Specification for water balance test of cooling towers

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Abstract. This test procedure describes the evaluation method used to determine the water consumption performance of cooling towers and evaporative cooling equipment, which provides a unified test instrument, test procedure, parameter measurement, test data processing, and test results. This test procedure provides the manufacturer and the owner an objective and fair evaluation, outlines practical methods for monitoring the water consumption performance of cooling towers. The loss of water in cooling tower is measured by U-type liquidometer, and the law of collecting basin liquid level. When the liquid level of the collecting basin decreased by 1 mm, the water quantity loss of one cooling tower diameter $D=42$ m was $1.38$ m$^3$. And cooling tower water loss and specification for water balance test is established. The water quantity loss of cooling tower can be obtained conveniently, accurately and quickly. This provides conditions for further accurate analysis of water quantity loss of cooling tower, etc. It is widely used and has great significance in the hydraulic design of cooling tower, the analysis of air status in the tower, the water balance test to determine the water used in cooling tower, the reduction of water loss and the drift recovery. And provides explicit test procedures that yield results with the highest level of accuracy and consistent with the best current engineering practices and knowledge in this field.

1. Introduction

Literature [1] shows that there is no direct test method for evaporation loss. In literature [1], [2] the evaporation loss of cooling tower is analysed by using complex methods of approximate estimation or air humidity ratio difference between inlet and outlet. However, the variation law of evaporation loss of cooling tower is not explained. Some standards [3],[4],[5],[6] also extensively use sensitive paper to test drift. And standards [6] adopted tracer and other measures to test drift and Literature [7] tested and analyzed the plume. Literature [1],[3] shows that empirical estimation is also widely applications in engineering. Oskar Javier Gonzalez Pedraza et al. [8] estimated the evaporation loss and used the Euler–Lagrange equation to simulate the falling process of drips numerically in forced airflow. M. Lucas et al. [9] investigated the effects of ambient temperature, humidity, drift temperature at the tower outlet on drift loss (and thus deposition). However, the failure of these analyses to obtain accurate water quantity loss of cooling tower will cause the analysis results to be inconsistent with the actual changes of drifts, and doesn't explain the law of drifts variation.

For a long time, water quantity loss of cooling tower is not convenient for direct, accurate and real-time measurement. At present, in practical engineering application, data collection is carried out by the make-up water meter. The test average of cooling tower water loss is obtained through long time tracking test, so as to reduce the error value as much as possible. For this reason, such average cannot well explain and further analyze the water quantity loss of cooling tower. It can neither provide...
accurate reference data in the hydraulic design and the application of water balance engineering of cooling tower, nor can it explain some scientific phenomena such as the air state in the tower. It brings difficulties to the design and application of cooling tower. Baohong Song [10] proposed to change the existing test mode of water quantity loss of cooling tower. The U-tube liquidometer was adopted to test the liquid level in the collecting basin, and it is used together with the make-up water flowmeter, so as to obtain the water quantity loss of the cooling tower. Baohong Song [11] studied the loss of water in cooling tower is measured by U-type liquidometer, and the law of collecting basin liquid level and cooling tower water loss and specification for water balance test is established. The water quantity loss of cooling tower can be obtained conveniently, accurately and quickly. This provides conditions for further accurate analysis of water quantity loss of cooling tower, etc. This test procedure describes the evaluation method used to determine the water consumption performance of cooling towers and evaporative cooling equipment, which provides a unified test instrument, test procedure, parameter measurement, test data processing, and test results. This test procedure provides the manufacturer and the owner an objective and fair evaluation, and explicit test procedures that yield results with the highest level of accuracy, and consistent with the best current engineering practices and knowledge in this field. The following review sequence is recommended to assist in a comprehensive study of this specification. This specification can be learned by reading the introduction to each section and the testing process that follows. Performance monitoring projects should check this specification or citation specification initially to examine the details of the code section. When this specification is used to determine the performance of contractual obligations, the contracting parties shall agree on test procedures, uncertainty estimates and definitions, data representation methods, and result representations in advance. Testing the thermal performance of the cooling tower and issuing an accurate test report are also suggested. Considerable efforts were exerted to write this cooling tower Code to contain all the related technology within the document itself. However, this approach was impossible in all instances. In these cases, and unless otherwise specified, all references to other codes refer primarily to standards [12] or to standards [13]. Instruments and equipment for water balance testing are described in detail in this specification. The descriptions of instruments and apparatus of thermal performance testing may be found in the standards ASME PTC 19 series of supplemental codes or standards [13]. The general basis of the uncertainty analysis beyond that specified in this Code may be found in the supplement standards ASME PTC 19.1, Test Uncertainty. A careful study of all the referenced codes should be conducted. However, quotative instructions shall govern when discrepancies between specific directions contained herein and those codes incorporated by reference arise. This specification mainly introduces the method of obtaining real-time and accurate cooling tower water loss data. The accurate thermal performance of cooling tower (relevant thermal performance parameters need to be collected) is investigated by establishing the accurate water balance condition of cooling tower, and the change in water loss in the cooling tower is analyzed on the basis of the alterations in water level in collecting basin, the law of water loss in cooling tower, the laws of evaporation loss and drift loss, and drift recovery. This approach is widely used in the fields of engineering application, design, and research on water loss control of cooling tower operation parameters.

2. Procedure

2.1. Range
This standard provides uniform procedures for the water balance testing of industrial circulating water wet cooling towers, the measurement of each parameter, the processing of test data, and the evaluation
of test results. However, this specification does not include the test of thermal performance-related items of the wet cooling tower. The ASME PTC 23 and CTI-ATC-105 test standards present the thermal performance test and analysis. However, the thermal performance of the wet cooling tower should be tested simultaneously, and the test report should be issued.

This specification provides the latest accurate data processing and evaluation of evaporation and drift losses.

This standard is applicable to the acceptance test of water balance for new or modified industrial circulating water cooling towers of wet mechanical and natural drafts. Water balance test of cooling tower with non-acceptance check nature can refer to this standard. This standard is applicable to the natural draft cooling tower with or without drift recovery projects.

This standard does not apply to air cooling towers and chimneys.

2.2. Criteria for quotations and references

The terms in the following documents are referenced by this standard and has become the terms of this standard. For undated references, the latest version applies to this standard.

CTI-ATC-140. Isokinetic drift measurement test code for water cooling tower. USA.

ASME PTC 23 American National Standard Atmospheric Water Cooling Equipment Performance Test Codes.

CTI-ATC-105 Acceptance Test Code for Water Cooling Towers;

CTI-ATC-150 Acceptance Test Procedure for Wet-Dry Plume Abatement Cooling Towers;

Baohong Song. Test Study of Water Loss of Cooling Tower on U-Type Liquidometer. International Conference on Energy Engineering and Environmental Protection (EEEP 2019) Xiamen. 2019.

Baohong Song. A accurate measurement method for water loss of cooling tower. [P] Chinese patent. CN 2019104830076. 2019.

2.3. Definition

The wet cooling tower contains mechanical draft wet cooling tower and natural draft wet cooling tower.

In this specification, the "evaporation" refers to form the water vapor of vapor phase in the cooling tower. "evaporation loss" refers to the loss of water vapor of invisible from the cooling tower outlet. Namely, it is the loss water quantity of increase of air humidity ratio in the tower.

Drift: In the operation of an evaporative cooling tower, moving air contacts water for heat transfer. The circulating water is distributed as droplets or films to maximize the surface area exposed to the air. In these processes, small water droplets are entrained in the air moving through the tower. Droplets that are not removed from the air stream are exhausted from the cooling tower into the environment. These droplets which possess the same minerals (but not necessarily in the same concentrations) as the circulating water.

Drift loss: Water lost from the tower as liquid droplets entrained in the outlet air.

Cooling tower cell: A cooling tower "cell" is the smallest subdivision of the tower, bounded by exterior walls and partition walls, which can function as an independent unit. Each cell may have one or more fans or stacks distribution system.

Air flow: Total quantity of air, including associated water vapor flowing through the tower.

Makeup Water flow: the makeup water added to the circulating water system to replace water loss from the system by evaporation, drift, purge arid leakage.

Surface area of collecting basin: It's the surface area of the liquid (water) in the collecting basin.

2.4. General rules

2.4.1. Test period selection. After the newly built or rebuilt industrial circulating water cooling tower is placed in normal operation, the water balance of the cooling tower should be tested or multi-term acceptance tests should be carried out on time. If the acceptance test cannot be carried out on time
after the normal operation of the cooling tower because the test conditions do not satisfy the requirements, then the acceptance test shall be completed within one year after the normal operation of the cooling tower. The water balance testing of drift water recovery devices in naturally draft cooling towers is presented in this test procedure. The acceptance test of cooling tower water balance shall be entrusted to the unit with cooling tower test capability and experience. When new or rebuilt cooling towers need to be tested for water balance acceptance, they should be clarified in the preliminary design stage of the project, and the cost of acceptance test should be included in the project investment estimate.

2.4.2. Step. The acceptance test of cooling tower water balance should follow the following procedure.
   a) Preparation of the test work outline;
   b) Preparation work prior to the test;
   c) Site test;
   d) Processing and analysis of test data;
   e) Preparation of the acceptance test report.

2.5. Preparation work prior to the test (conducting thermal performance test in accordance with CTI-ATC-105 at the same time is advisable).

2.5.1. Selection of test tower. The test tower shall be designated by the entrusting party. When the cell towers in the cooling tower group is tested, the test tower can be selected through negotiation between the entrusting party and the testing party. (For the purposes of this Code, a “cell” is defined as the smallest subdivision of the tower, bounded by exterior walls and partition walls; it can function as an independent unit. Each cell may have one or more fans or stacks and one or more distribution systems).

2.5.2. On-site investigation. The test department shall conduct on-site investigation on the test tower prior to the test.

2.5.3. Uncertainty Analysis. If an uncertainty analysis is desired, then it should be agreed to by both parties prior to the test because this analysis requires the recording of certain additional data.

2.5.4. Prepare the test outline. Prior to the cooling tower test, the test unit shall prepare the test outline. The test syllabus should include the following.
   a) Test purpose and requirements (to consider the impact of the following changes on the water loss of the cooling tower, corresponding tests or explanations should be performed).
   b) Design, construction, and operation overview of the tested cooling tower, including the following.
      • Cooling tower type, main geometric dimensions, water surface area of collecting basin, and design area of water drenching.
      • Form, material of packing, packing height, packing length of crossflow cooling tower, mounting support mode, and support material for packing. The design adopted the thermal and resistance characteristics of the packing.
      • Drift eliminator form, material, installation location, installation mode, and design adopted for drift eliminator resistance characteristics. The form and arrangement of the water distribution system, the form of splash water nozzle, nozzle diameter, nozzle spacing, number of nozzle with different diameters, and design pressure in different water distribution zones in the tower.
      • Mechanical draft cooling tower fan form, impeller diameter, fan characteristic curve and design working point air volume and full pressure, and fan design shaft power.
      • Problems that exist in the actual operation of cooling tower.
      • Analysis report of circulating water quality.
c) As-built drawings or construction drawings of the tested cooling tower, including
   - Location of the cooling tower in the general plan of the plant;
   - Plan and section of the cooling tower.

d) Test contents and test conditions.

e) Test items, measuring point arrangement, test methods, and instruments used.

f) Test tools and equipment that need to be machined.

g) Processed method of test data.

h) Analysis of cooling tower water balance.

i) Evaluation method of test results.

j) Composition and division of testers.

k) Test work schedule.
   - Safety operation precautions and safety measures taken.
   - Matters requiring the cooperation of the entrusted unit (owner).

2.5.5. Test condition. Before the test of the cooling tower begins, it should be comprehensively inspected, and the defects of each part of the cooling tower shall be eliminated in accordance with the design and test requirements. To ensure that the cooling tower is in a good operating condition for testing, its components and equipment should satisfy the following requirements.

a) The water distribution system of the cooling tower shall be clean, unobstructed, and free from debris blockage, leakage, and water overflow. The nozzle shall be intact and must have normal spillage.

b) The appearance of the packing should be neat without defect and deformation, and the surface of the packing should not have algae, oil, and other sundries.

c) The packing of the countercurrent cooling tower shall be filled with the packing layer. The crossflow cooling tower should avoid direct current air passage at the top of the wet packing.

d) The surface of the drift eliminator shall be clean and free from debris, algae, and other attachments that obstruct the normal flow of air.

e) Drift eliminator layer should be full of drift eliminator, and no air bypass channel is available. Special operating conditions are excluded.

f) The inlet pipe valve of the cooling tower and the connection pipe valve between the cooling towers should be opened and closed flexibly for easy adjustment.

g) The fan, motor, and reduction gear of the mechanical draft cooling tower shall operate normally.

h) The water level in the cooling tower collecting basin shall be at the normal operating level or at the level required by the test.

i) Makeup water and blowdown flowmeters are in good condition;

j) Other requirements set forth in the test outline.

2.5.6. Preparation of instrument. In the cooling tower test, the instrument that passed the checkout should be used, and attention should be provided to the inspection to ensure the accuracy of the instrument in the test process to satisfy the test requirements.

2.5.7. Determination of site conditions. The following tasks shall be completed at the test site prior to the cooling tower test.

a) The location of the measuring points is determined for each test item;

b) The test platform should be set up;

c) The automatic test items of the temporary power supply should be set up;

d) Processing and installation of platform and racks for placing instruments, preparation of test equipment and instruments.

2.5.8. Ready to forms. Record forms for various tests should be prepared prior to testing.
2.5.9. Predictive test. Prior to the test, the personnel participating in the test should be organized to familiarize with the test items and the instruments used, and the predictive test of the items is carried out in accordance with the requirements of the test outline.

2.6. Test instruments and measurement methods
This specification only describes the instruments and equipment required for water balance testing. CTI-ATC-105 shows the thermal performance test equipment.

2.6.1. Classification and structure type of level gauge. Different working principles can be divided into liquid column type, mechanical type, and sensor type forms.
   a) Liquid column. Liquid column, such as the u-tube level gauge, is based on the principle of hydrostatics to convert the pressure signal into the liquid column height signal, often using water as the working medium of the gauge. The scale is the standard length ruler, and the minimum resolution is 1 mm.
   b) Mechanical. The use of the principle of buoy, buoy mark, and mark up and down on the ruler can show the change in the level to obtain the level reading, and the minimum resolution is 1 mm.
   c) Liquid level sensor (automatic data recording system). The principle of liquid level sensor is to convert the liquid level signal into some types of electrical signal, such as infrared liquid level meter and radar liquid level meter. Then, the signal is sent back to the machine for reception, and the minimum resolution is 1 mm.

2.6.2. U-tube liquidometer material. The substrate is made of wood board, aluminum alloy, and glass reinforced plastic. The surface is painted yellow. U-tube is made of plexiglass tube or glass tube. The dividing ruler is a standard straightedge with a minimum resolution of 1 mm.

2.6.3. Method used by U-type liquidometer. The U-type liquidometer is vertically mounted at the same height with the same level as the collecting basin. Then, water was pumped to the transparent siphon tube and air is eliminated. One end of the tube was placed into the water of the collecting basin, and the other end was connected to the U-tube liquidometer. The working fluid (water) is shown between the upper and middle U-shaped glass tube.
   When reading, the line of sight should be consistent with the height of the liquid in the U-tube, and then the line value of the scale is the height value of the liquid level in the catchment tank. When waiting for the next test time, the method is the same as the above to obtain the reading value of another measurement.
   The change quantity of the liquid level in this period can be obtained through the difference of two readings, and the value of water loss of the cooling tower can be obtained according to the change law of the collecting basin liquid level and water loss of the cooling tower.

2.6.4. Liquid level sensor. The liquid level sensor is recommended to be used in accordance with the instructions to obtain accurate automated test data results.

2.7. Cooling tower water balance test

2.7.1. Test condition. When testing the water loss of the cooling tower, the environmental meteorological conditions shall satisfy the following requirements.
   a) The test should be conducted during the daytime in summer close to the designed meteorological conditions or higher temperature seasons (when thermal performance analysis is required). In accordance with the purpose of the test, water balance tests can also be conducted in winter or other seasons for testing purposes.
   b) Testing should not be conducted during rain or immediately after the rain. The start time of the test after the rain should be 1 h after the rain stops.
c) The average ambient wind speed of the mechanical draft cooling tower shall not be greater than 4.5 m s$^{-1}$, and the ambient wind speed of the gust per minute shall not be greater than 7.0 m s$^{-1}$. The average ambient wind speed of the natural draft cooling tower shall not be greater than 3.0 m s$^{-1}$, and the ambient wind speed of the gust per minute shall not be greater than 5.0 m s$^{-1}$.

d) During the testing of the natural draft cooling tower, the tester on the ground visually eyeballing that the hot and humid air flow from the air duct outlet of the natural draft cooling tower should fill the air duct outlet. No air flows back into the cooling tower at the top of the tower.

e) In circulating water quality, the cooling tower inlet should comply with the “Standard Methods for the Examination of Water, Sewage, and Industrial Wastes” published by the American Public Health Association of the relevant provisions.

In the test of water balance and thermal performance of cooling tower, the allowable deviation range of the main parameters from the design value is shown in Table 1. The testing range of each parameter can be determined according to the testing needs of the non-acceptance cooling tower test. When the water temperature in the tower inlet deviates from the design value and the water temperature difference from the design value is large, the influence of the water temperature in the tower inlet on the cooling tower performance should be calculated.

| Name of parameter | Deviation from the design value range is allowed |
|-------------------|-----------------------------------------------|
| Dry bulb temperature of tower inlet $t$ | ±4.5 °C |
| Wet bulb temperature of tower inlet $t$ | ±1.5 °C |
| Water flow of tower inlet $W$ | ±2% |
| The water temperature difference between tower inlet and outlet $\Delta t$ | ±5% |

f) The liquid level and the scale line misalignment of the artificial reading are in accordance with the liquid level in advance or appropriate to extend the time of testing within ±3–5 min. In the calculation, the data need to return to the original test time value for the omni hora. Taking pictures is suggested to record the liquid level value, and using a camera that can record the time to take pictures is advisable. The liquid level interpretation on the computer is carried out. Using the level sensor together with the U-type liquidometer is recommended.

g) During the test, the makeup water enters the circulating water system, and the makeup water pipeline shall be equipped with a flowmeter or ultrasonic flowmeter. Otherwise, the makeup water operation or test work shall be cancelled.

h) In the test, when a sewage blowdown occurs out of the circulating water system, the sewage blowdown pipeline should be equipped with a flowmeter or ultrasonic flowmeter. Otherwise, the sewage blowdown operation or test should be cancelled.

i) The readout of the supplementary water and the blowdown flowmeter shall be carried out simultaneously with the reading of the U-tube liquidometer. The U-tube liquidometer, the makeup water, and the blowdown flowmeter are set nearby and completed simultaneously.

2.7.2. Test project

a) Prior to the test, the surface area of the collecting basin should be tested first. Accurate and reliable data of collecting basin liquid area are ensured; they serve as data source for subsequent analysis.

b) When analyzing the thermal performance of the cooling tower and the water loss from evaporation and drifts, relevant thermal performance tests should be carried out according to CTI-ATC-105. Data collection items are as follows (as shown in the table 2);

| Minimum Number Each | Unit | Record to Nearest |
|---------------------|------|-------------------|

Table 2 List of thermal analysis test items.
| Parameter                     | Value          |
|-------------------------------|----------------|
| Hour Per Station              |                |
| Wet-bulb temperature          | 12 °C          |
| Relative humidity             | 12 %           |
| Dry-bulb temperature          | 12 °C          |
| Cold water temperature        | 12 °C          |
| Hot water temperature         | 12 °C          |
| Circulating water flow        | 2 m³ h⁻¹       |
| Tower pumping head            | 1 m            |
| Fan driver power input        | 1 kW           |
| Wind velocity                 | Continuous     |
| Collecting basin liquid area  | 1 m²           |
| Collecting basin liquid level | 3 m            |
| Makeup water temperature      | 2 °C           |
| Makeup water flow             | 2 m³ h⁻¹       |
| Blow-down temperature         | 2 °C           |
| Blow-down flow                | 2 m³ h⁻¹       |
| Barometric Pressure           | 1 kPa          |

Note: 1. Please select the parameter group under approach design conditions for thermal performance analysis to determine the actual performance index of the cooling tower.
2. The data can be averaged after three consecutive tests.

2.7.3. Test requirement

a) Each parameter shall be tested after the adjustment of the test condition and stable operation for a period of time, from the end of the adjustment of test conditions to the beginning. The testing time of each parameter is as follows: the single-cell mechanical draft cooling tower shall not be less than 3 h, and the mechanical draft cooling tower group and the natural draft cooling tower shall not be less than 6 h.

b) During the test of each working condition, the measured value of each main parameter shall be subject to the arithmetic mean value of the measured value of each working condition. The test duration for each working condition shall not be less than 3 h. The test times and time intervals for each parameter shall not be less than those specified in Table 3.

c) The effective working point of the collecting basin liquid level test includes more than two groups. One set uses U-tube liquidometer, and the other set uses liquid level sensor (automatic data recording system).

2.8. Test data processing

Each parameter of each working condition should consider the arithmetic mean value of its measured value as the representative value of this working condition.

2.8.1. Analysis of water balance. The cooling tower water balance:

\[
\frac{dW}{dt} = \frac{dE}{dt} + \frac{dW_b}{dt} + \frac{dL}{dt}
\]

where \( W \) is the makeup water flow (m³ h⁻¹); \( W_b \) is blowdown loss, (m³ h⁻¹); \( dL \) is leakage loss, (kg s⁻¹); \( dE \) (kg s⁻¹) is the variation of water loss per unit time of the cooling tower outlet.
When no blowdown and leakage losses, $W_b=0$ and $L=0$. Then, according to the law of collecting basin liquid level and water loss in the cooling tower in literature [10], Equation (2) is used in the calculation.

$$dE = W - W_b + A_a \times dh_w$$  \hspace{1cm} (2)

where $dh_w$ is the change in liquid level per unit time, ($m^3/h$); $A_a$ is the surface area of the collecting basin ($m^2$);

When makeup water, if the liquid level rises, it means that the amount of added water is greater than the amount of loss, then $A_a \times dh_w$ is a negative sign, conversely it's a plus sign.

2.8.2. Analysis of thermal performance of cooling tower (analysis of evaporation and drift losses only).

a) The analysis of evaporative water loss $d_e$ (kg s$^{-1}$) and drift loss $E_e$ (kg s$^{-1}$) in cooling towers prioritizes Equations (5), (6), and (7) introduced in literature [11].

- The partial pressure of water vapor can be obtained by adopting Equation (3), as follows:

$$\lg P' = 2.0057173 - 3.142305 \left(10^3 \frac{T - 373.16}{T}\right) + 8.21g \frac{373.16}{T} - 0.0024804(373.16 - T),$$  \hspace{1cm} (3)

where $P'$ is the water vapor pressure at air saturation, (MPa); and $T$ is the temperature of the air, (°C).

- The humidity ratio is obtained by using Equation (4):

$$d = 0.622 - \frac{d \Phi P'}{P - P'};$$  \hspace{1cm} (4)

where $d$ is the humidity ratio (kg kg$^{-1}$ DA); and $P$ is the atmospheric pressure, (MPa);

- The analysis of evaporation loss $d_e$ (kg s$^{-1}$) of the cooling tower is calculated according to Equation (5), as follows:

$$dd_e = (d_0 \Phi + d_2 - d_0) G,$$  \hspace{1cm} (5)

where $d_0$ is the saturation humidity ratio (kg kg$^{-1}$ DA) that corresponds to the ambient air isotherm; and $d \Phi$ represents the changes in the relative humidity of the ambient air at the unsaturation and saturation; $G$ is the air flow rate in the tower (kg s$^{-1}$).

- The ambient air and tower outlet air temperature $dt$ are in the range of 20 °C–40 °C, and it is recommended for use in Equation (6) in the evaporation loss of cooling tower to solve $d_e$.

$$dd_e = (d_0 \Phi + adt) G$$  \hspace{1cm} (6)

where $a=0.00172$;

- The air temperature $t_2$ at the tower outlet is obtained according to Table H in the appendix CTI-ATC-105. The humidity ratio $d_2$ at the tower outlet is calculated according to Equations (10) after Equation (9) separating the variables.

$$t = 1.005t + (2501 + 1.805t) d,$$  \hspace{1cm} (9)
where \( t \) is the air temperature (°C) at the outlet of the tower; \( d \) is the air humidity ratio at the tower outlet (kg kg\(^{-1}\) DA).

- Evaporation loss \( d_e \), that is, the increased air humidity ratio is calculated according to Equation (11), as follows:

\[
d_s = (d_2 - d_1)G_r
\]  
(11)

where \( d_2 \) and \( d_1 \) represent the air humidity ratios (kg kg\(^{-1}\) DA) in the tower outlet and inlet, respectively.

- The total water content of unit discharge air in tower outlet \( d_c \) (kg kg\(^{-1}\) DA) is calculated according to Eq. (12):

\[
dd_c = d_1 + dE/G
\]  
(12)

- According literature [10] the water loss \( dE \) of cooling tower outlet is equal to the evaporation loss \( dd_e \) (m\(^3\) h\(^{-1}\)) plus the drift loss \( dE_e \) (m\(^3\) h\(^{-1}\)). The drift loss \( dE_e \) is obtained according to Equation (13).

\[
dE = dE_e + dd_e
\]  
(13)

2.9. Test report

After the cooling tower test is completed, the test unit shall prepare the test report, which shall include the following contents:

a) Test tasks, test objectives, and requirements.

b) Overview of the cooling tower design, construction, and operation management, horizontal and sectional drawing of cooling tower under test, and location map of the measuring points of each test project.

c) Test items, test methods, placement of measuring points, instruments used, instrument names, specifications, and accuracy.

d) Test scope and test conditions.

e) Test data processing method and test data summary.

f) Test results, evaluation, and analysis of test results.

g) Existing problems and suggestions.

h) Issues that require special clarification in accordance with the contract and owner’s requirements.

i) List of units and personnel participating in the test.

2.10. Experiment

The two natural draft wet towers provided by the Guizhou Panjiang Coal Industry Co., Ltd., has the same size. The water drenching area of one tower is 1000 m\(^2\), and the height is 60 m. Two collecting basins, with a diameter of 42 m, are connected to each other and simultaneously supply water operation. The rated circulating water flow of the 45 MW unit (gangue small power plant) is 9720 m\(^3\) h\(^{-1}\), and its pressure is 0.15 MPa. The water distribution system consists of channels and water pipes. The drift eliminator is a 50–50/160 double-wave type, and the packaging is made of plastic 35×15×60° with a height of 1.2 m. The air inlet height is 5 m.

In the circulating pump room, the U-type liquidometer is vertically mounted on the stairs with the same level as the collecting basin (Figure 1). Then, water was pumped to the transparent siphon tube (Φ14 mm), and air is eliminated. One end of the tube was placed into the water of the collecting basin, and the other end was connected to the U-tube liquidometer. The U-type liquidometer is modified by a U-type manometer. The scale plate of U-type manometer was replaced with a 1 m ruler. The resolution is 1 mm.
3. Results

3.1. Test result
The change data of water quantity in the collecting basin per unit time are measured using the U-type liquidometer, result see Table 4.

| Items                | Code | unit | 0  | 1  | 2  | 3  | 4  | 5  | 6  |
|----------------------|------|------|----|----|----|----|----|----|----|
| Liquid level         |      |      | 55.3| 57.4| 58.2| 58.5| 58.6| 54.6| 50.1|
| Make-up water flow   | W    | m³ h⁻¹| 0  | 160| 142| 116| 107| 0  | 0  |
| Acquisition time     |      |      | 9  | 10 | 11 | 12 | 13 | 14 | 15 |

Note: 1. When calculating the liquid level data, the liquid level change is obtained by subtracting the previous data.
2. This is the water data when two cooling towers are connected in parallel and the water is supplied.
3. The no blowdown loss, \( W_b = 0 \).

3.2. Analysis of result
According to the liquid level of the collecting basin and the change law Eq. (2) of water quantity loss of the cooling tower analyzed data of Table 1, result show in Table 5:

| Items                | Code | unit | 1  | 2  | 3  | 4  | 5  | 6  |
|----------------------|------|------|----|----|----|----|----|----|
| \( \dot{E} \)         |      | kg s⁻¹| 14.15| 16.65| 14.96| 14.48| 15.38| 17.3 |

Note: The data refer only to one cooling tower.

4. Discussion
When the liquid level of the collecting basin decreased by 1 mm, the water quantity loss of one cooling tower diameter \( D = 42 \) m was \( \dot{E} = W - A_d * dh_w = 0 - 1384 * (0.574 - 0.553) \), \( E = 14.15 \) kg s⁻¹, in Table 5. The most water loss is group 6, \( \dot{E} = W - A_d * dh_w = 0 - 1384 * (0.501 - 0.546) \), \( E = 17.3 \) kg s⁻¹, in Table 5. The liquid level change between 9 am and 10 am is 2.1 cm h⁻¹, and the increased water quantity of the liquid level is 29.06 m³ h⁻¹. The minimum water quantity loss of one tower is group 1 \( \dot{E} = W - A_d * dh_w = 160/2 - 1384 * (0.574 - 0.553) \), \( E = 14.15 \) kg s⁻¹, in Table 5, instead of a constant.

5. Conclusion
We use the U-type liquidometer to test the water loss in the cooling tower. This work provides conditions for the further accurate analysis of the cause of water loss.
This specification mainly introduces the method of obtaining real-time and accurate cooling tower water loss data. The accurate thermal performance of cooling tower (relevant thermal performance parameters need to be collected) is investigated by establishing the accurate water balance condition of cooling tower, and the change in water loss in the cooling tower is analyzed on the basis of the alterations in water level in collecting basin, the law of water loss in cooling tower, the laws of evaporation loss and drift loss, and drift recovery. The method is widely used and is significant in the hydraulic design of the cooling tower, the analysis of air status in the tower, the water balance test for determining the water used in the cooling tower, and the reduction of water loss.

6. References
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