Bypass filtration in cooling water systems

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Introduction

In industry and electricity production cooling water systems are used on a large scale in order to remove excess process heat. A frequently used technique is the open circulating cooling water system, in which the process heat is discharged to the atmosphere by means of evaporation of a part of the cooling water to the air passing through the cooling tower. Some environmental aspects of this technique of excess process heat removal are:

- The withdrawal of water from natural resources;
- The evaporation of water to the atmosphere;
- The use of chemicals in order to prevent the cooling water system from corrosion, precipitation and microbial growth;
- The discharge of blow-down water, containing (in-) soluble components.

The concentration of pollutants in the cooling water system continuously increases because of partial evaporation, blow-in of mass via the airflow and because of microbial growth. These phenomena lead to contamination and corrosion in the cooling water system and require frequent maintenance efforts in order to minimize downtime of the production process and to prevent a decreasing heat transfer due to film formation on the surfaces of the heat exchanging equipment.
The conditioning of the cooling water should also be focussed upon a minimization of the environmental burden (discharge of blow-down and supply of make-up water) and to a maximization of the reliability of the cooling water system. These two objectives are met at low financial costs by applying moving bed filtration on a bypass of the cooling water system. The system features are highlighted below.

Open circulating cooling water systems

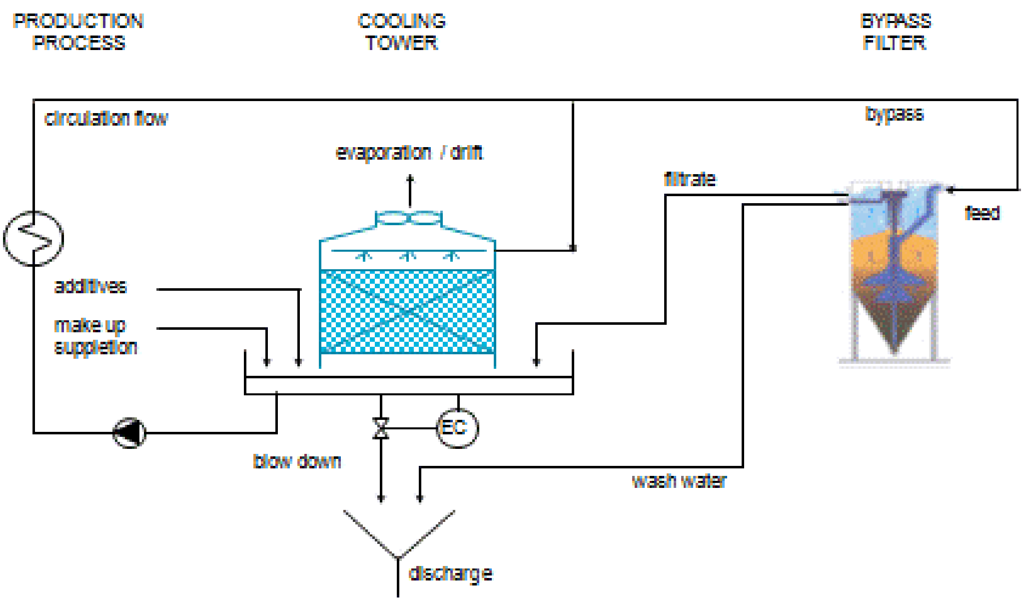
In an open circulating cooling water system the cooling water is pumped into the heat exchangers, in which it picks up the excess process heat which is removed in the cooling towers. In the cooling tower the warm cooling water is sprinkled and put in contact with a counter- or cross-flowing air flow, which removes the evaporated water.
In order to balance the evaporative losses fresh water has to be added, resulting in an increase of the concentrations of soluble and insoluble components in the cooling water system. The concentrations of soluble and insoluble components are maintained on a satisfactory level by means of a continuous blow-down of cooling water. The resulting up concentration for solids may be estimated by the flow ratio of suppletion and blow-down. This concentration factor is measured by means of conductivity or chloride content and is normally maintained at values between 1.5 and 4.
For a 10 MW_{th} cooling water system and a temperature decrease of 8°C the evaporative losses account for 15 m^3/h. A concentration factor of two is obtained at a 15 m^3/h blow-down. This results in a suppletion of 30 m^3/h.
The allowable concentration factor for a particular cooling water system is determined by the solubility products of specific ions at the surfaces of the heat exchanging equipment. Frequently found precipitates on the surfaces of heat exchangers are CaCO3 and Ca3(PO4)2 salts. These deposits may lead to reduced heat transfer efficiencies, corrosive attack, resulting in possible

product leakages into the cooling water system. In order to prevent formation of precipitates disperging agents, hardness stabilizers and corrosion inhibitors are added to the feed water.
The increase of the concentration of suspended solids in cooling water systems is even stronger than the increase in salts. Apart from the contribution of suspended solids in the feed water supply, the total suspended solids content in the cooling water system is mainly affected by 'scrubbing' of the air passing through the tower and by biological growth in the cooling water system. The air flowing through the tower contains insects, dust and organic matter, which are entrapped by the falling cooling water. The conditions in the cooling water system with respect to temperature, oxygen concentration and nutrient levels are optimal for biological growth. The organic matter formed by biological growth may induce corrosion on particular spots. These problems might be solved by increasing the blow-down flow, which is however a less favorable solution. A better option is to implement bypass filtration, which may be used both for plain solids removal and/or for bio-filtration.

Bypass filtration

In figure 1 a process flow scheme is given for an open circulating cooling water system equipped with bypass filtration. The bypass filtration unit consists of a moving bed filter, which is fed with a small part of the warm water flow, returning from the production processes. Treatment of the warm water flow is preferred because of better filtration characteristics (lower viscosity of the water) and because of favorable temperatures for biological activity in the sand filter. Because of the height of the cooling towers the moving bed filter can be fed by gravity. The filtrate is also discharged to the cooling water basin by gravity, as well as the continuous flow of wash water, which is discharged to the blow-down pit. The wash water flow is sufficiently low, in order to control the blow-down flow from the cooling water basin by monitoring conductivity. For the operation of the filter only a very small compressed air volume is required, which may normally be taken from the existing plant air supply.

Figure 1
Process flow scheme for bypass filtration in an open circulating cooling water system



The specific characteristics and advantages of bypass filtration are illustrated by means of an example for a 10 MW_{th} cooling water system with a temperature gradient of 8.6^{o}C across the cooling tower. The process characteristics are summarized in table 1. Two of those bypass filtration plants have been installed at the DOWLEX plant of DOW Chemicals, Terneuzen, the

Netherlands. In this particular example bypass filtration does not reduce the blow-down and feed supply, as the concentration factor is determined by the saturation of critical precipitates. Here the advantage of bypass filtration can be found in the protection of the most precious elements in the cooling system: the heat exchangers. The specific advantages are:

- improved heat transfer because of cleaner heat exchangers;
- removal of suspended solids;
- a shift of microbial activity from the cooling system to the moving bed filter;
- lower maintenance requirements and reduction of product leakages.

Table 1
Characteristics of an open circulating cooling water system equipped with bypass filtration

Parameter	Value	Unit
Cooling tower characteristics		
cooling power	10	MW_{th}
temperature gradient	8,6	°C
circulation flow of cooling water	1000	m^3/h
evaporation	15,0	m^3/h
blow-down (incl. wash water)	7,5	m^3/h
suppletion	22,5	m^3/h
'dead' volume of cooling water system	500	m^3
heat exchanging surface	2000	m^2
Water quality impacts of bypass filtration		
concentration factor for salts	3	-
concentration factor for suspended solids	1,3	-
decrease in turbidity after bypass filtration	80	%
decrease in TOC content after bypass filtration	30	%
Bypass filtration characteristics		
bypass flow relative to circulation flow	1,5	%
bypass flow	15	m^3/h
hydraulic load moving bed filter	10	$m^3/m^2.h$
filtration surface	1,5	m^2
filter bed height	2	m
compressed air flow bypass filtration	1,5	Nm^3/h
wash water flow bypass filtration	1,2	m^3/h

Heat transfer
The excess process heat is transferred through the internal surfaces of the heat exchanging equipment. Generally it is known that deposits of solids on the heat exchanging surfaces lead to a significant reduction in the overall heat transfer coefficients. A less controlled cooling water system shows temperature gradients across fouling films in the range of 1 to 4°C. If an additional energy requirement of 3.5 kWth/MW_{th}•°C is assumed then the extra resistance for heat exchange will lead to an additional energy consumption of 30 - 140 kW_{th}. Considering the price for primary thermal energy (€ 120/kW_{th}) these deposits contribute to additional costs in the range of 3,600 to 16,800 €/yr.

Suspended solids removal
The moving bed filter is well capable of removing suspended solids from the cooling water system. As can be seen in table 1 the concentration factor for suspended solids (1.3) is much lower than for salts (3.0), indicating a considerable removal of suspended solids. If a total suspended solids content of 5 mg/l in the feed water supply is assumed, then the moving bed filter removes 70 g/h of suspended solids, which is discharged by the wash water flow of the filter. Moreover periodic

chlorination in the cooling water system will contribute to the removal of organic deposits, as these deposits will be detached, released into the cooling water system and removed by the filter. In this way the organic suspended solids is removed efficiently from the cooling water system, and will not cause new deposits or biological growth.

Maintenance of heat exchangers

A relatively large part of the operational costs of a cooling system is determined by the costs for maintenance of heat exchanging equipment. In order to control corrosion and to prevent reduction in heat transfer efficiency periodical maintenance is necessary. These maintenance efforts require considerable manpower, down-time and costs. For the specific case as described in table 1 with a total heat exchanging surface of 2,000 m^2 the savings on maintenance efforts achieved after 5 year of bypass filtration account for over € 1,500/yr per MW_{th} of installed cooling capacity. With respect to reduced maintenance costs only the installation has become profitable after already a few years. Of similar importance is the longer product lifetime of the heat exchanging equipment, the lower chance of product leakages and the higher operational reliability of the cooling water system.

Design aspects

In the specific case the bypass flow is based on 1.5% of the circulation flow of cooling water. In practice the hydraulic filtration capacity should be large enough to treat the total cooling water volume ('dead volume') in about 1 to 2 days, resulting in sufficient control over suspended solids load and biological activity. The emphasis of bypass filtration is to be found in the control of the solids loads to the cooling water system, rather than in a complete removal of suspended solids from the system. Besides steady-state control of the solids load, bypass filtration also results in an improved handling of shock load conditions, for example at increased blow-in of suspended solids.
For suspended solids removal the design parameter of primary concern is the suspended solids removal capacity in mass per time, which is determined by the bypass flow [m^3/h] and the filtration efficiency [%]. The filtration efficiency mainly depends on the characteristics of the suspended solids to be removed and on the hydraulic load (in $m^3/m^2.h$). Despite the lower filtration efficiencies at higher hydraulic loads, an increased hydraulic load will result in a higher solids removal capacity. If for example the filtration efficiency decreases from 80% down to 65% because of an increase in hydraulic load from 10 up to 15 m/h, then the solids removal capacity will be 25% higher in the case of 15 m/h and 65% removal capacity. Apart from the positive effect of higher hydraulic loads on the steady-state performance, higher hydraulic loads also lead to faster removal rates after shock loads of suspended solids introduced into the cooling system.

Shift of biological activity to the sand filter

Apart from the removal of suspended solids the bypass filter also functions as a catalyst for biological activity. Biological activity in the cooling water system is caused by nutrients and micro-organisms, which enter the system via make-up, blow-in and product leakages. Biofilms may cause microbial induced corrosion (MIC), decreasing heat exchange capacities and local clogging of cooling towers. The use of oxidizing biocides is an effective means to control excessive growth of unwanted biofilms, but can also be characterized as “fighting the symptoms”, because it does not take away the main cause of biofilm growth: the presence of (soluble) nutrients in the cooling water. The use of a moving bed filter as a side stream biofilter enables biological removal of soluble nutrients and filtration of suspended micro-organisms and solids. The suitability of the moving bed filter as a biofilter in terms of adequate biomass control in combination with physical filtering gave rise to extend the physical side stream filter with a biological function. The hydraulic conditions in the sand filter are gentle in comparison to the turbulent flow regimes in the cooling tower and the heat exchangers, and will therefore lead to deposits of salt precipitates, formation and removal of biomass and to nutrients demineralization. Despite the fact that the moving bed

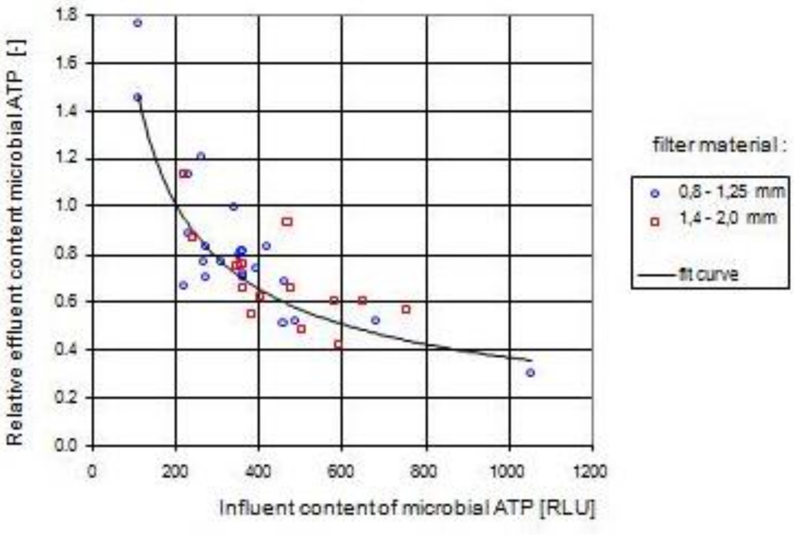
filter in the given example was not properly operated as a biological reactor, a considerable reduction in Total Organic Carbon (TOC) was measured if compared to the set-up without bypass filtration.
The more favorable conditions for biological activity in the moving bed filter in comparison to the conditions in the heat exchanging equipment are illustrated in table 2. The moving bed filter, characterized with a more laminar flow regime combined with a larger surface area, provides the necessary pre-conditions for promoting biological activity in the filter.

Table 2
Hydraulic conditions in the cooling water system and in the moving bed filter

parameter	heat exchanger	sand filter	ratio heat ex-changer/filter
flow velocity [m/s]	0,5 - 1,5	0,003 - 0,004	300
Reynolds number [-]	10.000 - 20.000	10 - 20	1.000
total contact surface [m^2]	2.000	10.000	0,2

The use of a moving bed bypass filter as a bio converter has been tested in depth at the DSM ammonia plant (AFA 2), the Netherlands. In the filter bed a considerable concentration of micro-organisms was found when compared to the cooling water contents. Based on the average content of micro-organisms in the wash water and the amount of sand being washed, the biomass concentration in the pores of the filter bed was found to be 40 to 200 times higher compared to the cooling water (about 200-400 RLU). Despite relatively high nutrient levels and high biomass contents in the filter bed it is of crucial importance to keep the filtrate level of micro-organisms as low as possible. The filtrate content of microbial organisms (expressed in ATP) was quite well correlated with the filter bed content of microbial ATP. In figure 2 this relation is shown.

Figure 2
Relation between bypass filter influent en effluent contents of microbial organisms



As shown in figure 2 the effluent content of microbial ATP tends to shift to values of about 200 RLU. Based on at least 10 years of experience with the interpretation of the ATP measurement on about 50 open recirculating cooling water systems at the DSM site in Geleen (the Netherlands) a cooling water system is considered to be biologically under control at ATP values below 300 RLU. This means that the operation of a side stream biofilter will tend to shift the content of micro-organisms in the cooling water to acceptable values.

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