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Energy Conservation through Filtration and Hydronic Free Cooling

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ABSTRACT

Cooling Water Filtration has the potential to save energy, reduce health risks and chemical usage as well as cleaning costs by keeping the system free from dirt and debris. The benefits of ongoing filtration and basin cleaning systems are often over-looked and under-estimated. A failed attempt to utilize free cooling with a plate and frame heat exchanger due to fouling by dirt and debris forced the need for proper filtration. A major Midwest department store chain and a Colorado State Energy provider sponsored a study to determine the savings realized when filtration is properly applied to water cooled systems.

Seven Colorado department stores water cooled HVAC systems were studied over a period of two years. The first year the stores cooling baseline energy, chemical usage, and cleaning costs data were recorded. Both the open and closed cooling water loops were studied. Following the first year centrifugal separator filtration systems were installed during the winter shutdown. The study included the three common methods for applying filtration to a cooling system: Full Flow, Side Stream, and Basin Sweeping. Common methods for handling the removed solids were also varied for comparison. Once the filtration systems were in place the energy and chemical usage, and cleaning costs were again recorded using the building management system.

The study found that filtration is critical to maintaining optimum heat transfer and minimizing energy usage. A total of 15% total electric savings was realized. Chemical usage was reduced 15 to 20% and major maintenance savings was recorded. The tower water was crystal clear and the risk of a Legionella outbreak reduced. It was determined that filtration is especially critical when using plate and frame heat exchangers for free cooling.

INTRODUCTION

A strainer cycle is a method of free cooling directly connecting the cooling tower (open system) to the building loop through a strainer that in theory would filter out particulates. Keep in mind that strainers are meant to keep particulates out of condenser bundles that have significantly larger tubes than cooling coils. Hydronic free cooling is commonly used in dry climates with wet bulb temperatures very near the dry bulb temperature to curb the use of chillers as an energy conservation measure. Implementing a strainer cycle with hydronic free cooling, when implemented improperly, can realize disastrous results.

In a case study of seven stores near Denver, Colorado, strainer cycle, free cooling was implemented. A few seasons of strainer cycle use and the cooling coils were completely plugged. Due to the system failure, significant maintenance and operational changes occurred. This entailed replacing all the cooling coils and of course dismantling the strainer cycle to

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keep this from happening again.

Decades later energy prices skyrocket and hydronic free cooling is re-examined as a method of curbing chiller use. The newly designed system utilized a plate and frame heat exchanger to isolate the tower from building loops. Plate and frame heat exchangers have a 1/10" plate spacing and are as susceptible to fouling as cooling coils. In order to avoid catastrophic failure a method of filtration had to be implemented to protect the heat exchanger, but designed to avoid the design pitfalls of the past.

How Dirt Gets In a Cooling Water System

Evaporative cooling towers provide cooling to buildings and processes by maximizing the direct contact of water to air in order to maximize evaporation and thus cooling of the water. Because of the huge volume of air moved through a cooling tower, open recirculating cooling towers are unintentional air scrubbers (Reference Chapter 39 ASHRAE Handbook) and are very effective at both removing debris from the air and depositing it into the cooling water. If dirt is not removed from the system it often ends up on heat transfer surfaces dramatically reducing operating efficiencies. To fully understand this basic knowledge of how a cooling tower operates is required.

There are several sources of dirt inherent in this process. The most common are: Airborne particles, Rust, Precipitated minerals, Biological matter, Dirt contained in the incoming water.

During normal operation dirt is removed from the air and deposited in the cooling tower when dust or debris come in contact with the water wetting the particle and causing it to become suspended in the circulating water of the tower. ASHRAE Handbook data indicates that there are 5 ppm of dirt in the air. Taking a typical induced draft 200 ton cooling tower operating 6 months at 75% load we can calculate the volume of air and thus dirt collected in a cooling tower. If we divide that number by the cold water basin plan area would result in collecting 5" of dirt accumulation in the bottom of the cooling tower.

Rust is another problematic source of suspended debris in cooling tower systems. Cooling towers, interconnection piping and condensers are made from iron, steel and other metals. While methods to control corrosion are usually employed, corrosion still takes place and usually increases as a system ages. These corrosion by-products end up in the cooling water system; especially in situations cooling towers are shut down during the winter. The start up shut down cycle often results in rust and pipe scale becoming loose and breaking away from the system structure.

Precipitated minerals are an additional source of fouling in evaporative cooling systems. As evaporative cooling systems operate water volume is lost through evaporation. This water is replaced by adding more water to the reticulating water of the system. This increases the concentration of dissolved minerals in the bulk water. Often, this process results in the dissolved minerals precipitating to a scale or suspended solids form. These precipitated solids like any other solids can impede heat transfer and require removal from the system to maintain peak system efficiency.

In a similar manner, biological activity can add solids to a system. Even with the addition of microbiocides and a good chemical treatment program algae and bacteria can be problematic. Additionally, as biofilm presents itself in cooling tower systems, under-deposit corrosion occurs. Corrosion due to micro-organisms is responsible for the most aggressive corrosion in cooling water loops and resultant solids from the corrosion debris. In some cases, the makeup water that is coming into a cooling system contains dirt and debris. This dirt then settles out in the basins and areas where the water velocities are lower.

The combination and contribution of all the different sources of dirt and fouling in a cooling system result in a situation where if the dirt is not continuously removed the buildup will affect the performance efficiencies of the system. As efficiencies in condensers continue to improve it becomes even more critical to keep the heat transfer surfaces perfectly clean in order to obtain the design heat transfer efficiencies.

Filtration Methodologies

There are two main types of evaporative coolers, fluid coolers which are a closed system (not part of this case study) and cooling towers which are an open system. Generally cooling towers employ strainers or screens as the primary means of controlling solids in a system. These devices are primarily on pump intakes or sump outlets and are normally designed to keep large solids such as leaves, paper, etc. from entering the system. Typical are strainers that have 1/8" to ¼" openings. Many of the solids that impede heat transfer pass through strainers and screens and become lodged in the enhanced tubes in the condenser. Barrier filtration devices such as the strainers and screens described above also have to be cleaned manually, or be installed in duplicate to provide continuous filtration/flow to the system. In either case the filtration provided, while needed, is not sufficient to prevent fouling in condensers where heat transfer is taking place.

Secondary filtration systems that were contrasted for effectiveness and operational impacts were multi-media filters, sand filters, and centrifugal action separators. The filter types and considerations are detailed below:

Multi-media filters typically are cartridge type filters that implement multiple types of media to clarify water. A good example are reverse osmosis filters which have 3 types of media including sediment filter, carbon filter for chlorine removal to preserve the osmotic membrane, and the osmotic membrane itself. Multi-media filters were considered too maintenance intensive and not cost effective due short cartridge lifespan. These filters can remove particulates less than 5 microns which was considered more than necessary.

Sand filters have media barriers on the inlet and outlet that contain the sand of either the same or progressively smaller media size depending on application. Sand filters can operate for a few years without media replacement but as the filter traps particulates the sand becomes a homogeneous mixture, essentially becomes concrete like. The extraction process is intensive not to mention removing the old media and supplying the new media. The media can easily weigh a few hundred pounds.

Multi-media and sand filters were also considered but rejected because of water lost during back flow and changing pressure drop. Because flow is interrupted during the backwash cycle the filters are impractical for full flow applications. In a different manner, basin sweeping is not adversely affected as the pressure changes during normal operation.

Filtration System Configurations

Filtration system configurations coupled with a filtration device that continuously remove 95% of particles down to 40 micron (side of a human hair) are not always used, or get value engineered out of designs. Also, there are 3 common means of providing increased filtration on condenser water systems.

The characteristic configurations are: 1) Side stream filtration (usually 5 to 10% of condenser water flow), 2) Full flow (all of the condenser water flows through the filtration device with each pass), 3) Basin sweeping (where filtered water is piped back to the cooling tower cold water basin under pressure and used to "sweep" dirt to the suction point of the filtration).

CASE STUDY

The case study's main objective are comparing energy usage versus filter configuration (side stream, full stream, and basin sweeping) and a base system utilizing pump strainer and cold water basin inlet screen to a filtration system capable of continuously removing 95% of all visible dirt (40 micron) from an energy usage perspective.

Very few scientific or case studies have been conducted to determine the effect of removing particles down to 40 micron level in the interest of determining how much filtration is enough filtration, and to extent improved filtration has on system energy efficiency. It is important to note that while filtration does dramatically influence the operating efficiencies of condenser water system, it does not improve the efficiency of the condenser or chiller. More correctly stated, effectively removing all visible (40 microns and larger) particles from an open re-circulating condenser water system maintains the condition of the condenser water system so that it continuously operates at or very near the design conditions thus providing the expected heat transfer efficiency. Consider a system that is not maintained in an effectively clean state the operating efficiencies drop off dramatically as the anticipated significant energy increase occurs.

The case study also included closed and open loops. The unique aspect of the case study is that seven different systems were studied. In addition significant expertise was available to design and carryout the research. The project was directed by a large department store chain in conjunction with the filtration system manufacturer and local utility provider. Locations were selected based on systems with abandon strainer cycles, ability to accurately measure baseline energy use, and the ability compare post filtration energy usage with base configurations.

Several different means of filtration were considered. Reviewed were self cleaning screens, sand filters, cartridge filters, and centrifugal action separators. The parameter that the owner imposed was minimal to effectively neutral increase in operational maintenance. This constraint forced the exclusion of media filtration systems, by the process of elimination only centrifugal action separators were installed. The centrifugal action separator has the ability to remove in excess of 90% of all visible particles in a continuous manner without additional maintenance required for either the separator or in removal of the filtered solids. The centrifugal separator uses a vortex column with a deflector plate and spin arrestor to induce the contaminates (40 microns and larger) to precipitate as opposed to the strainer cycle that removes contaminates equal or larger than the tubules (125 to 250 microns and larger).

At the beginning of the study all systems were thoroughly cleaned and the condition of the systems documented. Baseline date was recorded using TAC (Tour & Andersson Controls) building automation system. The filtration systems were operated for a full season recording the energy usage throughout the season. The systems were then again inspected, the conditions documented and cleaned.

During the winter shut down the filtration systems were installed. The different filtration approaches of side stream, full flow, and basin sweeping being tested were installed on buildings as follows: Building A – Side Stream, Building B – Side Stream, Building C – Side Stream, Building D – Full Stream, Building E – Basin Sweep, Building F – Side Stream both tower and building loops, Building G – Side Stream. See Figures 1, 2, and 3 for basic installation configurations.

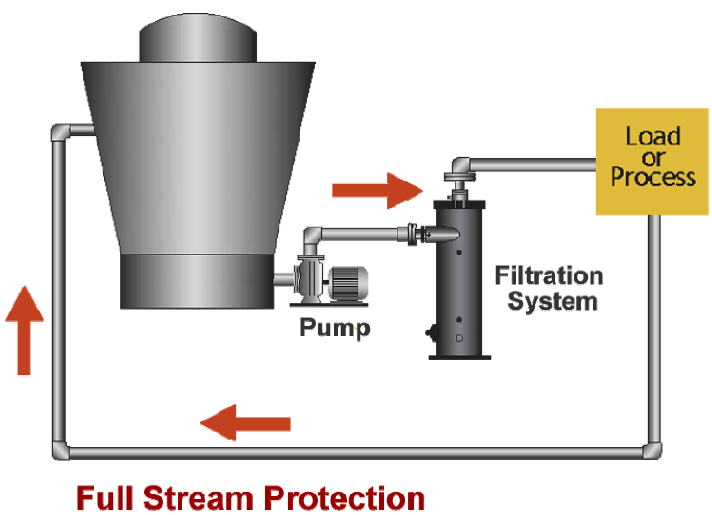

Figure 1. Full Stream Application

Full flow filtration is where all of the condenser water passes through the separator on every pass. When using full flow it is important to allow for the pressure drop (5 to 12 psi) through the separator and size the pump accordingly. Because of this design consideration full flow is most often used in new applications, or applications where the condenser water pumps are going to be changed out as opposed to retrofitting existing condenser water systems.

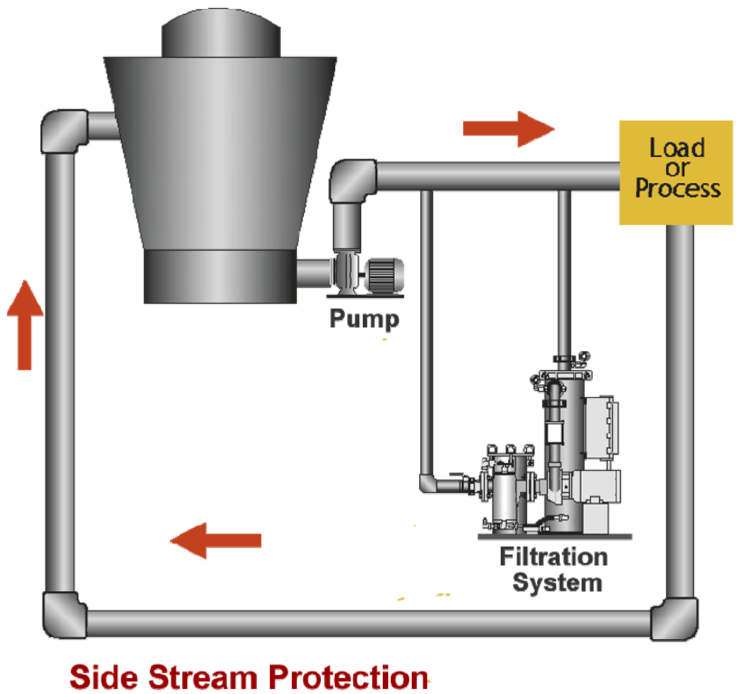

Figure 2. Side stream configurations included a booster pump which is designed to provide for the pressure drop through the separator. Side Stream filtration is where a portion of the circulating water is pulled off of the main loop and passes through the filtration device. A side stream flow that is 10% of the recirculation flow rate is common.

In a similar manner, a basin sweeping system (Figure 3) consists of a separator and motor and controls skid mounted. In addition, a basin sweeping system includes piping to and from the cold water basin of the cooling tower. The concept is to "sweep" dirt in the basin to the suction point of the basin sweeping package so that it is possible to get the dirt to the separator for removal. Included in the piping are a combination of sweeper jets and nozzles that provide for a 5:1 increase in flow. This is called activity flow. The increase in flow activity is comes from the venturi effect of induction type nozzles.

Condenser Water Purity

Condenser water purity is enhanced when implemented in layers which perform synergistically. The contaminant must go through all the barriers and can be removed at any stage. This technique includes cooling tower air inlet screens, chemical or ozone water treatment, appropriately sized strainers and centrifugal filtration.

The air inlet screens remove a significant portion of the lighter than water debris before it has the ability to contaminate the tower water. The water treatment controls the growth of biologics, the strainers remove the large particles, and the centrifugal filters remove particles down to the 40 micron level. The synergism exists for example between the inlet tower screens and the centrifugal filters as the layers remove lighter than water and heavier than water contaminants.

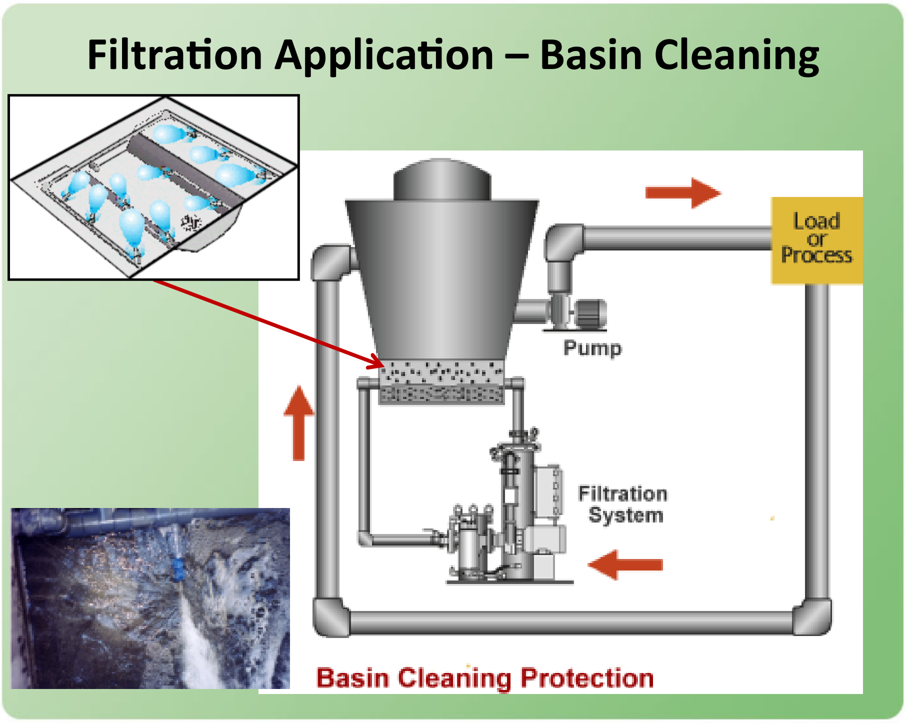

Figure 3. Basin Cleaning

ENERGY, MAINTENANCE AND EQUIPMENT SAVINGS

The annual store usage and savings data represents saving due to hydronic cooling as well as filtration. Benefits to clean tower water include higher specific heat capacity (water is 1 Btu/lb/ °F compared to dirt which is 0.2 Btu/lb/ °F), the higher the heat capacity the less water needs to flow for the same amount of Btu's to transfer. In other words the variable speed drive will operate at a lower speed with cleaner water than with dirty water. That is why removing glycol from the evaporator loop is a common energy conservation measure, glycol's heat capacity is 0.69 Btu/lb/ °F.

Building engineers clean the tubes annually and removed significant quantity of "mud" coating the surface of the bundles. The building engineers noted that the bundles had little no fouling the second year with the centrifugal filters and did not requiring any maintenance. Chemical usage was also reduced by approximately 20% due to increased hydronic conductivity. Deionized purified water is a very poor conductor, as contaminates are introduced conductivity increases. Chemicals are released into the cooling tower water based on the conductivity of water, the more contaminated the water is the greater the conductivity which increases the injection of chemicals.

The risk of Legionella outbreak has a high correlation to poor tower water quality which presumably is reduced with clarified water. Legionella is outside the scope of this case study and more information regarding this subject can be found in ASHRAE Technical Committee 3.6 publications.

Basin pitting is reduced due to corrosion from debris harboring sulfate producing bacteria. Typically basin corrosion is minimized at the expense of capital cost (stainless steel basin) or durability (polymer basin).The annual energy data summary is presented below in USD$:

Filter Configuration & Store Data									
				Annual		Annual			
Store	SQFT (000's)	Tons	Filter Configuration	Electric Cost (000's)	KWH Usage (000's)	Total Savings (000's)	Electric Savings (000's)	Chiller Maint Savings (000's)	Filter Maint. Savings (000's)
A	146	500	Side Stream	102.0	1,864	16.8	10.5	3.5	2.8
B	151	500	Side Stream	105.4	1,777	17.7	11.5	3.5	2.7
C	150	500	Side Stream	125.9	2,165	20.8	14.6	3.5	2.7
D	200	600	Full Stream	168.7	2,895	26.8	20.6	3.5	2.7
E	211	600	Basin Sweep	172.4	3,226	27.8	21.6	3.5	2.7
F	199	600	Side Stream*	141.5	2,316	23.8	17.6	3.5	2.7
G	179	600	Side Stream	141.5	2,316	22.8	16.6	3.5	2.7
*Side stream filter on tower and building loops									

RECOMMENDED FILTER CONFIGURATIONS FOR EXISTING AND NEW SYSTEMS

The case study installed side stream, full stream and basin sweeping systems on existing condenser loops and based on design and installation difficulties observations are made. Filters with blow down valves should have a spring return or a secondary valve down stream of the blow down valve that opens and closes with the blow down valve. This would prevent the basin from being drained in case of power failure during blow down or valve failure in the open position. The filters can also have a sediment discharge bag installed instead of the blow down valve which eliminates the blow down valve issue and saves water especially in water rights states.

Side Stream Filter Configuration

Side stream filters were the easiest of the three to install on existing systems. These filter systems do not affect flow characteristics, add system head and are the least expensive to install. The pipe "Ts" cut in are recommended to be line size with the drip loop being two pipe diameters long. The "Ts" are recommended to be at least ten pipe diameters apart or the length of the filter attachment points whichever is greater. The side stream should be sized to 10% - 20% of maximum flow.

Full Stream Filter Configuration

Full stream filters were the hardest of the three to install on existing systems and are best reserved for new installations. These filter systems do affect flow characteristics and add system head. The engineer will either need to upsize the pump impeller or install a new motor / pump to overcome the added head requirements for existing buildings. The electric service may have to be upsized to accommodate the larger motor.

Basin Sweeping Filter Configuration

Basin sweeping filters are harder than side stream filters to install on existing systems but easier than full stream. New cooling towers can be ordered with the basin piping and additional sump upstream of the main sump. These filter systems do not affect flow characteristics or add system head.

OBSERVATIONS AND CONCLUSIONS

Colorado is a dry state ideal for hydronic free cooling implementation. The majority of the total electric savings resulted from hydronic free cooling and the balance derived from filtration due to maintaining like new thermal efficiency, specific heat capacity of tower water, and reduced pump energy. Maintenance savings resulted from decreased chiller runtime, condenser bundle cleaning and tower cleaning.

Hydronic free cooling is the main driver behind the energy conservation measure but the filtration system is what keeps the system efficient and more importantly from falling into the precipice known as catastrophic failure. Particles larger than 100 microns would foul the plate and frame heat exchanger in short order as this is the plate spacing.

The free cooling systems were designed with the same parameters for each of the stores with the filtration methodologies (side stream, full stream, basin) as the main variance. Therefore presuming all other factors being equal the electric savings on a per square foot basis, stores D (full stream) and E (basin sweep) provide the greatest savings. Presumably most of the particles were remove versus the side stream. The basin system removes particles at the source as it was the only one of the three configurations that the basin water was visually clear. Note the table below.

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