated and controlled independently even though they share the same structure. The makeup water quality is also the same for both sides of the system. The critical nature of the accelerator cooling requires that only trace levels of suspended solids be present in the cooling tower bulk water; therefore, ORNL instituted a plastic disc filter system to manage suspended solid levels in the side of the cooling tower that serves the accelerator.

The disc filter system at ORNL has successfully maintained suspended solids within the threshold levels. Table 4.1 gives a side by side comparison of the overall particle volume for both the system with side stream filtration and the system without. The table shows particle volume, measured in cubic millimeters per one hundred liters (mm^3/100L). The total particle volume of the system without side stream filtration is 3,986 but is reduced to only 43 mm^3/100L in the system with side stream filtration. This represents a 95% reduction in suspended solids, including complete removal of particles larger than 80 microns.

Table 4.1. ORNL Particle Distribution Analysis.

Micron Range	Particle Volume without Side Stream Filtration (mm^3/100L)	Percentage of Overall Particle Volume without Side Stream Filtration	Particle Volume with Side Stream Filtration (mm^3/100L)	Percentage of Overall Particle Volume with Side Stream Filtration
0.5-1.0	45	1.1	3	6.5
1.0-5.0	95	2.4	8	17.3
5.0-10	302	7.6	7	15.7
10-15	442	11.1	5	11.3
15-20	553	13.9	4	10.1
20-30	1,018	25.5	3	6.5
30-40	575	14.4	5	10.6
40-50	318	8.0	3	7.1
50-60	213	5.3	3	7.4
60-70	178	4.5	1	3.0
70-80	128	3.2	2	4.6
80-90	86	2.2	0	0.0
90-100	34	0.9	0	0.0
Total	3,986		43	

5 System Implementation Considerations

When considering a side stream filtration system, there are several key parameters that are important to weigh including the level of particle removal, filtration sizing, installation methods, and cost and water savings potential. Carefully examine the following features to properly specify the proper side stream filtration system for the appropriate application:

- ***Particle removal analysis***: Understanding the specific characteristics of suspended solids in the cooling water is crucial to selecting the most appropriate type of side stream filtration system. The total volume of space that particles occupy can cause significant clogging and fouling of cooling tower systems. Therefore, the total volume of the particle matter that needs to be eliminated must be determined when choosing a filtration system. Particle size distribution and total suspended solid (TSS) tests are inexpensive and clearly indicate the population size of the contaminants and each size group's contribution to the TSS volume. Once the particle size and TSS volume are determined, the side stream filtration technologies' efficiency at removing different sized particles and targeted total particle volume removal can be evaluated. A properly selected and sized side stream filtration system should be able to eliminate enough solids to reduce clogging and fouling.

- ***Filtration sizing***: Properly sizing a side stream filtration system is critical to achieving optimum filter performance. Flow rate and filtration efficiency are major factors in sizing a filter. The flow rate should be targeted to achieve a certain percentage of the entire recirculation flow rate, depending on how efficiently the chosen technology removes the identified particles in the recirculation water. More efficient technologies require a smaller percentage of the recirculation flow since they capture more particles per gallon. The number of system volume turnovers per day is equally important to properly sizing the side stream filtration for a cooling system. A common guideline is to size the filter to handle a flow rate that turns the system volume over once an hour. A side stream filtration system's flow rate generally ranges from 3 to 10% (but can be up to 20%) of the total recirculated cooling water flow rate. A side stream filtration percentage of 3% or less of the total circulation flow rate has been shown to damage cooling systems, causing fouling throughout the cooling loop.

- ***Installation methods***: Two common methods are used to install side stream filters in cooling systems. One method is to install a filtration system on a tap off the water flow line. The installation on a tap off the water flow line takes a percentage of the flow downstream of the pumps and then delivers the filtered water back to the basin or back to the full flow stream with the aid of a booster pump. When a filter is tapped on the water supply line and filtered water is returned to the basin, additional pumps are not required. A major consideration with this installation is the downstream effect on the cooling capacity since it may affect the flow rate pressure of cooling water sent to the heat source. The second method is to install the system off the basin/sump of the cooling tower. With this type of installation, the system takes suction from the tower sump and returns treated water back to the basin. This installation method requires a dedicated pump rated at the required flow rate, control valve, and controller. It also requires the operating pressure of the filter system recommended by the chosen technology's manufacturer. This is a preferred installation option for process towers where common supply headers are inaccessible or difficult to tap.

- ***Filtration design features***: Once the types and sizing of filtration systems are selected for a cooling tower system, another important consideration is the design features of the selected filtration system. Automatic backwash functions are a key design feature for cost-effective systems. Side stream filtration systems with automatic backwash functions can reduce maintenance requirements, reducing operating costs. Side stream filtration systems without automatic backwash features, such as screen, cartridge, and bag filters, require more maintenance, making them difficult to justify as a long-term solution. Other considerations include whether the filtration system requires electricity and backwash water, and whether the system is simple to operate, because a complicated operating system can significantly increase operating costs. Another consideration is whether the system incorporates design features to allow easy upgrading.

- ***Financial analysis***: As explained earlier, the return on investment analysis of various filtration systems with proper filtration rates for a cooling system can clearly demonstrate the cost as well as the savings of the these filtration systems. Such analysis plays a key role in determining the most efficient and cost effective filtration systems for a specific cooling system that fit in the allowed budget.

  When performing a financial analysis, it is important to consider the costs associated with the different filtering technologies. The largest cost is the filtration system. However, there is a varying cost of different types of filters. A quote received during the evaluation priced a sand filtration system at $32,000 for a 400 ton cooling tower. In another estimate for the same cooling tower, a high efficiency sand filter was proposed at $23,000. As another example, a Spokane, Washington hospital installed a $22,000 centrifugal separator system. Each of these systems utilizes different technologies, which results in varying levels of performance. The high efficiency sand filter, for example, filters down to 0.45 micron particles, but the centrifugal separator generally only filters down to 40-50 micron particles. The costs, therefore, must also be weighed against the requirements of the system.

  Once a filtering system is selected, the material and labor costs associated with installation should also be included in the financial analysis. Pumps, piping, and installation will all vary with respect to system configuration.

- ***Savings considerations***: There are several different savings to consider and quantify when selecting the filtration systems. As the cooling water is filtered, there likely will be less fouling of the cooling lines, radiators and condensers which will increase the overall efficiency of the cooling system. Based on the particle analysis and estimated particle volume reduction, the efficiency improvement of the cooling systems as well as the related energy consumption savings can be calculated. Furthermore, an effective filtration system can reduce costs associated with the traditional cooling tower cleaning process include downtime, labor, lost water, and additional chemicals. Therefore, these operational and maintenance savings including water, labor and water treatment savings should be estimated and accounted in the financial analysis.

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