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# CTP METHOD

## DIAGNOSTIC METHOD FOR CONTROL OF COOLING TOWER OPERATION

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AERODYNAMICS

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## 1. INTRODUCTION

The CTP (Cooling Tower Profiler) method is a cooling tower diagnostic method enabling customer control of cooling tower operation, determination of maldistribution problems, and their adequate elimination. The CTP method can be used for regular (annual) control measurements, and pre-upgrade measurements. The CTP method includes:

a) Measurements of velocity and temperature fields of the airflow in the entire surface area of cooling tower.
b) Measurements of temperature and mass flow characteristics of the air and water flows in selected reference vertical segment of cooling tower (raised phenomenological model of heat and mass transfer).
c) Results of numerical modelling.

Velocity and temperature fields of the airflow are measured by a remote control mobile unit[1]. It was developed to enable air velocity and temperature exit air mapping measurements over the entire cooling tower area in an arbitrary measurement point above the spray zones. Measurements are performed with lower costs as state-of-the-art "air-mapping" methods, since no measurement preparations causing halting of the cooling towers operation are needed. Topological structures of the humid air velocity profiles and temperature profiles above the spray zones are obtained at known integral parameters of a power plant.

The measurements of temperature and mass-flow characteristics of air and water in a selected reference vertical segment of the cooling tower are performed as well. They are presented in a form of phenomenological dependence linking local cooling tower efficiency, geometrical characteristics of spray elements, and air and water flow rates. The experimentally obtained phenomenological model of heat and mass transfer is applied along with measured velocity and temperature fields above the spray zones to evaluate local and integral efficiency values of the cooling tower.

The velocity and temperature fields, and measurements of temperature and mass-flow characteristics, mapped on the structure of the cooling tower serve as input to the numerical model. When applying a numerical model, pressure, velocity and temperature distributions can be simulated in the entire cooling tower, not just in the plane above spray zones. This enables to determine which parts of the cooling tower has to be modified, leading to even better cooling tower operation.

## 2. WHY PERFORM CTP ?

The optimal cooling tower operation significantly raises the efficiency of the entire thermo-energetic system. With cooling tower reconstruction, considerable economic and ecological benefits are expected. Thermal performance, on the basis of which customers decide for reconstruction, is mostly related to maldistribution of water flow in an area of the cooling tower heat exchange system. Maldistribution problems with the water and the fill system, such as: high velocity, cool airflow patterns along the sides of water distribution flumes caused by non-optimal depth of the fill system underneath the flumes, local low-velocity regions caused by damaged or broken drift eliminators, reduced effective cooling volume caused by broken or outlined splash cups below some nozzles, etc. are normally isolated through implementation of expensive and time consuming diagnostic technique known as "exit air mapping". This method is, due to a large number of velocity and temperature

[1] EU Copernicus Project: "Optimising cooling tower efficiency by advanced measuring and analysis (OCTEBAMA)", Contract No. ERB IC15 CT98 0514.

sensors (200 to 400, depending on the size of the cooling tower and requirements of the analysis), linked with operation halting, thus income loss.

Consequently the above mentioned measurements are not regularly performed and users usually decide on reconstruction of their cooling towers on the basis of integral characteristics, numerical modelling and/or insufficient empirical estimations.

Therefore, according to the fact that basic impediments for the extension of the standard measuring method are high costs and relative long halting times, the described method is modified to enable the analysis of space and time characteristics of velocity and temperature field in cooling towers without halting. In 1999 the novel method based on the mobile unit was developed. The measuring system includes temperature and velocity sensors, a system for navigation in the measuring plane, processor unit supervising the motion of servo-positioning system (tracked vehicle), wireless transmission of measured values to the computer outside the cooling tower and wireless camera. Time fluctuations of the measured quantities are corrected using stationary sensors according to DIN 1947[2]. In contrast to a state-of-art air mapping method with hundreds of sensors mounted in the measuring plane of the cooling tower, velocity and temperature measurements and analysis are performed during a 2 to 3 days period without interference with the plant operation.

This significantly reduces the measuring process costs and therefore, expands applicability to numerous thermo-energetic systems. Because the air mappings completely characterise the air/water interface across the plan area of the cooling tower fill system, the method developed enables operation diagnostics of optional types of natural draft cooling towers. With the aid of the method the accurate determination of operational states with upgrade measures and prediction of expected results is possible. The customer is able to perform the upgrade measures and raise the thermal performance of the cooling tower by up to about 5%, depending on the state and type of the cooling tower. Considering these structures' output power, amounts to an enormous savings of both energy and money.

## 3. CTP DIAGNOSTIC METHOD

### 3.1 Air-mapping measurements

The basis of the presented measurement system is a servo-positioning system - mobile unit (**Fig. 1**), moving gradually over the entire measuring plane. With aid of the mobile unit, measurements of temperature and velocity field in cooling towers are performed in dependence of integral power plant parameters.

[2] Standard DIN 1947, Thermal acceptance tests on wet cooling towers (VDI cooling tower code), May 1989.

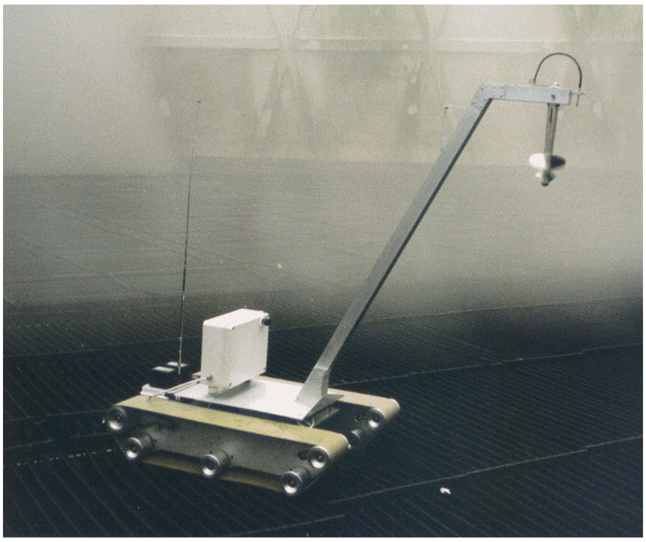

**Fig. 1**. Mobile unit

For temperature measurements vane anemometer, designed for operation in 100% humidity, and a Pt-100 temperature sensor are used. They are mounted on a servo-positioning system - mobile unit – in such a way that it is in accordance with todays standards. The duration of measurements in a single point, depending on chosen the magnitude of the observation scale (quasi-steady state condition), is 15 to 30 s. After the measurement is performed, the servo-positioning system is moved to a new pre-chosen measuring point. The mobile unit is equipped with a data acquisition unit and all measured data are wirelessally transmissed to a host computer, located outside the cooling tower, via an RF data link. The position of the mobile unit is determined by measuring the radial distance and angle from the reference point in the measuring plane. The radial distance and angle are converted to an *x-y* position. The distance is measured by a linear cable extension transducer with 50 m range and a typical uncertainty less than 0.1 m. Angular measurements are done by a device tracking the position of the cable and rotating the cable extension transducer. An angular resolution of about 0.15° is achieved. The servo positioning system of a mobile unit is developed by Optotek (Slovenia). The position signal, along with measured velocity and temperature data are sent to the outside of the cooling tower located external host unit, consisting of a host computer with hardware for communication with the mobile unit and software for evaluating data. To the mobile unit operator outside the cooling tower, a mobile unit remote control transmitter and a camera link with the monitor for observing the unit's path are available.

Measurement results are presented in a form enabling the determination of integral and local aero-thermodynamic characteristics in the measuring plane of the cooling tower. Simultaneously the integral and ambient parameters are measured according to DIN 1947. Air velocity and temperature in the cooling tower measuring plane are measured continuously with stationary sensors. As velocity and temperature measurements are not performed simultaneously over the entire measurement plane, the stationary velocity meter and integral parameters serve as correction elements of these measurements.

With aid of the measuring results of velocity and temperature fields in the measuring plane of the cooling tower obtained, 3D topological structure diagrams of velocity (**Fig. 2**) and temperature (**Fig. 3**) data are constructed. They provide a direct means of evaluating the extent to which the falling hot water droplets and the cooling air intermix. As the air mappings completely characterise the air/water interface across the area of the cooling tower, the exact location of the water distribution and fill system are identified in the mappings. Several main

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causes of the cooling tower air/water maldistribution problems normally can be identified[3] and afterwards successfully solved.

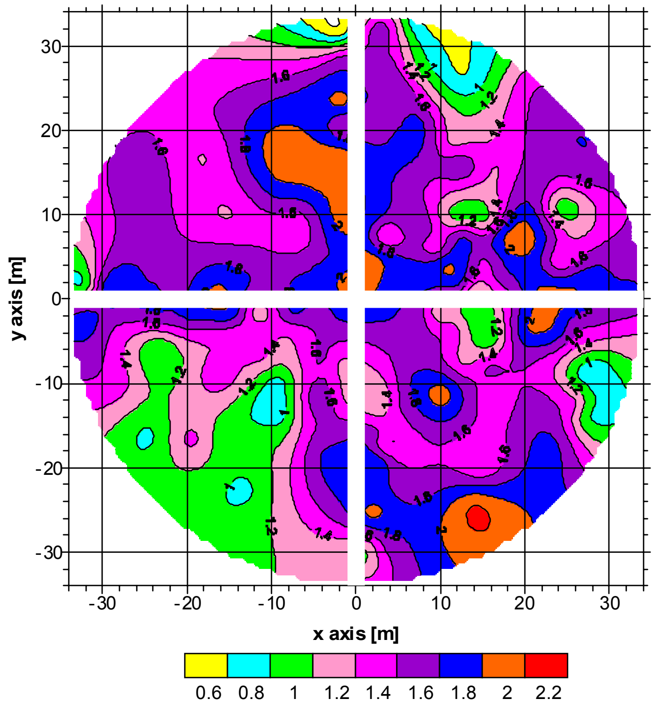


**Fig. 2**. Topological structure of the velocity profile [m/s]

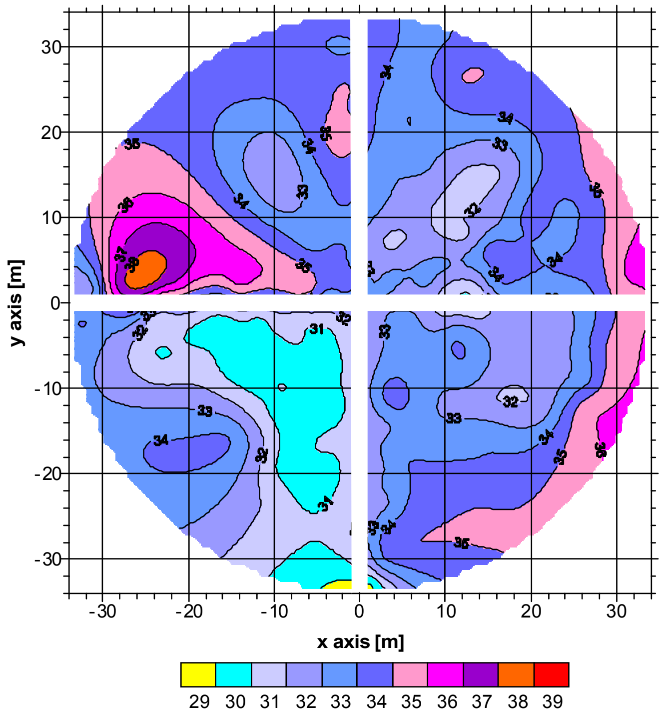


**Fig. 3**. Topological structure of the temperature profile [°C]

[3] G. W. Liffick and J. W. Cooper jr., Thermal Performance Upgrade of the Arkansas Nuclear One Cooling Tower: A "Root Cause" Analysis Approach, 57th Annual American Power Conference, V.57-2, pp. 1357-1362, 1995.

## 3.2 Determination of heat and mass transport properties of the cooling tower

To determine the basic heat and mass transport properties of the observed cooling tower, the measurements of aerodynamic and thermodynamic characteristics of air and water flows in a selected reference vertical segment (**Fig. 4**) are performed. The aim is to find parameters of the phenomenological model of heat and mass transfer of a reference cooling tower segment. On its basis the efficiency of cooling tower operation at various locations can be determined only by local air mapping measurements.

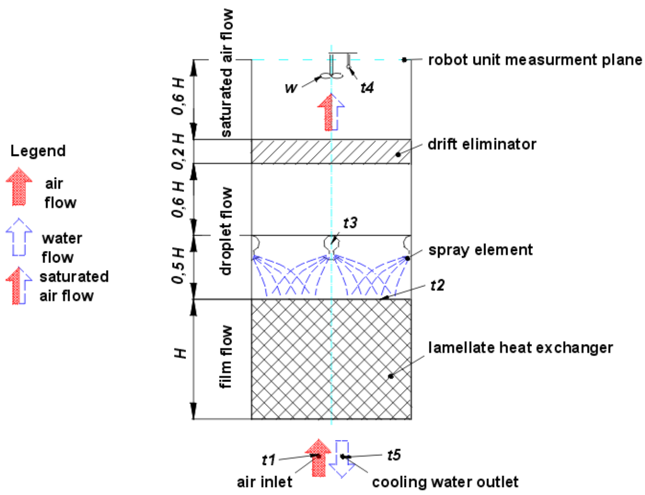


**Fig. 4**. Selected cooling tower segment

A reference vertical segment of cooling tower is selected in the region of the cooling tower where geometrical properties are homogeneous. It normally consists of a lamellate heat exchanger located at the bottom, a spray element at the central part, and a drift eliminator at the upper part of the segment. The following parameters are measured:

- $t_1$ - inlet humid air temperature,
- $t_2$ - sprayed water temperature at fill system inlet,
- $t_3$ - inlet water temperature on the spray nozzle in outlet water jet,
- $t_4$ - outlet air temperature,
- $t_5$ - temperature of the water at fill system outlet,
- $w$ - humid air velocity in the mobile unit measurement plane.

The parameters are observed while the independent variable - cooling water mass flow $\dot{m}_W$ is changed. The water mass flow in time is measured at the outlet spray nozzle.

For temperature measurements, 4-wire Pt-100 thermometers are used. Their position is presented in **Fig. 4**. The temperatures are acquired and stored using a precision data acquisition unit, connected to the personal computer. The uncertainty of the measurements is estimated to be less than 0.25°C. Air velocity measurements are performed using pre-calibrated vane anemometer. The same vane anemometer type is used for the mobile unit measurements.

Causal connection of velocity and temperature field is described with aid of phenomenological model, with parameters obtained in the observed cooling tower in the selected reference vertical segment of cooling tower. The method enables determination of local enthalpy efficiency (**Fig. 5**) and indirect estimation of the local deviations in enthalpy efficiencies, caused by local anomalies in the mass flow rates and constructional irregularities. Consequently, suitable reconstruction measures are proposed.

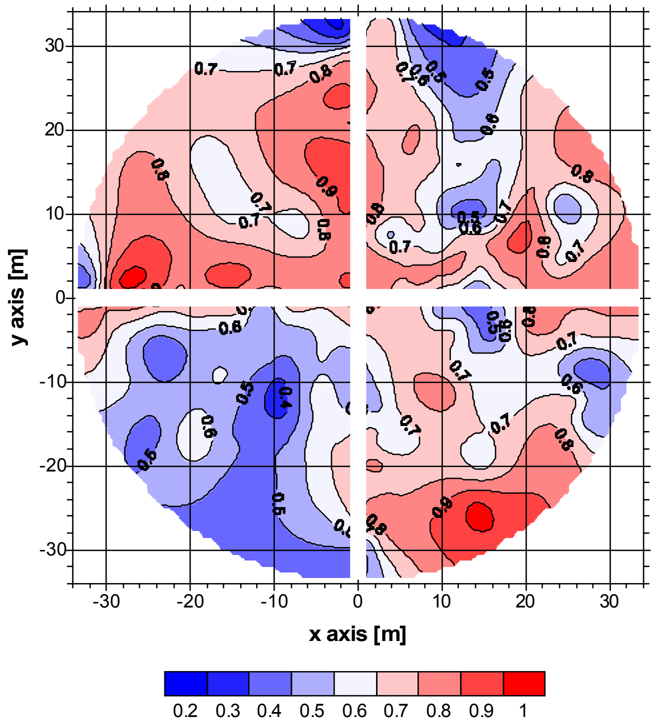


**Fig. 5**. Local normalised cooling tower efficiency

### 3.3 Numerical modelling

Using the experimental procedure described above, numerical modelling of aerodynamic and energy characteristics of mass and energy transfer on different space scales of the cooling tower is performed. Beside overall transport properties and real boundary conditions, the respective constitutional relations of homogeneous flow are used ensuring the adequate modelling quality. The modelling is performed on two scales (see section 3.2):

- entire cooling tower,
- a segment of vertical plates with drift eliminators, where the energy and mass transfer is performed.

The numerical model applied to the expert system is based on commercial programme package TASCflow3D™, where the single-phase model with the following constitutional relations is used:

- porous layer of the cooling tower heat exchange system,
- heat flow generation in the region of the cooling tower heat exchangers.

Heat flow generation in various cooling tower locations at the heat exchangers level is determined on the basis of the experiment in a reference vertical segment of the cooling tower and on the basis of local air mapping measurements performed by the mobile unit.

The model results, presented as velocity and temperature profile maps of the entire cooling tower (**Figs. 6** and **7**), present a solid basis for the detection of local anomalies in cooling towers and enable consequent reconstruction measures.

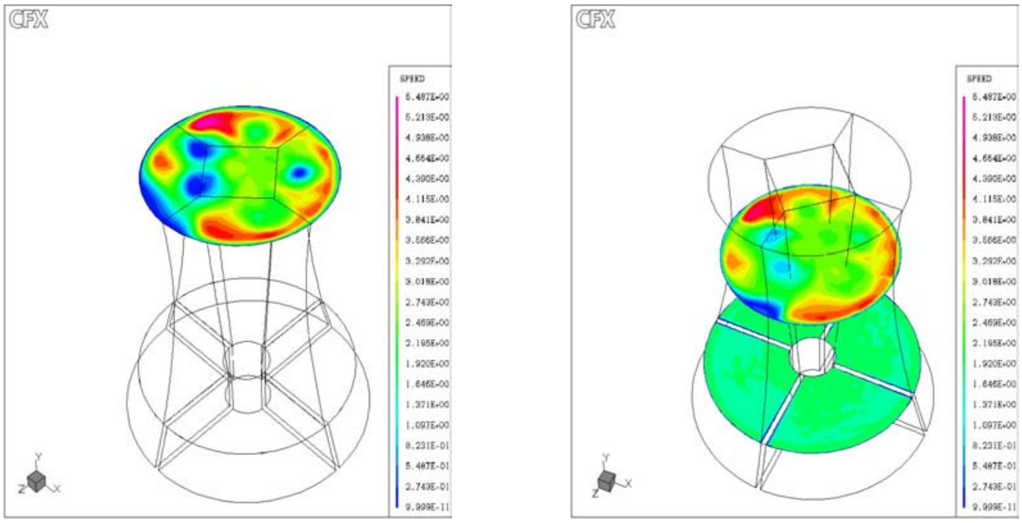


**Fig. 6**. Numerical model of velocity profiles at different cross sections of cooling tower

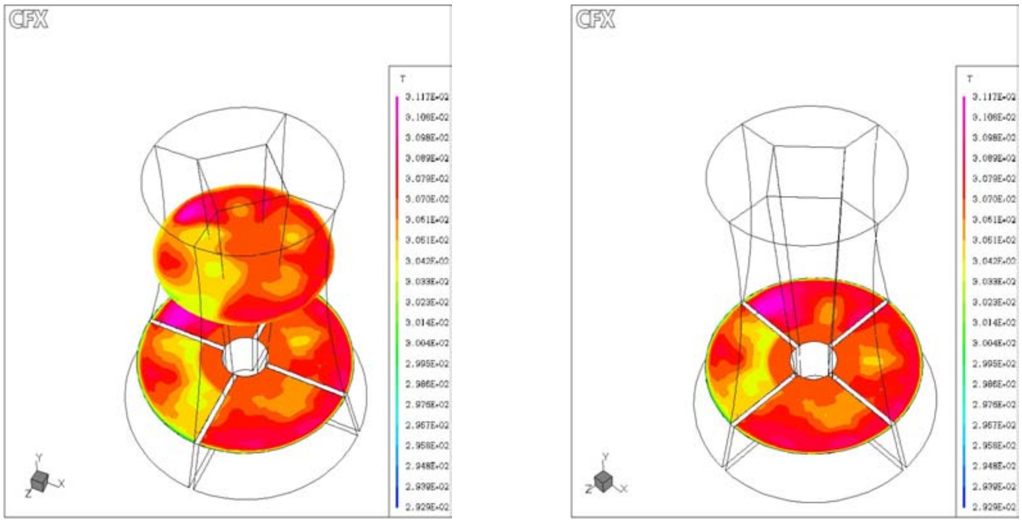


**Fig. 7**. Numerical model of temperature profiles at different cross sections of cooling tower

## 4. TECHNICAL INFORMATION ON THE MOBILE UNIT

The complete system includes: mobile unit, navigation and positioning unit, video camera with transmission system, and processor unit which via radio telemetry sends measured data to the central computer outside the cooling tower. Velocity and temperature measurements are simultaneously controlled by the computer system, where velocity and temperature data are saved and partially processed.

The mobile unit is designed to fulfil all specific demands for moving in the cooling tower measurement plane:

- mechanical demands (rated torque 24 Nm)
- temperature conditions (T ≈ 40 °C)
- humidity (φ ≈ 100%)

The mobile unit can also be applied in numerous other fields of application, where measurements have to be carried out without human presence, such as: hazardous working conditions, and inaccessible working places in chemical industry, nuclear power plants, mines, etc.

The mobile unit is equipped with the following elements:

- two electric motors with gearbox and safety clutch,
- two rechargeable Ni-Cd batteries for up to 1 hour operation with fast-charging unit,
- radio-control unit (4 channels),
- B/W CCD camera in water resistant casing, video transmitter and receiver unit,
- vane anemometer, designed for operation in 100% humidity,
- Pt 100 temperature sensor.

**Motors**

Installed motors (2) are motors with integrated gearbox and safety clutch, connected to the voltage regulator controlled by a remote control unit. Motor regulator voltage: U = 0 to 12V. At reverse movement regulator allows 80% of the maximum voltage. Maximum allowed current is 35 A for an operating time of 2 min. Motors have, during numerous endurance tests and measurements, proven to be adequate driving units in any circumstances inside cooling towers.

**Video transmission**

A video transmission system with waterproof camera and transmitter is mounted on the tracked vehicle. The receiver and monitor are mounted outside the cooling tower. The video transmission power is according to the European standards limited to 10mW.

**Power supply**

About 6A current per motor at full speed of the tracked vehicle is required, and therefore, a set of NiCd batteries used. It delivers 7.2 Ah, (12 V) per set, allowing each 30 minutes of full speed driving. There is also an emergency power supply (1.2Ah batteries) enabling evacuation of a mobile unit in the case of a primary source break-down.

**Mobile unit positioning**

Since ultrasound triangulation for the noisy environment of large cooling towers is not suitable, the position of the mobile unit is determined by a positioning unit. The positioning unit is generally located at the centre of the cooling tower. Information about the unit's position is transmitted to the host computer via a serial computer cable. All measured values from the cooling tower as temperature and air velocity, together with the unit's position, where those data are collected are processed by special program in the host computer.

The mobile unit's positioning electronics consist of a positioning sensor and a positioning electronics unit. The positioning sensor is divided into two sub systems: a linear position transducer and an angle sensor. With both sensors the polar position of the mobile unit inside the cooling tower (angle and distance) is obtained. The position electronics unit is located inside a plastic enclosure. It has connectors for the position sensor and a standard serial computer connector. All data collected from the position sensors and after being collected by computer are fed trough a serial connector via up to 50 m. long special cable to the host computer.

## 5. PRICES

Price of the pre-upgrade measurements: 20,000 Euro (passive analysis without numerical and phenomenological analysis)

Price of a measuring system: 40,000 Euro including operator training.

## 6. REFERENCES

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