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COOLING TOWER DRIFT MEASUREMENTS USING INTRINSIC TRACER H_3BO_3

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ABSTRACT

Several methods used to measure cooling tower drift emissions require isokinetic sampling of the air exiting the tower. The drift is obtained by analysing suitable tracers either added to the water flowing into the tower or naturally presents in the system. The former method is the most common and involves the measurement of conductance of sampled water in relation to circulating water, neglecting any possible external contamination affecting measurements. Our method uses H_3BO_3 as an excellent intrinsic tracer unaffected by the mixing of the external air with the water in the tower. Moreover, the presence of H_3BO_3 in all geothermal fluids and analytical detection limits for Boron with conventional spectroscopic techniques guarantee the reliability of this new method. A specific isokinetic sampling device, allowing sampling without warming the probe has been developed. The results of field tests are illustrated and compared with cooling tower manufacturer measurements, providing evidence of the wide applicability of this method.

1. INTRODUCTION

The measurement of drift emissions from cooling towers is a key task in the evaluation of environmental impact of this kind of cooling system. Drift outlet from cooling towers constitutes one of the main Short Range Polluting Agents (SRPA), while drift independent gas stripping can be regarded as a long to medium range pollution parameter. In this case, gases like H_2S have short residence times in the atmosphere, due to their oxidation in the air, and can therefore be considered a Medium Range Polluting Agent (MRPA). On the other hand, CO_2 stripped from the tower can spread in the air without significant modifications and can be defined as a Long Range Polluting Agent (LRPA). In Italian geothermal power plants, the SRPA from the cooling towers constitute the main emission sources. In contrast, MRPA and LRPA are mainly emitted by the Non Condensable Gases (NCG) extractor.

Drift outlet from the cooling tower is the amount of water from the condenser emitted through the air flow exiting the tower. It is quite difficult to detect drift directly, since the drift is emitted with the condensed water vapour formed during the cooling process in the tower. A simple picture of tower emission consists of the continuous flow of wet air containing small droplets of condensed vapour mixed with droplets of drifted water coming from the condenser.

SRPA emissions from geothermal power plants have been regulated in Italy and restrictions apply to the emissions of Hg and As in the drift of cooling towers. Tower specifications therefore require special attention to allow for all the restrictions that apply, using accurate and reliable methods for drift measurement. Different methods for drift measurement exist, including element dilution evaluation or conductivity methods. In both cases comparison between composition or conductivity of the water entering the tower and the sampled solution allow the calculation of the amount of drift recovered in each sampling. Special attention is required in the case of geothermal plants cooling towers where generally low elemental concentration occur except for boric acid. Moreover, in our experience, conductivity measurements have shown possible inaccuracies due to scrubbing effects of the cooling tower on the inlet air.

2. MATERIALS AND METHODS

This paper describes a simplified method for drift measurement taken from Cooling Tower Institute (CTI) specifications. The advantages of this method include simplified equipment and analytical approach required. Moreover, it can be easily applied to routine emission measurements in geothermal power plants. The method consists of measuring an intrinsic chemical marker, such as boric acid (H_3BO_3), naturally present in the waters in the water cooling stage of most geothermal power plants. Boric acid is particularly suitable because it is present in relatively high concentrations in the fluids and is easily detected in the moisture of drift and condensed vapour recovered from the cooling tower outflow. Under normal temperature conditions in the cooling tower, H_3BO_3 transfer in the gas phase can be neglected and the species can be considered exclusively confined to drifted water particles emitted from the tower. Drift is composed of micro droplets of water containing the salts originally carried by the steam and must not be confused with water droplets formed during condensation of water vapour in the tower. In the gas flowing out of the tower, a moisture of drift droplets is emitted (the size may vary, during tower crossing, due to evaporation and/or fragmenting or may increase due to condensation and/or mixing). A method that distinguishes between drift and condensed water is therefore necessary. Drift measurement is obtained by measuring the H_3BO_3 flow rate from the tower by the isokinetic sampling of the total water phase flowing in the tower. Knowing the H_3BO_3 in the warm water entering the tower, drift outlet can be obtained simply by calculating the amount of water needed to produce the measured boric acid flow rate from the tower.

Drift is obtained indirectly by measuring the emission of an intrinsic tracer. We used boric acid as it constitutes an excellent intrinsic tracer and enhances the reliability of the method adopted. This tracer possesses a number of special features:

- H_3BO_3 is exclusively originated endogenously; no air contamination effects can occur in the tower, unlike electrical conductivity drift measurements, which can be affected by salts in the air-flow.
- H_3BO_3 is essentially soluble in the water phase at the temperatures present in the tower and in the condenser.
- The low chemical reactivity of the tracer assures good recoverability during sampling and measurements.
- The usual H_3BO_3 concentrations in the circulating waters allow good measurability of the tracer, even after dilutions up to 1/1000, which apply to this method.

An isokinetic sampling of the air exiting the tower is necessary to provide accurate measurements. To this end, we set up a new and simplified sampling probe, described in section 3, guaranteeing reliability of the sampling without requiring special prerequisites such as probe warming during sampling.

Isokinetic sampling is done by positioning the sampling probe between demixters and fans in the tower. The water crossing the probe [moisture + micro droplets of condensed vapour + micro droplets of drift] is stopped in the various sections of the sampling probe. In the water sample obtained after rinsing the probe, the boric acid (H_3BO_3) content is determined with a suitable analytical method such as Inductively Coupled Plasma (ICP). Drift is calculated as:

$$D\% = \frac{A_{SP} W_T}{A_N Q_w t_S [M]_{HW} \rho_w} \qquad [1]$$

A_{SP}	total air outlet section in the tower
W_T	amount of marker recovered during sampling
A_N	probe section
Q_w	flow rate of water in the cooling loop
t_S	total sampling time
$[M]_{HW}$	marker concentration in the water entering the tower
ρ_w	mass density of the water entering the tower

The number and position of sampling points is chosen depending on accessibility in the cooling tower and according to **Cooling Tower Institute** specifications (1994).

3. SAMPLING APPARATUS

Sampling apparatus is divided into three separate sections: a collecting probe, Fig.1, an air pump and an instrumented pipe used to measure and control air flow rate. The apparatus is positioned in the cooling tower as shown in Fig. 2.

3.1 Sampling stack

The sampling probe (Fig. 1) is a plastic tube, 22 cm high, divided into three sections. There is a bulk sampling section, filled with 6 mm glass spheres to prevent most of the moisture crossing the device. In the upper part, two layers of cotton wool, laid one upon the other, are used to trap drift escaping from the lower portion of the probe. The two filters are placed 4 cm apart.

The probe is connected to the air pump with a 12m long corrugated flexible tube. An instrumented pipe between the end of the tube and the air pump provides air flow measurements.

3.2 Air pumping system

An air-pumping device (ring annulus with a 60 Nm^3/h at 0.2 bar pressure drop) without air flow control has been used. The pump had sufficient power to handle the sampling probe and tube pressure drops. The instrumented section was connected to the pump by a 15 cm long tube carrying several holes for additional air income in order to adjust the air flow in the sampling pipe with a regulating concentric external sliding plastic tube.

3.3 Air flow measurement section

The air flow in the sampling line was measured through a T-P-v measurement set, Fig. 3, positioned in a 180 cm long PVC tube and with the features described in the table below. The measurement of normalised volume air flow allows the control of air velocity at the probe entrance in order to assure isokinetic sampling. At the beginning of each sampling run, air speed (v), Temperature (T) and Pressure (P) were measured at the probe level. During sampling, T, P and v parameters at the measurement section were read again and adjusted for isokinetic sampling according to eq. [2] using an EXCEL macro routine; see Table 1.

Velocity measurements in the measurement section were conducted according to the "10 diameter upstream and 5 diameter downstream" rule.

3.4 Sampling procedure

v_t = Actual air velocity as measured at the instrumented section

$v_{ref.}$ = Reference velocity (isokinetic sampling)

v_{in} = Air velocity at probe level

P_{in} = Air pressure in the cooling tower

P_t = Pressure measured at the instrumented section

T_t = Temperature measured at the instrumented section

T_{in} = Temperature at probe level

Φ_S = Sampling probe diameter

Φ_t = Tube diameter in the instrumented section

Drift measurement is obtained without probe heating, allowing negligible transfer from liquid to the gas phase in the probe. Moreover, the condensation of the liquid phase following the adiabatic cooling of gas in the pipe can be neglected, allowing the regulation of air sampling with the direct measurement of air temperature in the instrumental section without wet bulb temperature measurements.

Sampling times were normally 30' in each point. At the end of sample collection the probe was opened and the sphere-filled stack rinsed with a known amount of water (1000 cm^3) four times recollecting and reusing the recovered water at the bottom of probe. At the end of rinsing, the amount of water wetting the sphere packing was discharged and all the calculations were made taking into account the initial volume (V_{LS}) of water used for sample rinsing. The two cotton wool filters were removed from the probe and rinsed with small (10-20 cm^3) amounts of water, collecting the liquid portions in a 100 ml flask. The upper and intermediate filter rinsing solutions were then brought to a final 100 ml volume and named V_{Cs} and V_{Ci} respectively in the calculations of eq. [3].

Boric acid determinations were conducted on the three liquid samples and the water entering the tower with standard analytical techniques, such as Inductively Coupled Plasma emission spectroscopy (ICP):

$[H_3BO_3]_{LS}$	(sphere packing rinse solution)
$[H_3BO_3]_{Cs}$	(upper filter solution)
$[H_3BO_3]_{Ci}$	(intermediate filter solution)
$[H_3BO_3]_V$	(water entering the cooling tower)

4. EXPRESSION OF RESULTS

Drift is calculated by a preliminary calculation of the total amount of the marker recovered in the sampling stack as:

$$m_{H_3BO_3}=[H_3BO_3]_{LS}V_{LS}+[H_3BO_3]_{Cs}V_{Cs}+[H_3BO_3]_{Ci}V_{Ci} \qquad [3]$$

and tracer flux per unit area is calculated as:

$$\Phi_{H_3BO_3}=\frac{m_{H_3BO_3}}{A_S\,t_S} \qquad [4]$$

A_S Probe section

t_S Sampling time

This allows the calculation of the drift according to the general expression [1] as:

$$Drift\% = \frac{\Phi_{H_3BO_3} A_{SP}}{\rho_w Q_w [H_3BO_3]_V}100 \qquad [5]$$

where mass density of water at room temperature is approximated to 1g/cm^3 and neglected at the numerator in [5]. The remaining parameters are defined as:

A_{SP} Cooling tower cross section

Q_w Water flow rate entering the tower

ρ_w Mass density of water in the cooling tower

5. RESULTS AND DISCUSSION OF FIELD TESTS

Table 2 shows the results of a field test conducted in the cooling towers of the Bagnore_3 geothermal power plant. The Hamon Sobelco wooden cooling tower system was mounted at this plant. The test was performed with the plant at 19.6 MW power generation rating at the beginning of the production period with tower under refinement and without supplementary drift eliminators. The results showed that the amount of trapped H_3BO_3 is decreasing in the three probe sections. Moreover, the results of DX_2 and SX_2 tests using a thick cotton wool filter show more than one order of magnitude difference in boric acid recovery between the main probe body and the upper filter, indicating the reliability of this method.

The results of Monteverdi_2 power plant drift measurements are summarised in table 3.

Results indicate a sufficient repeatability of the measurements at the same point whereas differences arise between determinations at points in different positions in the tower.

Many different samplings are required in order to obtain a good drift average. According to the recommendations of the Cooling Tower Institute, measurements should be made in at least 24 different locations in the tower. Although this is almost impossible for Italian plants, where accessibility is limited because of project and safety restrictions, a sufficiently high number of sampling areas must be pinpointed to allow a good drift average determination.

Although several drift test measurements exist, our method has shown sufficient reliability and has allowed the use of a simplified equipment. In fact our sampling probe has assured sufficient drift recovery without requiring heating for complete water evaporation in the probe as is normally required. Moreover several drift measurements conducted on different Italian geothermal plants have shown good agreement between measured drift and certified drift of the towers.

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Table 1: main features of measuring devices in the sampling apparatus

Anemometer with temperature probe at sampling point	Diameter (Φ) 9mm v=0.5-40 m/s (±1.5% repeatability) T=0-70°C ± 0.2 °C
Anemometer at the measuring section	Diameter (Φ) 18mm v=0.5-40 m/s (±1.5% repeatability)
Pressure transducer	Pmax=2 bar (repeatability 0.1% maximum read)
Temperature measurer at the measuring section	Pt/100 class B thermoresistance (0.1°C repeatability)

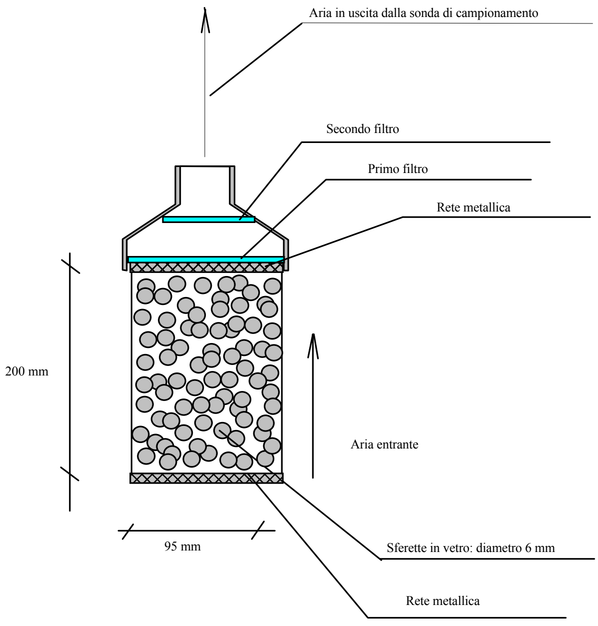

Fig. 1: Sampling probe

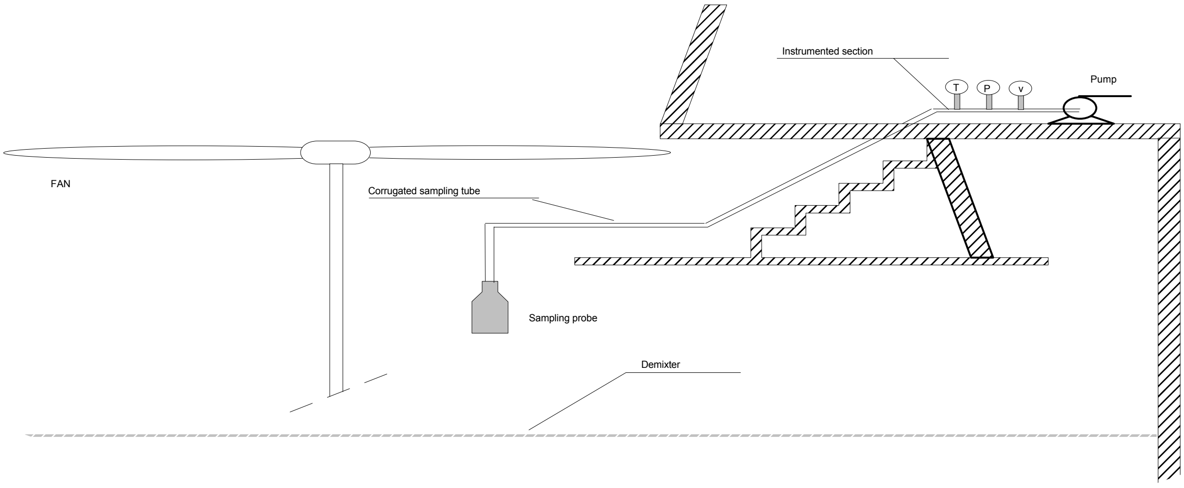

Fig.2 Sampling apparatus and air pumping devices arranged in the cooling tower

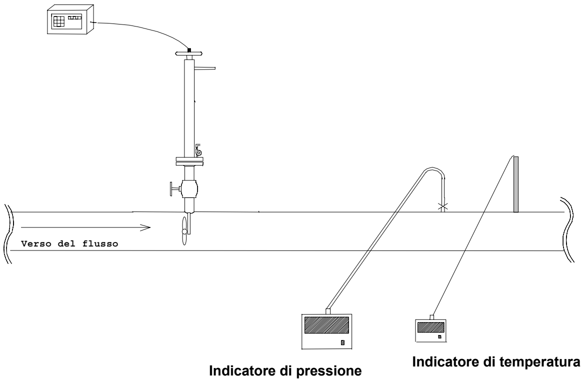

Fig. 3: Instrumented section for air flow measurement

Table 2: Bagnore_3 cooling tower drift measurement

	Probing point code			
$[H_3BO_3]_{LS}$ (mg/l)	1,090	0,740	1,090	0,800
$[H_3BO_3]_{Ci}$ (mg/l)	1,200	1,030	1,720	4,800
$[H_3BO_3]_{Cs}$ (mg/l)	1,030	0,320	3,890	0,300
$[H_3BO_3]_V$ (mg/l)	203,0	203,0	203,0	203,0
V_{LS} (ml)	1000	1000	1000	1000
V_{Ci} (ml)	100	100	100	100
V_{Cs} (ml)	100	100	100	100
H_3BO_3 (LS) (mg)	1,09	0,74	1,09	0,80
H_3BO_3 (Ci) (mg)	0,12	0,10	0,17	0,48
H_3BO_3 (Cs) (mg)	0,10	0,03	0,39	0,03
Tot.H_3BO_3 (mg)	1,31	0,88	1,65	1,31
Probe diam. (m)	0,085	0,085	0,085	0,085
A_s	0,0057	0,0057	0,0057	0,0057
T_s	30	30	30	30
$\Phi_{H_3BO_3}$	463	308	582	462
A_{SP}	300	300	300	300
ρ_w	0,994	0,994	0,994	0,994
Q_w	6000	6000	6000	6000
Drift %	0,0115	0,0076	0,0144	0,0114
<Drift%>	0,01124			

Table 3: Monteverdi_2 cooling tower drift measurement

	SX_1	SX_2	DX_1	DX_2
$[H_3BO_3]_{LS}$ (mg/l)	1.691	1.240	0.564	0.507
$[H_3BO_3]_{Ci}$ (mg/l)	3.551	1.127	2.255	1.015
$[H_3BO_3]_{Cs}$ (mg/l)	4.227	1.747	0.496	0.417
$[H_3BO_3]_V$ (mg/l)	204.6	204.6	204.6	204.6
V_{LS} (ml)	1000	1000	1000	1000
V_{Ci} (ml)	100	100	100	100
V_{Cs} (ml)	100	100	100	100
H_3BO_3 (LS) (mg)	1.69	1.24	0.56	0.51
H_3BO_3 (Ci) (mg)	0.36	0.11	0.23	0.10
H_3BO_3 (Cs) (mg)	0.42	0.17	0.05	0.04
Tot.H_3BO_3 (mg)	2.47	1.53	0.84	0.65
Probe diam. (m)	0.095	0.095	0.095	0.095
A_s	0.0071	0.0071	0.0071	0.0071
T_s	30	30	30	30
$\Phi_{H_3BO_3}$	697	431	237	184
A_{SP}	300	300	300	300
ρ_w	0.994	0.994	0.994	0.994
Q_w	6000	6000	6000	6000
Drift %	0.0171	0.0106	0.0058	0.0045
<Drift%>	0.00951			