

## A STUDY ON IMPORTED TIMBER PERFORMANCE IN INDUSTRIAL COOLING TOWER

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### Abstract:

Timber being a high strength and weight ratio material fulfills structural and fill area requirement of cooling tower. It helps to dissipate heat from hot water and allows cooling it timely. However the suitability of timber species for this purpose needs research attention, since probability of biological deterioration is high in humid conditions. In the present study, three softwood species i.e. *Pinus roxburghii*, *Pinus radiata* and *Pseudotsuga menziesii* were treated with CCA, CCB and ZIBOC at 2, 4 and 6% concentration and tested in industrial cooling tower. The samples were removed at 6, 12, 18 and 24 months and analyzed for preservative loss as well as weight loss. Results revealed that untreated timber was not durable and needs preservative treatment. Significant preservative and weight loss was occurred in all treated timber species after 24 month. Although, substantial preservative retention as required for cooling tower condition was achieved in samples treated at 6% concentration. Two imported species i.e. *Pinus radiata* and *Pseudotsuga menziesii* performed better as compared to indigenous *Pinus roxburghii*.

**Key words:** Cooling tower; CCA; CCB, *Pinus roxburghii*, *Pinus radiata*, *Pseudotsuga menziesii*, ZIBOC.

### INTRODUCTION

Timbers is one of the materials used in structural and fill areas of cooling tower and serve as efficient and economical means for dissipating heat from water, which is re-circulated through the pipes for cooling purposes. In cooling tower, timber is in direct contact with water having high moisture content, high temperature and variable pH of 4 to 9. This wet and humid environment of water-saturated wood provides suitable conditions for attacking of Ascomycetes and Deuteromycetes, which cause soft rot in untreated timber (Eaton and Jones 1971, Morrell and Smith 1988). Generally, soft-rot attack occurs in the fill area of the cooling tower; whereas, white rot and brown rot prevail in areas where timbers do not come in direct contact with water. Bacteria may also cause timber decay in cooling towers but it is relatively slow (Singh *et al.* 1992). Basidiomycetes or rotting fungi rarely occur in cooling towers and restricted to only upper parts in a tower which are not always wet (Udaiyan and Manian 1991). Recent changes in the water treatment schedules with various chemicals in cooling towers had resulted more severe wood attack and decay by other fungi (Schmidt *et al.* 1996). Therefore, timber used in cooling towers should either be of naturally durable heartwood or must be treated with suitable fixed type of water based preservatives in order to obtain long service life. The attack and decay is attributed to low preservative retention and improper impregnation. Thus, maintenance of timber in cooling towers is of great economic importance, since the towers represent high investment amount especially in large industries. Furthermore, the replacements are costly and adversely affect the industrial processes due to reduced cooling capacity during the forced shutdowns. Considerable work on testing the efficacy of preservatives and natural durability of timbers in cooling towers has been carried out in Forest Research Institute Dehradun, India (Chandra *et al.* 1972, 1973, Pant *et al.* 1982) and on the basis of work done at F.R.I., Indian specifications (IS:2372 2004) have been prepared. The Bureau of Indian Standards (BIS) (2372 2004) had listed out only *Abies pindrow* (Fir), *Cedrus deodara* (Deodar), *Picea smithiana* (Spruce), *Pinus kesiya* (Khasi pine), *Pinus roxburghii* (Chir), *Pinus wallichiana* (Kail), *Pseudotsuga menziesii* (Douglas fir), *Tectona grandis* (Teak) for use in cooling towers. Later on *Pinus radiata* (radiata pine) was also included in this list. The standard also exhibited that the structural and the shell members of timber are to be treated to a net retention of 12 kg/m<sup>3</sup> with copper-chrome-arsenic (CCA) or acid-copper-chrome (ACC) or 16 kg/m<sup>3</sup> of copper-chrome-boron (CCB) or 128 kg/m<sup>3</sup> of creosote/fuel oil mixture in accordance with IS 401(2001). Fill is to be treated under pressure with a minimum average retention of 16 kg/m<sup>3</sup> of timber with copper-chrome-arsenic (CCA) or acid-copper-chrome (ACC) or 20 kg/m<sup>3</sup>

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of copper-chrome-boron (CCB) or 160 kg/m<sup>3</sup> of creosote/fuel oil mixture. Although, all above preservatives are either carcinogenic or hazardous. Keeping this in view, a new environ-safe wood preservative ZiBOC (Zinc copper borate) was developed and tested in Forest Research Institute (F.R.I.) Dehradun and found comparable with CCA in exterior ground conditions (Tripathi 2013). Due to the limited availability of indigenous natural grown species, the focus is now shifting either to imported timbers like *Pinus radiata* from New Zealand and Australia, *Pinus elloti* from South Africa and *Pseudotsuga menziesii* from Europe or plantation grown indigenous timber. Comparative behavior of *Pinus radiata* species with *Pinus roxburghii* has not been studied so far on scientific lines in cooling tower applications. It is already established that *Pinus radiata* is inferior as compared to indigenous pine in ground contact condition in untreated form; however, performance improves after treatment with CCA (Tripathi 2005). Therefore, in the present study *Pinus radiata* and Douglas fir are taken to study its performance after treatment in industrial cooling tower and compared with *Pinus roxburghii*.

## MATERIALS AND METHODS

**PROCUREMENT OF WOOD SPECIES:** Logs of freshly harvested tree (10-15 feet long) of *Pinus roxburghii* Sarg. was procured from New Forest Campus, Dehra Dun, India and processed for sample preparation. Whereas, sleepers of *Pinus radiata* and *Pseudotsuga menziesii* were imported from New Zealand and USA respectively and procured through local trader.

**SAMPLE PREPARATION:** The logs and sleepers were converted into samples as per IS: 6497 (1990). Thin veneers of size 10 cm x 2.5 cm x 0.6 cm with two holes having diameter of 2 mm were prepared from defect free and seasoned sleepers of *Pinus roxburghii*, *Pinus radiata* and *Pseudotsuga menziesii*. Samples were marked and grouped separately for treatment. Total number of 720 veneer samples was prepared.

**PRESERVATIVE:** The following three water borne preservatives at 2, 4 and 6% concentration (conc.) were taken for the study

1. ZiBOC- ZnCl<sub>2</sub>, Na<sub>2</sub>B<sub>4</sub>O<sub>7</sub>.10H<sub>2</sub>O, CuSO<sub>4</sub>.5H<sub>2</sub>O as per (Tripathi 2013)
2. CCB- H<sub>3</sub>BO<sub>3</sub>, CuSO<sub>4</sub>.5H<sub>2</sub>O, K<sub>2</sub>Cr<sub>2</sub>O<sub>7</sub> as per IS 401(2001)
3. CCA- As<sub>2</sub>O<sub>5</sub>.2H<sub>2</sub>O : CuSO<sub>4</sub>.5H<sub>2</sub>O : K<sub>2</sub>Cr<sub>2</sub>O<sub>7</sub> as per IS 401(2001)

**TREATMENT METHOD:** The treatment was done with 2, 4 and 6% of CCA, CCB and ZiBOC in *Pinus roxburghii* and *Pinus radiata* by full cell method of impregnation (IS 401:2001), where an initial vacuum of 50 cm Hg for 30 min was followed by air pressure of 50 lbs/in<sup>2</sup> (3.5 kg/cm<sup>2</sup>) for 30 min. While in *Pseudotsuga menziesii* air pressure was increased upto 150 lbs/in<sup>2</sup> (10.5 kg/cm<sup>2</sup>) in full cell method. The amount of preservative solution absorbed by samples was calculated in kg/ m<sup>3</sup> on wet weight basis (Tripathi 2012). The samples were left for 21 days for preservative fixation. The retention of chemicals in veneer was calculated by the following formula:

$$\text{Retention of preservative (kg/ m}^3\text{)} = \frac{GC \times 10}{V}$$

where: G = weight of veneer after treatment – weight of veneer before treatment (g)

C = Concentration of preservative used (%)

V= Volume of veneer (cm<sup>3</sup>)

**SAMPLE INSTALLATION IN INDUSTRIAL COOLING TOWER:** Total 40 numbers of frames of size 10 x 65 cm<sup>2</sup> were prepared as per IS: 6497 (1990) with fixation of 18 veneers in each frame (Fig. 1). The arrangement of veneers was made in such a way that one frame consist of six samples of each species viz; *Pinus roxburghii*, *Pseudotsuga menziesii* and *Pinus radiata* with one concentration of one preservative. The frames were installed in Thermal Power Station, Yamuna Nagar, Haryana, India (Fig. 2) for field trial as given in (Fig. 3).



**Fig.1.**  
*Frame prepared with untreated and treated veneers.*



**Fig. 2.**  
*Cooling tower in Thermal Power Station.*

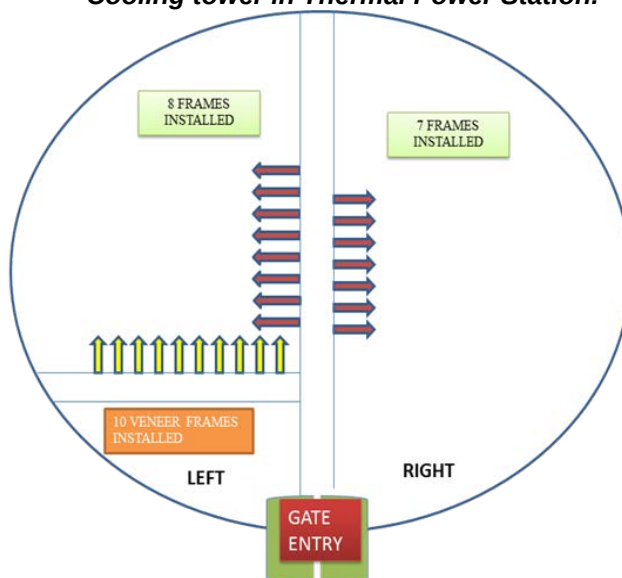


**Fig. 3.**  
*Schematic layout of sample installation.*

**SAMPLE INSPECTION AFTER REMOVAL FROM INDUSTRIAL COOLING TOWER:** Total 10 frames consisting untreated and treated veneer samples were removed from industrial cooling tower at six months interval from the date of installation up to two years i.e. 6, 12, 18 and 24 months (M). Therefore, total 40 frames were removed from cooling tower in two years. Veneer samples removed were examined for weight loss after oven drying at 50° C for 72 hrs. The samples were digested and prepared for determination of dry salt retention of preservative. Arsenic, Copper, Chrome, boron and Zinc were estimated in treated veneer samples before installation and after removal from industrial cooling tower as per IS: 2753 (1991).

## RESULTS

Table1 demonstrates average retention of preservative on wet basis in veneer samples treated with various conc. of preservatives. In *Pinus roxburghii*, CCA exhibited 9.49 kg/m<sup>3</sup> average retention at 2% followed by 18.50 kg/m<sup>3</sup> at 4% and 24.00 kg/m<sup>3</sup> at 6% conc. Whereas CCB and ZiBOC showed 9.10-25.00 kg/m<sup>3</sup> and 9.41-27.20 kg/m<sup>3</sup> average retention in *Pinus roxburghii* at different conc. respectively. Substantial higher retentions of different preservative i.e. CCA, CCB and ZiBOC could be observed in *P. radiata* (Table1). Average retention of 11.26-27.90, 11.00- 34.91 and 10.40- 32.20 kg/m<sup>3</sup> was recorded by CCA, CCB and ZiBOC respectively in *P. radiata*. In *Pseudotsuga menziesii*, the average retention was 9.44-27.00 kg/m<sup>3</sup>, 8.90-27.33 kg/m<sup>3</sup> and 10.90-24.70 kg/m<sup>3</sup> by CCA, CCB and ZiBOC respectively. Mean of preservative retentions was found 19.62 kg/m<sup>3</sup> by ZiBOC followed by 19.50 kg/m<sup>3</sup> by CCB and 18.85 kg/m<sup>3</sup> by CCA irrespective of species or concentration.

Table 1

**Average wet retention (kg/m<sup>3</sup>) of preservative in test species at different concentration**

| Preservative                 | CCA   |       |       | CCB   |       |       | ZiBOC |       |       |
|------------------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Species                      | 2%    | 4%    | 6%    | 2%    | 4%    | 6%    | 2%    | 4%    | 6%    |
| <i>Pinus roxburghii</i>      | 9.49  | 18.50 | 24.00 | 9.10  | 18.80 | 25.00 | 9.41  | 20.4  | 27.20 |
| <i>Pinus radiata</i>         | 11.26 | 21.60 | 27.90 | 11.00 | 23.30 | 34.91 | 10.4  | 20.21 | 32.20 |
| <i>Pseudotsuga menziesii</i> | 9.44  | 20.50 | 27.00 | 8.90  | 17.20 | 27.33 | 10.97 | 21.11 | 24.70 |

Table 2

**Average Dry Salt Retention and percent Dry Salt Retention loss of preservative in veneers in Industrial cooling tower at periodic inspection**

| Species                 | Preservative | Conc. % | Average Dry Salt Retention (Kg/m <sup>3</sup> ) |          |           |           |           | Dry Salt Retention loss% After 24 months |
|-------------------------|--------------|---------|-------------------------------------------------|----------|-----------|-----------|-----------|------------------------------------------|
|                         |              |         | Before Installation                             | 6 months | 12 months | 18 months | 24 months |                                          |
| <i>Pinus roxburghii</i> | CCA          | 2       | 9.1                                             | 8.70     | 7.80      | 7.60      | 4.50      | 50.55<br>(1.68)                          |
|                         |              | 4       | 17.1                                            | 15.15    | 13.50     | 12.20     | 7.60      | 55.56<br>(1.55)                          |
|                         |              | 6       | 22.9                                            | 21.22    | 19.50     | 12.60     | 11.70     | 48.91<br>(2.00)                          |
|                         | CCB          | 2       | 8.0                                             | 6.44     | 5.90      | 5.80      | 2.40      | 70.00<br>(1.45)                          |
|                         |              | 4       | 18.6                                            | 15.66    | 14.80     | 14.80     | 12.00     | 35.48<br>(1.36)                          |
|                         |              | 6       | 25.1                                            | 22.07    | 20.99     | 20.80     | 17.50     | 30.28<br>(1.43)                          |
|                         | ZiBOC        | 2       | 7.0                                             | 5.52     | 4.45      | 3.50      | 2.50      | 64.29<br>(1.72)                          |
|                         |              | 4       | 14.8                                            | 12.51    | 11.88     | 11.30     | 9.70      | 34.46<br>(1.24)                          |
|                         |              | 6       | 24.2                                            | 21.89    | 19.6      | 19.3      | 15.40     | 36.36<br>(1.34)                          |
| <i>Pinus radiata</i>    | CCA          | 2       | 11.2                                            | 9.92     | 9.52      | 9.40      | 7.20      | 35.71<br>(1.37)                          |
|                         |              | 4       | 20.5                                            | 18.24    | 17.60     | 17.20     | 10.10     | 50.73<br>(1.23)                          |

|                              |       |   |      |       |       |       |       |                 |
|------------------------------|-------|---|------|-------|-------|-------|-------|-----------------|
|                              |       | 6 | 27.1 | 24.88 | 21.76 | 18.00 | 14.80 | 45.39<br>(1.61) |
|                              | CCB   | 2 | 9.5  | 7.06  | 6.28  | 6.50  | 3.20  | 66.32<br>(0.86) |
|                              |       | 4 | 21.3 | 19.58 | 17.85 | 17.50 | 14.50 | 31.92<br>(1.30) |
|                              |       | 6 | 31.3 | 27.38 | 25.90 | 25.70 | 23.80 | 23.96<br>(1.06) |
|                              | ZiBOC | 2 | 11.4 | 9.01  | 8.66  | 8.50  | 4.90  | 57.02<br>(1.11) |
|                              |       | 4 | 19.1 | 16.19 | 15.51 | 15.10 | 11.50 | 39.79<br>(1.39) |
|                              |       | 6 | 30.8 | 26.02 | 24.78 | 20.30 | 15.80 | 48.70<br>(1.43) |
| <i>Pseudotsuga menziesii</i> | CCA   | 2 | 6.5  | 5.53  | 4.70  | 4.30  | 2.30  | 64.62<br>(1.97) |
|                              |       | 4 | 14.8 | 12.75 | 12.00 | 10.70 | 9.80  | 33.78<br>(1.37) |
|                              |       | 6 | 23.2 | 20.68 | 20.09 | 19.90 | 14.10 | 39.22<br>(1.28) |
|                              | CCB   | 2 | 6.4  | 4.34  | 4.05  | 3.90  | 2.70  | 57.81<br>(1.18) |
|                              |       | 4 | 14.1 | 12.62 | 10.98 | 10.80 | 8.10  | 42.55<br>(1.11) |
|                              |       | 6 | 24.2 | 20.89 | 19.88 | 19.70 | 14.80 | 38.84<br>(1.39) |
|                              | ZiBOC | 2 | 9.8  | 9.03  | 8.55  | 8.40  | 4.30  | 56.12<br>(1.04) |
|                              |       | 4 | 18.9 | 15.06 | 15.00 | 14.60 | 8.20  | 56.61<br>(1.35) |
|                              |       | 6 | 23.3 | 19.03 | 17.87 | 17.80 | 11.50 | 50.64<br>(1.40) |

\*The figures in parentheses represent standard deviation

Table 2 shows average Dry Salt Retention (DSR) and percent DSR loss of preservative in samples installed in industrial cooling tower at different time interval. Results exhibited mean DSR loss of 48.91-55.56%, 30.28-70.00% and 34.46-64.29% of CCA, CCB and ZiBOC in *Pinus roxburghii* respectively after 24 months. Whereas, *Pinus roxburghii* revealed average residual levels of 11.70, 17.50 and 15.40 kg/m<sup>3</sup> by CCA, CCB and ZiBOC at 6% conc. respectively and fulfilled the criteria as per IS 2372 (2004). CCB revealed 12.00 Kg/m<sup>3</sup> residual DSR at 4% conc. after 24 months, whereas CCA and ZiBOC recorded 7.60-9.70 Kg/m<sup>3</sup> average DSR after 24 months in *Pinus roxburghii*. Similarly in *P.radiata*, CCA and ZiBOC at 6% conc. exhibited sufficient residual levels of preservative i.e. 14.80 and 25.4 kg/m<sup>3</sup> respectively, while CCB exhibited it at 4% conc. exhibited 15.50 kg/m<sup>3</sup>. In *P.radiata* average DSR loss was found 23.96-66.32% after 24 months. In spite of this, the DSR observed after 24 months in *P.radiata* was higher than 10 Kg/m<sup>3</sup>, except 2% conc. of all preservatives. The highest DSR in *P.radiata* was noted in samples treated with 6% of CCB i.e. 23.80 Kg/m<sup>3</sup>. It is noted that in *Pseudotsuga menziesii*, the DSR loss was more than 50% at 2% conc. of CCA, CCB and ZiBOC and showed average DSR of 2.30-4.30 Kg/m<sup>3</sup> after 24 months, which is too low to impart resistance in cooling tower conditions. Whereas, optimum required retention in *Pseudotsuga menziesii* was observed at only 6% of all test preservatives i.e. 11.50-14.80 Kg/m<sup>3</sup>.

Table 3 exhibits average weight loss of untreated and treated veneers with different conc. in industrial cooling tower after 6, 12, 18 and 24 months. Untreated samples of veneers revealed that all species exhibited substantial weight loss after two years of installation. Even in initial 6 month, 13.8-16.9% weight loss was recorded in untreated species.

Table 3

*Average weight loss % in samples at periodic inspection after exposure to cooling tower*

| Name of Species              | Preservative | Conc.% | Average weight loss% |           |          |                |
|------------------------------|--------------|--------|----------------------|-----------|----------|----------------|
|                              |              |        | 6 Months             | 12 Months | 18Months | 24 Months      |
| <i>Pinus roxburghii</i>      | Untreated    | -      | 15.4                 | 15.4      | 16.2     | 19.8<br>(1.29) |
|                              | CCA          | 2      | 6.1                  | 6.5       | 17.1     | 20.9<br>(1.60) |
|                              |              | 4      | 13.9                 | 14.1      | 16.6     | 20.3<br>(2.16) |
|                              |              | 6      | 8.6                  | 9.5       | 13.3     | 17.5<br>(1.36) |
|                              | CCB          | 2      | 7.2                  | 11.9      | 16.3     | 20.2<br>(1.62) |
|                              |              | 4      | 12.8                 | 13.5      | 15.8     | 19.3<br>(1.56) |
|                              |              | 6      | 8.7                  | 9.3       | 16.4     | 18.5<br>(1.78) |
|                              | ZiBOC        | 2      | 7.3                  | 7.5       | 7.6      | 16.3<br>(1.34) |
|                              |              | 4      | 7.9                  | 8.6       | 18.0     | 21.8<br>(1.58) |
|                              |              | 6      | 8.0                  | 8.8       | 12.9     | 17.8<br>(1.97) |
| <i>Pinus Radiata</i>         | Untreated    | -      | 16.9                 | 17.0      | 18.1     | 36.2<br>(1.46) |
|                              | CCA          | 2      | 9.8                  | 13.8      | 17.9     | 21.0<br>(1.26) |
|                              |              | 4      | 13.6                 | 14.1      | 17.2     | 19.2<br>(1.93) |
|                              |              | 6      | 11.8                 | 13.6      | 15.5     | 19.8<br>(1.14) |
|                              | CCB          | 2      | 9.6                  | 12.4      | 16.2     | 20.3<br>(1.58) |
|                              |              | 4      | 12.1                 | 13.4      | 16.4     | 18.8<br>(2.06) |
|                              |              | 6      | 10.2                 | 13.4      | 14.4     | 19.3<br>(1.51) |
|                              | ZiBOC        | 2      | 9.3                  | 9.3       | 11.1     | 16.8<br>(0.78) |
|                              |              | 4      | 7.6                  | 11.5      | 13.5     | 22.5<br>(1.55) |
|                              |              | 6      | 13.8                 | 14.8      | 16.9     | 25.4<br>(1.27) |
| <i>Pseudotsuga menziesii</i> | Untreated    | -      | 13.8                 | 15.1      | 17.0     | 27.7<br>(2.17) |
|                              | CCA          | 2      | 8.1                  | 8.3       | 12.2     | 15.8<br>(1.87) |
|                              |              | 4      | 11.9                 | 14.6      | 15.5     | 21.8<br>(1.87) |
|                              |              | 6      | 11.1                 | 12.9      | 14.3     | 17.7<br>(2.20) |
|                              | CCB          | 2      | 9.1                  | 10.2      | 16.6     | 22.6<br>(1.50) |
|                              |              | 4      | 12.5                 | 12.6      | 15.5     | 18.2<br>(1.87) |

|  |       |   |      |      |      |                |
|--|-------|---|------|------|------|----------------|
|  |       | 6 | 13.8 | 14.5 | 16.2 | 19.3<br>(1.80) |
|  | ZiBOC | 2 | 9.8  | 11.1 | 14.9 | 25.1<br>(2.03) |
|  |       | 4 | 9.4  | 12.4 | 14.1 | 19.5<br>(2.35) |
|  |       | 6 | 13.0 | 14.5 | 15.6 | 22.1<br>(2.65) |

\*The figures in parentheses represent standard deviation

The weight loss increased with increasing exposure time to cooling tower conditions, especially from 18 month to 24 month time period. Results showed that in untreated samples *Pinus roxburghii* exhibited 19.8% average weight loss, whereas *P.radiata* exhibited higher i.e 36.2% average weight loss, while untreated samples of *Pseudotsuga menziesii* exhibited 27.7% of average weight loss after 24 months. *Pinus roxburghii* treated with CCA, CCB and ZiBOC recorded 17.5-20.9%, 18.5-20.2% and 16.3-21.8% average weight loss respectively after 24 months. Whereas, in *P.radiata*, it was found 19.2-21.0%, 18.8-20.3 and 16.8-25.4% in samples treated with CCA, CCB and ZiBOC respectively. It is noted that weight loss of treated samples of *P.radiata* and *Pseudotsuga menziesii* was found less than untreated samples. Results exhibited that after treatment, weight loss in *Pseudotsuga menziesii* was noted 15.8-21.8%, 18.2-22.6% and 19.5-25.1% by CCA, CCB and ZiBOC respectively after 24 months.

## DISCUSSION

The present study exhibits that 2% conc. of all the preservatives resulted only 8.90-11.20 kg/m<sup>3</sup> of retentions, which is lower as prescribed in IS 2372 (2004). However, substantially high retention level i.e.18.50-23.30 kg/m<sup>3</sup> could be observed with different preservative at 4% conc., which can be recommended to treat wood for cooling tower applications as per IS: 2372 (2004). The structural and shell members must be treated to minimum retention of 12 Kg/m<sup>3</sup> with copper chrome arsenic (CCA) or 16 kg/m<sup>3</sup> of copper chrome boron (CCB) as per IS: 2372 (2004). Although 24.00-34.91 kg/m<sup>3</sup> average retention could be achieved at 6% conc., but as compared to 4% conc., it is not economical. Overall ZiBOC and CCB resulted similar retention level in test species, whereas CCA resulted less retention than ZiBOC and CCB. Mean retention of preservative in different species exhibits that *P.radiata* demonstrated maximum retention i.e. 21.42 kg/m<sup>3</sup> followed by 18.57 kg/m<sup>3</sup> in *Pseudotsuga menziesii* and 17.98 kg/m<sup>3</sup> in *Pinus roxburghii*. High retention of preservative in *P.radiata* was also observed by Lal and Tripathi (2009). It may be due to ease of treatability of *P.radiata*, which falls in treatability class of 4 (EN 350-2:1994).

It was observed that the average of DSR loss irrespective of species and conc. was in the order ZiBOC 49.33% > CCA 47.16% > CCB 44.13%. Whereas, average of preservative loss in different test species irrespective of conc. and preservative was in the order *Pseudotsuga menziesii* 48.90% > *Pinus roxburghii* 47.32% > *P.radiata* 44.39%. Similar DSR loss was recorded in *Pseudotsuga menziesii* i.e. 48.29% when the samples were tested in prototype cooling tower in study by Sadhna et al. (2018). However in the same study *Pinus roxburghii* and *P.radiata* revealed 49.63 and 51.15 % DSR loss respectively. It showed similar performance of species in both prototype and industrial cooling tower conditions. Average of preservative loss at 2% conc. irrespective of preservative is 56.44%, whereas at 4% it reduces to 42.36 followed by at 6% conc. 40.4%. Results showed that threshold retention could be obtained after 24 months of exposure to cooling tower conditions when treated at 6% conc. only. At 2% conc. all preservative resulted less than 4 Kg/m<sup>3</sup> average DSR after 24 months, which is too low to impart resistance in cooling tower conditions. Therefore, CCA, CCB and ZiBOC at 6% can be suggested to treat the test species used for cooling tower purposes. Average weight loss i.e.19-36% of untreated samples in two years period strongly suggests that all test species are nondurable; hence treatment is mandatory for all test species. Stakes samples were also visually inspected for the presence of decay. The stakes tests exhibits severe to very severe attack in untreated samples, whereas, treated specimens were protected against decay. The work done by Tripathi and Bagga (2008) also showed high weight loss in untreated species after two years. Average weight loss (%) in samples treated with CCA, CCB and ZiBOC was 19.33, 19.61 and 20.81 respectively. Whereas, average weight loss was in this order *Pinus radiata*- 20.34 > *P. menziesii*-20.23>*Pinus roxburghii*- 19.17. Similar pattern of weight loss by species was noted in previous study done in prototype cooling tower (Sadhna et al. 2018). All preservatives and species were performed at par in industrial cooling tower.

Highest preservative loss was observed in *Pseudotsuga menziesii* followed by *Pinus roxburghii* and *Pinus radiata*, whereas, *Pinus radiata* exhibited highest weight loss followed by *Pseudotsuga menziesii* and then *Pinus roxburghii*. Although DSR loss in *Pseudotsuga menziesii* was almost 1.7 fold more as compared to *P.radiata* and 1.6 fold more as compared to *Pinus roxburghii* but even then it had exhibited overall

minimum weight loss. Weight loss is basically the loss of wood after exposure to cooling tower conditions, which may include preservative inside in case of treated samples. It means that preservative may help to bind wood material inside it and reduce the weight loss. Water soluble preservatives are liable to leach from treated wood according to physical laws i.e. law of mass action (Nair 2006). It depends on combinations of species with preservative at particular concentration. Therefore, binding mechanism of preservative in wood is needed to be addressed in future.

## CONCLUSION

All test preservative recorded sufficient net retention i.e. 17-23 kg/m<sup>3</sup> at 4% conc. and fulfilled the criteria of IS: 2372(2004). However the residual preservative amount in samples treated with 6% was found sufficient as per IS: 2372 (2004). Therefore treatment at 6% is most suitable conc. of preservative to enhance the durability of timbers in cooling tower. In case of preservatives, ZiBOC acquired highest retention followed by CCB and then CCA, whereas the trend of loss of preservative was ZiBOC followed by CCA and CCB. *Pseudotsuga menziesii* showed maximum preservative loss followed by *Pinus roxburghii* and *Pinus radiata*, whereas, in case of weight loss *Pinus radiata* exhibited maximum followed by *Pseudotsuga menziesii* and *Pinus roxburghii*. At present conventional preservatives are being practiced by industries, while the performance of ZiBOC was found comparable to the conventional preservative such as CCA and CCB and can be suggested to industries. *P. radiata* and *P. menziesii* are most preferred timber species for cooling tower application and treatment is important to save the maintenance cost of tower. In the present study their performance was found as comparable to *Pinus roxburghii* and can be used in cooling tower after proper treatment.

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## REFERENCE

- BS-EN 350-2 (1994) Durability of wood and wood-based products. Natural durability of solid wood. Part 2: Guide to natural durability and treatability of selected wood species of importance in Europe. British Standard.
- Chandra A, Willeitner H, Liese W (1972) Investigation on protection of Indian timber species in cooling towers. Part-1. Journal of Timber Development Association, India 18(2):2-9.
- Chandra A, Sharma RP, Pant SC, Willeitner H, Liese W (1973) Investigations on the protection of Indian timber species in cooling towers. Part-II. Journal of Timber Development Association, India 19(3):14-16.
- Eaton RA, Jones EBG (1971) The bio deterioration of timber in water cooling towers, II. Fungal growing on wood in different positions in a water cooling system. Material Organismen 6: 81-92.
- Hingston JA, Collins CD, Murphy RJ, Lester JN (2001) Leaching of chromate copper arsenate wood preservative: A review. Environment Pollution 111(1): 53-66.
- IS 401 (1982) Code of practice for preservation of timber Bureau of Indian Standard, Manak Bhawan New Delhi, India.
- IS 6497 (1990) Method of test for the efficacy of preservatives and evaluating the natural durability of timbers used in cooling towers. Bureau of Indian Standards. Manak Bhawan, New Delhi, India.
- IS 2753 (1991) Methods for estimation of preservatives in treated timber and in treating solutions – specifications Bureau of Indian Standard, Manak Bhawan New Delhi, India.
- IS 2372 (2008) Timber for cooling towers – specifications Bureau of Indian Standard, Manak Bhawan New Delhi (India).
- Lal R, Tripathi S (2009) Studies on performance of plantation grown species in cooling towers Project report of FRI-351/FPD/WP-61. ICFRE, Dehradun.
- Morrell JJ, Smith SM (1988) Fungi colonizing redwood in cooling towers: Identity and effects on wood properties. Wood Fiber Science 20:243-249.
- Nair SS (2006) Effectiveness of Copper-Boron Diffusion Treatments for Wood Master of Science Thesis. College of Graduate Studies University of Idaho, 91pp.

Pant SC, Kambo AS, Chandra A (1982) Suitability of *Pinus kesiya* for cooling towers use Journal of Timber Development Association India 28(4):5-8.

Singh AP, Hedley ME, Page DR, Han CS, Atisongkroh K (1992) Microbial degradation of CCA-treated cooling tower timbers. IAWA Bull 73:215-231.

Schmidt O, Liese W, Moreth U (1996) Decay of timber in a water cooling tower by the basidiomycete *Physisporinus vitreus* Material und Organismen 30:161-177.

Tripathi S (2005) Evaluation of *Radiata pine* from New Zealand. Project Completion Report, WP/R.PINE/WP-2005 F.R.I Dehradun, India.

Tripathi S, Bagga JK (2008) Suitability of Eucalyptus hybrid, *Melia azedarach* and *Mangifera indica* treated with CCA, ACA and Copper lignite in cooling tower India Journal of Forestry, Vol. 31(2):209-216.

Tripathi S (2012) Treatability evaluation of Meranti with ZiBOC and CCA International Wood Products Journal 3:70-76.

Tripathi S (2013) New eco-friendly, economical and non-hazardous wood preservative ZiBOC-. Patent No. 257394 India.

Udaiyan K, Manian S (1991) Fungi colonising wood in the cooling tower water system at the Madras Fertilizer Company, Madras, India International Bio deterioration 27(4):351-371.