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OPTIMISATION OF COOLING WATER USAGE AND REDUCTION OF ENVIRONMENTAL IMPACT AT THE CERN INSTALLATIONS (GENEVA, CH)

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ABSTRACT

An optimisation study has been carried out to reduce the water consumption at the CERN installations in Geneva. Currently about 15-20·10^6 m^3/year of water are consumed, almost exclusively for cooling purposes. Such a high water consumption has a strong impact on the local environment, and is also a relevant component of the operation costs. The presence of two water sources with different characteristics, that are often mixed in variable proportions and employed as a make up in cooling towers make particularly difficult to optimise the water treatment. Trough the analysis of the available data it has been possible to estimate that a reduction up to 20% of the water consumption in the cooling tower circuits is possible . Modifications of the control systems have been proposed, including a continuous data acquisition and storage system. The contractual aspects have also been discussed.

INTRODUCTION

CERN, the European Organisation for Nuclear Research, is located in the townships of Meyrin, canton of Geneva, Switzerland, and Prévessin, department of the Ain, France. The purpose of CERN is to provide collaboration among European States in research of a purely scientific and fundamental character in high-energy physics.

At CERN operates an electron-positron storage ring called LEP in which colliding beam experiments are performed. This accelerator is installed in an underground tunnel with a circumference of 27 kilometres, straddling the border between the Swiss Canton of Geneva and the French department of the Ain. It mainly consists of a vacuum tube, bending, focusing and correcting magnets, radio frequency cavities and 4 "experiments", located in the four evenly numbered points of the ring. The other two accelerators (PS, Proton Synchrotron Accelerator; SPS, Super Proton Synchrotron) besides their own heavy particles physics, have the function of

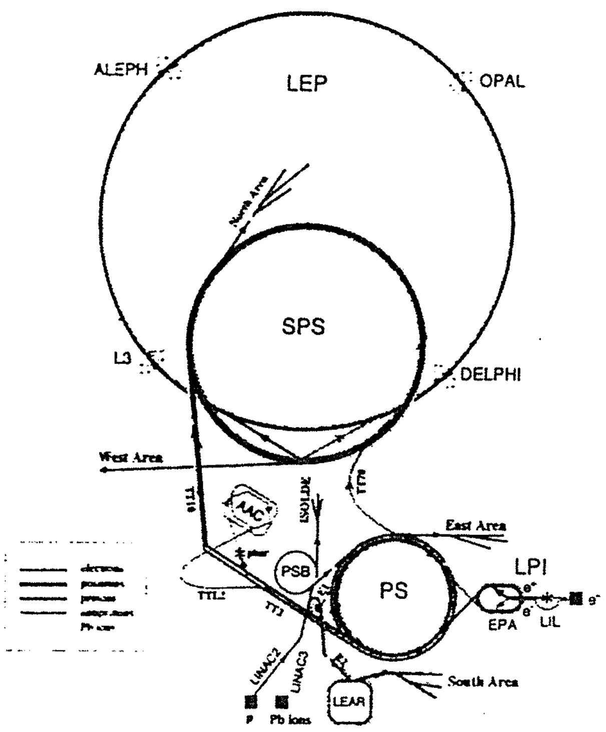

Figure 1. Scheme of the accelerators at CERN

being pre-accelerators for the LEP (Figure 1). At the moment a new project is going on: the construction of LHC, Large Hadron Collider; it is an accelerator that will bring protons into head-on collision at the highest energies (14 TeV) ever achieved.

A quantity of up to about 4000 m^3/h of water is used at CERN for cooling purposes when the accelerators are in operation (about six months a year): experiments, magnets and radio frequency cavities are refrigerated by closed circuits filled with de-ionised water; other utilities, such as air conditioning, also employ water in closed circuits. These utilities all use a cold source, the primary water supply coming from the cooling towers. As in the cooling towers refrigeration occurs by evaporation of a fraction of water, the water remaining in the basin increases its concentration of salt, mostly calcium carbonate ($CaCO_3$).

When the salt reaches its solubility limit, it starts to precipitate producing scaling formations. The most critical points are those inside the heat exchangers as the solubility of $CaCO_3$ decreases with the increase of temperature. Once scaling is present, a sensitive reduction of the heat transfer coefficient occurs and hence the heat exchangers must be cleaned. As maintenance of such a number of heat exchangers represents a very relevant cost because of human resources as well as of the oldness of the apparatus, a high performing anti scaling treatment is needed in order to minimise the cleaning interventions. But probably the most relevant aspect is that of the reliability of the system: due to the intensive use of the installation for research by an international scientific community, it is of utmost importance to guarantee the availability of the system and the tight respect of the required temperature in the experimental sections.

Two other important features of the water treatment are anti-corrosion and biological treatment: although water with a high scaling power is not aggressive, it is better to perform a light anti-corrosion treatment as a precaution. At the same time, biological treatment is essential because the eventual presence of algae and bacteria can obstruct both filters and heat exchangers.

Another aspect concerns the level of water consumption in the cooling tower circuits, mainly due to evaporation and purges. Even if the CERN towers operate in an "open circuit mode", the high level of salt concentration would enforce an anti-scaling treatment. Furthermore the increased solubility level permits the re-circulation of the water in the towers and hence reduces the number of purges necessary, providing important savings in water consumption.

As water treatment is not a core activity for CERN, in the last years an outsourcing policy has been followed. Furthermore, forecasting the next call for tenders it has been tried to find out a new contractual approach that should allow CERN to evaluate contractor's performances by controlling few parameters, leaving the contractor himself the full management of cooling plants.

In this work reliability, economical aspects and environmental impact have been considered; the target is the evaluation of any possible technical improvement as well as contractual modification aiming at a better management of water treatment.

WATER CHARACTERISTICS AND COOLING SYSTEM STRUCTURE

Currently CERN receives water from two different sources, the Leman Lake and some water wells ("Puits de Peney"). LEP cooling towers receive as make up water a part (about one fourth) of the water employed to refrigerate SPS secondary circuits. The latter is water coming from the lake at a constant temperature of 7-8°C all year round, as it is taken at 40 meters depth; its characteristics are very favourable as the quantity of salt contained is rather low and the conductivity is very stable (300µS/cm). The water in the SPS is employed once through, except for a fraction in the North Area; the main part is cooled and partly discharged into the river nearby, partly used to feed the LEP cooling system; to reduce substantially the water consumption it has been planned to close the SPS circuit recirculating large part of the water.

On the other hand, the water coming from the "Puits de Peney" mostly feeds the PS cooling towers. Its characteristics have been changing sensibly over the last few years: the salt concentration is increasing and the presence of manganese since the Seventies obliged CERN to introduce a step of sedimentation. The conductivity varies between 500 and 750 µS/cm and its average temperature is around 10-13°C. Often there is an uncontrolled mixture of these two different kinds of water, causing its characteristics to change and generating some troubles to the water treatment.

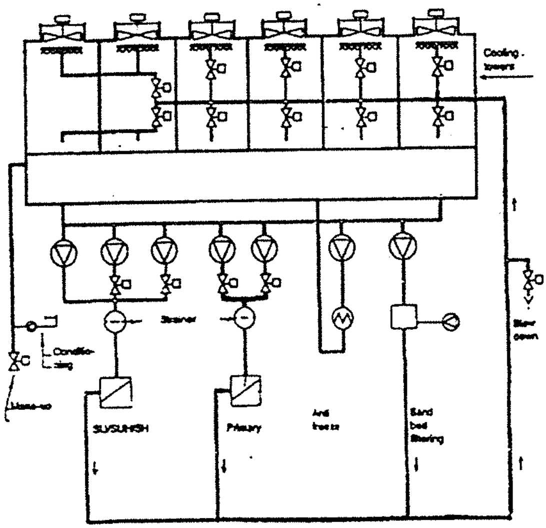

Figure 2. Scheme of a refrigeration circuit (LEP, point 2); the primary water and the secondary water heath exchangers are shown.

An example of the CERN cooling circuits structure is represented in Figure 2. Many towers are equipped with fans, to favour evaporation in summer time, when higher power is required.

Cooling towers are fed with raw water (make up) coming from the above mentioned sources; the cooled water (primary water) is employed to cool down water running in closed circuits (secondary water), that can be employed especially for accelerators temperature control or for utilities such as air conditioning of underground tunnels. When used for cooling accelerators components, secondary water is demineralised in order to avoid perturbations of magnetic fields.

When the salt concentration reaches the set up value, an automatic valve opens and let the water be discharged. A control level inside the basin makes the make up valve open in order to compensate discharged water.

A very important parameter to be kept under control when treating water is the concentration ratio.

This parameter (*CR*) can be rigorously expressed as: $CR = [salt]_{BD} / [salt]_{MU}$ where $[salt]$ is the concentration of any of the salts contained respectively in the discharged (BD = Blow Down) and in the make up (MU) water. In order to have a reliable value, the calculations have to be made taking as a reference a salt that does not precipitate; for this reason we are led to employ the concentration of Cl^- or SO_4^{2-}.

Another way to express the concentration ratio is: $CR = Q_{MU} / Q_{BD}$, where Q is the volume of make up (MU) and discharged (BD) water in the considered time interval.

CR represents a value that can intuitively be explained as the number of times the same water is re-circulated. It is then clear that a reduced value of *CR* causes a higher quantity of make up and a higher quantity of chemicals injected into the circuits, as a constant concentration of antiscaling agent is maintained. It is also clear now that the value of *CR* must be fixed by CERN as a minimum threshold (CR_{min}) in order to force the contractor to perform a water treatment which aims at the reduction of water and chemical consumption.

ANALYSIS OF CURRENT SITUATION AT CERN

Analysing the situation at CERN it has been realised that a relevant quantity of water employed in the cooling towers circuits could be saved. The LEP circuit, the most recent one, has a monitoring system; this made possible to calculate accurately water consumption and thermal load during the last past years. The calculated data evidenced that the average value of concentration ratio in the LEP towers circuits was often kept at a very low level (1.2 – 1.4). The consequence was an excessive water consumption and at the same time a waste of chemical products added in order to avoid scaling, fouling and corrosion.

Unfortunately, the cooling tower circuits serving the PS complex (and partly the SPS) had not a proper monitoring system so that it was impossible to know the "history" of the plant working conditions and the variation of the different control parameters like flow rates, temperatures and concentration ratio during the year.

For this reason, the evaluation has been made on LEP data only and then extended under certain hypothesis to the other circuits. Furthermore a proposal of monitoring system improvement that consists mostly in investments for new equipment and connections into a data acquisition network has been made.

Estimation of heat load and water consumption

In order to have a real supervision of the cooling tower system, an on-line monitoring of the real value of the cooling power required must be implemented, using the input data of primary water flow rate and temperature variation in the heat exchangers. This datum is the first important parameter that will permit the calculation of the minimum water demand and an estimation of the actual concentratio ratio.

The cooling power P (in MW) can be easily calculated with the formula:

$$P=F\,(T_{out}-T_{in})/860 \qquad (1)$$

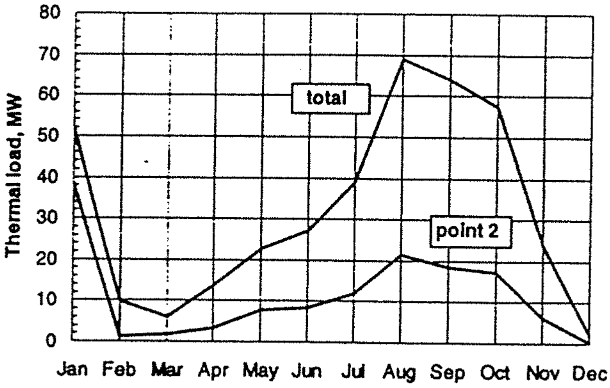

Figure 3. Thermal load for LEP in 1997

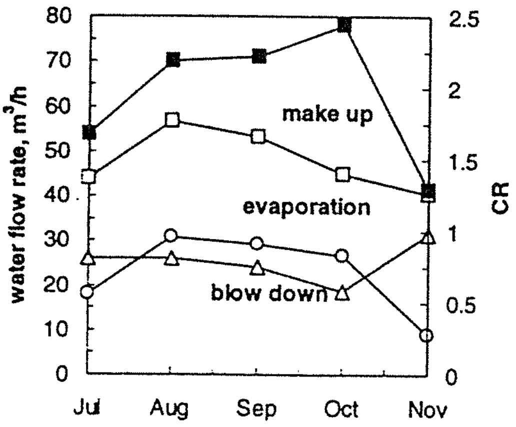

Figure 4. Variation of make up, blow down and evaporation flow rate in the period of maximum activity of the accelerator in 1997 (LEP, point 2). The CR value is also shown (filled symbols).

where F is the flow rate in m^3/h and T_{in} and T_{out} are the inlet and outlet temperatures in °C of the primary water circuit. Once this punctual value is available, a set of daily and monthly averaged values can be automatically calculated. Figure 3 shows the variability of the thermal load.

Starting from the cooling power values, the evaporation rate can be approximately calculated as:

$$Ev = 34.56\, P_{ave} \quad (\text{m}^3/\text{day}) \qquad (2)$$

Ev is the daily water evaporation, calculated from the averaged value of the thermal load. At this point, from the calculated evaporation rate and the given concentration ratio CR, it is possible to calculate the quantity of make up water (Q_{MU} in m^3/day) needed as well as the water discharged in purges (Q_{BD}, m^3/day):

$$Q_{MU} = Ev\, CR\,/\,(CR-1) \qquad (3)$$

$$Q_{BD} = Ev\,/\,(CR-1) \qquad (4)$$

An example of the actual make up flow rate and of the other quantities estimated from the calculated thermal load for the LEP circuit, for which data are available in a data base are shown in Figure 4 (Zagaria, 1998a).

Effects of the concentration ratio on the water treatment

It is evident that the variability of the make up water characteristics makes difficult to fix a priori a target that must be reached, once the limit salt concentration is fixed and thus the dosage of chemicals, depending on the characteristics of the additive chosen: if salt concentration increases, the anti-scaling chemical products may not be able to assure the fixed level of concentration ratio. This is the first inconvenient met when it was decided to impose a minimum value of concentration ratio in the contract. In fact, a conductivity probe on blow down pipe would allow the automatic water discharge when, independently from the *CR* value, the maximum acceptable salt concentration is reached in the basin. But a conductivity probe on make-up pipe would easily indicate the eventual increase of salt concentration, justifying the eventual higher water consumption.

As it has been verified that the variations in the relative concentration of the salts are not very large, as a first approximation the water conductivity can be used to monitor the variation in the concentration of calcium carbonate, that is the salt responsible for scaling; chemical analysis of the water performed on a regular basis allow to take into account the variation of carbonate concentration exactly. By this way, a range of acceptable *CR* values should be established.

On the other hand, the variation in the concentration ratio affects the biological treatment: in water cooling circuits, the system can be considered well treated from a biological point of view when aerobic bacteria are up to 10000 colonies/ml with slime-forming aerobic bacteria up to 1000 colonies/ml. The action and the effectiveness of biocide products are linked to two parameters: the killing level and the time of permanence inside the basin. A concentration of biocide product lower then the killing level as well as a too fast evacuation from the basin would not allow to obtain the desired sterilisation.

For these reasons the quantity and the strength of the biocide product that must be added changes for each circuit and depends on the parameters that influence the water turnover of the circuits itself: the liquid hold up, *V*, and the value of the concentration ratio.

In order to choose the appropriate biocide, the most important parameter to evaluate is the Holding Time Index (HTI). It represents the time after which the concentration of a chemical specie is reduced to the half of the initial value.

By writing the differential equation describing the concentration variation inside the basin, it is possible to find out a simple relationship for HTI. Being Q_{BD} the blow down flow rate, C_b the biocide concentration, and considering that the biocide is not present in the make up water, the variation of biocide concentration inside the basin is given by:

$$0 = Q_{BD}\ C_b + V\frac{dC_b}{dt} \tag{5}$$

Integrating and considering the initial condition $C_b = C_{b0}$ at $t=0$, it follows:

$$C_b = C_{b0}\ \exp(-Q_{BD}\ t/V) \tag{6}$$

As HTI is the time needed by chemical species to reach half of the initial concentration, the relationship between HTI and the operating parameters follows from eq. (6):

$$\mathrm{HTI} = 0.69\frac{V}{Q_{BD}} \tag{7}$$

It is now easier to understand that an increase in the incoming water conductivity leads to faster turn over of water in the basin and thus to a lower HTI. Reasonable values for HTI are around 24 hours.

The addition of biocide must be controlled considering the variation of the blow down flow; the best solution is to measure this parameter directly, but it can also be estimated as shown above (equations 2 and 4).

According to data collected about the efficiency of antiscaling chemical products available on the market, it has been established a reasonable range of concentration ratio reachable with

CERN average water characteristics. According to that, by knowing and estimating the thermal load along the year and trough the calculations previously explained, an evaluation of the possible economy and of future water consumption for the LEP cooling towers has been estimated. For the SPS and PS complex cooling towers, only a rough estimation of future water consumption has been possible under the assumption of an average thermal load equal to the 40% of the total installed cooling power. In Table 1 the possible future reduction of water consumption is evidenced by the comparison between the water consumption in the last years and the estimated water consumption with the new working conditions.

Table 1. Make up water consumption (m^3/year)

Circuit	1995	1996	1997	1997 (new conditions)
LEP (4 "experiments")	724,000	769,000	768,000	550,500
SPS and PS (estimated)	n.a.	n.a.	n.a.	888,000

NEW APPROACH IN THE CONTRACT

Once a base level for CR_{min} has been established and P, CR, Q_{BD}. Q_{MU} data are available, the supervision of the cooling treatment becomes an easy matter.

In the call for tender the bidders will be asked to provide the best price per cubic meter of treated water, C, including scaling, corrosion and biological treatment. Once a reference value of the cooling power (P_{ref}) during the year has been established, the bidders will also be asked to provide a second parameter: the estimation of a maximum value of Q_{MU} in m^3/year (Q_{MUmax}).

At the end of the contractual period CERN will apply the following retribution formula:

$$R = K + C\,Q_{MU} + f \tag{8}$$

where K represents the costs related to services, personnel and equipment and f is a function that can be positive if there was a water saving with respect to the contractual base, but assumes negative values in case there are any penalties that have to be imposed on the contractor.

At the end of each contractual period CERN will compare the value of Q_{MU} with the value of Q_{MUmax} initially declared. If $Q_{MU} > Q_{MUmax}$ then CERN will check the absorbed cooling power P compared with the reference value P_{ref}. If the increase in water consumption is related to the increase in the cooling power required, there will be no penalty. On the other hand, $P < P_{ref}$ implies $CR < CR_{min}$, which shows a contractual responsibility; then CERN can decide to pay up to $Q_{MU\,max}$, and enforce a penalty on the contractor in order to compensate for their higher water consumption fees, unless it can be proved that this has been caused by the variation in the water salt concentration.

Furthermore each new contractual period will start with an initial cleaning treatment in order to eliminate all scaling or biological pollution previous to the contract start. Then a set of analysis will be periodically performed in order to guarantee the conditions of the cooling system. Every damage or performance reduction of the CERN installation due to scaling, corrosion and/or fouling will also result in a specific penalty for the contractor.

In order to make possible the new contractual approach, it has been proposed to buy new equipment and to improve the existing monitoring system (Zagaria, 1998b). Flow rate, consumption and conductivity of make up water, flow rate, quantity and conductivity of blow down water, flow rate of primary water (in the primary circuit), incoming and out coming temperature of primary water are the parameters to control.

It means that on each make up and purge pipe there should be a flow rate and total counter of water and a conductivity probe; on each primary water circuit a flow rate counter and two temperature probes

The principal advantage of this new contractual approach is that it allows a very simple and clear monitoring of the contract, performed by checking a small number of parameters, mainly Q_{MU}. A set of periodical tests and analyses will complete the supervision of the circuits, while non-professional people will be discharged from the responsibility of following and managing the aspects directly linked to the water treatment. This has been made possible by the knowledge of the behaviour of the plant and the estimation of its optimal performances.

This new approach will also facilitate the procedure of future contract renewals for new companies, by recreating a real competitive environment, which is the main and only factor for a substantial cost reduction. Furthermore, in a results oriented contract, once the reference parameters have been clearly fixed, the contractors will have the possibility to work more independently with respect to the general statement and safety rules, easily implementing new products and techniques in order to increase their own benefits.

CONCLUSIONS

A possible reduction of water consumption from 10 up to 20% through an improvement of the monitoring system and control equipment as well as a different contractual approach has been estimated. This is very relevant, for both the economical and the environmental impact, considering the actual level of water consumption.

In order to make it possible, a proposal of investments has been made. It consists in having on each group of towers conductivity probes, flow rates and total counters on make up and blow down pipes, inlet and outlet temperature probes and flow rate counters on primary water circuits. Then, an appropriate data acquisition and elaboration should be implemented in order to make automatic the procedure explained in this paper and to employ it as a control instrument in the management of the contract.

All the above mentioned features are likely to bring both CERN and the companies involved to more profitable perspective of collaboration.

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