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Date: YYYY-MM-DD0

Bamboo-based packing products for cooling tower

WD/CD/DIS/FDIS stage

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This second/third/… edition cancels and replaces the first/second/… edition (ISO #####:####), which has been technically revised.

The main changes are as follows:

— xxx xxxxxxx xxx xxxx

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Introduction

Evaporative cooling has long been used as an economical method to cool air for providing comfort. Cooling tower is one of the most popular cooling devices widely used in power plants, petrochemical, refrigeration and air conditioning processes. It removes heat via application of the thermal exchange between hot water and ambient air. The working principle is that the heat is transferred from hot water to the air via the interface of water/air, which can easily improve the heat transfer rate and reduce the energy consumption cooling tower requires distribution of water over the packing materials under a flowing stream of air to remove heat by reducing the water temperature. With the rising of energy costs and water scarcity, efforts are also made to improve efficiency of the cooling tower to save energy costs. In China, the power consumption of circulating water in cooling tower was about 30–45 billions of kWh each year. It was assessed that approximately 5% of thermal energy was wasted due to the inefficient operation system of existing cooling towers. Therefore, the efficiency of cooling tower plays a critical role toward energy conservation. In order to improve efficiency of cooling tower, it is desired to modify the packing material. The packing material is the heart of cooling tower, and the performance of heat and mass transfer can be improved by increasing the air-water interface through the reduction of water drop size of the packing. The packing material occupies 20–25% of the total cost of building the tower. also responsible for 60%–70% of the heat dissipation (Goshayshi, 2006). There are several types of packing material used in cooling tower, such as wood (Obreg´on Qui˜nones et al., 2017), concrete (Kong et al., 2018), paper honeycomb and plastic (Ramkrishnan and Arumugam, 2013).Before 1960s, wood packing was widely used in China, showing some advantages such as easy to process, install and low cost. Due to the subsequent shortage of wood resources (Wu et al., 2020c), paper honeycomb and concrete packing replaced the wood packing. Paper honeycomb packing has good cooling efficiency, but this type of packing is easily broken. Concrete packing has been used for a long time for its good stiffness and thermal performance, but it is difficult to be installed because of its high density and negative environmental impact, for instance, concrete is difficult to be naturally degraded (He et al., 2020). From 1970s, polyvinyl chloride (PVC) packing began to be used in cooling tower. It has low density, high strength and good cooling performance, dominating over 96% of market share in cooling towers (Goshayshi and Missenden, 2005). However, the PVC packing also has drawbacks such as fouling and deposit buildup and low durability. In addition, PVC is harmful to environments due to its difficulty and extremely long duration of degradation.

Bamboo grid packing is a new cooling packing material, increasingly being used in power plants in China. It belongs to vertical grid aparatus type of packing and is made of bamboo culm derived from abundant and fast-growing bamboo species. The bamboo grid packing technology appeared in 1970s in China, but had not developed until the beginning of this century because the traditional bamboo packing production process has low-efficiency and the raw materials for the bamboo packing were not standardized. From 2006, our group started the experiments of bamboo grid packing to promote this new packing technology. Compared with the PVC packing, the operation and transportation costs of bamboo grid packing are higher because of different manufacture methods and high weights of bamboo. However, bamboo grid packing also has many advantages, including good cooling capacity (Fei et al., 2016), high strength and long service life (Ma et al., 2016). The outline of bamboo culm outer surface is irregular arc, which can easily break up the water flow into small drops and is difficult to build up fouling for bamboo grids. The modulus of elasticity of vertical bamboo grid slat decreased only by 25% after 9-year service, which still meets the requirements of application standards according to the “Technical specifications for bamboo filler of fossil fuel plants cooling tower (2014)” (Chen et al., 2018, 2019). The properties of bamboo grid packing used in a cooling tower after 9 years of service were evaluated (Chen et al., 2018) and the effect of the hygrothermal environment in cooling towers on the chemical composition of bamboo grid packing after 9-year service was examined (Chen et al., 2019). These studies focused on the changes of mechanical property and chemical

composition of bamboo packing before and after 9-year service. Owing to the sent study focuses on the energy efficiency and environmental impact of bamboo packing materials in cooling towers.

The thermal transfer from hot water to ambient air and in the cooling packing material is very important. The thermal performance and pressure drop characteristics are usually examined to evaluate the efficiency of different types of cooling packing material. Goshayshi et al. (2006) studied the thermal performance and pressure drop of corrugated packing and found that the coefficient of thermal transfer decreased by increasing the rib pitch to height ratio and the packing pitch. Another study on the use of corrugated packing highlighted that the mass flow ratio of water to air and the type and arrangement of packing materials are also the important factors (Goshayshi and Missenden,

2005). There were however limited studies on the thermal performance of bamboo packing. Chen et al. (2016) compared thermal performance of bamboo packing with PVC packing, and concluded that

the thermal performance of bamboo grid packing was slightly lower. Another investigation on using different types and arrangements of bamboo packing found that there were different cooling performances from using different types of packing (Xi et al., 2000). Even though it is usually considered that the utilization of bamboo packing would be beneficial to environment, the literature review did not find any report regarding the evaluation of environmental performance of bamboo packing in cooling towers.

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Title (Introductory element — Main element — Part #: Part title)

Bamboo-based packing products used in cooling tower

1 Scope *(mandatory)*

Type text.

It always used in cooling tower, removes heat as a cooling materials used for power plant, petrochemical，refrigeration and air condition processes.

2 Normative references *(mandatory)*

Two options of text (remove the inappropriate option).

1) The normative references shall be introduced by the following wording.

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 11855-2:2021 Embedded radiant heating and cooling systems — Part 2: Determination of the design heating and cooling capacity

ISO 16345:2014 Water-cooling towers — Testing and rating of thermal performance

2) If no references exist, include the following phrase below the clause title:

There are no normative references in this document.

3 Terms and definitions *(mandatory)*

Four options of text (remove the inappropriate options).

1) If all the specific terms and definitions are provided in Clause 3, use the following introductory text:

For the purposes of this document, the following terms and definitions apply.

3.1 Filler axle: Bamboo round rods for the filler sheets.

3.2 Plastic sleeve: The plastic material placed on the bamboo rods to space the packing.

3.3 Packing unit: The individual units of the bamboo-based cooling packing

3.4 Assembly lump: A bamboo grid block composed of a certain number of packing units forming pieces staggered up and down

3.5 Simple beam support: The support form where the two ends of the assembly block are placed on a strip support

3.6 Thickness of water drenching direction: The tangential distance between the dripping direction of the forming sheet and the two long sides.

2) If reference is given to an external document, use the following introductory text:

For the purposes of this document, the terms and definitions given in [external document reference xxx] apply.

3) If terms and definitions are provided in Clause 3, in addition to a reference to an external document, use the following introductory text:

For the purposes of this document, the terms and definitions given in [external document reference xxx] and the following apply.

4) If there are no terms and definitions provided, use the following introductory text:

No terms and definitions are listed in this document.

The text below is always included after each option:

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp
— IEC Electropedia: available at https://www.electropedia.org/

3.1
term
text of the definition

Note 1 to entry: Text of the note.

[SOURCE: …]

3.2
term
text of the definition

4 Clause title

Type text.

Bamboo

4.1 Bamboo should be used in stage, which 3-6 years old. The diameter is between 8-15cm. It is recommended that bamboo species are moso bamboo、*Dendrocalamus chinensis* and other bamboo with good straightness. According to the different bamboo forest environment in different areas, the specific circumstances will be adjusted situation to choose the appropriate. shall not use cracks, dead and moth-eaten decay of bamboo. Diameter class, defects and other reference standards GB/T 2690, see Table 1 for details.

Diameter	Wall thickness	tapering	Defect type	Calculating	Allowable limit
8-15cm	3-7mm	Not exceed 1%	bending	The maximum bending arch height shall not exceed the horizontal length of the inner bend	8%
			Dry rot	Within the length of the scale	forbidden
			mildew	Within the length of the scale	forbidden
			damaged by worms	Within the length of the scale	forbidden

			wormhole	A wormhole with a minimum diameter of more than 5mm over the length of the scale	forbidden
			Cracking	Both ends of the measuring scale should not exceed the length range	Two bamboo node
			Surface defect	The arc length and width must not exceed the circumference where it is located The maximum length of the longitudinal part shall not exceed the length of the measuring scale Depth shall not exceed	30% 10% 3mm

EXAMPLE Text of the example.

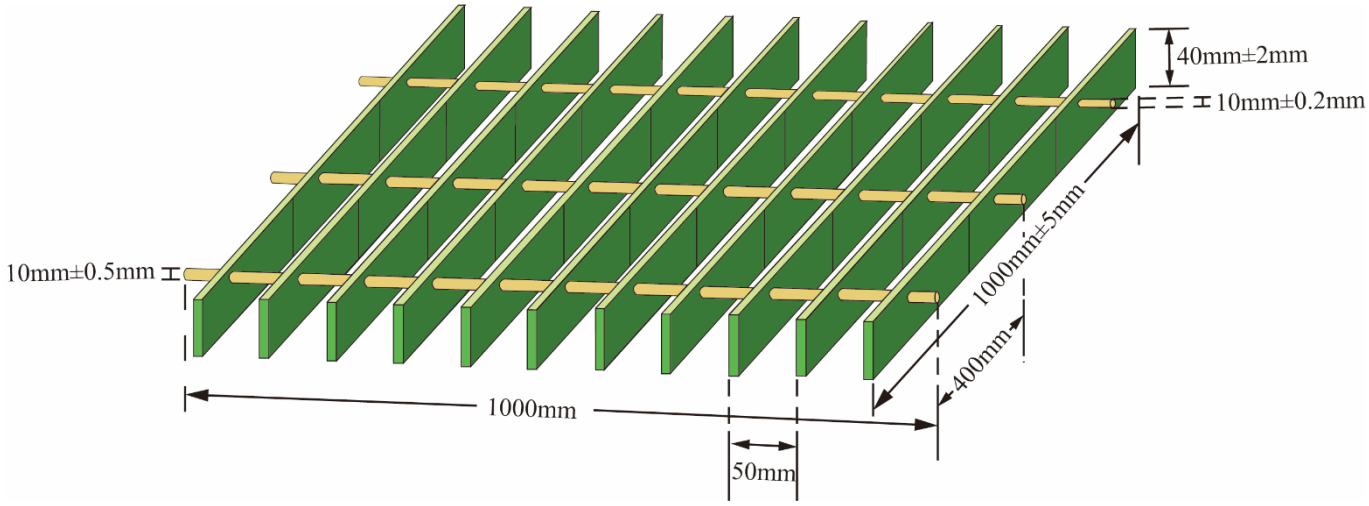

Figure 1 — Example

4.2 The initial moisture content of bamboo should be 8%-15%
4.3 The expansion coefficient of bamboo should meet the following requirements:
4.1.3 The expansion coefficient of bamboo shall meet the following requirements:

a) The coefficient of thermal expansion along the grain should be 2.98×10^{-6}~4.28×10^{-6}

b) Radial thermal expansion coefficient should be 21.8×10^{-6}~30.7×10^{-6}
c) The coefficient of chordal thermal expansion should be29.7×10^{-6}~42.7×10^{-6}
d) The maximum deformation under high humidity conditions does not exceed 40% of the maximum bending strain.

4.2 Threading Rod

The densified bamboo can be chosen, which the compression rate is about 33%, and the diameter should be 8.5mm after compression, the allowable deviation is ±0.5mm. The rebound after hydrothermal environment is about 15%. The mechanical properties of the packing rod shall be determined by bending test in accordance with Appendix A.

4.3 Casing

Soft pipe or other degradable pipe can be used for the casing to temporarily fix. The inner diameter is greater than 11mm, and the length of the casing should be 38mm or 50mm according to different needs, and the allowable deviation should be ±2mm.

5. Filler forming sheet

5.1 The size and length of the filler forming sheet should be 1200mm~1600mm, and the allowable deviation should be ±5mm; The width should be 30mm~40mm, and the allowable deviation should be ±2mm. The thickness of the water surface should be 4mm~8mm.

5.2 The holes on the filler forming sheet should be on the center line of the width of the bamboo sheet, the spacing between the two holes should not be greater than 500mm, the aperture should be 10mm, and the allowable deviation should be ±2mm.

5.3 The surface of the filler forming sheet should have no obvious burrs, cracks and notches.

5.4 The plane warpage of the packing sheet in the direction of length should not be greater than 1.5%, the side warpage in the direction of length should not be greater than 0.8%, and the warpage should be f/L×100%.

5.5 The water surface of the filler forming sheet should be parallel to the center line of the filler piercing rod.

5.6 The physical and mechanical properties and inspection methods of the molded sheet shall comply with the provisions of Table 2.

Table 2 Physical and mechanical properties and testing methods of the molded sheet

Number	Project name	symbol	units	index	Test method
1	density at dry condition		g/cm^3	≥0.70	GB/T 15780
2	density of saturated water absorption		g/cm^3	≤1.40	GB/T 15780
3	compressive strength at 10% MC	σ_{12}	MPa	≥60	GB/T 15780
4	Flexural strength at 12%MC（lateral）	σ_{b12}	MPa	≥100	GB/T 15780
5	Elastic modulus at 12%MC（lateral）	E_w	MPa	≥8500	GB/T 15780

5.3 Assembly Blocks

5.3.1 The stiffness and bearing capacity of the assembly block should meet the design requirements, and obvious deformation and rupture should occur within -50 ° C ~100 ° C, and should be maintained and not loose, and the service life should not be less than 15 years.

5.3.2 The assembly block can be divided into supporting type and non-supporting type. The bottom layer of the supporting assembly block shall be the bamboo packing material with simple support type placed on the bar support at both ends; The unsupported assembly block shall be the bamboo packing material resting on the supported assembly block.

5.3.3 The size of the supporting assembly block should be 1600mm×500mm×40mm, and the spacing of the forming pieces should be 38mm; The size of the non-supported assembly block should be 1200mm×500mm×40mm, and the spacing of the forming pieces should be 50mm. The allowable deviation of spacing should be ± 3.0mm.

5.3.4 The supported assembly block should have sufficient stiffness and meet the standard specimen under the uniformly distributed load of 8500N/m^2 under simply supported conditions. The supporting surface and load surface should have no obvious warping, lodging and other deformation phenomena, and the downward displacement at the bottom should not exceed 50mm. The test method is shown in the appendix.

5.3.5 The non-supported assembly block should have sufficient stiffness. Under the uniform load of 8500N/m^2, the standard specimen under simply supported conditions have no obvious warping, lodging and other deformation phenomena on the support surface and load surface. See the appendix for the test method.

5.3.6 The plane of the assembly block parallel to the packing rod shall be flush and consistent.

5.3.7 All six sides of the assembly block shall be rectangular or square, and its geometry shall remain stable under normal conditions of use.

5.3.8 The passage of the assembly block should be smooth, not easy to block, not easy to scale, should not pollute the water quality, and should maintain long-term stable heat exchange characteristics.

5.4 Packing Installation

5.4.1 Bamboo-base packing should be installed flat. It should be corrected and adjusted when it tilts. The difference value of relative height shall not exceed 20mm.

5.4.2 The bamboo-base packing inside the tower should be filled with the cylinder, and the pores between the edge of the packing and the inner wall of the air duct should not be greater than 50mm. The whole packing layer in the tower should not have a straight joint greater than 50mm.

5.4.3 Handle the components gently during installation to prevent damage. Replace the components if they are damaged or broken.

5.4.4 The bamboo-base packing should be laid tightly in the tower. In the irregular area, the packing should not be suspended for too long, missing and other incomplete support phenomena. If there is no reliable shelving condition, the supporting frame should be added.

5.4.5 The support span of the bamboo-base packing material should be suitable, not greater than 1500mm. The suspension length of the packing should not be greater than 0.2 times the total length of the filler block (L); The hanging length of the packing material in the corner area should not be greater than 0.2L.

5.4.6 The three layers at the bottom of the packing shall adopt the support type assembly block, and the cross-lap joint shall be adopted on the shelved support, and the cross-lap length shall not be less than 100mm; Other non-supported assembly blocks shall be jointed.

5.4.7 The upper and lower assembly blocks shall be laid in a criss-cross and positive "#" shape, and the packing channels shall be uniform.

6 Packing acceptance

6.1 General Requirements

The acceptance of the water filling shall be based on the batch, and the formed pieces and assembly blocks produced by the same origin, specification and process shall be regarded as one batch, and the sampling inspection method shall comply with the provisions of GB/T 2828.1.

6.2 Forming Sheet

6.2.1 The effective form inspection report of the formed sheet shall comply with the requirements of 5.2.1~5.2.6.

6.2.2 The appearance and specifications of the molded sheet shall comply with the requirements of 5.2.1~5.2.5 of this standard, and those that do not meet any of the requirements shall be judged as unqualified products, and the sampling inspection of the molded sheet shall comply with the provisions of Table 3.

Table 3 Checking the formed bamboo-based grid pieces

Count(piece)	Number of sampling	Acceptable number of nonconformities	Unacceptable number of nonconformities	Checking list
501~1200	32	≤5	≥6	5.2.1~5.2.6
1201~3200	50	≤7	≥8	
3201~10000	80	≤10	≥11	

10001~35000	125	≤14	≥15	
35001~150000	200	≤21	≥22	
150001~500000	315	≤21	≥22	
>=500001	500	≤21	≥22	

6.2.3 The properties and inspection methods of the molded pieces shall comply with 5.2.6. The supplier shall provide the physical and mechanical properties inspection report of the bamboo for each batch of the molded pieces according to the requirements in Table 1.

6.2.4 Acceptance of molded pieces shall take any two pieces in each batch of molded pieces, and conduct material performance inspection according to Table 1. If one index fails to meet the requirements, the sample of the original batch of molded pieces shall be doubled, and the unqualified items shall be reinspected. If the reinspection results are still unqualified, the batch of molded pieces shall be judged unqualified.

6.2.5 Type inspection shall be conducted at least once every two years, and in any of the following cases, type inspection shall be conducted:

a) New products or old products transferred to the factory production of prototype identification.

b) When the structure, material and process are greatly changed, which may affect the performance of the product.

c) When the product is resumed after 1 year of discontinuation.

d) When there is a big difference between the factory inspection result and the last type inspection result.

e) When a qualified quality inspection structure is proposed for type inspection.

6.3 Packing rod

The type inspection of the packing rod should meet the requirements of this standard 4.2, and the appearance sampling should meet the provisions of Table 3, in which the mechanical property inspection should meet the provisions of Appendix A. If the requirements are not met, the original batch of rod should be double reinspected, and if the reinspection results are still unqualified, the batch of rod should be judged unqualified.

6.4 Assembling Blocks

6.4.1 The specifications, appearance and assembly process of the assembly blocks shall comply with the provisions of 5.3.1~5.3.8 of this standard. Those that do not meet the requirements of any article shall be judged as nonconforming products, and the sampling inspection shall comply with the provisions of Table 4.

Table 4 The judgment provisions of assembly block sampling inspection

Count(block)	Number of sampling	Acceptable number of nonconformities	Unacceptable number of nonconformities	Checking list
51~90	5	≤1	≥2	5.3.1~5.3.8
91~150	8	≤1	≥2	
151~280	13	≤2	≥3	
281~500	20	≤3	≥4	
501~1200	32	≤5	≥6	
1201~3200	50	≤7	≥8	
3201~10000	80	≤10	≥11	

10001~35000	125	⩽14	⩾15	
35001~150000	200	⩽21	⩾22	
150001~500000	315	⩽21	⩾22	
>=500001	500	⩽21	⩾22	

6.4.2 The stiffness of the supporting assembly blocks shall meet the requirements of 5.3.4, and nine assembly blocks shall be selected in each batch for load test according to the prescribed inspection and determination method. If the assembly blocks fail to meet the requirements, they shall be reinspected twice. If there are still unqualified, the assembly blocks shall be judged to be unqualified.

6.4.3 The stiffness of non-supported assembly blocks shall meet the requirements of 5.3.5 and shall be determined according to the prescribed inspection method. One assembly block shall be selected in each batch for load test. If it fails to meet the requirements, it shall be reinspected twice.

7 Packaging, storage and transportation

7.1 Packaging

The product should be firmly bundled and packed with clear marks. The name of the product, the name of the manufacturer, the address of the manufacturer, the date of production, the implementation standard and the operation manual of the product shall be indicated.

7.2 Transportation

Products should be stacked smoothly during transportation, and should avoid long-term direct exposure to the sun or rain.

7.3 Storage

Storage should be stacked in accordance with the specifications on the flat ground, should prevent damage, exposure and away from heat sources, should prevent moisture, keep dry, ventilated.

8 Shutdown maintenance

8.1 The cooling tower should be regularly checked and sprayed during long-term outage to prevent damage to the packing material.

8.2 Before operation, check the bamboo water filling, and there should be no tilting, cracking, collapse, decay and other phenomena.

Annex A
(informative)

Test method for bending of bamboo grid packings

A.1 *Basic Principles*

The bamboo dripped packing depends on the packing rod to form the packing sheet to form the assembly block. The test simulates the practical condition of the packing piercing rod, and bends the packing piercing rod to evaluate its material toughness and manufacturing quality.

A.2 *Instruments*

A.2.1 *Universal mechanical testing machine*

A.3 Sample

The bamboo packing rod length is (150±0.5) mm uniform straight rod segment. There are 2 groups of 5 sticks in each group.

A.4 Test Operation

4.1 The sample of the piercing rod was soaked in water at room temperature for 24h and then taken out and placed in room temperature environment for 30min.

4.2 Adjust the testing machine so that the compression speed of the indenter of the three-point bending test device is (5±2) mm/min, the support span L is 10D, D is the diameter of the tie rod, the diameter of the end of the support and the end of the indenter, and the diameter of the support and the end of the indenter is 30mm.

4.3 The sample should be placed flat on the support, align with the indenter, use the chord plane loading (bamboo green face up), start the testing machine to make the indenter press down, stop the pressure when the deflection f of the sample center is 4.0mm, keep the indenter rise after 30s, and take out the sample.

A.5 Result Determination

If there is no fracture in the test of each group (5) piercing rod samples, it is judged to be passed.

Annex B
(informative)

Test method for bamboo assembly lump

B.1 Basic Principles

The stiffness of the assembly block is mainly reflected in the pressure resistance characteristics of the upper and lower boundary layers and the overall tightness of the assembly block. Load test is a comprehensive assessment of the assembly stiffness of packing block. After loading, the buckling and collapse in the middle of the support cause the assembly block to tilt, and the general instability of the assembly block is aggravated by the disintegration of the internal connection points of the assembly block and the rupture of the filler forming sheet. If the bending exceeds a certain range (about 50mm), the assembly block will lose the ability to continue bearing and accelerate the rupture, loose, and lodging.

B.2 Instruments

Simple support device: support length 1500mm, support width 100mm, support height 200mm, clear distance 1400mm, the two strips of support parallel and located on the same level; 150mm steel ruler (measuring accuracy 0.5mm), precision 1% standard load blocks.

B.3 Sample

Supporting type assembly block size: length □ width □ height =1600mm□500mm□40mm, three layers, a total of nine pieces, the assembly block should be soaked in room temperature water for 3h~4h before the test.

B.4 Test Operation

B.4.1 Temperature: room temperature.

B.4.2 Supporting method: Place the upper and lower three-layer supporting assembly block on the supporting device in the form of "#", and record the distance from the middle bottom of the assembly block to the ground.

B.4.3 Loading method: Load 8500N/m2 at the top surface of the supporting assembly block at a time, evenly distributed.

B.4.4 Loading Time: 1h.

B.5 Result Determination

It should be qualified that the downward displacement of the bottom of the assembly block is not more than 50mm, no rupture, no lodging.

Bibliography

[1] ISO #####-#, *General title — Part #: Title of part*

[2] ISO #####-##:20##, *General title — Part ##: Title of part*