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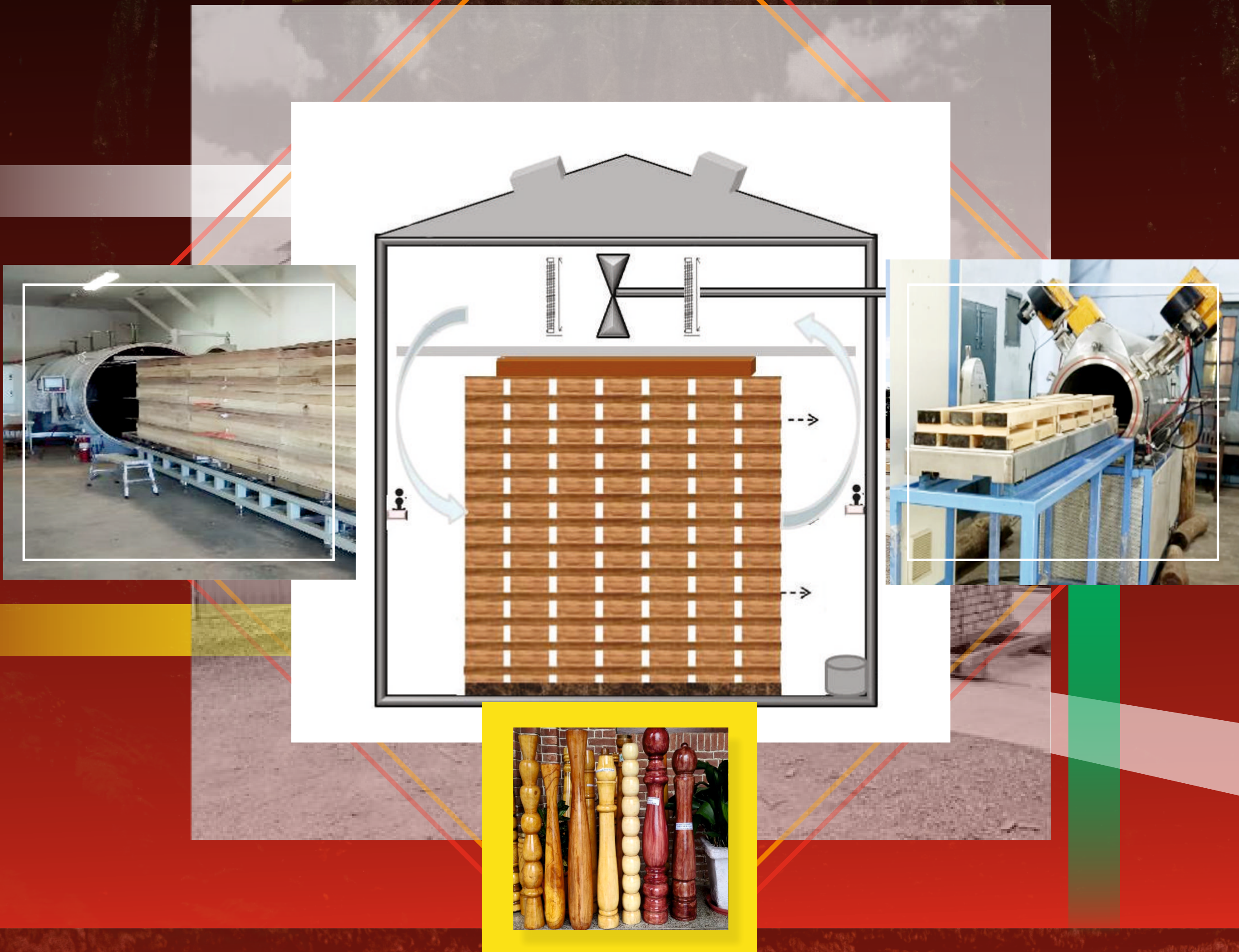

Wood Seasoning

Vol. 6, Issue 1, January - June 2025

ICFRE-INSTITUTE OF WOOD SCIENCE AND TECHNOLOGY, BENGALURU

Indian Council of Forestry Research and Education

(An Autonomous Body Under Ministry of Environment, Forest & Climate Change)

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Submissions for publication of articles & Advertisements
may be made to extension_iwst@icfre.org

INDIAN COUNCIL OF FORESTRY RESEARCH AND EDUCATION

(An Autonomous Council of Ministry of Environment Forest and Climate Change, Government of India)

VISION

To achieve long-term ecological stability, sustainable development and economic security through conservation and scientific management of forest ecosystems

MISSION

To generate, advance and disseminate scientific knowledge and technologies for ecological security, improved productivity, livelihoods enhancement and sustainable use of forest resources through forestry research and education

ZiBOC

- A new wood preservative which is comparable to CCA.
- Judicious use of preservative in a non-durable wood greatly enhances (6-8 folds) life of products.

Varieties/ Clones developed

- Developed improved germplasm of many forest tree species.
- Released 47 high performing and disease resistant clones of *Eucalyptus, Casuarina, Shisham, Melia* and *Sarpagandha* with a envisaged production gain of more than 20%. The developed germplasm are being made available to the State Forest Departments and farmers for use in plantations.

High performing and disease resistant clone of *Melia* sp.

CYCUS v. 1.0

- Casuarina Yield Calculator Utility Software (CYCUS v1.0) software has been developed to facilitate the farmer and other user agencies in yield estimation which requires only observations on girth of 100 sample trees per acre of plantation.

Wood Welding

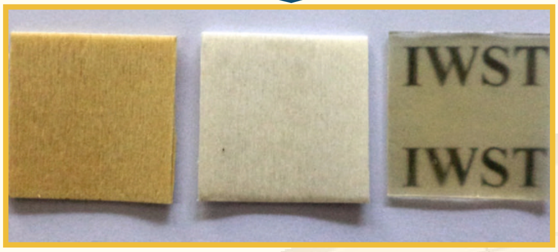
Wood welding is new to our country. In this technique wood joints can be made without using nails and adhesives making them more natural and chemical free. A wood welding machine has been designed and fabricated at Forest Research Institute, Dehradun. Success has been achieved in spin welding of wood pieces of few species.

Wood Welding Machine

Indian Council of Forestry Research and Education

New Initiatives

- Transparent wood- a flexible and biodegradable transparent wood has been fabricated using poplar wood veneer and water soluble polymer- polyvinyl alcohol. The transparent wood exhibited high optical transmittance, high haze and light diffusing property.



Natural wood (Left most), Lignin modified wood (middle) and Transparent wood (right most) placed on a paper with letters "IWST"

Heat storage based modified Solar Kiln

- Solar heat storage system based solar kiln has been developed by Forest Research Institute, Dehradun for timber drying. The solar heat is trapped using suitable phase change material (PCM). The New solar kiln is able to trap 39 % more heat in winters as compared to traditional green-house based traditional FRI solar kiln developed during 1970.

Head based storage Solar Kiln

Xylarium

- Collection of authentic wood samples both from India and other countries, depicting wood biodiversity of the country like lightest, heaviest, sweet-smelling, foul smelling, smoothest, streaked, variegated wood and wood of different colours, etc. The collection of wood cross sectional discs depicting variation in sapwood and heartwood colour is a unique feature of the xylarium.
- Wood identification services.

Xylarium- Collection of Authentic wood samples

Tree hollowness detection technique based on ultrasonic waves

- Forest Research Institute, Dehradun has developed ultrasonic techniques (Non-destructive testing) to detect the location and magnitude of the hollowness of the standing tree. This will help to remove the potential human hazards by way of falling down of such trees during a high wind regime in Urban Forestry.

Measurement of hollowness in a tree using ultrasonic detector

Agroforestry models

- Various agroforestry models (Poplar, Eucalyptus, Melia, Casuarina and Babool) have been developed to improve green cover, enhance farmers income and to mitigate climate change .

Poplar based agroforestry model with wheat

Innovative Bamboo Bottles

- Techniques for making bamboo bottles by using Bamboo Treatment Technologies of ICFRE. Most suitable bamboo species for making bottles are Shil Barak (*Bambusa salarkhanii*) & Barak (*Bambusa balcooa*). One full bamboo is sufficient for making 21 full size bottles and 12 small bottles.

Bamboo bottles

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PREFACE

ICFRE–Institute of Wood Science and Technology (IWST), Bengaluru is pleased to bring out the next issue of *Wood is Good* magazine, with a special focus on ***Wood Seasoning***: one of the most critical and fundamental processes in wood utilization and value addition. In the Indian context, where timber is sourced from diverse species, moisture conditions, and supply chains, proper wood seasoning plays a decisive role in improving product quality, dimensional stability, service life, and overall competitiveness of wood-based industries. Efficient seasoning not only reduces defects and material losses but also enhances resource efficiency, sustainability, and value realization across sawmilling, furniture, plywood, and construction sectors. Properly seasoned wood reduces processing losses, minimizes rejections and customer complaints, and enables industries to meet quality standards and export requirements. The Prime Minister's consistent focus on making *"Made in India"* a global symbol of quality and reliability, guided by the "Zero Defect, Zero Effect (ZED)" philosophy, reinforces the need for Indian industries, including the wood sector, to adopt robust processing practices that enhance product quality, competitiveness, and environmental sustainability.

This issue comprehensively covers various dimensions of wood seasoning. The contents have been carefully curated to address both scientific principles and practical industry applications, making this issue particularly relevant for researchers, students, professionals, and stakeholders in the wood-based sector. In addition to the thematic articles, the issue also features our regular sections such as activities and achievements of IWST, Package of Practices for cultivation of an important timber species, and timber trade statistics, which together provide a holistic perspective on developments in wood science, forestry, and the timber industry.

I am also glad to share that ICFRE–IWST has successfully published 19 quarterly editions of *Wood is Good*, covering a wide spectrum of topics in wood science and technology, silviculture, forest management, and allied areas. Over the years, the magazine has addressed most of the core themes relevant to the sector, leaving limited scope for continuing it as a quarterly publication. Therefore, from the present issue onwards, *Wood is Good* will be published as a half-yearly magazine, keeping in mind the need for greater thematic depth, content quality, and sustained relevance to wood-based industries and stakeholders. I am confident that this transition will further strengthen the magazine's impact and usefulness.

We sincerely acknowledge the continued support and encouragement of our esteemed readers, contributors, and reviewers, and we look forward to your active engagement in the future editions of *Wood is Good*.

Dated: 9th February 2026

(Dr. Shakti Singh Chauhan)

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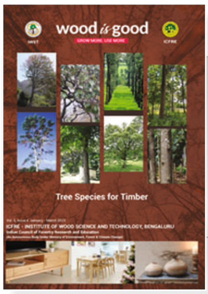

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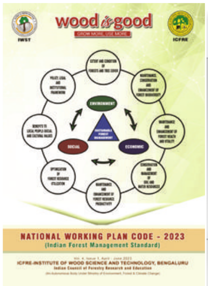

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Association of Timber Imorters, Traders, Saw Mill Owners, Plywood & Veneer Manufacturers

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Activities of ICFRE-IWST during January - June 2025

Conference on From Concrete to Canopy: Urban Forestry for Greener Cities

As cities continue to grow and urbanize, the need for green spaces has never been more critical. Urban forestry plays a vital role in transforming concrete jungles into vibrant, sustainable and livable environments.

A one-day conference on "From Concrete to Canopy: Urban Forestry for Greener Cities" was held on 30 January 2025 at ICFRE-IWST in hybrid mode. The conference aimed to understand the issues, perspectives, challenges, and opportunities related to the importance of trees, green spaces, and sustainable urban planning and management in creating greener and more resilient cities and enhancing the quality of life for city dwellers. The event was jointly conducted by ICFRE-Institute of Wood Science and Technology and Elixir Technologies, Bengaluru.

The dignitaries for the inaugural program comprised the chief patron, Smt. Kanchan Devi, IFS, Director General, Indian Council of Forestry Research and Education (ICFRE), Dehra Dun. The guests of honour for this event were Dr. T. V. Ramachandra, Professor, Centre for Ecological Sciences, IISc, Bengaluru, and Shri. B. P. Ravi, IFS, PCCF (EWPRT & CC), Karnataka Forest Department. The chief guest was Shri. I. B. Srivastava, IFS (Retd.), Chairman, Tree Expert Committee, Government of Karnataka.

The inaugural program was followed by a technical session consisting of expert speakers from various fields, such as environmental science, remote sensing, management, planning & designing, and arboriculture, sharing their insights and strategies with real-world examples. The technical session ended with a live demonstration of tree climbing with essential safety measures.

The participants consisted of representatives from research institutes, universities, educational institutions, the Karnataka Forest Department, the Bangalore Development Authority, the Bruhat Bengaluru Mahanagara Palike, Real Estate Developers, Non-Government Organizations, Residential Welfare Associations and others.

Forestry Training and Capacity Building: Training of Personnel of other services on testing and applications of sustainable building materials: Wood and Wood Products

ICFRE- IWST, Bangalore organized three days training on "Testing and applications of sustainable building materials: Wood and Wood Products" under the MoEF&CC sponsored Forestry Training and Capacity Building –Training of Personnel (Class – II and III Officers) of Other Services from 19- 21 February 2025. 23 officials from across the country working in various departments such as CIPET, RITES, CQA(GS), Central construction unit, Commissionerate of rural development & PWD (Govt. of Karnataka). Indian Institute of Packaging, National Test House and others participated in the program

The training was conducted by experienced scientists and technical staff of the institute. The training program provided participants with a comprehensive insight into wood as a sustainable building material. The session covered wood properties and identification, bio-deterioration, wood protection, treatment procedures, wood and bamboo-based composites, adhesives, material testing, processing techniques, mass timber application and sustainability aspects. Hands-on learning experience including a visit to Karnataka State Forest Industries Corporation (KSFIC), Bangalore enriched the participants practical understanding of wood and wood-based composites. Overall the program was aimed at ensuring that participants gained scientific knowledge and industry oriented practical exposure. Further, the feedback from participants highlighted the relevance of the training and its impact on their professional understa ding of sustainable wood utilization.

Training of Master Trainers on Promotion of sandalwood cultivation

Under the National Compensatory Afforestation Fund Management and Planning Authority (CAMPA) funded project – 'Promotion of Sandalwood Cultivation Through Training Programs Across India to Improve the Economic Status of Farmers', five days master trainers training program on promoting sandalwood cultivation was organized at ICFRE-IWST from 17th to 21st March. The master trainees comprised of 19 Scientists/Technical staff representing following ICFRE institutes: ICFRE-RFRI – 3 participants; ICFRE-IFP – 3 participants, ICFRE-IFB – 3 participants ICFRE-AFRI – 3 participants, ICFRE-HFRI – 1 participant ICFRE-IFGTB – 3 participants, ICFRE-FRC – 1 participant ICFRE-TFRI – 2 participants. They were trained on different aspects related to sandalwood such as seed harvest, collection, storage, nursery raising, agroforestry models, pests and diseases, protection, heartwood estimation, and different products from oil. The training also included field visit to various plantations and an industry visit to Karnataka Soaps and Detergents Limited, Bengaluru.

Specialized workshop on Building with Bamboo: Sustainable Innovations & Techniques

The two-day workshop on "Building with Bamboo: Sustainable Innovations & Techniques," was organized by the ICFRE - Institute of Wood Science and Technology (IWST), Bengaluru during 15- 16 April, 2025. It aimed to promote the use of bamboo as a sustainable and versatile construction material and to create awareness and skills to integrate bamboo into mainstream architecture and infrastructure projects for a greener future.

Key topics included bamboo anatomy, bamboo bending & drying, bamboo preservation methods, and mechanical properties of bamboo composites. Emphasis was placed on bamboo-based entrepreneurship, with discussions on its opportunities and challenges. The workshop also delved into bamboo housing systems, structural joints, and innovative building techniques. Practical demonstrations provided hands-on experience in preservative treatments, bamboo testing, bamboo housing, and construction.

Thirty-nine students from the School of Architecture, Reva University, Bengaluru joined the workshop physically and gained deeper understanding of bamboo's structural capabilities and sustainable advantages. Overall, the workshop highlighted bamboo's potential and its importance in eco-friendly building construction.

Short term training on Sandalwood Farming and Management of its Health

ICFRE-IWST organized a five days short-term training on "Sandalwood farming and management of its health" through physical mode during 21 – 25 April 2025. Shri. Rajesh S. Kallaje, IFS, In-Charge Director addressed the participating farmers and sandalwood growers of the program. The training covered sandalwood nursery technology together with demonstration at plant nursery of IWST campus; agroforestry systems; inter-cropping of sandalwood with medicinal plants and cloning of sandalwood using tissue culture methods. management of insect pest and diseases in nursery and plantations was followed by a demo on internal decay measurement in trees using Sonic Tomograph. utilization and assessment of oil content with laboratory demonstration of oil extraction; value addition for its pharmaceutical applications; policy and schemes of State Forest Department; heartwood estimation in standing trees followed by field demonstration and economics of sandalwood cultivation was also explained in detail. Marketing of sandalwood and its products was told by C. M. Suvarna Kumar, General Manager (Retd.), KSDL, Bangalore. During the training Mr. Ramesh Balutgi, progressive farmer from Kustagi, Karnataka and others shared their field experiences on raising sandalwood plantations. The training also included a field visit to Karnataka Soaps and Detergents Limited (KSDL), Bangalore and interaction with the Managing Director and technical staff. The participants actively interacted and showed keen interest in the program. The participants were

taken to sandalwood plantations to get a first-hand field information on growing sandalwood along with various combinations of trees and plants, interaction with the farmers and exchange their experiences.

One-month training program on Plywood Manufacturing Technology.

ICFRE- IWST Field Station, Kolkata conducted one-month training program on Plywood Manufacturing Technology from 10 December 2024 to 10 January 2025 and from 01 April 2025 to 05 May 2025 to strengthen human resource development in the wood-based panel industry. The programs addressed the growing demand for skilled technical manpower in plywood and allied manufacturing sectors. The participants included industry personnel, technicians and supervisors from plywood units, graduate freshers etc. The trainings had a blend of theoretical instruction and hands-on exposure. The curriculum covered timber defect identification; veneer peeling and drying; resin manufacture and testing; plywood and allied panel manufacturing; testing of plywood, blockboard and flush doors; preservative chemical retention, and industrial power requirements

Specialized training on manufacturing of phenol lignin adhesives

Three days specialized training on manufacturing of phenol lignin adhesives was organized by ICFRE-IWST during 20 – 22 January 2025. Research Director and three team members from M/s. Chemprocess Systems Pvt. Ltd, Ahmedabad attended this training program. The industry sought this training as they intended to take up industrial trial on phenol lignin adhesive manufacturing using the lignin developed at their pilot scale. This is beneficial to the industry since utilization of lignin in adhesive development minimizes the emission of volatile organic compounds and reduces occupational hazard to workers, also being a non-toxic material it addresses the pollution aspect.

Demonstration on Engineered Fire-Retardant Door (FRD) shutter for 60 minutes rating

ICFRE- IWST demonstrated the technlogy on Engineered Fire-Retardant Door (FRD) shutter for 60 minutes rating in accordance with IS 3614 standards and also provided training to ten industry personnel from M/s. Surani Ply Industries, Gandhidham, Gujarat from 3rd March to 7th March 2025. This training on the manufacture of fire retardant doors provides significant environmental benefits by reducing the carbon footprint, utilizing sustainable material and also limiting the release of toxic gases during fire incidents.

Short term training on Bamboo Preservation

A two-day training program on Bamboo Preservation was successfully conducted by ICFRE-IWST, Bangalore on March 20 and 21. The training aimed to provide hands-on experience and theoretical knowledge on bamboo preservation techniques. A total of 12 participants comprising architects from Maharashtra attended the training. In his Inaugural address Shri Rajesh S Kallaje IFS, I/C Director, ICFRE-IWST emphasized the importance of bamboo as a sustainable construction material and the need for its preservation for enhanced durability. Over the three days the technical sessions covered fundamentals of bamboo drying and preservation followed by practical demonstrations of Boucherie/Sap Displacement methods of preservation. A detailed practical session on Pressure Treatment Method was included apart from other methodologies. Lastly qualitative tests and mathematical calculation of preservative retention in treated bamboo was taught to the trainees.

Personalized training on determination of formaldehyde content by extraction method

Three days personalized training on determination of formaldehyde content by extraction method as per IS 13745 was organized from 28 - 30 April 2025 for the manager, chemist and technician of M/s. Sabari Plywood Production. This program provided detailed information about formaldehyde emission from panel products and the existing emission classes for formaldehyde with respect to the test method employed for determination. Hands on experience on determination of formaldehyde content by perforator method was also part of the program. The imprortance of sampling, storing of samples prepared for testing and measurement methods, both analytical and by use of sphectrophotometer were explained in detail to the officers..

Two weeks customized training on Wood science and Technology

Two weeks customized training course on Wood Science and Technology was conducted for under graduate students of College of Forestry, SHUATS, Prayagraj from 9 – 20 June 2025. Starting with the overview of wood science and technology, they were told all about wood anatomy& its relevance in wood identification together with practical session on sample preparation, microtomy, staining techniques, preparation of slides up to identification of few important timbers. Next, topic taken up for the training was wood properties, defects & significance of timber grading combined with practical on property evaluation and testing of wood. This was followed by wood seasoning & kiln schedules, seasoning methods with a detailed explanation on its estimation methods and calculation of the same. After seasoning, it was biodegrading agents acting on wood, wood preservatives types and methods together with demonstrations of Boucherie/Sap Displacement methods of preservation. Applied aspects such as wood modification, wood polymer composites, wood based adhesives and its manufacturing and bamboo based products were introduced to the students. Finally, Wood working and finishing was taught at the Advance Wood working Training Centre at the institute.

Short Term Training on Resin manufacturing and plywood manufacturing

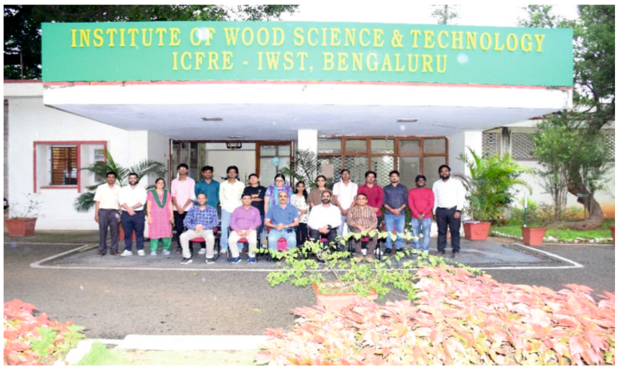
Short Term Training on Resin manufacturing and plywood manufacturing was organized by ICFRE-IWST during 2- 6 June 2025. This training course provided an overview of resin and plywood manufacturing covering raw material analysis, processing steps and quality control. It focused on aspects of improving bonding performance, process optimization and compliance with standards, theoretical know how on importance of resin and manufacturing process of resins used in plywood industry. Hands on skills were provided for analysis of raw materials used for the manufacture of resin. Manufacturing of conventional phenol formaldehyde resin, modified phenol formaldehyde resin and urea formaldehyde resin at plant scale was demonstrated.

Short term course on Testing of Plywood and Block Board

Short term course on Testing of Plywood and Block Board was organized by ICFRE-IWST from 23 -27 June 2025, considering the implementation of Quality Control Order for the panel industry sector. The main goal of this training was to create awareness and the testing requirements for plywood and block board as per IS:303, IS:710, IS:4990, and IS:1659. The understanding on the testing requirements helps the industries to comply to the relevant standard requirements for their panel products and it eases BIS licensing. Personnel from panel industry sector attended this training

One day training on Sandalwood Nursery Techniques

ICFRE-IWST conducted a one-day training program on Sandalwood Nursery Techniques on 17 June 2025 with a view to sensitize prospective sandalwood growers or even enrich the working knowledge of farmers who are already raising plantations or agroforestry. The course mainly focused on collection of sandalwood fruits and processing of seeds; nursery techniques on raising seedlings, hardening of seedling and management of seedlings in nursery for growing healthy plantations. Hands on nursery techniques was also provided during this training.



Short term training on Sandalwood based Agroforestry Models - Establishment and Plantation Management

The one-day training on sandalwood nursery techniques instilled interest in many participants and most of them enrolled for the next three days of training on Sandalwood based Agroforestry Models - Establishment and Plantation Management from 18- 20 June 2025 to know more about sandalwood cultivation, management and prospects. Hence this training covered aspects on raising of sandalwood plantation; management of plantation; agroforestry using sandalwood; raising of sandalwood through tissue culture; estimation of growth, yield and heartwood formation in sandalwood; sandalwood oil utilization; assessment of oil content, protection, harvest, trade and economics. One day field trip to Sandalwood plantation in Kolar District, Karnataka together with interaction with plantation owners in and around the area was arranged for getting first hand information and sharing of experiences. A few sandalwood agroforestry model plantations were also shown to the participants to give them an idea of field spacing, performance of host plants and their effect on sandalwood growth.

Research Consultative Workshop

Research consultative meeting was held on 28 May 2025 at the ICFRE - Institute of Wood Science and Technology (IWST), Bengaluru. The meeting began with the inaugural address by Dr. Meenakshi Negi, IFS, Principal Chief Conservator of Forests (HoFF), Karnataka Forest Department (KFD). The technical session was chaired by Shri B.P. Ravi, IFS, Principal Chief Conservator of Forests (EWPRT & CC), KFD. Shri A.K. Singh, IFS, APCCF (Research) and other senior officers from KFD were present on the occasion. In his address, the Director outlined the purpose of the meeting and underscored the significance of strengthening research collaboration between the two institutions. He highlighted the key initiatives, including the development of Soil Health Card under the All India Coordinated Research Project (AICRP). Shri B.P. Ravi emphasized the importance of effective dissemination of research findings. He advocated for the translation of research outcomes into local languages to enhance their accessibility and practical relevance for farmers and stakeholders. Further, in her inaugural address, Dr. Meenakshi Negi, IFS, Principal Chief Conservator of Forests (HoFF), Karnataka Forest Department, stressed on the importance of adopting a "Lab to Land" approach in the forestry sector. She advocated for the development and widespread dissemination of comprehensive packages of practices for key tree species such as Sandalwood, Bamboo, Mahogany and Red Sanders as these scientifically curated guidelines would empower farmers to adopt sustainable agroforestry practices, facilitating the cultivation of high-value forest species that offer both ecological benefits and economic returns. Recognizing the increasing biotic pressure on natural forests, Dr. Negi highlighted agroforestry as a viable strategy to alleviate the burden on forest ecosystems while enhancing rural livelihoods. She also underscored the necessity of raising awareness among stakeholders about the regulatory frameworks governing the cultivation and trade of forest species. She opined that, by ensuring that farmers and traders are well-informed about relevant policies and compliance requirements, the forestry sector can promote responsible resource management and support informed decision-making at the grassroots level. Based on the presentations and discussions few actionable points were summarized for ICFRE-IWST namely, development of SOP for tree transplantation, research on RET species and research support to Karnataka Forest Department.

Release of Forest Soil Health Cards

In a significant milestone towards promoting sustainable forest ecosystem management & climate resilience, Forest Soil Health Cards prepared by ICFRE-IWST, Bangalore for 40 forest divisions of Karnataka were released on 19 June 2025 by Dr. Meenakshi Negi, PCCF (HoFF), Karnataka Forest Dept at Aranya Bhavan, Bangalore. This project involved the preparation of forest soil health cards across various agro-climatic zones in Karnataka. It includes detailed soil sampling and nutrient analysis, with zone-specific recommendations shared with forest divisions through the soil health cards. Wide spread dissemination and field-level application of the comprehensive assessment of nutrient status across all forest divisions of Karnataka will provide valuable insights to tree growers for raising quality plantations.

Trainings under Vana Vigyan Kendra

During March 2025, ICFRE_IWST organized three training programs on “Sandalwood based agroforestry models and its health” under CAMPA extension funding. A training was conducted through Krishi Vignan Kendra (KVK), Tukkanatti, Belagavi on 4 March 2025 in the presence of Sri R. M. Patil, Chairman and Dr. D. A. Mhetre, Senior Scientist from ICAR-BIRDS KVK, Tukkanatti, Gokak. The second training was conducted on 5 March 2025 at Sirsi (Joida, Kumbarawada) which was inaugurated by Smt Veena Bedikar, Assistant Director Agriculture, Joida, Sri Shantharam Kamath, President Kali Farmers Production Centre, Kumbarawada and Dr. Arjun. R. S., Scientist KVK-Sirsi through watering of sandalwood sapling. Further, similar training was conducted for farmers through ICAR-KVK, Chintamani, Chikkaballapur, District on 19 June 2025. Sri Narasimha Reddy, Professor (Retd.). GKVK, Bangalore and Dr. M. Papireddy, Senior Scientist and Head KVK were present on the occasion. The participants were given a brief of the research activities, extension activities and trainings imparted at IWST. They were also sensitized about Mission LiFE initiative and pledge was administered. The trainings mainly focused on basics of agroforestry, suitability, types, establishment, maintenance and benefits of sandalwood agroforestry system together with different sandalwood hosts. Recent insect pests emerging in sandalwood plantation was also explained in detail. Forest Policies related to sandalwood growing and recent amendments, harvest, sale and market procedures were dealt by the respective forest department staff. Around 200 farmers improved their understanding on sandalwood cultivation and plantation management. Farmers interacted with resource persons on various issues faced by them during raising of sandalwood plantations.

A training on Wood Science and Technology was conducted by ICFRE-IWST, Bangalore for students of Forestry College, Sirsi, Uttar Kannada District on 6th March 2025 under CAMPA Extension Funding. Around 125 students participated. Dr. Vasudev, Dean (Forestry) and Dr. P. Ramana, Professor and Head FPU, College of Forestry, Sirsi inaugurated the program. Scientist of the institute enriched the learning of students though technical sessions highlighting durability and importance of secondary timbers, utilization and value addition of timber through engineered wood products, recent trends in wood science and advancements in wood technology. The program ended with an interaction session and distribution of participation certificates to the students.

ICFRE-IWST, Bangalore organized one day training program on Nursery management and value addition of bamboo through ICAR-CCARI-KVK North Goa on 26 June 2025 for about 100 farmers and forest department officials. The training program was inaugurated through watering of sapling by Dr. Praveen Kumar, Director, Dr. Bommayasamy. N, Senior Scientist and Dr. Uttappa, Scientist, ICAR-CCARI-KVK, Goa. At the outset, the participants were briefed about the research and extension activities at IWST, sensitized on Mission LiFE initiative and pledge administered. This was followed by a lecture on vegetative propagation of bamboo in nursery and bamboo composite technology for industrial application. The farmers showed great enthusiasm and interacted with the resource persons.

Awareness programs at Demo Village

To commemorate World Forest Day and World Water Day on 21 and 22 March 2025 respectively, ICFRE-IWST, Bangalore conducted an "Awareness Program on Forests, Wildlife and Environment Conservation" for students of Government Kannada Primary School at Demo Village, Attivatta, Hosakote Taluk, Bangalore Rural District on 14 March 2025. During the interactive session, the students of were told in very simple terms about the role of forests in soil conservation, water retention, air purification, & positive effects of trees on climate, forests types, biodiversity, afforestation, conservation, The children were highlighted about environment as a whole and how it is being affected by human activity such as pollution, waste disposal and unsustainable practices that are damaging ecosystems, water resources, and the air we breathe. The Oscar winning documentary film "Elephant Whisperers" was screened for the students. The children enjoyed the movie and also enhanced their knowledge. At the end of the session, the students and teachers were also sensitized about Mission LiFE initiative and pledge was given.

On the occasion of Women's Day celebration, ICFRE-IWST, Bangalore conducted awareness program on the theme "Women and Girls: Rights, Equality and Empowerment" for ladies and girls student of Demo Village Attivatta, Hosakote Taluk, Bangalore Rural District on 19th March 2025. During the program, the ASHA workers, or Accredited Social Health Activists who are community health workers, ladies residing locally in the village and teachers & girl students of different age groups from Government Kannada Primary School, Attivatta, Hosakote Taluk, Bangalore Rural District were addressed and told about the importance of rights, equality, and empowerment of women and girls. It was emphasized that this is not just about gender, but about fairness, justice, and creating a world where every individual has the opportunity to thrive. Every woman and girlhas the right to live a life free from violence, discrimination, and oppression. It was also stressed that every woman and girl, regardless of her background, has the right to education, health, safety, and the freedom to choose her own path. Equal opportunities to women and men, girls and boys to succeed without being limited under societal expectations. They were made to understand that, equal access to education, employment, and leadership positions for women and girls are not only empowering but also creates a stronger and more just society for all. It was highlighted that, women and girls should speak up to injustice, be given confidence, resources, and support to make decisions for themselves and to act on their aspirations since empowerment will help them stand up for their right to achieve their goals and also inspire others to do the same.

Institute Industry Integration Meet at Kolkata

The Institute-Industry Interactive Meet (IIIM) was chaired by Shri Rajesh S. Kallaje, IFS, Director (I/C), ICFRE-IWST. He was accompanied on the dais by Dr. Geeta Joshi,, ADG (Media and Extension), ICFRE; Dr. Shakti Singh Chauhan, Scientist-G and Head of the Wood Properties and Processing Division; Ms. Sujatha D., Scientist-G and Head of the Plywood and Panel Product Technology Division; and Ms. Shreya Kumari, Assistant Director, BIS. The meeting began with a presentation on the research activities and technological developments at various ICFRE institutes, followed by an open discussion with industry representatives. The industries were encouraged to come forward to throw some light on possible future research opportunities upon which the institute can work and that which will ultimately benefit the industries. They were requested to share the issues faced by them so that the Institute can work to address the same. Ms Shreya Kumari, Assistant Director, BIS, Eastern Region Office Headquarter presented on "Quality Control Orders for Wood Based Products.", in which she explained about basics of QCO (Quality Control Orders), its importance and need. She also touched on BIS Act 2010, Section 16, Section 17 and Section 29 and detailed about QCO for plywood and wooden products and online accessibility to BIS.

Participation in Melas/Exhibitions

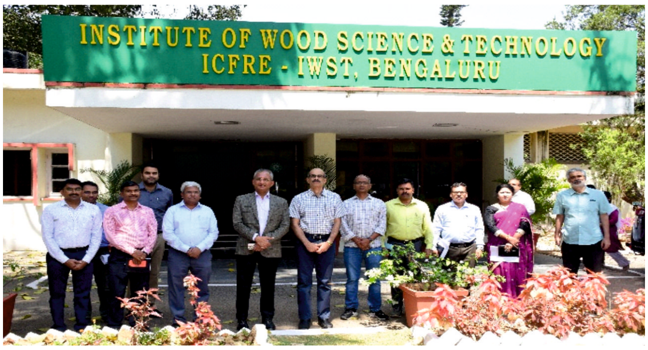
- ICFRE-IWST technologies were demonstrated at IFGTB, Coimbatore on 23 Jan 2025 for the visiting delegation of Shri. Bhupender Yadav, Hon'ble Union Minister for Environment, Forest and Climate Change and Shri. Kirti Vardhan Singh, Union Minster of State along with 22 members of Parliament.
- ICFRE-IWST Field Station Kolkata participated and showcased institute developed products at Sunderban Mela at Canning, West Bengal 2025 from 3 -12 Jan, 2025
- Shri. Rajesh S. Kallaje, IFS, In-ChargE Director, ICFRE-IWST inaugurated Matecia exhibition 2025 organized at BIEC during 21- 23 Feb 2025. IWST participated in the event by showcasing its wood technologies and products.
- ICFRE-IWST participated in Vision Karnataka 2025 Expo at Belagavi, Karnataka during 11-13 June 2025 by showcasing its research activities.

Memorandum of Understanding Signed

- Memorandum of Understanding was signed between ICFRE-Institute of Wood Science and Technology, Bangalore and Global Green Growth Co Foundation (GGGC), UHS Campus, GKVK Post, Bangalore on 21 Jan 2025 for promoting green growth, sustainable forestry and climate resilience through research, technology and capacity building.
- Memorandum of Understanding was signed between ICFRE-Institute of Wood Science and Technology, Bangalore and Climeverse Pvt Ltd (Equilibrium Earth) (India), Bangalore on 30 Jan 2025 for accessing sustainability of biomass feedstocks as provided by EQ) for production of desired quality biochar for soil and bio-energy application.
- Memorandum of Understanding was signed between ICFRE-Institute of Wood Science and Technology, Bangalore and KLE Society's S. Nijalingappa College, Bangalore on 17 March 2025for academic and technical collaboration and sharing of facilities.
- Memorandum of Understanding (MOU) is made and entered in to on 28 March 2025 between ICFRE-Institute of Wood Science and Technology, Bangalore and University of Agricultural Sciences, Gandhi Krishi Vignana Kendra, Bengaluru to establish "Vana Vignana Kendra"
- Memorandum of Understanding was signed between ICFRE- Institute of Wood Science and Technology, Bangalore and Sandalwood Society of India, Bangalore on 8 May 2025 towards research, extension, education, capacity building and scientific management of sandalwood.
- A Memorandum of Understanding was signed on 28 May 2025 between ICFRE- Institute of Wood Science and Technology, Bangalore and M/s Karnataka State Forest Industries Corporation, Bangalore to provide consultancy in preparing a Detailed Project Report for setting up a plywood manufacturing unit at the KSFIC, Timber Yard Layout unit to manufacture plywood as per relevant Indian Standards.

Visit of Dignitaries

Shri. Atul Kumar Tiwari, IAS, Secretary, Ministry of Skill development and entrepreneurship visited ICFRE-IWST on 20 February 2025 and discussed with Director, GCR & Scientists about way forwards to improve skilling ecosystem in the field of wood sector. He also visited AWTC and interacted with the students



Visit of trainees from Forest Academies and others

A total of 28 State Forest Service Officer trainees from CASFOS, Dehradun and 132 Range Forest Officer trainees from Chadrapur Forest Academy, Maharashtra, Uttarakhand Forestry Training Academy, Haldwani, Nainital and Tamil Nadu Forest Academy, Coimbatore interacted with Director, officers and scientists of ICFRE-IWST, Bangalore. They also visited laboratories, workshops and other facilities like Xylarium, Advanced Woodworking Training Centre, Wood Museum, Technology Demonstration Centre, plywood and particle board plant, fire testing facility, bamboo processing unit and other facilities at both Malleswaram and IPIRTI campuses of the institute.

Visit of students under Prakriti program of ICFRE

An overview of research activities carried out at ICFRE-IWST is given to visiting students of different age groups and disciplines from universities, colleges & schools as part of Prakriti program of ICFRE. According to their curriculum needs, interests and education level, students are taken to various facilities like Tissue Culture lab, Molecular Biology lab, Pathology lab, Chemistry lab, Plant Nursery, Xylarium, Wood workshop and Advance Woodworking Training Centre, Wood Museum and Technology Demonstration Centre. Few student batches visit the IWST-IPIRTI Campus to get exposed and to enhance their knowledge at Adhesive Technology lab, Plywood pilot plant, Particle Board pilot plant, Fire door testing facility, Bamboo Processing units and Coir Composite centre. Students and faculty are sentisized about Mission LiFE Activity and Pledge is also administered.

About 23 institutions comprising of 1035 students and faculty visited ICFRE-IWST. Students from N E T Public School, Bangalore; Cluny Convent, Bangalore; Mitra Academy, Bangalore and students of Government Schools of Davanagere District visited the institute. Few colleges and universities that visited ICFRE-IWST are Dr. Y S Parmar University of Horticulture & Forestry, Nanuni, Solan, Himachal Pradesh; Forest College and Research Institute, Mulugu, Hyderabad; Odisha University of Agriculture and Technology, College of Forestry, Bhuvaneshwar; St. Joseph University, Bangalore; SJR College, Bangalore; Keladi Shivappa Nayaka University of Agricultural and Horticultural Sciences (Forestry), Iruvakki, Shivamogga; BEST Innovation University, Andhra Pradesh; Jain (Deemed University), Bangalore; Maharani Lakshmi Ammani College for Women, Bangalore; NMKRV College, Bangalore; BMS College for Women, Bangalore; Government First Grade College, Yelahnaka, Bangalore; Administrative Management College, Bangalore; K.L.E. Society's S. Nijalingappa College, Bangalore; Vijaya College, Bangalore; M E S College, Bangalore; NMKRV College for Women, Bangalore; REVA University, Bangalore; National College, Bangalore

Republic Day

Shri. Rajesh S Kallaje IFS, In-Charge Director, ICFRE-IWST unfurled the National flag on the occasion of 76th Republic day. Director in his speech highlighted the achievements of IWST and motivated the employees of IWST to achieve excellence in their field of work. Shri.M. R Vijayan, Stenographer Grade-I and Smt. Vijaya Kumari T, Section Officer. were honoured with ICFRE outstanding employee award for year 2024 for their dedicated & exemplary work done in their field. Shri Rajesh S Kallaje IFS, In-Charge Director, ICFRE-IWST felicitated the award winners and encouraged all employees to work with

Women's Day Celebration

International Women's Day was celebrated on 14 March 2025 at ICFRE-IWST, Bengaluru. Smt. U. N. Vasantha Kumari, Group Director (Retd) – Spacecraft Checkout Group, U. R. Rao Satellite Centre (ISRO) graced the occasion and delivered a talk on "Women as Scientist – Responsibility and Challenges". She shared her work experiences, challenges and opportunities in her scientific organization. She quoted on her accomplishments especially the tasks during the rocket launch and how her family fully cooperated and supported her in her endeavor. She stressed that women's education plays a vital role in women empowerment as well as societal progress and because of which lately we see women working in all arenas without physical barriers.

Ambedkar Jayanthi

ICFRE-IWST, Bangalore celebrated 134th birth anniversary of Dr. B.R Ambedkar on 15th April 2025. Shri. Rajesh S. Kallaje, IFS In-Charge Director and other Officers / Staff/ students offered floral tribute to the chief architect of the Indian constitution.

World environment Day

On the occasion of World Environment Day, 70 Girl Guides & 5 Adult Leaders from Cluny Convent, Bangalore visited Nursery & Wood museum at ICFRE-IWST on 5 June 2025 to learn about sustainable forestry practices, wood science and environmental conservation. Director, ICFRE-IWST addressed the students, further Mission LiFE pledge was given to the students. A talk on Guardians of Nature-India's Place in Global Land, Biodiversity & Climate Pacts by Ms. Anuja Malhotra, Policy Manager, Centre for Policy Design, Ashoka Trust for Research in Ecology & Environment Bangalore was arranged for staff and students of the institute.

Yoga Day

International Day of Yoga was celebrated at ICFRE - IWST, Bengaluru. Staff and students came together for Yoga session inspired by Hon'ble PM Shri Narendra Modi's message for collective participation and for a healthy life.

Roll Out and Preparedness of States for using National Transit Pass System (NTPS)

National Transit Pass System cell of ICFRE-IWST successfully conducted 23 training programs during the period of January-June 2025 to Forest Department and other key stakeholders of 12 States/UTs (Andaman & Nicobar Islands, Assam, Karnataka, Kerala, Maharashtra, Manipur, Nagaland, Odisha, Puducherry, Tamil Nadu, Uttar Pradesh, Uttarakhand) for smooth roll out and implementation of National Transit Pass System.

A Toll-Free Number / Help Desk (1800-425-1545) has been established at ICFRE–IWST to assist the general public and stakeholders from various States/UTs to address queries related to National Transit Pass System (NTPS). During this period, the Help Desk has received around 551 calls, and the queries were resolved amicably.

Training for Puducherry SFD

Training for Assam SFD


Training for Uttarakhand SFD


Training for Manipur SFD

Kannada Learning Centre

ICFRE-IWST, Bangalore inaugurated Kannada Learning Centre on 20 June 2025. The chief Guest of the day Dr. Santosh Hanagal, KAS, Secretary, Kannada Development Authority, Govt. of Karnataka addressed the gathering regarding the importance of learning Kannada for providing better services to the public of Karnataka.

Wood Seasoning in India - Challenges, Opportunities and Future Prospects

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Summary

Wood seasoning (drying) is a critical process in the Indian wood products manufacturing industry. Proper seasoning reduces moisture content (MC), stabilizes dimensions, improves mechanical properties, reduces susceptibility to fungal and insect attack, and ensures product quality and longevity. This paper reviews prevailing practices in India from traditional air-drying to modern kiln technologies (conventional, Solar, dehumidification, vacuum, RF/Microwave cum vacuum) discusses species-specific considerations, monitoring and quality control, common problems faced by manufacturers, environmental and safety considerations, and recommendations for adopting best practices that balance cost, quality, and sustainability. Wood seasoning is at the heart of India's transition from traditional hardwood-based industries to plantation-driven, value-added, globally competitive wood products. The challenges species variability, infrastructure gaps, energy intensity, and skills shortage are significant but surmountable.

With strategic investment in modern kiln technologies, shared facilities, skill development, and policy support, India can establish a sustainable, efficient, and export-ready seasoned wood value added products. By integrating seasoning into broader plantation, processing, and engineered wood strategies, the country can unlock immense opportunities for rural livelihoods, industry growth, and environmental sustainability.

Introduction

Seasoning is the reduction of the moisture content of wood to a level suitable for its intended end use. In the Indian market, seasoned wood is essentially needed for furniture manufacturing, construction, and handicrafts items, making it essential for competing with imported wood products besides promoting use of short rotation agroforestry wood. Seasoning provides superior dimension stability, durability, and resistance to moisture-related defects like warping and fungal attacks. Its uses include structural components, high-quality furniture, and interior finishing where dimensional stability and a good finish are crucial. In India, wood products range from structural timber, furniture, and doors to plywood, veneer, and engineered wood products. Each product category has specific moisture content requirements influenced by end-use conditions (interior/exterior, humid/dry climates). Improper seasoning leads to warping, checking, fungal decay, adhesive failure, and poor finishing whereas seasoning under controlled conditions reduce moisture content to the equilibrium moisture content (EMC) appropriate for the end use and local conditions, stabilize wood dimensionally to reduce shrinkage, warping, and checking, improve strength and stiffness and reduce weight, reduce susceptibility to fungal and insect attack by passing through moisture levels unfavourable for pests and ensure compatibility with adhesives and finishing systems for composite products. Typical target MC values in India for interior furniture and interior joinery are 8–12% (often 10% ±2%), while exterior structural timber may be conditioned to 12–14% depending on exposure. India's diversity of climates (tropical, subtropical, arid, and temperate) and the wide range of commercial species (teak, rosewood, sal, mango, eucalyptus, poplar, pine, and many lesser-known species) make practical seasoning strategies both complex and essential. Foreign buyers often offer a premium for well-seasoned wood, as it is essential for meeting international quality standards and remains a critical requirement for exporters.

Historical Development of Wood Seasoning in India

Wood seasoning in India has a long history, beginning with traditional practices in the pre-colonial period. Craftsmen and indigenous communities relied on empirical methods such as sun-drying, air seasoning, soaking logs in rivers or ponds, and applying mud or cow dung to reduce cracking. These low-cost, region-specific techniques were widely used in temple construction, boat building, and household carpentry, providing durable timber through natural processes. In India a start was made by R S Pearson in 1914 when the first series of air-seasoning experiments were initiated. Air drying (seasoning) even today remains the most common among SMEs and rural workshops due to its simplicity and negligible energy cost, though it is slow, climate-dependent, and prone to defects if poorly managed. Solar kilns first time developed at ICFRE-FRI, Dehradun provided an intermediate solution with reduce drying time but are limited during monsoons.

The colonial era marked a shift towards systematic practices with the establishment of the Indian Forest Department and growing demand for durable wood in railways, shipbuilding, and public works. Controlled air-drying yards and experimental steam-heated kilns were introduced in major timber depots, while scientific documentation of seasoning methods for Indian hardwoods began. With the creation of the Forest Research Institute (FRI) in 1906, research gained momentum through the development of kiln schedules, manuals, and comparative studies, which laid the foundation for scientific wood seasoning in India. The real fillip to the seasoning industry however came during Second World War 1940-45). Kiln seasoning schedules for nearly 250 commercially important Indian hard and softwoods were developed to ensure uniform drying, minimize defects, and optimize timber utilization. Indian hardwoods exhibit wide variations in density, permeability, and shrinkage characteristics, requiring species-specific drying schedules. By carefully regulating temperature, relative humidity, and air velocity at different stages of seasoning, the risk of surface checking, honeycombing, collapse, and case-hardening could be reduced. Research-based kiln schedules help shorten drying times compared to air seasoning, improve dimensional stability, and enhance strength and durability, thereby making the timber suitable for high-value applications in furniture, joinery, and engineered wood products. Industrial manufacturers increasingly adopted kilns for better control and faster throughput: conventional steam/hot-air kilns are still widely used though energy-intensive.

Post-independence industrial growth further expanded research and infrastructure for seasoning. Regional research centres and sawmills set up mostly steam heated overhead fan reversible air circulation type steam heated kilns, focusing on efficient techniques for most of the commercially available wood form forest. From the 1990s onwards, modern methods such as dehumidification kilns which offer energy efficiency and precision for high-value timbers; solar cum dehumidification, vacuum kilns enabled rapid, low-temperature drying for difficult species, seasoning were experimented to improve speed, uniformity, and energy efficiency. Today, controlled kiln drying is integral to industries like furniture, plywood, and engineered wood, while ongoing research explores advanced Microwave / RF/vacuum systems and sustainable solutions, balancing traditional practices with modern innovation.

Recent development at ICFRE-FRI/IWST Institutes in the area of RF/Microwave-Vacuum systems for seasoning of problematic plantation timber resulted better quality due to uniform volumetric heating for thick and problematic woods. Experimentation has also shown that even plantation-grown tree trunks can be successfully dried to produce high-end products. Since species-specific responses vary considerably, it is necessary to develop conservative schedules to minimise energy consumption and avoid cracking, warping, and internal checks in species such as Eucalyptus, Rubberwood, Melia dubia, and Poplar. To optimize quality, industry should adopt species- and thickness-based schedules, conduct pilot tests, and refine practices balancing cost, efficiency, and end-use requirements.

A brief comparison of Drying Technologies in India

Technology	Typical Energy Use	Drying Time	Suitability	Challenges
Air Drying	Negligible (climate dependent)	Weeks–months	Low-cost, SMEs	Weather dependent, 18–20% MC floor
Conventional Kiln	1000–1200 kWh/m³	5–20 days	Large sawmills, plywood	High energy cost, poor automation
Dehumidification Kiln	500–700 kWh/m³	7–15 days	SMEs & medium industries	Higher capital cost
Vacuum Drying	400–600 kWh/m³	2–7 days	High-value timber	Expensive, needs trained staff
RF/Microwave Drying	300–500 kWh/m³	Hours–days	Fast-grown plantation wood	Very high CAPEX, limited availability

Common Problems and Remedies

Drying defects are among the most common challenges in timber processing, often leading to reduced strength, poor appearance, and loss of commercial value. Surface checking and splits typically result from excessively rapid drying or steep temperature gradients, and can be minimized through careful control of initial drying conditions with higher humidity, lower temperature differentials, and proper stacking practices.

Case hardening, where a hardened outer shell develops while internal stresses remain locked inside, poses difficulties during machining and can be addressed by incorporating conditioning or re-conditioning phases that temporarily raise humidity toward the end of the drying schedule.

Warping and twisting, which distort the shape of timber, usually stem from non-uniform drying or uneven airflow, and can be avoided by ensuring uniform stacking, maintaining balanced air circulation, and following schedules suited to each species.

Another major concern is fungal growth and blue stain, particularly when timber is stored too long in warm, humid conditions; faster kiln-drying, fungicidal pre-treatment, and strict sanitation measures help reduce this risk.

Finally, discoloration often associated with heat exposure or the chemical reactions of extractives can undermine the appearance of high-value timber and is best prevented by adopting lower drying temperatures for sensitive species, or by using advanced methods such as vacuum or radio-frequency (RF) drying. Collectively, these measures highlight the importance of species-specific, carefully managed drying schedules to ensure that timber retains both its structural integrity and aesthetic appeal.

Challenges and Opportunities

One of the foremost challenges in seasoning of Plantation-grown species having higher juvenile wood proportion are prone to collapse, checking, and greater shrinkage. Large variation between clones, sites, and ages makes standardisation much more difficult. However better seasoning results were obtained by adopting change in the sawing methods such as Balanced Tangential , Radial sawing and using Saw Dry Rip (SDR) in case of plantation timber spp. like Eucalypts & Poplar wood.

Second big challenge is High energy consumption in seasoning. Conventional seasoning methods, particularly traditional kiln operations, often rely on outdated technologies with low energy efficiency. These systems not only increase production costs but also contribute to environmental concerns. Optimising kiln design, incorporating renewable energy sources, and adopting modern control systems such as temperature, air circulation rate and humidity regulations are critical steps toward reducing energy intensity in the process.

Another key issue is the quality of seasoned wood. Inconsistent seasoning practices often result in under-seasoned or over-seasoned timber, leading to significant losses in value addition. Uniformity of moisture content is difficult to achieve without precise monitoring and skilled operation. This directly affects industries such as furniture, construction, handicrafts, and plywood, where dimensional stability and strength are essential. Advanced techniques like RF/microwave-based seasoning, solar-assisted kilns, and computer-controlled drying chambers are emerging as promising solutions to achieve high-quality, defect-free seasoning.

Apart from these technical issues the scarcity of trained manpower is another challenge. Skilled operators and technicians with knowledge of modern wood seasoning practices are limited in India. Training programs, capacity-building initiatives, and industry–academia collaborations are urgently needed to bridge this gap. Without adequate expertise, even advanced equipment often remains underutilised or inefficiently operated.

At the same time, these challenges present significant opportunities. With India's growing demand for quality wood products in domestic and export markets, there is immense scope for adopting energy-efficient, sustainable, and technology-driven seasoning practices. Establishing training centres, pilot projects, and demonstration units can help build confidence among industries. Government support, coupled with private sector investment in modern seasoning infrastructure, can transform the sector into a more competitive and environmentally responsible industry.

There is absence of mandatory moisture standards in trade. Logistical delays in moving fresh timber to kilns increase risk of blue stain and fungal damage. Buyers, especially in export markets, remain cautious about plantation species unless seasoning is reliable and certified. Develop species- and clone-specific drying schedules. Promote decentralised shared kilns.

In conclusion, minimizing energy consumption, improving seasoned wood quality, and developing trained manpower are interlinked priorities for strengthening the wood-based industry in India. Addressing these challenges will not only enhance product quality and reduce costs but also open pathways for sustainable growth and global competitiveness.

Quality control

Quality control in wood drying relies on a combination of equipment used for monitoring and measurement, records keeping, and use of well-established kiln schedules to ensure consistent results. Portable moisture meters (pin or pin less) are used for quick checks, while kiln sensors such as thermo-hygrometers and stack thermocouples track temperature, humidity, and core conditions across zones. Documented kiln schedules with detailed batch logbooks capture key parameters like starting and final moisture content, species, time, and operator notes. Laboratory facilities using the oven-dry method provides higher accuracy when required, supported by visual inspection for defects such as surface checks, discoloration, case-hardening, honeycombing, and fungal stains. Effective quality assurance depends on systematic record-keeping, trained operators, and applying simple statistical process controls to monitor averages and variations in moisture content across batches.

Future prospects

In India, the demand for seasoned wood is steadily increasing across construction, furniture, packaging, handicrafts, and emerging engineered wood industries, as seasoning improves dimensional stability, strength, and durability. The annual industrial wood requirement is estimated at over 90 million cubic metres, a significant portion of which comes from sawn timber used in housing, furniture and infrastructure. While traditional sources such as natural forests have been restricted due to conservation policies, availability is being met from trees grown outside the forest, Agro-forestry and timber imports. With growing plantation resources of Teak, Shisham, Eucalyptus, Melia dubia, Acacia, Rubberwood, Gamari, Mahogani, Siris. Babul, Neem, Corymbia, Toon, Poplar, and Bamboo, coupled with expanding kiln-drying and RF/microwave seasoning facilities, India has a strong potential to bridge the gap between requirements and availability through sustainable, technology-driven utilization. India's industrial demand for wood, measured in round wood equivalents, is projected to rise sharply from 90 million m^3 in 2020 to 220 million m^3 by 2030. It is estimated that by then, over 95% of the country's wood supply will originate from trees outside forests (ToF). One of the major problems generally noticed in the utilizing short-rotation plantation-grown timber species is their tendency to warp excessively during sawing into planks or scantlings. This problem arises primarily from residual longitudinal growth stresses present in the logs. However, research carried out at FRI and IWST has led to the development of effective processing technologies. These include the adoption of special sawing patterns for logs, the use of high-humidity-oriented kiln schedules, and the application of top-weighting on timber stacks during seasoning.

References : Contact author at
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Wood Seasoning Explained: Why Moisture Matters and How Timber is Properly Dried

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Abstract

Wood seasoning is a critical operation in timber processing that directly influences product quality, service performance, and production economics. Freshly felled wood contains high levels of moisture, which must be reduced in a controlled manner to prevent defects such as warping, cracking, fungal attack, and loss of strength. This article provides a practical overview of wood seasoning for industry use, covering the fundamentals of moisture behaviour in wood, including moisture content, free and bound water, equilibrium moisture content, and fibre saturation point. Methods for determining moisture content, recommended seasoning levels for different climatic zones in India, and classification of Indian timbers based on seasoning behaviour are explained. The article also highlights key pre-seasoning practices and briefly reviews commonly used seasoning methods ranging from air drying and steam-heated kilns to dehumidification, vacuum, microwave, and radio-frequency drying. The article aims to provide a brief practical understanding of wood seasoning for students, professionals, and practitioners in the wood sector.

1.0 Why Season Wood?:

Freshly felled timber contains a large amount of moisture—often more than 100 percent when calculated on an oven-dry weight basis. For timber to perform satisfactorily in service, this excess moisture must be removed while the wood is still in the green condition. As moisture is removed, wood shrinks. If drying is not carried out in a controlled and systematic manner, this shrinkage can lead to several defects and quality losses in the timber.

Wood seasoning is therefore one of the most important steps in wood processing. It involves drying timber to a specific moisture content that is appropriate for the surrounding atmospheric conditions, using a controlled process. The primary objective of seasoning is to improve the properties of wood while minimising defects, thereby increasing the value and service life of timber products.

Some of the major advantages of wood seasoning are:

- Timber dried to below 20 percent moisture content has little risk of stain, decay, or mould caused by fungal activity.
- Dried timber is generally more than twice as strong as wet timber.
- Seasoning improves the nail- and screw-holding capacity of wood.
- Seasoned timber is lighter, reducing transportation and handling costs.
- Proper seasoning improves dimensional stability; products made from wet wood often shrink significantly during service.
- Gluing, machining, and finishing are much easier with dry wood.
- Timber intended for preservative treatment must be properly dried to allow effective penetration of chemicals.
- Dried timber exhibits better electrical and thermal insulation properties.

When drying wood, the key question is: "What level of quality is required?" The major quality criteria for dried timber include achieving the correct moisture content—both the average value and its uniformity within individual pieces and across the entire load. In addition, good-quality dried wood should be free from surface and internal checking, end splits, warping (such as cup, bow, crook, or twist), and case hardening. Desirable attributes also include good colour, adequate strength, minimal fungal or chemical staining, and good machinability and glueability.

Beyond understanding quality requirements, successful seasoning also depends on skilled operation. A trained kiln operator must have suitable equipment, ensure it is properly operated and maintained, work with well-stacked and good-quality timber, and allow sufficient time for the drying process to be carried out correctly.

2.0 Moisture in wood:

Moisture is one of the most critical factors influencing the utilisation, performance, and service life of wood. From the moment a tree is felled to its final use in products such as furniture, construction, or packaging, the amount of moisture present in wood governs its strength, dimensional stability, durability, and workability. Excess or poorly controlled moisture can lead to problems such as shrinkage, warping, cracking, fungal attack, and poor machining or finishing performance, while wood at the correct moisture level performs reliably in service. To understand and control these behaviours, it is essential to be familiar with a few key moisture-related concepts used in wood science and technology. Terms such as moisture content, free water, bound water, fibre saturation point, and equilibrium moisture content form the basis for understanding how wood interacts with its surrounding environment and how it should be dried and used effectively.

2.1 Moisture Content: Wood is made up of individual cells that resemble hollow tubes. These cells, or fibres, typically have a diameter of about 0.25 to 0.5 mm, with an average length of around 1 mm in hardwoods and up to 3 mm in softwoods. Most of these fibres are oriented along the height of the tree, which strongly influences the movement of moisture within wood. Freshly felled timber contains a large amount of water—often two to three times the oven-dry weight of the wood. A major portion of this moisture is present in the cell cavities (lumens) and is known as free water, while the remaining moisture is held within the cell walls and is referred to as bound water. The total amount of water present in wood is expressed as a percentage of its oven-dry weight and is termed moisture content (MC). Oven-dry weight represents a standard reference condition, obtained by drying wood in an oven at 100–105°C until a constant weight is achieved, indicating that practically all moisture has been removed.

2.2 Equilibrium Moisture Content: When wood is exposed to air at a constant temperature and relative humidity, it either gains or loses moisture until it reaches a state of balance with the surrounding environment. The moisture content at this stage is known as the equilibrium moisture content (EMC) and is numerically equal to the EMC of the air. While temperature and relative humidity primarily govern EMC, the actual moisture content attained by wood can also be influenced by natural variability in wood structure and by external factors such as stress and heat.

2.3 Fibre Saturation Point: The fibre saturation point (FSP) is the moisture condition at which all free water has been removed from the cell cavities, and the wood begins to lose bound water from the cell walls. This is a critical stage in wood drying because shrinkage starts only below the FSP, when the swollen cell walls begin to release bound water. The fibre saturation point varies among wood species and can also differ within the same species depending on factors such as growth conditions and geographic origin.

3 Basic Drying Concepts

Understanding the basic principles of timber drying helps in selecting economical and efficient drying methods that produce high-quality wood products. This knowledge enables kiln operators to apply general drying concepts effectively to specific situations. To dry wood successfully, three fundamental requirements must be met: the supply of energy, and proper control of temperature, humidity, and airflow.

Energy must be supplied throughout the drying process to evaporate moisture from wood. Wood contains two types of water: free water and bound water. Free water occupies the cell cavities and is relatively easy to remove. Drying green wood with high free-water content typically requires about 2.4 MJ of energy per kilogram of water evaporated. Bound water, on the other hand, is held within the cell walls when the moisture content falls below approximately 30 percent. Because bound water is chemically associated with the cell wall, progressively more energy is required to remove it as moisture content decreases. Additional energy is also needed to compensate for heat losses due to conduction and ventilation in the drying system.

Temperature control is critical for achieving good drying quality. Higher temperatures increase the drying rate but also raise the risk of defects such as checking, cracking, honeycombing, collapse, and warping. Elevated temperatures may also darken the wood. At the same time, higher temperatures promote more uniform drying across the timber stack and reduce the activity of insects, insect eggs, and fungi, particularly above 54°C. Balancing drying speed with quality considerations is therefore essential.

Humidity control plays an equally important role in timber drying. Relative humidity (RH) refers to the amount of moisture in the air compared to the maximum amount the air can hold at a given temperature and is expressed as a percentage. In practice, RH is commonly measured using a wet-bulb thermometer, in which a temperature sensor is covered with a wet muslin wick. The wet-bulb temperature is always lower than the dry-bulb temperature, except at 100 percent RH, where both are equal. The difference between the two temperatures, known as the wet-bulb depression, is used along with reference tables or charts to determine RH. Very low RH at the early stages of drying can cause excessively rapid moisture loss, leading to cracks, splits, and honeycombing in some species. RH also plays a key role in controlling the final moisture content of timber.

Air velocity is another critical but often underestimated factor. Adequate airflow is especially important at high and intermediate moisture contents. Insufficient air velocity can result in high local humidity within the stack, slowing drying and leading to warping, poor colour, or staining in certain species. Conversely, excessively high air velocity at high moisture contents can accelerate drying too much, increasing the risk of checking, cracking, and honeycombing. At low moisture contents, however, air velocity has a relatively minor influence on drying rate and timber quality.

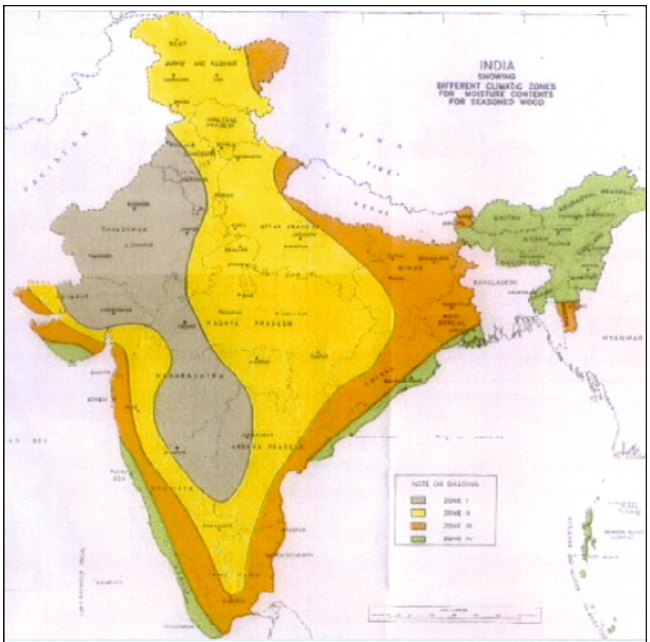
In practice, the drying rate of timber is governed by the combined effects of temperature, relative humidity, and air velocity. These parameters must be carefully adjusted based on the species being dried, its initial moisture content, grain direction, and thickness. Different wood species dry at different rates due to variations in anatomical features such as pit structure and aspiration, alignment and continuity of the capillary system, and the presence of extractives. Understanding these fundamentals is essential for achieving efficient, defect-free timber drying.

4.0 At What Moisture Content Should Wood Be Seasoned?

To avoid manufacturing problems in the finished product such as warping, splitting, and checking timber must be dried to a final (post-conditioning) moisture content that closely matches the expected moisture conditions during service. Ideally, the final moisture content should lie near the middle of the range of in-use moisture levels, allowing the wood to adjust safely to small changes in ambient humidity without developing defects.

From the point of view of optimum seasoning moisture content, India has been divided into four climatic zones based on average annual relative humidity. These zones provide useful guidance for selecting appropriate target moisture contents for seasoned timber.

- Zone I: Average annual RH less than 40%
- Zone II: Average annual RH between 40% and 50%
- Zone III: Average annual RH between 50% and 67%
- Zone IV: Average annual RH above 67% For certain



Climatic zones of India

specialised applications such as timber used for bending operations or wood intended for export the final moisture content may differ from that recommended for furniture, cabinetry, and interior woodwork. Typical target moisture contents for such uses are usually specified separately in Table 1. Once timber has been properly seasoned, it is essential that storage, manufacturing, and warehousing are carried out under humidity conditions close to, or slightly lower than, the expected in-service environment. Ignoring these principles can lead to significant dimensional changes in wood and serious economic losses for manufacturers.

> From the point of view of optimum seasoning moisture content, India has been divided into four climatic zones based on average annual relative humidity.

Table 1 : Recommended moisture content for different zones of India

Use	Moisture content (%)			
	Zone-I	Zone-II	Zone-III	Zone-IV
Aircraft	12	12	14	15
Agricutural implements	12	14	16	16
Ammunition boxes	10	12	14	15
Artificial limbs	81	01	21	2
Automobile bodies				
50 mm and above thickness	10	8	12	10
thinner than 50mm	14	12	14	12
Beams and rafter	12	14	17	20
Doors and windows				
more than 50mm thickness	10	12	14	12
Less than 50mm thickness	0	10	12	14
Furniture and cabinet making	10	12	14	15
Shuttles and bobbins	81	01	21	2
Sports goods	10	12	14	16
Ship and boat building	12	14	16	18
Handles	12	12	14	15
Toys, carved items, pencils	8	10	12	12

5.0 Determination of Moisture Content:

In practice, moisture content in wood is commonly determined using two methods: the oven-dry method and electronic moisture meters.

5.1 Oven-dry method:

The oven-dry method is the most accurate way of determining moisture content, except in woods containing volatile extractives. However, it involves a delay of one to two days to obtain results and places practical limits on the size and number of samples that can be tested. The method involves the following steps:

1. Weigh the wood sample whose moisture content is to be determined.
2. Place the sample in an oven maintained at about 100°C.
3. Dry the sample until it reaches a constant weight.
4. Reweigh the dried sample.

Moisture content is calculated using the following equation:

By seasoning timber to the appropriate target moisture content as indicated in the table 1, the risks of performance-related failures can be minimized. The table serves as a practical guide to select suitable seasoning levels.

Although the oven-dry method is time-consuming and requires laboratory facilities and sample cutting, it is widely accepted as the standard reference method for most purposes.

5.2 Moisture meters:

Electronic moisture meters provide a quick and convenient means of measuring moisture content. Two main types are commonly used: resistance meters and dielectric meters. Resistance meters determine moisture content by measuring the electrical resistance of wood using a pair of needles driven into the timber, either along or across the grain. These meters are reasonably accurate within a moisture-content range of about 6 to 30 percent. Dielectric meters, on the other hand, operate on the relationship between moisture content and the dielectric properties of wood. They are fast, non-destructive, and do not leave holes in the wood, making them especially suitable for routine field measurements.

6.0 Classification of Indian Timbers for Seasoning Purposes

For seasoning purposes, Indian timbers are broadly classified into three categories based on their drying behaviour, particularly their susceptibility to drying defects and their rate of moisture loss. This classification provides a general indication of how different species respond to seasoning and helps in selecting suitable drying methods and precautions.

Class A – Highly Refractory Woods:

Timbers in this class dry very slowly and are difficult to season without developing cracks and splits. They are highly sensitive to rapid drying, especially in the green condition, and therefore require careful control and protection during seasoning. Typical examples include heavy structural timbers such as sal (*Shorea robusta*), laurel (*Terminalia alata*), and axlewood (*Anogeissus latifolia*).

Class B – Moderately Refractory Woods:

These timbers exhibit a moderate tendency to crack and split during drying. With reasonable control and some protection against rapid moisture loss, they can be seasoned with relatively few defects. Common examples include furniture timbers such as sissoo (*Dalbergia sissoo*) and teak (*Tectona grandis*).

Class C – Non-refractory Woods:

Timbers in this group can be dried rapidly without serious defects. However, if drying is too slow, they are prone to surface discoloration and mould growth. Typical examples include packing-case timbers such as semul (*Bombax ceiba*), mango (*Mangifera indica*), rubberwood (*Hevea brasiliensis*), and salai (*Boswellia serrata*).

Sal (Highly refractory)

Teak (Mod. refractory)

Mango (non-refractory)

7.0 Key Considerations Before Wood Seasoning:

The success of wood seasoning does not depend on the kiln alone; it begins much earlier with how logs and sawn timber are handled before drying. Poor handling at this stage can permanently affect timber quality, leading to defects that no amount of careful seasoning can fully correct. Proper protection of logs, suitable sawing practices, and correct stacking methods are therefore essential prerequisites for producing well-seasoned, defect-free timber.

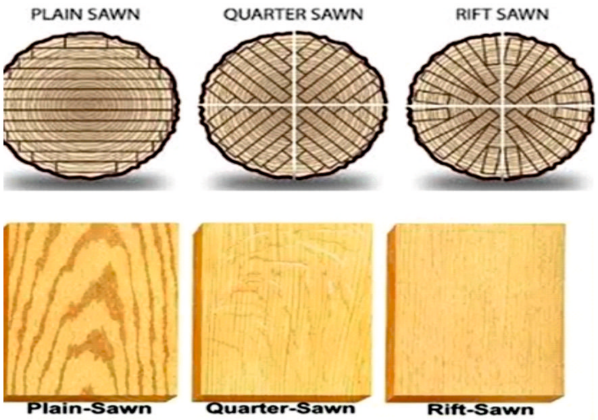
7.1 Protection of Logs: To a large extent, the quality of kiln-dried timber is predetermined by the treatment the logs receive during harvesting, storage, and processing prior to drying. Several precautions taken at this stage can significantly reduce warp, checking, and other seasoning defects.

Logs piled without protection are highly susceptible to end checking and attack by fungi and insects, particularly during warm weather. One effective method of protection is storing logs under water—commonly, though not technically, referred to as water seasoning. During water storage, logs must be completely submerged. If stagnant water is used, it should be replaced approximately once every fortnight, and the bark should be removed before submergence.

When storage under water is not practical, continuous water spraying has proven to be an effective means of reducing end checking, splitting, fungal staining, and decay. For spraying to be effective, it must be uninterrupted, and the spray system should remain free from clogging. Both the sides and ends of logs must be adequately covered. Cold, fresh water is more effective than warm, recycled water. For high-value sawlogs, end coating is often an economically sound practice. Applying wax or similar sealants immediately after cutting helps prevent end splitting and retards fungal staining.

Endcoating of logs

7.2 Sawing Procedures: Sawing patterns strongly influence the tendency of timber to warp during drying. Timber sawn parallel to the bark is generally less prone to bowing and twisting than timber sawn at varying angles to the bark. Flatsawn timber is more susceptible to cupping than quartersawn timber. Boards cut close to the centre of the log often show higher longitudinal shrinkage, especially when the wood is near the pith. Careful sawing practices can therefore reduce drying defects and improve dimensional stability.



7.3 Stacking: For most drying processes, timber must be stacked in horizontal layers, with each layer separated by thin wooden strips known as stickers. Proper stacking is critical and cannot be overemphasised. The primary purposes of correct stacking are to ensure uniform air circulation for even drying and to minimise or eliminate warping during seasoning.

7.4 Stickers: Stickers (also known as sticks, fillets, or strips) work together with bolsters or crossers to control warp and maintain stack stability. Good-quality stickers are essential for producing uniformly dried timber. Stickers should be of uniform thickness, well seasoned, dry, and of appropriate length for the stack width to prevent sticker stain and uneven loading. Most hardwood drying operations use stickers 19–25 mm thick, spaced at intervals of 60–75 cm. Sticker thickness

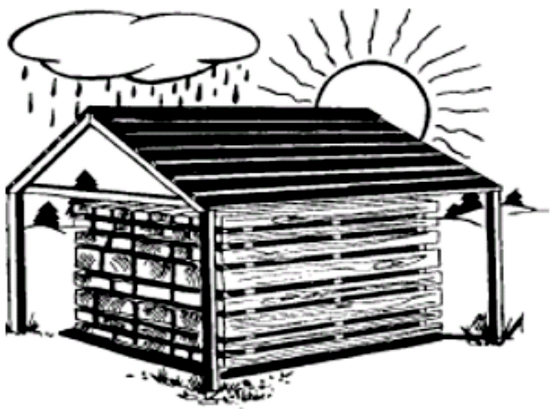
Stacking with stickers

has a strong influence on drying speed, uniformity, and kiln capacity. Uniform thickness from sticker to sticker is especially important, as variations can significantly increase warp. Thicker stickers also reduce kiln capacity; as a general rule, every 3 mm increase in sticker thickness reduces kiln capacity by about 7 percent.

8.0 Main Wood Seasoning Methods:

Wood seasoning can be carried out using a range of methods, from simple natural drying to advanced high-technology systems. The choice of seasoning method depends on factors such as wood species, thickness, required final moisture content, available infrastructure, energy cost, and quality expectations. Each method has its own advantages and limitations in terms of drying speed, cost, energy use, and quality control.

Air Drying : Air drying is the oldest and most economical method of seasoning wood. Timber is stacked in the open or under sheds, allowing moisture to be removed naturally by ambient air movement. While air drying requires minimal investment and energy input, it is slow and highly dependent on weather conditions. Moisture content cannot be controlled precisely, and drying defects, fungal staining, and insect attack are common risks if stacking and protection are inadequate. Air drying is often used as a pre-drying step before kiln seasoning.



Steam-Heated Kiln Drying: Steam-heated kilns are the most widely used industrial drying systems. In these kilns, temperature, relative humidity, and airflow are carefully controlled using steam as the heat source. Standard drying schedules are followed based on species and thickness, allowing predictable and uniform drying to specific moisture contents. Although steam kilns offer good quality control and high production rates, they are energy-intensive and require skilled operation and significant capital investment.

Dehumidification Drying: Dehumidification kilns dry wood by removing moisture from the circulating air rather than venting it outside. These systems operate at relatively lower temperatures and are considered energy-efficient, particularly for small- and medium-scale operations. Dehumidifier kilns provide good control over drying conditions and are well suited for temperature-sensitive species, producing timber with minimal defects when properly operated.

Solar Drying: Solar kilns use solar energy to heat air and drive moisture removal from wood. They are environmentally friendly and have low operating costs, making them attractive for small-scale or rural applications. However, solar drying is weather-dependent, offers limited control over drying conditions, and is generally slower than conventional kilns. It is best suited for small batches and non-critical applications.

Vacuum Drying : Vacuum drying removes moisture by lowering the atmospheric pressure around the wood, allowing water to evaporate at much lower temperatures. This method significantly reduces drying time and can produce high-quality timber with minimal defects, especially in thick or refractory species. However, vacuum drying systems are expensive, have limited capacity, and require careful control, making them suitable mainly for high-value products.

Steam heated drying kiln

Solar kiln

Dehumidification kiln

Vacuum kiln

Microwave (MW) and Radio Frequency (RF) Drying: MW and RF-based drying methods use electromagnetic energy to heat wood volumetrically, enabling rapid and uniform moisture removal from the interior. These technologies can dramatically shorten drying time and are particularly useful for thick sections or difficult-to-dry species. Despite their technical advantages, high capital cost, operational complexity, and safety considerations have limited their widespread commercial adoption. At present, they are mainly used for specialised applications and research-driven operations.

MW Drying

RF Drying

9.0 Conclusion:

Effective wood seasoning is as much an operational discipline as it is a technical process. Moisture control lies at the heart of timber performance, affecting strength, stability, durability, machinability, and suitability for end use. For industry professionals, understanding moisture-related concepts and drying behaviour is essential for selecting appropriate seasoning methods, setting correct drying targets, and avoiding costly defects.

Equally important are pre-seasoning practices such as log protection, correct sawing patterns, and proper stacking, which strongly influence drying outcomes and cannot be corrected later in the kiln. Different seasoning methods offer different advantages, and their selection should be based on species, thickness, production scale, quality requirements, and energy considerations. When timber is dried to the correct moisture content for its intended service environment and handled properly throughout processing, the benefits are reflected in improved product quality, reduced rejections, lower costs, and greater customer satisfaction.

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Kiln Drying Schedule for some Indian Timbers

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Introduction:

Wood straight from the forest or freshly harvested contains a large amount of water, which makes it heavy, weak, and prone to shrinking or cracking as it dries. To make it suitable for furniture, construction, or other uses, this extra moisture must be carefully removed — a process known as drying. While air drying depends on natural weather conditions and can take several weeks or months, kiln drying provides a faster and more controlled alternative. In this method, wood is placed in a chamber (called a kiln) where temperature, humidity, and airflow are regulated to achieve uniform drying with minimal defects. A kiln drying schedule is essentially a step-by-step plan that tells how the drying process should proceed — what temperature and relative humidity to maintain, and when to adjust them. The schedule is designed based on the species, thickness, and initial moisture content of the wood. It ensures that the wood dries neither too fast (which causes cracking or warping) nor too slow (which wastes time and energy).

As depicted, the kiln drying schedule of timber species coming under different refractoriness classes is discussed via example (1 to 3) for understanding. In these examples it can be seen that at the beginning of kiln drying, relatively low temperatures and high humidity are maintained. This is because the timber is freshly sawn and contains a high level of moisture; at this stage, the moisture gradient and internal stresses are crucial, as they can lead to surface and end cracking or initiate case-hardening, which may later cause honeycombing. As drying continues, the temperature is gradually increased and the humidity reduced. This middle phase is particularly important since improper control can result in honeycombing or warping. Therefore, the temperature must remain within safe limits that the wood can withstand. Toward the end of the seasoning process, higher temperatures and lower humidity levels are used. However, the temperature must not exceed a level that could weaken the timber, as excessive heat can cause permanent loss of strength. In the final phase, the aim is to equalize the moisture content between the surface and the core, and among different boards. The process concludes with a conditioning step that helps release any remaining case-hardening stresses within the wood's cross-section.

The schedules vary depending on the species. For instance, *Acacia nilotica* (babul), *Shorea robusta* and other timbers that are prone to splitting and cracking during drying require a low initial temperature of 40 to 45 °C and a high relative humidity of 85 percent. The drying conditions are then gradually increased. Usually, the charge is steam-cooked at 55 °C with 100% relative humidity before the drying process begins. This is done to wet the wood's surface layers and heat up the charge. Whereas, the light soft timbers used for packing cases, like *Tetrameles nudiflora, Trewia nudiflora, Hymenodictyon excelsum,* etc., need to be kiln-dried at a relatively high temperature, say 55 °C, and at a low humidity, say 50 percent, at the start of the seasoning operation. This is done to prevent the growth of mold and stains. After around 30 hours, the drying conditions are rapidly increased to 65 °C and 30% relative humidity, for instance, if 1.3 cm thick boards are being employed.

In commercial practice, two main types of kiln-drying schedules are commonly used. These are moisture content–based schedules, where the drying conditions are adjusted according to the moisture content reached by the timber during seasoning, and time-based schedules, where specific drying conditions are maintained for fixed time intervals until the timber is assumed to be dry. In India, moisture content–based schedules are generally preferred, as they are better suited for the diverse and often refractory hardwood species typically encountered, where uniformity of timber is difficult to achieve. Such moisture-dependent drying schedules have been developed for nearly 150 commercially important Indian timber species.

Sterilization of timber to prevent mould growth, sapstain fungi, and insect attack can be effectively carried out in a kiln by applying a high-humidity treatment at elevated temperatures. The temperature and relative humidity values specified in Schedules I to VII are designed for seasoning timber of 2.5 cm thickness. For timber thicker than 2.5 cm and up to 5 cm, the relative humidity at each stage should be maintained about 5 percent higher. In the case of timber 5 to 10 cm thick, preliminary air seasoning to approximately 25 percent moisture content is recommended to ensure economical drying, followed by kiln drying under the same humidity conditions as those for 5 cm thick timber.

The seasoning kiln can also be used for sterilisation by initially steaming the timber charge at 55–70 °C and 100 percent relative humidity, provided the moisture content is below 30 percent. For 2.5 cm thick timber, the steaming duration should be 2 hours, with an additional hour of heating for every 1.25 cm increase in thickness beyond 2.5 cm. The seven drying schedules were developed through a trial-and-error approach, involving the application of progressively adjusted drying conditions during successive experiments on each species. The final schedules were selected to achieve the shortest possible drying time while minimising drying defects. Over the past 40 years, these schedules have performed satisfactorily; however, there remains potential to further accelerate the drying rates for certain Indian hardwood species depending on their individual characteristics. The average moisture content of the wettest half of the total number of samples on the side where air enters may be taken as a guide for making changes in the kiln schedule in preference to one single sample which happens to be the wettest. This refers to the study of rate of drying of timber and changes in kiln schedule to be made during kiln drying of timber.

Schedules (I to VII) as recommended for seasoning of Indian Timbers: (Source: IS 1141 (1993): Seasoning of timber- Code of practice).

Schedule I for 2.5 cm thick planks

Moisture content of the wettest timber on air-inlet side	Temperature		
	Dry bulb °C	Wet bulb °C	Relative humidity %
Green	52	44	62
60%	55	45	55
40%	60	46	44
30%	65	48	39
20%	68	48	33.5

Schedule I: Woods for packing-case manufacture, such as *Abies spp., Ailanthus spp., Bombax spp., Duabanga Grandifolra, Ficus spp, Picea smithiana, Spondias spp* etc., are covered under this tentative schedule.

These timbers will take about 4 to 5 days to season. Initial steaming of the charge for about 2 hours at 55°C and 100 percent relative humidity should be carried out to kill mold growth.

Schedule II: Timbers commonly used for cheap planking or for moderately heavy type of packing-cases, such as *Ficus spp, Mangifera indica, Pinus roxburghii, Pinus wallichiana, Populus spp., Vateria indica* are covered under this tentative schedule.

Schedule II for 2.5 cm thick planks

Moisture content of the wettest timber on air-inlet side	Temperature		
	Dry bulb °C	Wet bulb °C	Relative humidity %
Green	45	40	72
60%	47	40	64
40%	49	40	56
30%	53	40	44
20%	58	40	32.5

These timbers will take about 5 to 7 days to season. Initial steaming of the charge for about 2 hours at 55°C and 100 percent relative humidity should be carried out to kill mold growth.

Schedule III: Most of the light furniture woods, such as *Artocarpus heterophyllus, Cedrus deodara, Cupressus turulosa, Gmelina arborea, Grevillea robusta, Machilus, Micelia champaca, Salix spp Terminalia myriocarpa, Tsuga dumosa* etc., are covered by this tentative schedule

Schedule III for 2.5 cm thick planks

Moisture content of the wettest timber on air-inlet side	Temperature		
	Dry bulb °C	Wet bulb °C	Relative humidity %
Green	42	38	76
60%	45	40	72
40%	47	40	64
35%	49	40	56
30%	51	40	50
25%	53	40	44

These timbers will take about 8 to 10 days to season. In addition to the initial steaming, one intermediate steaming and one steaming towards the end for 2 to 3 hours at 55°C and 100 percent relative humidity would be required.

Schedule IV: Most of the furniture woods, such as *Albizia lebbeck, Albizia procera, Amoora wallichii, Calophyllum spp., Dalbergia latifolia, Dalbergia sisso, Eucalyptus tereticornis, Lagerstroemia hypoleuca, Morus spp., Pterocarpus dalbergioides, Schima wallichii, Wrightia spp* etc., are covered by this tentative schedule.

Schedule IV for 2.5 cm thick planks

Moisture content of the wettest timber on air-inlet side	Temperature		
	Dry bulb °C	Wet bulb °C	Relative humidity %
Green	42	38.5	80
60%	42	38	76
40%	45	40	72
35%	47	40	64
30%	49	40	56
25%	52	40	47
20%	55	40	39

These timbers will take 12 to 15 days to season. One intermediate steaming and one steaming towards the end of drying at 55°C and 100 percent relative humidity for about 2 to 4 hours would be required. For precision drying for high class works, conditioning treatment should be given.

Schedule V: Timbers used for furniture, constructional work or for certain special items such as bobbins and other turnery articles, such as *Acer spp., Cinnamoum spp. Dipterocarpus spp., Fraxinus spp., Gardenia spp, Hevea brazilliensis, Juglans spp, Tectona grandis, Toona ciliate, Zanthoxylum limonella* etc., are covered by this tentative schedule.

Schedule V for 2.5 cm thick planks

Moisture content of the wettest timber on air-inlet side	Temperature		
	Dry bulb °C	Wet bulb °C	Relative humidity %
Green	42	38.5	80
45%	45	40	72
35%	46	40	68
30%	48	40	60
25%	50	40	53
20%	52	40	47
15%	55	40	39

These timbers will take about 13 to 16 days to season. In addition to the initial steaming, two intermediate and one final steaming at 55°C and 100 percent relative humidity for 2 to 4 hours would be required for these timbers.

Schedule VI: Heavy planking timbers, most of which are also used for structural purposes, such as Acacia nilotica, Eucalytus globulus, Pterocarpus marsupium, Quecus spp., Swietennia spp., Terminalia arjuna, Terminalia tomentosa etc., are covered by this tentative schedule.

Schedule VI, for 2.5 cm thick planks

Moisture content of the wettest timber on air-inlet side	Temperature		
	Dry bulb °C	Wet bulb °C	Relative humidity %
Green	40	37	82
60%	42	38	76
40%	45	40	72
35%	46	40	68
30%	47	40	64
25%	48	40	60
20%	50	40	53
18%	52	40	47
15%	55	40	39

These timbers will take about 16 to 20 days to season. They slow and careful drying. The charge will have to be steamed at least twice during the course of drying in addition to the initial and final steaming at 55 OC and 100 percent relative humidity for 2 to 4 hours.

Schedule VII: Some highly refractory timbers, such as *Acacia tortilis, Anogeissus latifolia, Cassia fistula, Heritiera spp, Hopea spp., Prosopis julifors, Shorea robusta, Syzygium spp., Vitex spp.*, are covered by this tentative schedule.

Schedule VII, for 2.5 cm thick planks

Moisture content of the wettest timber on air-inlet side	Temperature		
	Dry bulb ° Temperature (C)	Wet bulb ° Temperature (C)	Relative humidity %
Green	40	38	88
60%	41	38	82
40%	42	38	76
35%	45	40	72
30%	46	40	68
25%	47	40	64
20%	50	42	61
18%	52	42	54
15%	55	42	45

These timbers will take about 24 to 30 days to dry. The charge will need at least three intermediate steaming operations in addition to initial and final steaming at 55°C and 100 percent relative humidity for 2 to 4 hours.

Conclusion

Each wood species behaves differently when it dries, and kiln drying schedules are designed to match these characteristics. By following the right schedule, sawmills and industries can produce high-quality timber that is stable, strong, and long-lasting. Kiln drying thus plays a vital role in efficient wood utilization, resource conservation, and sustainable forest management. Kiln drying schedules specified in IS 1141 (1993) serve as a valuable guideline for the systematic seasoning of Indian timbers under controlled temperature and humidity conditions. These schedules are formulated based on the refractory nature of wood species—classified as Class A (highly refractory), Class B (moderately refractory), and Class C (non-refractory)—to ensure uniform drying with minimal defects. By adhering to the prescribed schedules, the quality of seasoned timber can be significantly improved, reducing issues such as warping, cracking, and fungal attack. The standard thus plays a crucial role in promoting the efficient utilization of wood resources, enhancing the dimensional stability and service life of timber used in construction, furniture, and other industries. Adoption of kiln drying schedules as per IS 1141 not only improves productivity and quality but also supports sustainable forest resource management and value addition in the wood-based sector.

References : Contact author at ritesh@icfre.org

One year Diploma in Advanced Woodworking

Course Description:

The Diploma Course was launched in the year 2018-19 jointly with M/s. Biesse Manufacturing Company Private Limited. This program offers an excellent opportunity for trainees to acquire required skill set to work on wood and wood products. This course structured to provide first hand experience in handling state of the art machineries to make them employable in wood based industries. This course has eight major modules namely, Fundamentals of wood materials, Fundamentals of Engineering, Wood processing using advanced machines & allied processes, Loading & unloading systems, machinery safety, maintenance of machines, Assembly & Joinery, Advanced application of software (CNC, CAD/CAM & 3D-Pytha) and project work. Upon successful completion of training, the trainees will be able to handle most of the advanced woodworking machines that are used in the wood based industries.

Eligibility	:	Pass in Pre-University Course/Senior Secondary/ XII/ Equivalent from recognized Board. (Graduates in Science / Forestry / Engineering are encouraged to apply).
Course Fee	:	Rs. 50,000/- for the entire course
Extra	:	Rs.1,650/- per month towards Accommodation Charges Food Charges (as per actual)
Security Deposit	:	Rs. 5,000/- (Refundable)
Intake	:	Maximum 30 Candidates

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Wood Drying Standards: A Foundation for Quality Timber

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Introduction:

India, as a developing nation with a vast and growing population, faces an ever-increasing demand for raw materials. Among these, wood remains one of the most significant natural resources, valued for its versatility, availability, and universal acceptance (Leiker and Adamska, 2004). Drying is the first and most critical step toward efficient utilization of wood. The dried timber not only exhibits improved dimensional stability and enhanced finishing quality but also becomes lighter for transportation, more receptive to preservation treatments, and superior in its mechanical performance (Oloyede and Groombridge, 2000). Thus, drying is rightly regarded as one of the most fundamental operations in timber processing. Defined as the process of removing or reducing moisture before utilisation, wood drying has been practiced since humans first discovered the use of wood (Owoyemi, 2015).

Over centuries, drying methods have advanced from simple air seasoning to controlled kiln operations and, more recently, to innovative technologies such as microwave and vacuum drying (Hansson and Antti, 2003). The choice of technique largely depends on the size, shape, and anatomy of the timber being dried and its intended application (Simpson, 1983a). Historical evidence indicates that wood drying has accompanied civilization since its beginnings, reflecting its central role in human development (Shukla, 2001). Today, with more than 300–400 species in commercial use, each with unique anatomical and physical characteristics, no single method suits all. Variations in species, climate, and end-use requirements mean that drying practices often differ significantly (Simpson, 1983b).

This diversity highlights the urgent need for standardisation in wood drying. Without harmonized practices, industries risk inconsistency in product quality, inefficient resource utilisation, and economic loss. Standardisation ensures uniformity, improves trade reliability, and enables the adoption of best practices across regions and species. Understanding wood drying and its standards is therefore not merely a technical requirement but a key to sustainable utilisation, long-term performance, and global competitiveness of wood and wood-based products.

Key Aspects of standardisation in Wood Drying

1. Moisture Content (MC) Determination

Standards define the acceptable moisture content range for different end uses (e.g., 8–12% for furniture, 15–20% for construction timber). Methods for MC measurement (oven-dry method, electrical resistance, and capacitance meters are also standardized to reduce variability.

2. Drying Schedules

Standard drying schedules prescribe time, temperature and humidity combinations for different species and thicknesses. These schedules prevent drying defects such as warping, case-hardening, and honeycombing.

3. Drying Quality Assessment

Parameters such as drying defects and uniformity of MC are part of standardized evaluation. Grading rules are established to assess the severity of checks, splits, or collapse.

Evolution and Need of Standards in Wood Drying

The practice of drying wood has accompanied human civilization for centuries, yet for a long time it remained a craft guided by experience rather than by science. Traditional air seasoning and rudimentary kiln operations were often carried out without uniform guidelines, leading to inconsistencies in timber quality, durability, and performance. With the expansion of industrial production, global trade, and the demand for reliable timber products, the absence of standard practices became increasingly evident. This created the necessity for formal standards in wood drying, aimed at harmonizing procedures, minimizing defects, and ensuring product reliability across regions and industries.

The evolution of standards in wood drying reflects both technological progress and the growing importance of timber in trade and construction. Early standards primarily focused on defining permissible moisture content levels for different uses, recognizing that inappropriate drying often led to warping, cracking, or decay. As knowledge advanced, standards began incorporating methods of moisture determination, guidelines for conditioning, and recommendations for drying schedules specific to species and climatic conditions.

In India, the Bureau of Indian Standards (BIS) has established key documents such as IS 287, which specifies permissible moisture content for timber across climatic zones; IS 11215, which outlines methods for determining moisture content; and IS 1141, a comprehensive code of practice for the seasoning of timber. Internationally, organizations like ASTM, ISO, and CEN (EN standards) have developed similar benchmarks, ensuring consistency in testing methods and acceptable moisture ranges. Together, these frameworks not only provide technical clarity but also form the foundation of quality assurance in wood processing.

The need for such standardisation lies in its ability to bridge the gap between science and practice. Without a uniform approach, industries risk uneven quality, increased wastage, and trade disputes arising from non-compliance with buyer requirements. Standards bring credibility to manufacturers, enhance consumer confidence, and facilitate smoother global trade by ensuring that timber products meet universally accepted benchmarks. Thus, the evolution of wood drying standards is not merely a regulatory development but a response to industrial, commercial, and environmental imperatives.

Standards on Wood Drying Practices

Standardization in wood drying is not limited to moisture measurement alone; it also encompasses the processes, methods, and control frameworks that ensure drying is carried out in a consistent, efficient, and defect-free manner. Several national and international organizations, such as the Bureau of Indian Standards (BIS), the European Committee for standardisation (CEN), the American Society for Testing and Materials (ASTM), and the International Organization for standardisation (ISO), have issued standards that provide guidelines on seasoning, conditioning, and process control. These standards form the backbone of quality assurance in the timber industry, bridging scientific understanding with industrial application.

In the Indian context, IS 1141: 1993, Code of Practice for Seasoning of Timber (BIS, 1993) serves as the principal guideline for timber drying. It provides a detailed framework for both natural and artificial seasoning, covering methods such as air seasoning, kiln drying, solar drying, and chemical drying techniques. The standard prescribes essential practices for stacking timber, maintaining airflow, protecting wood from direct sunlight and rain, and designing kiln schedules tailored to specific species. Importantly, it emphasizes the control of moisture content in relation to end-use requirements, referring back to IS 287, which specifies permissible moisture values for different applications. IS 1141 also underscores the need to minimize drying defects such as surface checking, warping, collapse, and honeycombing, which can severely impair the quality and service life of timber. In doing so, the standard aligns traditional practices with modern process requirements, offering industries in India a reliable reference for maintaining quality across diverse climatic zones and wood species.

Table 1: Relevant National and International Standards on Wood Drying & Moisture Content

Standard No. & Year	Title	Scope / Coverage	Method / Key Notes
BIS (India)			
IS 707: 1976	Glossary of terms applicable to timber technology and utilization	Covers standardized terminology related to timber technology, processing, and utilization.	Provides definitions to ensure consistency in research, trade, and industry communication.

IS 11215: 1991	Moisture content of timber and timber products – Methods for determination	Defines methods for MC determination in timber and wood products.	Oven-dry method (reference), electrical resistance meters, species correction factors.
IS 287: 1993	Permissible moisture content for timber used for different purposes – Recommendations	Specifies permissible MC for different timber uses (construction, furniture, joinery, etc.) across Indian climatic zones.	Prescribes target MC ranges with tolerances for trade/usage.
IS 1141: 1993	Seasoning of timber - Code of Practice	Provides guidelines for seasoning (air/kiln), schedules for Indian timbers, and permissible MC levels for end uses.	Covers kiln & air seasoning methods, seasoning defects, monitoring.
ASTM (USA)			
ASTM D 4442-92: 2003	Standard Test Methods for Direct Moisture Content Measurement of Wood and Wood-Based Materials	Primary reference for MC measurement in wood, veneer, wood-based materials.	Methods: Oven-dry (primary, secondary), distillation; used for lab testing.
ASTM D 4933-16: 2021	Standard Guide for Moisture Conditioning of Wood and Wood-Based Materials	Procedures to condition wood to equilibrium moisture content (EMC) before testing.	Defines RH/temperature conditioning protocols; linked to EMC tables.
ISO (International)			
ISO 13061-1: 2014	Physical and mechanical properties of wood — Test methods for small clear wood specimens — Part 1: Determination of moisture content	Standard method for MC determination of small clear specimens used in physical/mechanical property testing.	Oven-dry method until constant mass (103 ± 2 °C).
ISO 16979: 2003	Wood-based panels — Determination of moisture content	Applies specifically to plywood, MDF, particleboard and other panel products.	Oven-dry method with specimen preparation and calculation guidelines.
ISO 3130: 1975	Wood — Determination of moisture content for physical and mechanical tests	Earlier international reference for MC determination; now superseded.	Oven-dry reference method.
EN / CEN (Europe)			
EN 13183-1: 2002	Moisture content of a piece of sawn timber — Part 1: Determination by oven-dry method	European reference standard for MC measurement of sawn timber.	Oven-dry reference method (similar to ISO/ASTM oven-dry).
EN 13183-2: 2002	Moisture content of a piece of sawn timber — Part 2: Estimation by electrical resistance method	Defines electrical resistance method for in-field MC estimation of sawn timber.	Electrical resistance meters, with calibration; compared against oven-dry.
EN 14298: 2018	Sawn timber — Assessment of drying quality	Specifies assessment of drying quality (target MC, variability, defects).	Used for batch-level quality control and acceptance in Europe.

At the European level, EN 14298:2004, Process Control in Timber Drying (CEN, 2004) takes a different but complementary approach. Rather than prescribing drying methods, this standard focuses on the control and monitoring of drying processes in industrial kilns. It requires that operators document kiln schedules, monitor drying conditions such as temperature, relative humidity, and air velocity, and maintain calibration of measurement instruments. The standard also emphasizes traceability, ensuring that each batch of timber has a documented drying history, and establishes feedback mechanisms to adjust parameters in real time. By embedding process control into timber drying, EN 14298 enables European industries to achieve uniformity across mills, optimize energy consumption, and enhance product quality. This systematic approach is particularly critical in Europe, where timber is traded widely across borders and must comply with harmonized standards.

In the United States, ASTM standards provide significant guidance, although with a greater emphasis on conditioning and testing rather than prescribing kiln operations. ASTM D4933 outlines procedures for conditioning wood to equilibrium moisture content under controlled humidity and temperature, a critical step for laboratory testing and performance evaluation. Similarly, ASTM standards such as D4442 (moisture content determination) and D7031 (evaluation of physical and mechanical properties) indirectly influence drying practices by specifying how drying affects performance characteristics. Together, they establish a reliable framework for ensuring that laboratory evaluations reflect real-world service conditions, reinforcing the importance of drying in determining wood's behavior in use.

On a broader international level, the ISO framework harmonizes moisture determination, conditioning, and sampling practices across countries. ISO 13061-1:2014 specifies oven-drying methods for determining moisture content in small clear specimens, while ISO 4471:1982 provides guidance for measuring moisture content in roundwood. Standards like ISO 3129:2019, which describes sampling and conditioning procedures for small clear specimens, also indirectly shape drying practices. While ISO does not prescribe species-specific kiln schedules, it provides a baseline of internationally accepted methods, ensuring comparability of data across borders and supporting global timber trade.

Taken together, these standards highlight the multidimensional nature of wood drying standardisation. BIS standards such as IS 1141 provide species and climate specific guidance tailored to Indian conditions; EN 14298 introduces stringent process control mechanisms that are essential for large-scale industrial operations and ISO standards promote global harmonization, facilitating international trade. By integrating these frameworks, industries can not only enhance product quality and minimize defects but also reduce costs, save energy, and improve sustainability in timber utilisation. Ultimately, these standards represent a critical step in bridging traditional practices with modern technological requirements, ensuring that wood drying remains efficient, reliable, and globally competitive.

Permissible Moisture Content Values in Standards

As discussed, moisture content is the most important indicator of whether timber has been properly dried for its intended use. Even if the drying process is technically sound, wood that does not reach the recommended moisture content is prone to defects such as shrinkage, warping, and decay. Standards therefore prescribe permissible limits of moisture content, reflecting both regional climatic conditions and functional requirements. In India, IS 287:1997 specifies moisture content ranges tailored to local environments, with stricter requirements for indoor furniture and more relaxed ranges for heavy outdoor use. This aligns with IS 1141:2019, which ties seasoning schedules to these recommended values. In Europe, the EN 14298 ensures that kiln drying is monitored to achieve these targets. In the United States, ASTM standards do not prescribe fixed values but guide conditioning procedures that reflect end-use equilibrium moisture contents. Globally, ISO standards focus on measurement consistency, thereby supporting international trade by ensuring comparability of values across borders. Table 2 consolidates the permissible moisture content ranges for different applications as referenced in BIS.

The standards provide not only the methods for moisture measurement and conditioning, but also the permissible ranges of moisture content for different end uses. By doing so, these standards ensure that wood products remain dimensionally stable, structurally reliable, and resistant to biological degradation. The growing demand for sustainable use of timber, energy efficient drying practices, and increased global trade, the need for standardized drying protocols is greater than ever before. Standards help industries adopt modern technologies like high frequency drying, vacuum drying and others, while still aligning with established benchmarks of quality. They also foster research comparability, enabling scientists and engineers worldwide to work with common reference points.

Application / End Use	BIS (IS 287:1997 & IS 1141:2019)
Furniture & Interior Joinery	8–12%
Indoor Joinery (unheated bldgs.)	12–16%
Structural Timber (general construction)	15–20%
Heavy Construction (outdoor use)	Up to 25%
Specialty Uses (musical instruments, precision joinery)	6–8% (controlled drying required)

In nutshell, standardisation in wood drying is not just a technical necessity but also a strategic enabler of quality, efficiency, and global competitiveness. By adhering to established standards, industries can reduce wastage, minimize defects, and deliver timber products that perform reliably across diverse applications and environments. For countries like India, where climatic conditions and species diversity pose additional challenges, understanding and implementing these standards is fundamental for strengthening the timber sector and ensuring its long-term sustainability.

Conclusion

Wood drying remains a cornerstone of timber processing, directly shaping the quality, durability, and usability of wood products. Yet, due to the inherent variability of species, climates, and applications, the absence of uniform guidelines can lead to inconsistency and defects. Standardisation provides the much-needed framework to overcome these challenges, offering clear procedures, permissible moisture content ranges, and process control mechanisms that ensure reliability and efficiency. By aligning national frameworks like IS 1141 and IS 287 with international references such as EN 14298, ASTM standards, and ISO guidelines, industries can achieve not only technical excellence but also trade harmonization and consumer confidence. In an era where sustainable utilisation and global competitiveness are critical, embracing standardized wood drying practices is essential for minimizing losses, improving product performance, and ensuring that timber continues to serve as a dependable natural resource for generations to come.

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An Indian Innovation in Wood Processing: Microwave Vacuum Drying for Bamboo and Logs

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Introduction:

Drying process is fundamental to the efficient utilization of wood and bamboo resources. Drying is one of the most important and energy intensive process. Conventional drying processes are often time consuming, particularly for thicker sections. Microwave heating based drying technology has received significant attention in recent past in agriculture, food processing etc. due to its higher efficiency, easy control and environmentally friendly nature. Microwave has been extensively used for heating of materials those especially with good dielectric properties. Apart from food industries, other industries including wood based industries have also utilised it for wood drying and curing of adhesives. The mechanism of microwave drying is quite different as compared with conventional drying. In the microwave drying, heating occurs inside out, while that with conventional drying, it occurs outside in. This makes microwave drying unique, more efficient and quicker. The major advantages of microwave heating are: short duration of drying, precise control and volumetric heating. Simultaneous moisture movement in the wood requires effective moisture removal system, for which, vacuum system is the best option. Vacuum drying is reported to be known for short drying period, good quality, and lower energy consumption. Species like Eucalyptus hybrid, P. deltoids, Melia dubia and bamboo are a very fast growing but their round timber (logs) can't be directly used for product making. Biggest hurdle in popularisation of round wood and bamboo utilisation is their problematic drying characters. A dryer is developed at FRI, Dehradun by combining microwave and vacuum technologies suitable for round logs, thick section wood and bamboo drying.

An All India Coordinated Research Project (AICRP-05) titled 'Development of Dielectric Heating Based Processing Technologies for Solid-wood, Bamboo, and their Composites', is under progress and moving towards its last phase. Under this project, a prototype level (capacity 0.28 m^3) Microwave Vacuum Wood Dryer is developed and under testing for its performance. Drying studies of wooden logs (poplar, *Eucalyptus and Melia dubia*) and large diameter bamboo (*Dendrocalamus asper*), handicrafts bamboo (*Bambusa tulda*) and *Bambusa balcooa* have been carried out (Fig. 1).

Fig. 1: The Microwave Vacuum Dryer

Drying of round bamboo

The microwave drying of bamboo offers faster and uniform heating, instant start and stop options in processing. A comparative drying of structural bamboo *D. asper* was carried out using microwave dryer and conventional kiln. Results suggest that it took 10 days in an electrical heated convective kiln to dry *D. asper* from 62.4 % average moisture content to final 14.2% moisture content. Whereas, in microwave vacuum dryer, it took only 14 h to bring from initial moisture content 67.1% to final 14.5%. The number of the defects were higher in conventional kiln dried bamboo. Microwave vacuum dried *D. asper* was used to develop some turnery and carving bamboo products as shown in Fig. 2.

Similarly, mature culms of *Bambusa balcooa* and *Bambusa tulda* were dried in Microwave Vacuum Dryer in 30-40 hours as compared to the conventional kilns in which it takes approximately 15-17 days to bring final moisture content in the range of 8-12%. Thus, the microwave vacuum drying technology can offer a huge option for wood processing.

Fig. 2: The Microwave Vacuum Dryer and some wooden and bamboo products

Drying of tree logs

With the help of microwave vacuum dryer, low girth poles etc. can be used to make high end products. Drying of logs and poles is very difficult as severe drying defects occur especially around pith portion. Conventional drying methods are seldom practised for poles and logs. Moreover, using round logs and poles without sawing has huge advantage as 40-50% of the wood is wasted during saw-milling in form of off cuts and saw dust. Microwave vacuum drying of poplar (*Populus deltoides*) and *Eucalyptus hybrid* has shown a huge potential towards use of low girth, plantation logs and poles

or handicrafts production. Fig. 3 presents images of poplar logs (girth= 21 inches) dried using microwave vacuum dryer. The dried logs were cut into small lengths and turned on lathe machine to make handicrafts products. Similarly, a 3 feet girth log of poplar wood, was dried using microwave vacuum drying technique and converted into useful products.

Fig. 3: Wood-based products made from microwave vacuum dried wood

Results indicate that a log girth up to 3' (0.91 m) and length 6-8' (1.83 to 2.44 m) can be successfully dried from 75-80% initial moisture content to final 12-14% moisture content within 30-40 hours without any noticeable defects (Fig. 3). Since, the current practice in wood utilisation is based on sawing of the logs into plank form and followed seasoning; the technique can help to develop products directly from plantation logs into products without sawing.

On similar lines, *Eucalyptus hybrid*, low girth logs (18-24 inches' girth) and branches (8-10 inches' girth) were successfully dried. The turnery pieces (Fig.4) indicates that high quality of wooden handicrafts production is possible using *Eucalyptus* wood. Surface check were only defects visible after drying. Since, Microwave Vacuum Dryer runs on electricity, the power consumption is the machine becomes a critical factor for acceptance by wood based industries. Currently, the prototype level machine is consuming approximately 3.75-4.25 kWh/kg water removed, which is approximately two times of that of conventional drying. Moreover, speed of drying, making drying of round logs and bamboo possible etc. are the significant strength to offset the energy consumption.

Fig. 4: Products developed from wood logs and bamboo after the microwave vacuum drying

For the making of ornamental handicrafts, low-girth plantation timber logs can be effectively dried with a microwave vacuum dryer. A microwave with a lower frequency (915 MHz) as opposed to 2450 MHz might be able to penetrate the wood more deeply, allowing for larger logs and more even moisture removal. The distribution of moisture in the logs after drying should be the main focus of research. For a thorough grasp of the benefits of microwave vacuum drying in log drying, it is also necessary to assess the mechanical and physical characteristics of the dried logs, including their strength, colour, and drying stresses.

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Radiofrequency Vacuum Drying of Wood-Prospects and Challenges

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Introduction:

Wood, a naturally derived and renewable material, has supported human civilization for centuries—transitioning from a simple energy source in ancient times to a key element in modern construction, including advanced mass timber structures. Its remarkable and versatility makes it a suitable raw material for furniture making, tools, sports equipment, and both structural and decorative uses in architecture. This adaptability arises from the inherent diversity in physical, mechanical, and aesthetic properties of wood. Beyond functionality, wood also plays a vital environmental role through carbon sequestration, reinforcing its significance as an eco-friendly material amid global sustainability concerns. However, effective utilization of wood requires proper processing, particularly drying or seasoning. Moisture present in wood possess challenges in its effective utilisation. Controlled drying is therefore crucial to reduce moisture content, enhancing dimensional stability, strength, and longevity of wood-based products (Mishra et al., 2024).

Moisture within wood exists primarily in two forms: free water and bound water. Free water occupies the cell cavities (lumens) and is retained by capillary forces, while bound water is absorbed within the cell walls and held by hydrogen bonds to the wood's structural polymers (Pandey and Jain, 1992). During drying, free water is removed first, followed by bound water. The fiber saturation point (FSP) marks the stage where all free water has been eliminated but the cell walls remain fully saturated (Simpson, 1983). Once drying continues below the FSP, the loss of bound water causes the cell walls to contract, leading to shrinkage and dimensional changes. Managing this phase carefully is crucial to avoid structural defects and preserve wood quality. Therefore, controlled drying is an essential pre-processing stage in wood manufacturing, ensuring dimensional stability, preventing defects, and maintaining the structural integrity of the final product.

Wood drying techniques have advanced significantly over time, progressing from traditional air drying methods used in ancient times to advanced kiln-based systems today. Among these, kiln drying (KD) remains the most prevalent approach for seasoning timber, favoured for its operational efficiency and moderate capital requirements (Jia et al., 2017). In this method, heated air is circulated through stacked wood inside a kiln, while moisture-laden air is periodically vented out and replaced with fresh air to maintain low humidity. However, this venting process leads to substantial thermal energy loss, as the exhaust air carries away a large portion of the heat (Avramidis and Liu, 1994).

In India, steam-heated conventional kilns are the dominant drying systems. Despite their widespread use, they operate with relatively low thermal efficiency, utilizing only about 45% of the input heat for moisture removal, while the rest is lost through heat transfer and exhaust (Pandey and Jain, 1992). Additionally, maintaining the high temperatures required for efficient drying demands significant energy input. Achieving uniform drying without defects remains challenging, particularly for dense or refractory hardwoods that are prone to warping, checking, and case-hardening.

To address these challenges, researchers have developed alternative drying technologies aimed at improving energy efficiency and drying quality. Emerging methods include high-temperature drying, solar drying, dehumidification, vacuum drying, and dielectric heating techniques such as microwave and radio-frequency drying. Hybrid systems combining dielectric and vacuum processes have also shown promise. Each method presents unique benefits and limitations, but only a few have gained broad commercial acceptance due to considerations of cost, efficiency, and scalability. Radiofrequency (RF) heating of wood alone or in conjunction with vacuum technology has emerged as a promising technology for rapid and uniform drying of wood. A brief description about working of RF heating of wood is provided in subsequent section:

Basics of RF heating of wood

Radio frequency (RF) energy, a form of electromagnetic radiation within the dielectric heating category, is widely utilized for generating heat inside various materials. As part of the electromagnetic spectrum, RF waves occupy the frequency range of 3 kHz to 300 MHz (Zhang et al., 2020). For industrial, scientific, and medical (ISM) applications, specific frequencies such as 13.56 MHz, 27.12 MHz, and 40.68 MHz have been internationally designated for use (Resch, 2006).

Unlike conventional heating methods, which depend on external heat transfer through conduction or convection, RF heating works by directly penetrating the material and exciting the polar molecules present in it. This mechanism allows for volumetric and uniform heating, leading to faster and more energy-efficient processing compared to surface-based thermal techniques (Zhang et al., 2020). RF heating owing to its long penetration depth is suitable for drying large batches of timber in lesser time periods and with more uniform quality.

In an RF heating system, a high-frequency alternating electric field is applied between two electrode plates, with the wood sample placed in between (Piyasena et al., 2003), as shown in figure 1.

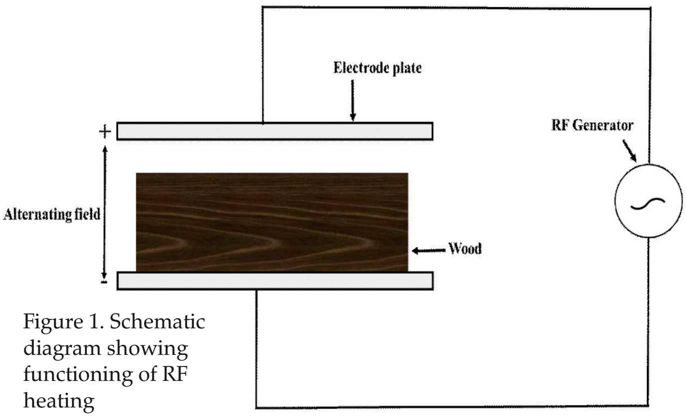

Figure 1. Schematic diagram showing functioning of RF heating

Heat generation occurs through the interaction between radio waves and the wood, governed primarily by two mechanisms: ionic conduction and dipolar rotation of water molecules (Avramidis et al., 2023). In ionic conduction, charged ions present in the moisture within the wood's cell lumens move in response to the oscillating electric field. Their motion converts electrical energy into kinetic energy, and subsequent collisions among these ions produce heat. Dipolar rotation, meanwhile, involves the alignment behaviour of polar water molecules with the rapidly alternating electric field. As the field reverses direction millions of times per second, these molecules continuously attempt to realign, resulting in molecular friction that transforms electrical energy into thermal energy. This process results in a uniform temperature rise throughout the wood, ensuring efficient and uniform drying.

As the name suggests, Radio Frequency-Vacuum (RFV) drying integrates two advanced techniques, RF heating and vacuum drying, to enhance the efficiency and quality of wood drying. In a vacuum environment, the boiling point of water is significantly reduced, enabling moisture removal at much lower temperatures compared to conventional methods. This not only accelerates the drying rate but also helps preserve the natural colour of the wood by minimizing its exposure to oxygen. The pressure differential between the interior of the wood and the low-pressure chamber generates a strong moisture migration force, facilitating rapid and uniform moisture removal. As a result, RFV drying offers a faster, more energy efficient, and higher quality drying process, making it especially suitable for hardwoods and species prone to defects during traditional drying (Mishra et al., 2024; Zwick and Avramidis, 2000). The drying of wood in RFV heating systems depends upon a variety of factors, out of which dielectric properties of wood, electrode voltage, power density, moisture content being important ones.

Research and Development:

Research and development on the use of radio frequency (RF) heating technology for wood drying dates back to the late 1920s. However, in India, the application and commercial adoption of this technology are still at an early stage. With the rising demand for wood and wood-based products, the country's wood processing sector is expanding rapidly. To meet production targets and ensure timely supply, there is an increasing need for faster and more efficient drying methods, as conventional wood drying remains both time-consuming and labour-intensive.

The adoption of RF–vacuum (RFV) drying technology offers a promising solution to overcome the limitations of slow and uneven drying. Recognizing this potential, the ICFRE–Institute of Wood Science and Technology (IWST), in collaboration with the Society for Applied

Microwave Electronics Engineering and Research (SAMEER), Mumbai, has initiated efforts to develop an indigenous RFV wood dryer (Figure 2). Preliminary trials using this system on several refractory wood species including mango, teak, silver oak, and Eucalyptus have shown encouraging results.

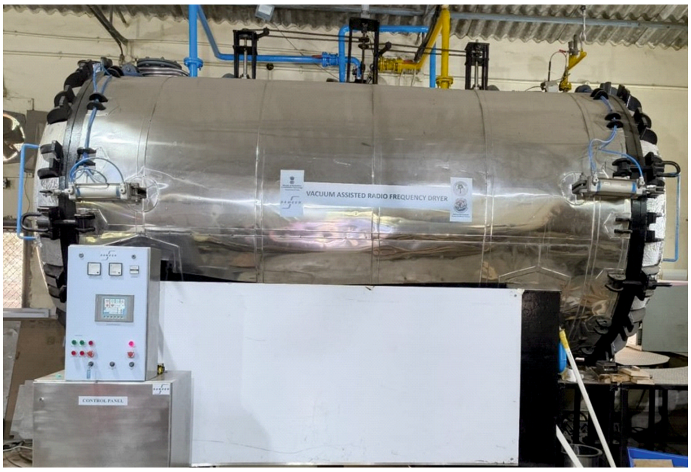

Figure 2. RFV dryer designed and fabricated by SAMEER, Mumbai

The preliminary drying experiments were performed at a constant reduced pressure of 200 mbar (absolute) with an applied RF power of 8 kW. Based on initial trials and supporting literature, two drying protocols, designated as Run 1 and Run 2, were formulated. In Run 1, RF heating was applied for 8 minutes followed by a 2-minute idle period, whereas Run 2 involved 16 minutes of heating followed by a 4-minute idle period. Both drying schedules commenced with an initial RF heating phase of approximately 45 minutes to raise the temperature.

Mango wood planks could be dried from an initial moisture content of about 75% to about 12% in 10.5 hours under Run 1, whereas Run 2 required 13 hours to reduce the moisture content from 85% to 10%. The corresponding drying rates were 6.0% h^{-1} for Run 1 and 5.8% h^{-1} for Run 2. In both runs, the moisture distribution between the surface and core regions remained relatively uniform. For silver oak, the planks were dried from an initial moisture content of 56% to 12% within 5.8 hours in Run 1, whereas Run 2 required approximately 9.9 hours to reduce the moisture content from 87% to 13%. The corresponding drying rates were 7.63% h^{-1} for Run 1 and 7.48% h^{-1} for Run 2.

For teak wood, moisture reduction from 48% to 8% was achieved in 12.3 hours in Run 1, whereas Run 2 required approximately 16.7 hours to lower the moisture content from 41% to 8%. The corresponding drying rates were 3.28% h^{-1} for Run 1 and 1.97% h^{-1} for Run 2. For eucalyptus, the planks were dried from an initial moisture content of 29% to 15% in 7.33 hours during Run 1, while those in Run 2 required approximately 12 hours to reduce moisture content from 40% to 15%. The respective drying rates were 1.96% h^{-1} for Run 1 and 2.08% h^{-1} for Run 2.

The results indicate the suitability of RFV drying technology far achieving faster and uniform drying of wood. The characteristics of dried wood, particularly in terms of drying defects need to be examined thoroughly to avoid any untoward reduction in quality of dried wood, as severe drying conditions may deteriorate the quality of dried wood.

In addition to improving drying uniformity and speed, the RFV process has also demonstrated effectiveness in phyto-sanitation, a critical regulatory requirement for the export of wood and wood products. In North America and Europe the technology is already adopted at commercial level (Figure 3 and 4). While these initial outcomes are promising, comprehensive studies are still needed to evaluate the technology's suitability across different species, ensuring optimal drying quality within shorter durations along with measuring it energy efficiency. Moreover, detailed investigations into how this drying technique influences the physical and mechanical properties of wood are essential. Such extensive research will support the development of species-specific drying schedules, providing valuable guidelines for the wood industry and paving the way for the large-scale implementation of energy-efficient, high-quality RFV drying technology in India.

Figure 3. Commercial RF vacuum dryer at Silver Valley Custom Drying Upper Michigan USA

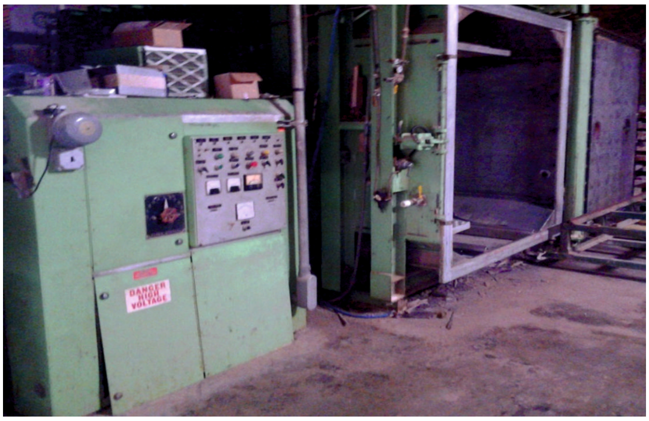

Figure. 4: Commercial dryer at Ms Ben Aron Lumber , Forestville, New York

Challenges in adoption of RFV drying technology:

Despite its advantages in terms of faster and more uniform drying, the widespread adoption of Radio Frequency Vacuum (RFV) drying technology faces several significant challenges. Some to the major challenges are as follow:

- High Initial Investment: The most significant drawback of RFV dryers is their high capital cost, as designing and constructing an RFV system requires much greater investment compared to traditional kiln dryers. Such costs are often prohibitive, especially for small and medium-scale wood processing industries
- Lower Drying Capacity: Although RFV systems provide faster drying rates, their processing capacity is generally smaller than that of conventional drying kilns (Avramidis et al., 2023).
- Risk of Internal Damage: If the process is not properly controlled, the rapid pressure buildup inside the wood can surpass the mechanical strength of its fibers, resulting in internal checking or fiber rupture (Espinoza and Bond, 2016).
- High Energy Consumption: RFV drying can be energy-intensive, potentially leading to increased operational costs compared to traditional methods.
- Requirement for Skilled Operators: The RFV process demands highly trained personnel, as it involves precise control over multiple parameters. Inexperienced operators may find it challenging to maintain optimal drying conditions.
- Species-Specific Sensitivity: The response of wood to RFV drying varies across species; hence, the drying schedule must be carefully adjusted, requiring specialized knowledge and expertise.
- Maintenance and Repair Costs: Unlike conventional dryers, RFV systems require professional maintenance and repair, which can add to operational expenses.
- Safety and Radiation Shielding: RFV equipment must be properly sealed to prevent RF radiation leakage. Although RF energy is non-ionizing, improper handling may still cause occupational hazards.

Conclusions

Although RFV drying technology presents certain challenges, it remains a highly efficient method and shows strong potential for achieving faster drying of wood. Unlike traditional kiln drying—which is often unsuitable for thicker sections—RFV drying can effectively handle thicker materials because heating initiates from the core, enabling more uniform and rapid moisture removal. Longer drying times in conventional methods have long been a bottleneck for the wood industry and often discourage small and medium-scale enterprises from adopting proper wood seasoning practices. By significantly reducing drying time, RFV dryers may encourage these industries to adopt wood drying technologies, ultimately promoting more rational and sustainable utilization of timber.

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Veneer Drying: The Hidden Pathway to Quality and Efficiency in Plywood Manufacturing

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Introduction:

Wood being a hygroscopic material, absorbs or releases moisture from and to the surrounding air respectively depending on the relative humidity, temperature, and its own moisture content. This exchange of moisture between wood and its surroundings leads to dimensional changes in wood leading to swelling and shrinkage on absorbing and loosing moisture respectively. When wood is converted into engineered products like plywood it is utmost critical to control the geometrical changes through proper drying to ensure dimensional stability, minimal defect and longer service life.

Veneer refers to thin sheets of wood obtained either by peeling a round log or slicing a flitch. The production of high-quality veneer depends on several critical factors namely precise machine adjustments (settings of peeling lathe or slicer), a well-maintained cutting tool (peeling or slicing knife) and most importantly, adequate moisture content in the logs or flitch. Freshly peeled veneers generally contain a relatively high level of moisture, sometimes even exceeding 70-80%. This moisture exists both as free water in the cell lumens and bound water in the cell walls which must be reduced to a lower range (6 – 8%) before they can undergo further processing.

Veneer drying refers to the process of moisture removal from freshly peeled or sliced veneers through the application of heat. Working on the principles of heat and mass transfer, veneer drying plays a decisive role in determining veneer behaviour during subsequent stages of plywood manufacture. Properly dried veneers enhance adhesive bonding, improve dimensional stability, and ensure superior overall product quality. Conversely, improper drying adversely affects adhesive performance, often leading to weak bonds and delamination of plies during performance tests leading to rejection of the panel branding them as substandard. Drying the veneer to required level of moisture is the key for superior panel as both under-dried and over-dried veneers contribute to dimensional instability in the finished panels, ultimately reducing their service life. If veneers are not properly dried and are stored with excess moisture, they become prone to fungus and mold growth, which is highly undesirable and damage veneer aesthetics, bonding performance and durability, ultimately resulting in quality loss and rejections in plywood production. Hence it is crucial to dry the veneer to lower moisture level immediately after peeling or slicing.

Mechanism of veneer drying

Veneer drying is fundamentally a heat and mass transfer process, wherein heat supplied to the veneer surface by a heating medium (high-velocity hot air) raises the temperature of the moisture within the veneer. This mobilized moisture migrates toward the surface, where it evaporates as vapor and is subsequently removed from the drying chamber through exhausts or vents.

Objective and Methods of veneer drying

At its core, veneer drying aims to deliver uniformly dried veneers with the desired moisture content, minimizing defects and keeping drying costs as low as possible. Outcomes of an Optimal Veneer Drying Process are as follows:

- Uniform moisture content across the veneer
- Free from defects such as buckling, splits, and waviness
- Desired surface colour maintained
- No case-hardening
- Surface favourable for adhesive bonding

Drying veneers can be as simple as leaving them under the sun or as advanced as using high-tech machines like press dryers, band dryers, and roller dryers. Modern machines with automated controls are capable of accurately adjusting temperature and the time veneers travel through different drying zones ensuring consistent quality and production efficiency.

Methods of Drying

Traditional Open-Air Drying (Sun drying)

This technique is being in practice for centuries where wood is stacked in shaded area ensuring good air circulation and ventilation and the same technique is employed for drying veneers under sun. In-spite of being a low-cost method, the process is slow which delivers veneers with inconsistent moisture levels.

Figure 1. Sun drying of veneers

Veneer Hot Press Drying

This method involves pressing veneers between heated steam pipes assuming the shape of platens in a hydraulic hot press. While simple in operation, it offers limited accuracy in drying and often results in inconsistent moisture distribution across the veneer surface.

Figure 2. Core veneer press dryer

Jet Dryers: The Advanced Technology in Veneer Drying

Jet dryers represent the most advanced form of industrial veneer dryers. In this system, atmospheric air is drawn in and passed over a heat exchanger, which rapidly elevates the air temperature. The heated air is then directed into jet boxes, from where it impinges on the veneer surface at right angles at very high velocity.

This impinging jet of hot air transfers heat directly to the veneer, raising the temperature of its internal moisture and causing it to vaporize. As drying progresses, the air inside the drying chamber becomes progressively saturated with moisture. To maintain the required balance of temperature and humidity for efficient drying, this saturated air must be expelled. Exhaust vents or outlets provided in jet dryers serve this critical function, ensuring consistent drying conditions, higher productivity, and uniform veneer quality. Jet dryers can be classified into two main types i.e. roller dryer and the band dryer, based on the method of conveying veneer from the wet end to the dry end.

Figure 3 below depicts interior of a veneer dryer, ambient air is drawn and pumped (blown) into the dryer by the blower 'D', this air after passing through the heat exchanger coil picks up the heat and the hot air 'F' is directed towards the inlet of jet boxes 'C'. There are two rows of jet boxes one above the other, the upper jet box has the bottom surface perforated whereas the lower jet box has the upper surface perforated. Hot air directed into the jet box picks up the velocity due to the cross section of the jet box which continuously decreases along the length. Through the perforated surface of jet boxes high velocity air impinges at right angles on either surface of veneer 'A' passing through the drying chamber between the upper and lower jet boxes breaking the boundary layer if any and facilitates the moisture removal. Moisture laden air is vented out through the damper 'E' for enhancing the efficiency of the dryer.

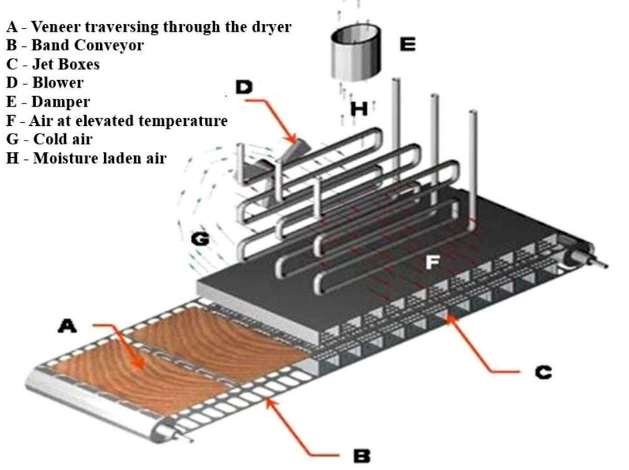

Figure 3. Air circulation and heat flow inside a veneer dryer

In Figure 4 given below, 'A' depicts the air which is drawn from ambience after passing through the heat exchanger coil enters jet boxes as shown in 'B' and through the perforations in the jet boxes as shown in 'C' high velocity hot air impinges on either side of the surface of veneers carried between the upper and lower jet boxes as shown in 'D'.

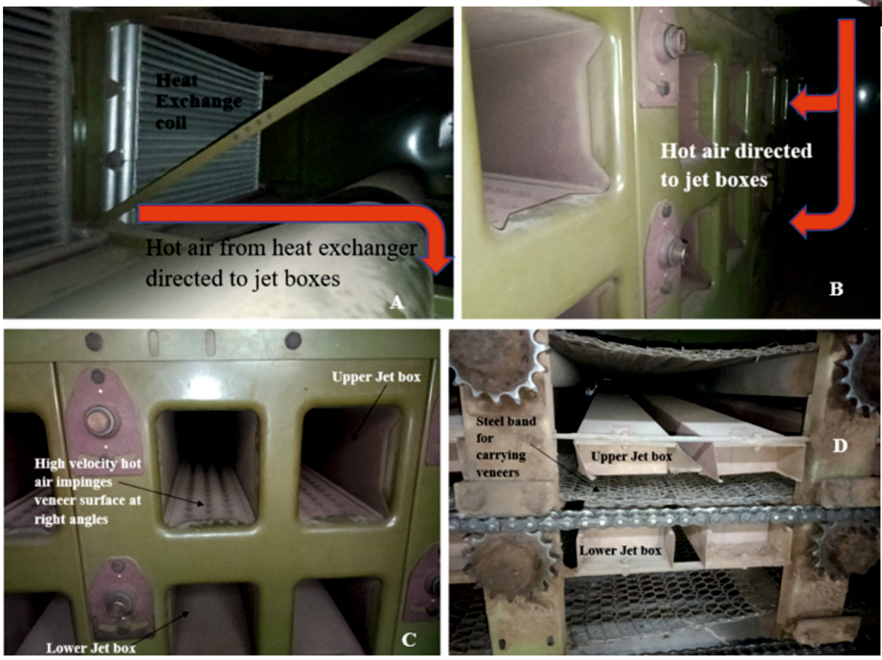

Figure 4. Interiors of a Band Dryer (Jet dryer with steel band convryor)

Roller Dryer

In this type, veneers are passed between a series of rollers. The veneer travels lengthwise through the dryer (grain direction parallel to the direction of motion). In this machine, veneers are passed through the heated surroundings within an enclosure called the heating zone, veneers are held and moved due to frictional forces that exists between the roller and the veneer. As the rollers continuously hold the veneers and conveys them from wet end to dry end of the machine, veneers remain flat after drying due to the roller pressure applied during drying. Roller dryers are widely used in plywood industries for their drying speed and ability to dry continuous sheets of veneer.

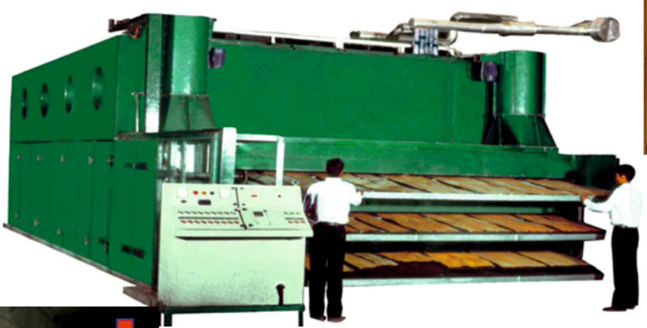
Figure 5. Veneer roller dryer

Band Dryer

Here, veneers are carried in-between continuous steel bands running along the length of the dryer. The veneers are oriented such that the grain direction is parallel to the width of the dryer or grain direction is perpendicular to the direction of veneer movement. In advanced designs, jet dryers may also be constructed with multiple decks. Each deck is equipped with jet boxes both above and below the veneer, ensuring uniform impingement of hot air on both surfaces thereby improving drying efficiency.


Figure 6. Veneer band dryer

Drying Method	Speed	Moisture content	Energy Use	Cost	Efficiency
Air drying	Slow	Non-uniform, may show gradients	Very Low	Low	Low
Press drying	Moderate	Moderately Uniform	Medium	Medium	Moderate
Jet drying	Fast	Uniform	High	High	High with automatic controls

Factors to be considered for effective and efficient drying operation

- **Production capacity of dryer**

This is a crucial factor to be considered while installing a dryer. There are many ways to determine the dryer capacity but two most commonly used methods are explained below

- **Capacity based on dryer evaporation capability**

Dryer evaporation capability refers to the amount of water in kilograms that a drier can evaporate in one hour. A simple and reliable way to calculate the evaporation rate is to measure the weight of input and output veneers at wet end and dry end respectively in one hour and the dryer evaporation capacity can be calculated using the formula given below.

Dryer evaporation capacity (Kg) = VW_Input-VW_output

Where, VW_Input is the weight of the input veneer at wet end and VW_output is the weight of the output veneer at dry end

This method is most practical and can be relied on as it includes all the losses i.e. thermal energy lost in heating the wood and air, leakage and radiation. This is the simple method that can be used during installation and commissioning of a dryer.

- **Capacity based on input thermal energy**

It is known that the latent heat of evaporation of water i.e. heat required to evaporate 1 kg of water is 540 Kcal/Kg. Now when the thermal energy input to the dryer is known then the drying capacity can be calculated as follows:

$$\textbf{Dryer evaporation capacity (Kg)} = \frac{Q}{540} \times \eta$$

Where Q is the heat input for the dryer in Kcal/hr and is the efficiency of the dryer

If the boiler also supplies other users (processes, heating, etc.) in the plant, then the fraction of thermal energy 'f' diverted to the dryer should be measured and the dryer capacity can be calculated using the formula:

$$\textbf{Dryer evaporation capacity (Kg)} = \frac{Q}{540} \times f \times \eta$$

Where f is the fraction of boiler thermal energy which is input to the dryer and is the dryer efficiency.

Note: In practice, the dryer's useful heat is reduced by thermal losses (insulation, radiation) and by the heating of wood and process air, so the dryer's overall useful efficiency is always less than unity and the practical evaporation capacity is lower than the theoretical capacity computed based on thermal energy supplied by the boiler.

Species, Permeability and Drying Schedules

Permeability, the ability of timber to absorb and release moisture is primarily governed by its porosity, which differs significantly from species to species. This characteristic plays a decisive role in determining how a veneer responds to drying. Key drying parameters such as temperature and the retention time or veneer's travel time through the drying chamber must be carefully calibrated for each species. These parameters ensure that the veneers are exposed to optimal conditions for required time duration resulting in efficient moisture removal without compromise in the quality.

Getting the drying parameters right is the key to designing efficient drying schedules that deliver quality and consistent veneers. Since no two species behave identically, drying schedules cannot be generalized for all species of timber. In fact, even within the same species, veneers of different thickness demand unique adjustments to the drying schedule. This species and thickness specific approach is essential to achieve uniform drying, prevent defects, and ensure that the veneer is ready for subsequent processing. Scientifically designed drying schedules not only minimize issues such as warping, surface checking, collapse, and case-hardening, the defects that compromise both quality and productivity but also ensure that the veneers attain a uniform moisture content, enabling stronger adhesive bonding in the final product. Well-optimized drying schedules not only prevents over-drying of veneers which results in case hardening of the surface but also reduces unnecessary energy consumption, contributing to overall plant efficiency. In essence, precise drying schedules are the bridge between natural variability in wood and the consistent performance demanded by modern plywood industries. Ideal retention time is key to flaw less veneer and energy savings as longer retention time causes over heating resulting in defective veneers and shorter retention time yields veneer with higher moisture content than desired. As a general rule it is advised not to mix veneers of different species or different thicknesses from the same species in a single batch for drying as it results in defective veneers.

Figure 7. Frilling of veneer due to faster evaporation of moisture from the end grain of the veneer.

Figure 8. Buckling and splitting of veneers due to variation of initial moisture content across veneer surface

Initial and final moisture content

Initial moisture content in the veneer and final moisture content to be achieved should also be given equal importance, it is a tedious task to achieve a set temperature in the drying section and the task becomes next to impossible when the dryer is not equipped with automated controls. But this can be tackled by varying the travelling time with respect to initial moisture content and thickness of veneer to attain desired moisture level for a set temperature in the drying chamber. Before drying, segregating the veneers into categories of different initial moisture content with each category having a small band width of variation will be an added advantage for effective drying.

Loading the veneers into the dryer

A very important factory yet given less importance, loading the veneer into the dryer in such a way that

- There should be enough gap between the veneers for air circulation and moisture to escape.
- Also, there should be enough gap before and after each veneer along the length of the drying chamber to ensure optimal loading pattern.

Challenges in veneer drying

With a wide range of timber species and different peeling techniques such as conventional peeling (lathe with chuck or spindle), spindle less peeling, slicing for producing face veneers etc. drying puts forth numerous challenges which should be addressed for obtaining quality product and enhancing the drying efficiency.

Sl. No	Challenge	Solution
1	Thickness variation in veneer	This can be addressed by adhering to recommended peeling lathe adjustment for the given timber species also maintaining the accuracy of peeling lathe adjustments helps in reducing veneer thickness variation.
2	Moisture gradient	Moisture movement from interior of veneer to surface is slow compared to the evaporation from the surface which creates moisture gradient, drying temperature and retention time should be adjusted such that these two-moisture movement i.e. from interior of veneers to the surface and the evaporation form the surface should be synchronized to reduce the moisture gradient which would otherwise results in defective veneers.
3	Energy consumption	Veneer drying represents a major share of energy consumption in plywood manufacture. Beyond the thermal energy needed to evaporate large volumes of water from freshly peeled veneers, electric power for fans, belt/roller drives and auxiliary systems also contributes significantly. To use energy optimally the dryer must be loaded correctly: avoid long gaps between veneers (which wastes heat) and also avoid overly tight loading that impedes air circulation and leaves veneers under-dried requiring second round of drying. Real-time

		monitoring of temperature and humidity across dryer sections, together with automated vent/exhaust control, improves thermal energy use and moisture removal, reducing energy consumption and overall drying cost.
4	Recurring maintenance	To minimise unplanned downtime and avoid excessive energy loss, dryer preventive maintenance must be performed at regular intervals. Routine checks should cover blower/fan drives, belts, bearings, rollers, drive gears and seals; any maintenance that requires opening the dryer when it is at operating temperature causes long delays and large thermal energy losses, so such work should be planned during shutdowns. Insulation and door seals must be inspected frequently for damage or gaps that drain heat. Operators should report unusual noises, smells (for example burnt blower belt rubber), vibrations or visible belt wear immediately so that the maintenance team can schedule corrective action during the next planned maintenance activity.

Tapping Technological advancement for enhanced efficiency

- Tapping latest technological developments in artificial intelligence (AI) and Machine Learning (ML), algorithms can be developed to predict moisture profile and control the air flow to obtain defect free veneers with uniform moisture content.
- Machine vision systems can be used to detect defects in dried veneers, while online moisture scanners can be adopted to measure moisture levels, enabling automatic sorters to grade veneers by quality and moisture content.
- Adoption of Variable Voltage Variable Frequency (VVVF) drives for blower and conveyor motors in veneer dryers enables dynamic speed control, ensuring that motors operate only at the level required by process demand. Instead of running continuously at full speed, VVVF drives adjust motor speed in real time to match airflow or conveyor requirements. This not only prevents unnecessary energy consumption but also reduces mechanical stress, lowers wear and tear of the machine parts, and improves process flexibility.
- The above technologies i.e. VVVF drives, improved airflow control, insulation, sealing upgrades, inline sensors) are designed specifically to be retrofitted into existing veneer dryers without needing to replace the whole machine. These retrofits typically require minimal structural modification, making them quicker to implement and resulting in significantly reduced downtime during installation. Plants can therefore achieve energy savings, improved drying uniformity, and extended equipment life without major capital investment or long production interruptions.

Conclusion

Veneer drying though often overlooked, forms strong base for quality of plywood and efficient manufacturing process. It directly influences adhesive performance and dimensional stability resulting in enhanced service life of the plywood. Being the highest energy consuming process in plywood plant, optimization of this process offers immense benefits resulting in lower operating cost, enhanced quality of panels with reduced rejections during the quality check.

Adoption of modern technologies and integration of automated controls, inline sensors, AI-driven optimization and energy-saving retrofits marks the future of veneer drying. Combination of scientific drying schedules and smart monitoring results in efficient dryers through which plywood industries can achieve not only superior quality but also sustainable, energy-conscious production.

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Dehumidifier Drying: A Case Study on Drying Characteristics and Energy Efficiency of Plantation Timbers Using a Dehumidification Kiln

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Abstract

Dehumidifier-based wood drying emerged as an alternative to conventional kiln seasoning, particularly for plantation-grown timbers. The moisture removal in dehumidification process can either be through heat pump technology or absorption by desiccant chemical. This paper presents the drying behaviour and energy efficiency of a desiccant-based dehumidification kiln while drying species such as eucalyptus, silver oak, rubberwood, acacia, teak, and casuarina. The results showed that drying rates varied among species due to differences in density and moisture movement, but overall drying at moderate temperatures produced good-quality timber with minimal defects. Most drying-related problems were linked more to natural wood variability than to the drying process itself, highlighting the system's gentle and controlled drying capability.

From an energy perspective, the dehumidifier kiln performed efficiently, especially when operated close to full capacity. Energy consumption was significantly lower above the fibre saturation point and increased sharply during the final stages of drying, when bound water is removed. Rubberwood required the least energy, while thicker teak sections consumed the most. Overall, the system demonstrated lower energy use per kilogram of water removed compared to conventional kilns, confirming that desiccant-based dehumidifier drying can deliver both quality and energy savings when properly managed.

Introduction

Wood drying is one of the most critical steps in the efficient utilisation of timber. Achieving quality drying of hardwoods with acceptable recovery and grading remains a major challenge in wood processing (Innes & Redman, 2003). The economics of wood drying are primarily governed by three factors: drying time, energy consumption, and drying-related defects. Drying time is determined by the drying rate under specific operating conditions. Considerable research has focused on accelerating drying rates through elevated temperatures and advanced techniques such as radio-frequency (RF) drying and vacuum drying.

The inherent variability in wood properties, combined with inappropriate drying procedures, often leads to deformation during drying. Common drying deformations include bow, crook, twist, and cup, which arise due to differential shrinkage along the three principal directions of wood. Shrinkage behaviour varies widely among species and within wood types, such as low-density versus high-density wood, and sapwood versus heartwood. Two additional factors that further complicate the drying process are non-uniform initial moisture content and non-uniform drying rates within the material. Improper drying practices can result in defects such as splitting, surface checking, cracking, and case hardening, all of which originate from internal drying stresses.

Energy consumption is another major concern in timber drying. Drying processes are inherently energy-intensive, as a large amount of energy is required to evaporate water (Damodaran, 1997). Timber drying is essentially a two-step process involving moisture migration from the interior to the surface of the boards, followed by evaporation into the moving air stream (Walker, 1993). It is estimated that drying alone can account for nearly one-third of the total timber processing cost. Depending on kiln design and operating efficiency, drying systems may consume 1.5 to 4 times the theoretical energy required for water evaporation (Denig et al., 2000). Consequently, significant research efforts have been directed towards improving kiln efficiency while maintaining drying quality.

In India, the seasoning behaviour of approximately 200 commercially important timbers has been studied, and these species have been classified according to their refractoriness to seasoning. Kiln-drying schedules (IS: 1141-1993) have been developed for more than 150 species (Anon, 1993). These schedules are primarily designed for conventional steam-heated kilns, where temperature and relative humidity are controlled according to the moisture content of the timber.

Dehumidifier drying represents an enabling technology with unique advantages for drying high-quality, temperature-sensitive products. Dehumidification-based wood drying systems are generally considered energy-efficient and capable of producing defect-free timber. Heat-pump dehumidifier dryers have been used commercially since the 1970s, particularly in the timber and food-drying industries. More recently, desiccant-based dehumidification systems have been explored for wood drying. However, these systems are relatively new, and limited information is available on their drying performance and product quality, apart from early technical evaluations by Pandey et al. (1995), who studied the drying rate and energy requirement for 40 mm-thick teak, toon, and sissoo planks.

This article provides information on drying behaviour of few plantations grown species in a desiccant based dehumidification dryer.

Dehumidification drying

Dehumidifier drying technology offer several potential benefits for drying high-quality temperature-sensitive products. The technology is very effective and convenient to use when there are not in terms of heat generation as the latent heat generated during condensation is often used to maintain the temperature. There are mainly two types of dehumidification systems namely heat pump based and desiccant based. In heat pump-based dehumidification system. In the heat-pump based system, warm and moist air which has passed through the timber heats up a liquid refrigerant, which evaporates and condensation of water takes place. The condensation of the water also heats the refrigerant and that results in dry air. The refrigerant is compressed which warms it and the warm refrigerant warms the air entering into the kiln thus producing warm and dry air. This warm dry air is used to remove moisture from the timber. Heat pump dehumidification dryers tend to have limitations in maintaining low relative humidity resulting in low moisture extraction rate. Poor design, over-sizing of equipment, and poor operational management are few of the major concerns in such systems.

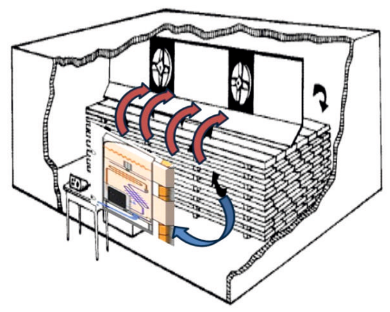

Fig.1: Heat-pump based dehumidification wood drying

Desiccant based dehumidification is most popular where low relative humidity is required particularly in food processing, plastic processing etc. A desiccant-based dehumidifier wood-drying system operates on the principle of chemical dehumidification, where moisture is absorbed by a fluted flat-bed desiccant rotor. The drying chamber remains self-contained and well insulated. The system is generally equipped with a uniform laminar transverse airflow arrangement, with provision for airflow reversal. The air-circulation system comprises an air plenum, circulating fans, heater banks, and perforated air inlets and outlets. The dehumidifier is connected to the air plenum, where mixing of dehumidified air and recirculated air takes place. The desiccant-based wood drying system is shown in figure 2. The moist air is exposed to the absorbing media (desiccant) in a sealed air stream. Once the desiccant absorbs moisture, it is exposed to secondary air-stream at an elevated temperature to reactivate the desiccant. The wood dryer requires an auxiliary heat source to maintain the temperature, a heat source to reactivate desiccant and energy for maintaining air-flow in the chamber. Reactivation of dehumidifier is one of the most energy intensive operations in this type of system. Once timber is heated up to the desired temperature, energy requirement for maintaining the temperature is small.

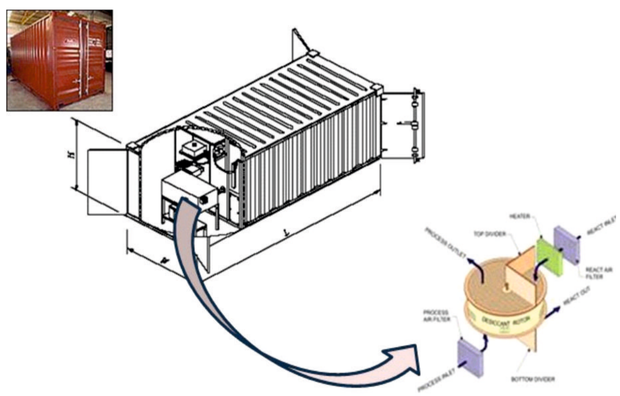

Fig. 2: Desiccant based wood drying system

A Bry-Air India make (200 cft capacity) was used to study the drying behaviour of plantation timbers. The system includes a heat extractor with evaporator and condenser sections. The evaporator was installed at the inlet of the dehumidifier to cool the air before dehumidification. The system has two primary controls: a drying-intensity controller, which regulates the cyclic operation of the dehumidifier, and a temperature controller, which maintains the desired chamber temperature. Drying rates can be increased either by raising the temperature or by increasing dehumidification intensity. The normal power consumption of the system ranges from 6 to 8 kW.

Wood species:

Four commercially important plantation timber species—*Eucalyptus tereticornis, Grevillea robusta, Hevea brasiliensis,* and *Acacia auriculiformis*—were selected for the study. In addition, teak (*Tectona grandis*) and Casuarina *equisetifolia* were also included in selected trials.

Drying experiments Drying experiments were conducted using 25 mm-thick boards of each species. For each trial, representative boards were selected and their initial moisture content was determined according to standard procedures (Anon, 1993). Boards were stacked inside the drying chamber using 20 mm-thick stickers. Drying was carried out at different temperatures and drying-intensity levels. Moisture loss in selected sample boards was monitored periodically until a final moisture content of 12–15 % was achieved.

Major findings

Drying behaviour of plantation timber:

The study generated substantial information on drying rates under different operating conditions. All species exhibited different drying rates and required varying drying durations, attributable to differences in basic density, permeability, and diffusion coefficients. In all species, drying rates varied with moisture-content reduction. The drying curves exhibited three linear segments, corresponding to different moisture-migration mechanisms. Above the fibre saturation point (FSP), both drying temperature and dehumidifier cycle intensity significantly influenced drying rates.

Timber	Trial (Thickness)	Volume of wood	Initial moisture content	Final moisture content	Days taken	Total Energy consumed (kWh)	Average Energy consumed per unit MC
Silver oak	Trial-II (25 mm)	50 cft	114%	9%	17	1548	14 kWh
Silver oak	Trial-III (25 mm)	50 cft	99%	10%	17	1613	18 kWh
Rubber wood	Trial-I (25 mm)	50 cft	56.5%	8%	7	637	13 kWh
Rubber wood	Trial-I (25 mm)	50 cft	62%	6.5%	6	760	13.7 kWh
Teak	Trial-I (75 mm)	180 cft	43%	20%	15	1853	80 kWh
Teak	Trial-II (25 mm)	80 cft	72%	11%	25	2275	37 kWh
Teak	Trial-III (25 mm)	150 cft	43%	13%	13	987	33 kWh
Teak	Trial-I (25 mm)	50 cft	85%	12%	27	1932	26 kWh

Drying of teak, silver oak, rubberwood, and acacia at temperatures recommended for conventional kiln dry-bulb conditions produced satisfactory results. The dried timber was largely free from major defects such as surface checking and end cracking. Silver oak showed some tendency to warp, which was attributed mainly to inherent variability in wood quality rather than drying conditions. Overall, the desiccant-based system demonstrated advantages in terms of operational simplicity and low maintenance compared to conventional kilns. Although such systems are often regarded as energy-efficient, systematic information on energy-consumption patterns has been limited.

Energy efficiency:

Dehumidification-based drying systems are considered energy-efficient because vent losses are minimised and latent heat released during moisture condensation contributes to maintaining air temperature. To evaluate energy consumption, an electrical energy meter was installed to monitor electricity use during drying. As the drying chamber is sealed and vent-free, vent losses were assumed to be negligible. Energy consumption was measured for silver oak, rubberwood, teak, and acacia. Table 1 summarises the total electrical energy consumed during drying.

Among all species, rubberwood required the least electrical energy, approximately 13 kWh to reduce moisture content by one percent. The highest energy consumption was observed in teak, averaging about 35 kWh per percent moisture reduction. Higher energy demand in teak can be partly attributed to the larger wood volume used and, in some trials, greater board thickness. Thicker sections require additional energy to raise the timber temperature to the desired level. It has been reported that for every 0.8–1.0 mm increase in thickness of a 25 mm board, energy demand for evaporation increases by about 3 % (Denig et al., 2000).

Energy consumption varied polynomially with moisture content. Lower energy was required during the early stages of drying at high moisture content, while energy demand increased sharply as moisture content decreased. During the initial drying phase (from approximately 100 % to 24 % moisture content), energy consumption averaged about 13 kWh per percent moisture reduction. Below 24 %, energy demand increased nearly threefold. Rubberwood consistently required nearly half the energy of silver oak above the FSP. Similar trends were observed in other species, although absolute energy requirements varied.

Timber	Trial	Energy required above FSP)kWh/mc)	Energy required below FSP)kWh/mc)
Silver oak	II	10.0	27.0
Silver oak	III	13.4	38.0
Rubber wood	I	9.4	18.8
Rubber wood	II	9.4	25.0
Teak	I	64.9	110.4
Teak	II	19	127
Teak	III	26	46
Acacia	I	19	50

Table 2 presents the energy required above and below FSP for all trials.

Energy required to remove moisture above the FSP was significantly lower than that required below the FSP for all species. In thicker teak sections, energy demand below the FSP was particularly high. As drying progresses and moisture content decreases, permeability-controlled flow gives way to diffusion-controlled moisture movement. Diffusion is inherently slower, resulting in steep moisture gradients between the core and surface. Substantial energy is therefore required to enhance moisture migration and remove bound water from the cell walls, leading to higher energy consumption below the FSP.

Kiln energy efficiency is strongly influenced by ₹apacity ₹utilisation. Dr₹ying costs increase disproportionately when the kiln is operated below its rated capac₹y. For example, in this study, drying 50 cft of silver oak (approximately one-fourth of kiln capacity) consumed about 1,550 kWh, costing roughly 8,500 at 5.5 per kWh, or 170 per cft. In contrast, drying 150 cft of 25 mm-thick teak required an energy cost of only 36 per cft.

Energy efficiency is also expressed as energy required per kilogram of water removed. Although most trials involved partial kiln loading, a conservative estimate from the 150 cft teak trial indicated an energy consumption of 0.86 kWh/kg of water removed. This value closely matches reported figures for dehumidification drying of sissoo and siris wood (0.86–0.98 kWh/kg; Sharma, 1988) and is lower than the energy consumption reported for conventional kilns (>1 kWh/kg; Pandey & Jain, 1992).

Conclusion:

This study provides baseline data on the drying behaviour and energy efficiency of plantation-grown timbers dried using a desiccant-based dehumidifier kiln. Energy consumption was found to be directly proportional to drying duration. Across all species, the energy required to reduce moisture content by one percent below the fibre saturation point was approximately two to three times higher than that required above the FSP. For teak, the estimated energy requirement to remove one kilogram of water was 0.86 kWh/kg, consistent with values reported for dehumidification drying systems elsewhere.

The findings of this study can assist in developing optimised drying strategies for plantation timbers and provide useful reference data for researchers and wood-processing industries employing desiccant-based dehumidification drying systems.

References : Contact author at aksethy@icfre.org

Solar Kiln Drying: An Eco-friendly Path to Better Wood Processing

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Introduction

Wood drying is a very important and indispensable operation in any wooden roduct manufacturing. Wood drying is the most energy intensive process and consumes about 70 % of the total energy utilized in wood processing operations (Taylor et al., 1996, Comstock, 1975). Therefore, any changes made in drying practices to reduce energy requirement and the drying costs would have a significant impact on cost of production as a whole.

Wood drying in India is mostly done in steam heated kilns, in which only 45% of the input heat is used for water evaporation while the rest go wasted through transmission and venting losses (Pandey and Jain, 1992). Steam consumption for drying of wood is 1.66 to 4 kg per 1 kg water removed in a steam heated kiln, while in electrical heated kilns, 2 to 4 kWh electricity is consumed for each kg of water evaporated from wood (Sharma et al., 1980). With present technology of steam generation and kiln drying, the fuel consumption is very high. Wood industries generally use off-cuts, saw dust etc. as fuel for boilers, which may otherwise could have been used to make other panel products e.g. particle board, fiber board etc. With recent shortage and soaring cost of fossil fuels, saw mill and agro waste for heating kilns, the cost of wood drying has increased considerably. Solar timber drying has some advantages with respect to other drying methods. Lower drying degrade is observed in solar drying. Cost of drying is comparatively very low and it requires little supervision.

Solar Dryer Theory

Solar dryer theory is discussed by Wengert (1971). It describes a simple solar dryer. It has transparent or translucent walls which are designed to transmit a large practical percentage of the incident solar energy into the dryer. The inner side of the dryer is blackened as it allows maximum heat absorption. As energy is absorbed, absorbing surfaces are heated up. The energy is then transferred from heated (high temperature) surfaces to air (low temperature) primarily through mode of convection. The heated air is then circulated through fans to the timber stack, where the energy is utilized to evaporate water.

How a solar drying kiln is different from a greenhouse?

A simple solar kiln is a greenhouse, constructed with a glazing, collector and facilitated with air circulation. The prime objective of glazing (transparent cover) is to allow solar rays to enter the kiln and strike on solar collector. The collector converts solar radiation into heat energy.

The solar kiln is different from a greenhouse in the following aspects (Plumptre, 1979):

1. Solar kiln needs to trap heat as much as possible.
2. Forced air circulation is an important component in solar kiln.
3. Maintenance of desired level of relative humidity is important.

Advantages of Solar Wood Drying

Solar wood drying has emerged as a sustainable and cost-effective alternative to conventional drying methods. Studies conducted globally indicate that solar drying significantly reduces the overall drying duration when compared to open air drying, owing to improved heat utilization and controlled ventilation. Additionally, the incidence of drying related defects such as cracking, warping, and surface discoloration is markedly lower, thereby improving the quality and value of the dried timber.

One of the key advantages of solar drying systems is their low energy demand. Since the drying process primarily relies on freely available solar radiation, operational energy costs are substantially reduced. Moreover, solar kilns are relatively simple to operate and require minimal manual supervision, making them suitable for small and medium-scale wood industries, particularly in regions with limited access to conventional energy sources.

Economic assessments have revealed that solar kiln drying can be more cost-efficient than both air drying and steam kiln drying, with drying expenses reported to be less than half of those associated with steam-based systems (Sattar, 1994). Furthermore, solar drying technologies can be seamlessly integrated with auxiliary heating systems to form hybrid kilns, enabling year-round operation and enhanced process control.

Overall, solar wood drying represents an environmentally friendly, economical, and technically feasible approach for efficient timber utilization.

Components of solar kilns

Apart from three basic components, solar kilns have other important aspects too. Luna et al. (2009) grouped such aspects into seven groups as shown in fig.1:

- Drying chamber (A)
- Heating unit (B)
- Storage unit (C)
- Control unit (D)
- Meteorological data (E)
- Sun (F)
- Wood (G)

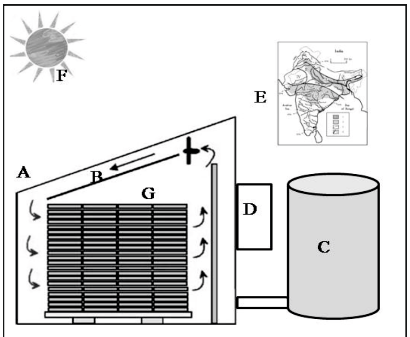

Figure 1: Solar kiln components

Solar kiln designing is all about re-arranging these components or adding new components in order to maximize the output.

One can see that the Sun and meteorological data play important roles in the design of a solar kiln. For example, Dehradun (30.3165° N, 78.0322° E), mean temperatures varies between 10.9 °C in January and 27.1 °C in June. July and August are the highest rainfall months with above 600 mm of precipitation recorded. The global radiation (direct and diffuse radiation) from the sun varies between 3.69 kWh/ m^2-day in December and 7.42 kWh/ m^2-day in May. These values are the average of values collected over 22 years. Another aspect which can affect the performance of any solar kiln is the solar elevation angle. At Dehradun, this angle varied between 36.36° in winters and 83.23° in summers at solar noon.

Factors affecting the performance of solar kiln

Solar flux, ambient temperature, relative humidity of air, airflow rate, geometric configuration of the solar collector, material of construction etc. are the factors which determine thermal performance of a solar kiln (Khater et al., 2004). Plumptre (1985) enlisted factors which affect solar kiln efficiency as: latitude, climate (temperature, humidity and insolation), initial and final moisture content of wood, species and permeability of the timber, thickness and size of crossers, design of kiln etc.

Various physical parameters/quantities should be recorded while assessing the performance of a solar drying kiln. Theses parameters can be classified into two broad classes elaborated below:

I. Quantities to be measured continuously

- Incident global solar radiation
- Transmitted global solar radiation
- Ambient air temperature
- Wind speed
- Temperature of absorber, glass cover, timber surface and air temperature at various locations
- Relative humidity inside the kiln

II. Quantities to be measured at specific time intervals

- Initial timber moisture content
- Timber moisture content during drying
- Air velocity inside the kiln

Types of solar wood drying kilns

Simpson (1992) categorized solar kilns into four major groups on the basis of complexity and working:

➢ Simple insulated agricultural dryers.

➢ Agricultural green houses.

➢ Semi-automatic dryers and.

➢ Automated solar kilns equipped with thermo-stat, humidostat, vents, reversible air circulation and complementary heating source.

On the other hand, Plumptre (1985) classified solar kilns into roughly four classes:

I. Green House Type Kilns: walls and roof covered with translucent/ transparent cover with collectors within the structure.

II. Semi-green House Type Kilns: Walls and roof glazed and floor insulated. Air circulation and collector system within the system.

III. External Collector Kilns: air/ water based collectors laced outside the main structure.

Solar Dehumidifier Kilns: dehumidification unit connected with solar kiln. Chen et al. (1982) designed and constructed an experimental solar-dehumidifier by combining two energy efficient methods. An open compressor dehumidifier using a high temperature refrigerant was able to achieve temperatures as high as 71°C. It was concluded that solar dehumidifier drying was faster than solar drying alone.

However, the above kiln types may also have some additional features like heat storage, micro-processor control of vents and air circulation and water condensation devices.

Luna et al. (2009) has grouped solar kilns into three classes on the basis of arrangement of main components of kiln:

Group one: drying unit and heating unit integrated into one (Maldonado and Peck, 1962)

Group two: more flexible kilns with separate heating and drying units and

Group three: consisting of solar kilns having heat storage unit.

Luna et al. (2009) further classified the simple solar heated kiln into two types on the basis of positioning of fans and collector. In the first type, air is drawn from collector and thrown on to wood stack and in the second type it is in reverse order.

Solar kiln designs

Since 1960s, several types of solar timber dryers have been developed and studied. The kilns ranged from very simple designs to external collector based automated dryers with an integrated energy storage system (Luna et al., 2009). More than 40 designs of research kiln using solar energy have been developed in addition to a number of varieties of the commercial solar kilns (Plumptre and Jayanetti, 1996). A detailed description of 31 solar kilns has been presented by Wengert and Olivera (1983). These drying kilns have been constructed across the globe e.g. USA, India, Australia, Uganda, England, Puerto Rico, Brazil, South Africa, Madagascar, Canada Japan etc. These solar kilns represent latitudes varying from 60° N (Anon, 1982) to 35° S (Steinmann et al., 1980) through equator (Plumtere, 1967). Details of 34 research kilns and 7 commercial kilns have been presented by Plumptre (1985). Aktas et al. (2017) investigated convective-infrared drying characteristics of timber under controlled temperatures.

Limitations of using Solar Kilns for drying

All the limitations in availability of solar energy affect functioning of solar kilns significantly. Thus, the drawbacks associated with solar kilns are:

I. Total dependence of weather for its heating.

II. It works on relatively low temperature.

III. It takes long drying times.

Further, the limitations of solar kilns could be improved by introducing auxiliary heating, thermal energy storage etc.

Solar kiln versus steam heated kilns wood drying

Unlike conventional drying systems (steam heated kilns) solar drying kiln is a mechanically simple system which results in lower maintenance and energy costs (Boryen, 1994). Installation cost of solar kiln too is much lower as compared with steam heated kiln (Ali et al., 2013). Unlike steam heated kilns, solar kilns don't require boiler, piping and pumping etc. Many workers have suggested that solar drying is most suitable for small-scale operations that have flexibility and non-critical supply schedules.

Drying rate is an important parameter because it is closely related to energy consumption and economic feasibility of the process. Many comparative studies suggest that solar wood drying is relatively slower than conventional drying methods. Gan and Choo (2001) defined the drying rate as percentage of water lost per unit time. Steinmann (1992) reported drying of Pinus radiata from initial moisture content of 100% to 12% moisture content in a solar kiln requires roughly three times the time of conventional drying. Gough (1981) also found solar drying to be 2-3 times longer than conventional methods. There is difference in time taken to dry wood in summer and winters too. Results show that it takes drying in winters about 2.2 times longer as compared to summer and 1.6 times longer as compared to autumn and spring (Khater et al., 2004). However, solar kiln is reported to utilize only one fourth of electrical energy compared to that used by a steam heated kiln (Chen, 1981).

The following parameters are suggested to be considered before choosing a timber drying kiln (Boryen, 1994): Energy source and consumption, drying time and predictability, scale of operation, operator input, capital cost and operating cost. If we consider solar drying kiln with respect to these parameters, all are favorable for solar kilns except drying time and predictability.

Studies on solar wood drying kiln in India

The first-generation solar kiln

A considerable amount of work has been reported at the national level on solar kilns. Forest Research Institute, Dehradun (FRI) is regarded as the pioneers in the field of solar timber drying kilns not only at national level but at international level too. Early 1960s witnessed serious efforts to develop a solar wood drying kiln at FRI. In the early stages of the development of solar kilns, Rehman and Chawla (1962) tested a number of designs of solar heated system. In these designs a flat plate collector was used to heat up fresh atmospheric air, which was then made to rise through the timber stack inside the kiln by virtue of density differences. The results were not very encouraging. Practically no advantages in drying rate were obtained in the solar kiln relative to air drying. The main reasons for this were found to be sluggish thermal circulation which resulted in high humidity conditions in the kiln. Sharma et al. (1972) designed and constructed a glass house type of solar kiln (3.5 m^3) provided with forced air circulation and made comparison between time required to dry green wood planks (25 mm thick) to a moisture content of 12% and air drying. Later, Sharma et al. (1980) carried out some improvements in the design and developed a 7.1 m^3 capacity commercial kiln (Fig. 2). The kiln was installed at Ballarshah (20° N and 79° E) and Rajahmundary (17° N and 82° E) which are located in humid and coastal conditions. From the results, it was concluded that solar drying was feasible in most part of the country where at least 8 months of the clear weather during a year is available (Sharma et al., 1980).

Figure 2: First commercial solar kiln developed by FRI in 1980

Many works (Sharma et al. 1972, 1973, 1980) have shown that 2.5 cm thick planks of moderately refractory timber can be solar dried from green to 12% moisture content within 16-20 days as against 8-12 days taken in steam heated kiln. Sharma (1981) carried out trials of drying of building timbers and concluded that the solar kilns could be useful to dry thick building timbers without significant defects. Sharma et al. (1981) carried out extensive studies on drying of shisham wood in the solar kiln at Dehradun location. Shisham wood of cross section 75 mm x 100 mm requires approximately 18 days to dry in a steam heated kiln which runs 24 x 7. In the month of April, solar kiln drying took 25 days to bring MC of shisham from initial 55% to final 18%. The solar kiln dried planks were found to develop only light to moderate drying stresses. No serious defects were observed during the drying.

Sharma et al. (1983) designed packed bed type solar air heaters with a total collector area of 10.3 m^2 and were able to achieve 90°C to 105°C maximum temperature at air flow rate of 2.77-5.54 kg/min in the month of April at Dehradun. The air heater was used successfully to dry veneers, sal seeds and dhak leaves using solar heat. Pandey et al. (1986) carried out trials on drying of minor forest products e.g. tendu leaves and found solar kilns to be very useful.

In order to increase heat intake by solar kilns, blackened galvanized iron sheet sheathing was tried on east, west and south walls of FRI solar kiln by Pandey et al. (1992). It was concluded that a net gain of 20.6% of energy could be realized as a result of sheathing. It was further concluded that total drying time reduction due to sheathing was 16.7%. Kambo and Pandey (2002) incorporated dehumidification unit in the existing double glass wall solar kiln. The kiln worked on two principles - heating by solar heat followed dehumidification and recycling of heat by the dehumidification unit. This proved to be a very efficient and energy saving kiln. The drying time of this kiln was found slightly longer than conventional steam heated kilns but significantly lower than the original solar kiln.

The second-generation solar kiln: Modified Design Solar Kiln for drying of wood and other non-wood forest produce

A modified solar kiln design having a charge capacity of 250 cft for one-inch thick plank was developed in 2009 (Upreti, 2009) (Fig. 3). The design consisted of a super structure of timber/metal frame, single sheathed on the roof; southeast and west wall 5.5

mm clear transparent glass. The north wall was sheathed with 9.5 mm BWR grade plywood. The kiln was oriented east west along its length. The roof tilted towards the south at an angle to the horizontal equal to 0.9 times the latitude for maximum year round absorption of solar energy. Corrugated blackened galvanized iron sheet was used for false ceiling and the entire structure was painted black on inside to absorb maximum solar radiation. Two electric fans were installed at the floor level in north wall for uniform air-circulation. The improved chimney type vents in south wall helped in recovery of heat loss during venting operation. The modified design kiln was equally efficient and approximately 30 % cheaper compared to old version. The solar kiln could also be used for drying seeds, bidi leaves, raw material of ayurvedic medicines etc. The approximate cost of installation was about Rs. 8.0 Lakh for a 250-cft capacity kiln.

Figure 3: The modified single glass Solar Kiln for Timber Drying

The third-generation solar kiln: A dual inclination Solar wood drying Kiln and a solar thermal storage system

Basic kiln design was improved in the third generation kiln. Tilt of south facing roof and wall of the kiln are optimized using the standard mathematical relationships for two major seasons of the year (Kumar et al., 2015). The optimum collector tilt angle for the months of September to March for Dehradun is 43.14°, and that for March to September is 18.42°. These were adopted as the tilts for the south wall and roof respectively for the envisaged double inclination kiln (fig. 4).

Total solar flux falling on the three faces (roof, south wall and east wall) of the two kilns designs (New double inclination kiln and Old design FRI solar kiln) was calculated and it was found that New Double Inclination received overall 39.2% higher flux in winters as compared with that of Old Design FRI Solar Kiln.

The roof and south wall collectors of the kiln were finned from lower side. Aluminum finning was done in kiln's main flat plate solar collector made of G.I. (Galvanized Iron) sheet for efficient heat removal, which ran parallel to the roof. The air circulating fans were positioned such that force air to flow from north to south direction while interacting with Aluminum fins. The east and west walls of the kiln were also provided with inbuilt blackened G.I. sheet flat plate collectors to trap solar energy in early morning and late evening. Empty run test in month of April, 2014 showed quicker temperature rise in kiln especially in morning and evening, and maximum temperature of 98.6°C was achieved inside the kiln at 14:00 hrs.

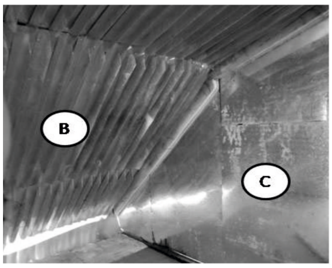

Figure 4: External view of the solar kiln showing double inclined roof (A), internal view of the kiln showing the aluminum fins attached to lower side of the roof solar collectors (B), G.I. sheet solar collectors fitted beside the kiln east/west walls (C)

Drying of 3.8 cm thick teak wood (The third-generation solar kiln)

The following experiment will give a clear insight on the drying performance. Teak (Tectona grandis) wood of 3.8 cm thickness, having initial MC 70% was stacked in the kiln. The kiln ran only in day time in month of May, 2014 from 09:00 hrs in morning to 17:00 hrs in evening. After the kiln was stopped in evening the both windows were kept open during night. It was possible to maintain certain dry bulb temperature inside kiln during day time but night temperature was not in control and fluctuated as per ambient temperature. It is important to mention that the temperature of the kiln had to be reduced frequently by opening and adjusting the windows in day time. Up to day 6 (above MC 30%), 42°C was maintained. As soon as MC went below 30%, the temperature was raised to 47°C in day time. The total length of the drying run was 15.5 days. However, out of 15.5 days, the kiln did not run for 6 days due to some unavoidable reasons including 1 day fully cloudy sky. During these 6 days windows were fully opened in day as well as night and fan didn't run. Out of the remaining 9.5 days; 2 days were partially cloudy before noon and kiln ran only in afternoon.

Thus, total length of the drying run was 15.5 days to bring down 70% MC to 11.1% MC, including the 6 days during which the kiln did not run at all. However, it is evident form Fig. 4 that the moisture content (MC) reduced even during after-sunset hours. There may be two reasons behind this. First, there is a significant amount of energy stored in the form of sensible heat in kiln structure and wood itself. The MC could be reduced using this stored energy. Moreover, open windows during night hours ensured quicker removal of the humid air from kiln and maintained lower Equilibrium Moisture Content (EMC) inside kiln.

This supports the fact that providing sufficient venting in early stages in solar drying helps increased drying rate (Chen 1981). The second reason may be that drying occurred as collector system trapped energy even when kiln run was stopped, resulting little higher kiln temperature than ambient. Although end cracks of very minute size were visible, no serious defects were observed during the test run. Thus, the improvements in design of the kiln in the form of double inclination angles and flat plate solar collectors finned from inside resulted better heat trapping and heat removal performance. Temperature as high as 98.6°C kiln could be observed in the kiln during empty test run. The side wall flat plate collector system helped to gain temperature about 57.8°C in early morning i.e. 09:00 hrs. A reduced drying time was observed with 3.8 cm teak planks with the help of the new design.

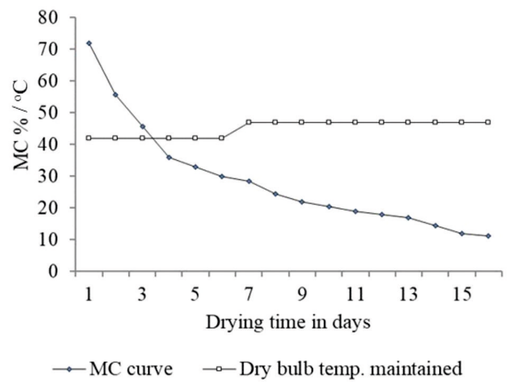

Figure 5: Drying curve for 3.8 cm thick Teak wood

Fig. 6: The third generation kiln installed at Churu

The third generation solar kiln was installed recently at Churu, Rajasthan for a wooden handicrafts manufacturing firm (Fig. 6).

Thermal energy storage system developed for the third generation solar kiln

For construction of appropriate size of thermal storage system (TSS), heat budget of the kiln was estimated. Mean usable heat per day in winter months was maximum in October (45.46 kWh) and minimum in January (34.61 kWh) with mean 39.44 kWh (CV=10.38%). The rate of heat loss from the solar kiln was found to be 1710 W. The heat loss calculations carried out through empirical method, it was found that 95% heat losses occur through glass glazing. With the current design of TSS, it was estimated that same amount of additional solar heat (1710 W) will be required in the winter months for wood drying in presence of TSS. It was further estimated that only 28.5% energy of the TSS will be utilized for wood drying and the rest of the heat will be used to make up the heat losses.

The newly constructed packed bed type TSS i.e. based on phase change material (PCM) and water, was designed and developed (Fig. 7).

Figure 7: Thermal energy storage system assisted with Evacuated Tube Collector (ETC) array

The TSS was tested in empty kiln run conditions in which the kiln temperature during the day time was maintained above 65°C for 5.5 to 5.8 hrs. During the empty run test (without timber charge) of the TSS in the kiln, it was observed that the kiln could successfully sustain 45 °C and 50 °C in the nights of October when the night ambient temperature was 14°C (Fig. 8).

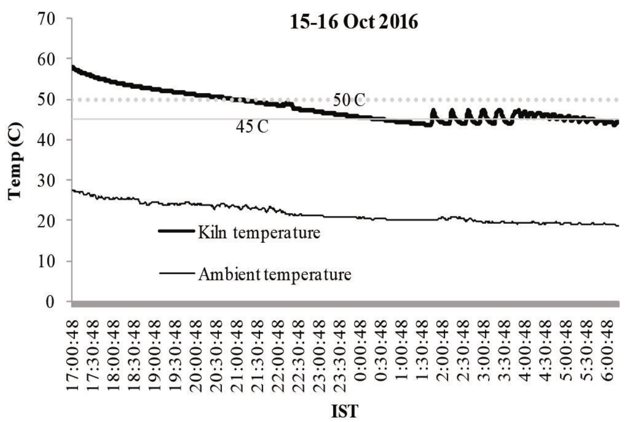

Figure 8: Kiln and ambient temperature in the night time (October)

Two charges of 2.5 cm thick wood of Ailanthus excelsa were dried in the kiln under two conditions: in absence and in presence of TSS in the month of October. During wood drying in absence of TSS, the kiln temperature fell quickly after 16:00:00 hrs and went below 45°C at around 05:00:00 hrs. However, the kiln temperature remained above ambient temperature by at least 10°C throughout the night. During the drying of wood in presence of TSS, the night kiln temperature up to 48-50°C was able to be maintained till 06:00:00 hrs in the next morning. Fig. 5 shows the variation in moisture content (MC%) of Ailanthus excelsa wood during drying, both with and without TSS treatment. In the presence of TSS (black line), the wood exhibits faster moisture reduction compared to that in absence of TSS (gray line) (Fig. 9). Over the drying period of up to 92 hours, treated wood reached a lower final moisture content, indicating enhanced drying efficiency.

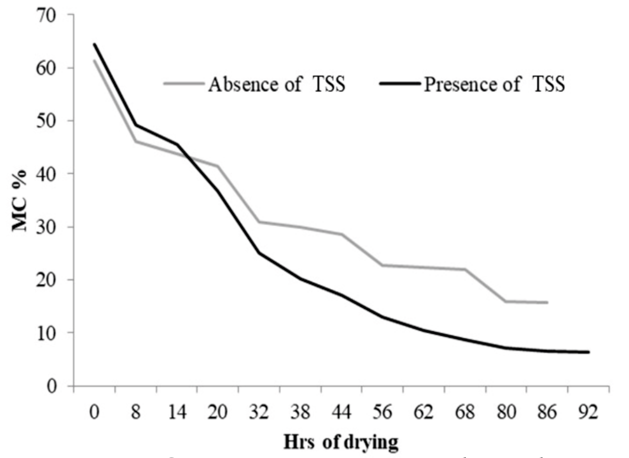

Figure 9: Comparative moisture content drop under absence and presence of TSS

MC of Ailanthus excelsa could be brought down to 15% from near 60% initial moisture content in 50 h in the presence of TSS against 92 h taken by the kiln in the absence of TSS. In the case of Melia dubia, this was achieved in 43 h in the presence of TSS against 80 h taken by the kiln without TSS.

The study demonstrated the potential of solar thermal storage using sensible heat of water and latent heat of phase change material for release in night times is amply illustrated which can be a boon in wood drying applications. It is expected that the technology will end up comparably economical when the costs of fuel, manpower etc. are considered to run a boiler-based wood dryer. Therefore, adoption and use of solar thermal storage based industrial processing can help to achieve the aims of clean economic growth and development.

Cost of the solar kiln construction

The solar timber drying kiln can be constructed using wooden framework. For longer service life, iron angled frame can be used. The kiln incorporates double glass glazing for both roof and vertical walls, comprising two 5 mm thick glass panes separated by a 38 mm air gap for enhanced thermal retention. A cemented foundation supported the lower inclined glazing section is also required. The floor is thermally insulated by placing a 7.5 cm thick layer of glass wool over the concrete base, covered with a 1.2 cm thick plywood sheet. A similar plywood wall formed the north side of the kiln, externally insulated with another 7.5 cm thick glass wool layer and aluminum sheet cladding to minimize heat loss.

The solar energy collection arrangement consists of blackened galvanized iron (G.I.) flat-plate collectors positioned parallel to the dual-inclined double-glazed roof, maintaining a 10 cm air gap to facilitate heat transfer. Additional tray-shaped raised collector extensions are provided along the east and west directions to intercept low-angle solar radiation during morning and evening hours, while full-height vertical G.I. sheet collectors on the east and west interior walls further reduced heat losses and contributed to early and late-day heat gain. All G.I. collectors are coated with matte black paint to create a selective absorbing surface. To improve convective heat transfer from the collectors to the circulating air, aluminum fins of 6 cm width are riveted to the underside of the main roof collectors, and a blackened aluminum baffle was installed near the south side to direct heated air upward. A plywood partition is installed 92 cm from the north wall, housing electric fans that circulate air from the north toward the south end of the kiln. For operational access and ventilation control, an inspection and loading door is provided on the east wall along with adjustable windows in both side walls. All structural joints and attachments are secured using standard construction hardware including rivets for fin installation. The third-generation kiln is expected to require an investment of about ₹6–8 lakh for its construction.

Conclusion

Solar wood drying kilns represent a smart and sustainable step forward for India's wood processing sector. They make use of an abundant and freely available energy resource—the sun, while significantly reducing dependence on conventional fuels. Over the years, Forest Research Institute, Dehradun, has developed several indigenous solar kiln designs that are cost-effective, energy-efficient, and well suited to diverse climatic regions of the country. These technological advancements have led to faster drying rates, reduced timber defects, improved product quality, and lower production costs for carpenters, small industries, and rural entrepreneurs as well as bigger manufacturers.

With growing concerns about climate change and rising energy prices, solar timber drying has the potential to play a major role in sustainable industrial development. Wider adoption, technological refinement, and policy support can help transform this green technology from research prototypes into mainstream industrial solutions. By harnessing solar energy for wood drying, India can not only conserve valuable natural resources but also promote cleaner manufacturing practices and a healthier environment for the future.

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A Solar Vacuum Dryer Integrated with Thermal Energy Storage System

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Wood drying is identified as the most energy intensive step of all wood processing operations and consumes 60–70% of the energy. Thus, any changes made in drying practices would have an impact on the cost of production as a whole. Conventionally, steam-heated kilns are widely used in India for wood drying purposes. The production of steam is costly and requires burning a large amount of fuel. Solar wood drying kilns use free-of-cost available solar energy which needs no fuel for operation.

Vacuum drying can reduce drying time and be more energy efficient compared with conventional steam drying. In a conventional kiln, the process of timber drying is deterred by the rate of diffusion, whereas, in vacuum drying, bulk flow dominates the drying. The bulk flow is made up of water vapour generated through boiling of water under lower pressure. Moreover, vacuum drying is also suitable for temperature-sensitive timbers as higher drying rates can be achieved at lower temperatures.

Present technology relates to a solar vacuum timber dryer capable of utilizing and storing solar heat during the day time and reutilizing the stored heat in the night time for timber drying, resulting in a fast and eco-friendly timber drying process. The heat storage for solar kiln drying may provide an additional tool which may shorten drying times significantly. Since solar heat is free of cost, the infrastructure needed for thermal storage will prove cheaper than steam generation through boilers. Most of the solar kilns (greenhouse type) report relatively longer drying times of wood. Thus, application of vacuum using solar heat for wood drying can be a faster drying option for industrial wood processing.

The work comprises the development of a mechanism to connect a solar evacuated tube collector (ETC) water heater with a vacuum dryer. The vacuum dryer is a metallic tank in which aluminium platens are specially designed to receive solar heat from water circulating from the ETC array. This heat received from hot water is partially transferred to wood layers above and below the platens and partially to store the heat within phase change material (PCM) integrated inside the platens.

A pilot-scale vacuum dryer with a thermal energy storage system was developed at ICFRE- FRI, Dehradun. For thermal storage and heat transfer arrangement inside the vacuum tank, aluminium platens were fabricated in which arrangements were made to flow hot water and PCM encapsulation. Aluminium tubes laid in parallel were filled with phase change materials (PCM) for the thermal energy storage system.

Solar hot water consists of an array of ETC tubes (50 No.) connected in parallel. The inlets were connected to the array headers from the lower side. Thus, a loop of circulating water is made by connecting the PCM-filled aluminium platens with the help of rubber hose pipes and manifolds. Motor pumps were used to circulate hot water through the manifolds/platens in a circular loop.

A cubical stainless steel vacuum tank (91.4 × 91.4 ×

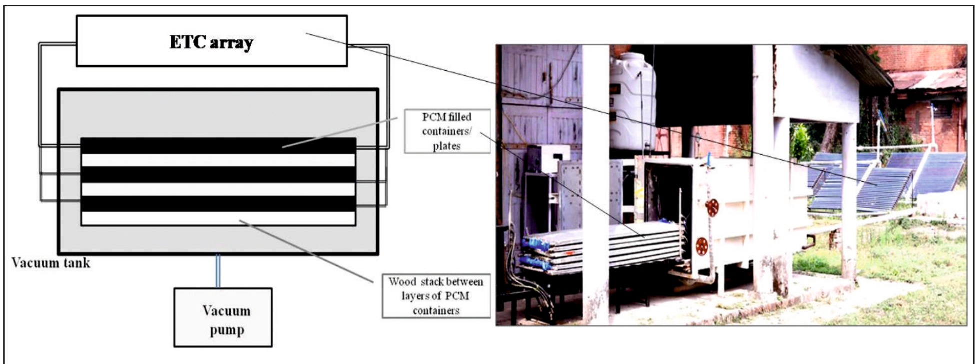

Figure 1: The solar vacuum dryer with thermal energy storage system

305 cm³) was used to accommodate the timber stack with the aluminium platen. Rails on the vacuum tank floor were connected through a rail stand which is kept outside. The wood layers could be stacked between aluminium platens.

The study conducted in the empty pilot plant on comparison between heat storage in the form of sensible heat (water) and latent heat (PCM), suggests that PCM platens maintained significantly higher temperature throughout the night time as compared with water when wood was not stacked. Sufficiently higher wood core temperature could be maintained in the night time using PCM in the platens. Drying runs of poplar and mango wood in the solar vacuum dryer with thermal storage system performed very well during the day as well as in the night time.

Wood drying in the "Solar Vacuum Dryer"

Figure 2: Stored heat is transferred to the platens through conduction

This section will present wood drying trials in the solar vacuum dryer with temperature and moisture content (MC %) data. All the vacuum wood drying experiments were carried out in the month of January 2020 which is also the coldest month in Dehradun. All the platens (6 No.) were filled with PCM 48C and were used in wood drying experiments and five layers of wood planks (38 mm thick) were stacked among the plates. The upper two wood layers were of Populus deltoides and the lower three wood layers were of Mangifera indica. Wood core temperatures were recorded from each wood layer. One wood plank from each layer was randomly selected for preparation of wood sample for determination of initial moisture content (IMC %) and final moisture content (FMC %). The methodology described in IS: 1141 (1993) was used for making the moisture content samples. Thus, two samples of poplar (P1, P2) and three samples of mango (M1, M2 and M3) were used for the determination of moisture content during drying runs. A vacuum level of 330 mm of Hg (gauge) was applied during three drying runs.

Fig. 3 presents drying run 1 (DR1). It can be seen that a maximum mean temperature of 54°C could be achieved and more than 44°C wood core temperatures were maintained for most of the night.

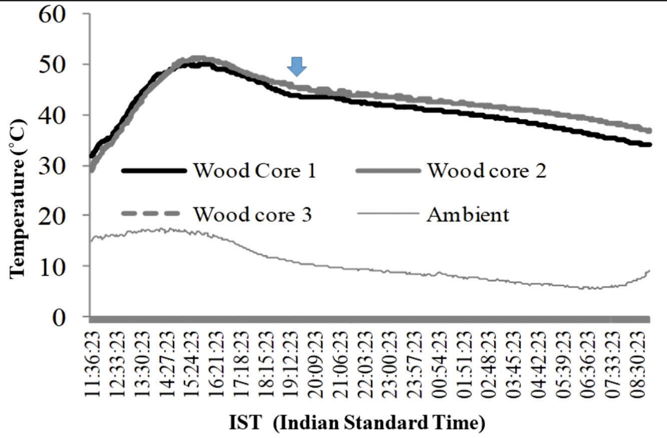

Figure 3: Temperature curve during drying

The moisture content decrease from nine drying runs on 38 mm thick mango and poplar wood is shown in Fig. 4. In nine drying runs, the poplar's moisture content decreased from 110.4% at the beginning to 14% at the end, with an average daily decrease of 10.7%. On the other hand, mango wood's initial moisture content of 94.7% decreased to 14% at an average rate of 8.9% per day.

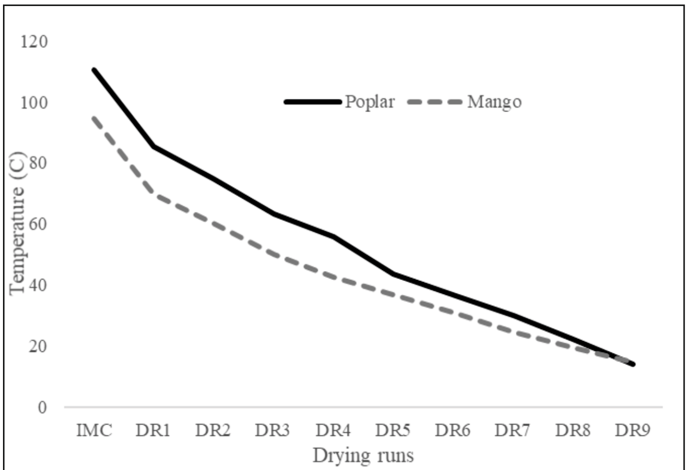

Figure 4: Drying curves for solar vacuum dryer

Several studies show that a greenhouse-type solar kiln can dry 38 mm teak wood in 15 days. Overall drying times for wood in greenhouse-style solar kilns are said to be between two and four months. However, this study found that January, one of the coldest months in northern India, has a drying cycle of nine drying runs (days). Furthermore, it is anticipated that the kiln will function much better during other seasons with higher ambient temperatures and more solar energy available.

Aluminium platens with phase change material (PCM) resulted in higher plate temperature throughout the night time as compared with platens without PCM. PCM-based thermal storage was able to sustain a higher wood core temperature (over 45°C) throughout the night time. Moisture content of Populus deltoides (initial moisture content 110%) and Mangifera indica (initial moisture content 95%) dropped to the final moisture content of 14% in nine days of drying in the month of January. The developed dryer offers a unique, fast and continuous drying method using solar heat and its storage.

The techno-economic analyses suggest that when all the cost components were taken into consideration, the solar vacuum dryer resulted in an 11% lower drying cost in the solar vacuum dryer as compared with steam-heated kilns. Various costing scenarios discussed like fuel consumption, interest on timber being dried, land rent etc., found that wood drying using the solar vacuum dryer was still competitive with that of steam-heated kilns. However, in the scenario in which no fuel cost, no interest on the value of timber and no rent of land were considered, the drying of wood using steam-heated kilns was found to be most economical and profitable. However, this does not present the real picture of the cost.

The research highlights proof of the concept and demonstrates an eco-friendly approach for the utilization of solar energy in wood-based industries. Such research and developments will provide efficient clean technology solutions to targeted beneficiaries like wood handicrafts industries, small wood-based industries, and wood saw-millers for catering to the needs of seasoned timber in the country. A patent has been filed on the technology. Entrepreneurs and kiln manufacturers can take up this technology for further improvement for commercialisation in collaboration with ICFRE-FRI, Dehradun.

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Common Facility Centre at IWST

Common Facility Centre (CFC) has been established inside IWST campus during the year 2016. The CFC houses many modern wood working and bamboo processing machines. CFC extends wood and bamboo processing facilities to various stake holders, self-help groups, NGOs, wood based small scale/cottage industries and local artisans. All the machines can be used on payment basis during all working days (Monday to Friday) from 9:00 AM to 5:30 PM. The details of available wood working and bamboo machines and their description are given below.

A. List of Wood and Bamboo Working Machines

No.	Name of Machinery	Description
1	Surface Planer	Suitable for removing rough surface of the wood by planing.
2	Thickness Planer	Suitable for sizing the piece of wood in two dimensions
3	Sliding Table Panel Saw	Suitable to cut a wood lumber/panel board to the required sizes in different cutting like rip cut, & scoring for pre lamboard.
4	Small Table Circular Saw	Suitable for rip cutting, cross cutting, and chamfering of wood.
5	Multi Spindle boring	Suitable for multi boring on wood/panel boards like vertical, horizontal and angular bores.
6	Spindle Molder	Suitable for edge profiling and contouring.
7	Belt Sander	Suitable for sanding the surface
8	Finger Jointing Machine	Suitable for joining small solid wood pieces
9	Seasoning Kiln	Suitable for seasoning the wood(Capacity: 200 cft)
10	Bamboo Cross Cutting	Suitable for cross cutting of Bamboo culms.
11	Bamboo Semi Half Splitting	Suitable for splitting the bamboo culms to rectangular strips.
12	Bamboo Variable Size splitting	Suitable for splitting the bamboo culms to number of strips.
13	Bamboo External Knot Removing	Suitable for removing external knots of bamboo culms.
14	Bamboo Thickness Planning	Suitable for thickness planning of bamboo strips to variable size.
15	Bamboo Slat Gluing	Suitable for gluing the bamboo strips for making panel of different sizes.
16	Bamboo Panel Drier	Suitable for drying glues bamboo panels.

To use the facility and for further details, please contact:
Officer incharge of Common Facility Centre, **Institute of Wood Science and Technology**
18th Cross, Malleshwaram, Bangalore Ph:080 22190178, E Mail: cfc_iwst@icfre.org

Vacuum Drying of Timber and Its Scope in India

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1.0 Introduction

Wood in growing trees contains considerable quantities of water, and most of this water has to be removed in order to obtain satisfactory performance from the wood in use. Freshly felled timber contains a large amount of moisture, in many cases more than 100% based on the oven-dry weight of the wood; in some light timbers, the quantity of water in the green condition is roughly twice as much as the weight of the wood substance (approximately 200%). During the removal of this moisture, the wood shrinks, and if the drying process is not carried out properly and in a controlled manner, this shrinkage can give rise to defects such as surface cracking, end splitting, and warping, which ultimately result in wastage of wood. To ensure that timber products maintain their shape and size and to eliminate losses through cracking, splitting, and warping in service, it is necessary to "season" the timber that is, to reduce its moisture content to an average equilibrium with the atmosphere of the locality where it will be used. Seasoning is the controlled removal of moisture from wood.

Seasoning of wood is one of the important processes to ensure satisfactory service from manufactured wood products. The main reasons for drying timber are

- To prevent unacceptable shrinkage after product manufacture.
- To maximize strength, as the mechanical properties of timber generally increase as it dries below 25% to 30% moisture content.
- To reduce susceptibility to fungal decay, since timber maintained at less than 20% moisture content is unlikely to be attacked by wood-decaying fungi or sap stains.
- To make processed timber easier to handle, as seasoned timber is not as heavy as green timber.
- To increase the effectiveness of preservative treatments, because many preservatives should only be applied when the moisture content of the timber has been reduced.
- To effectively glue, paint, stain, fill, and polish timber.
- To prevent the corrosion of metal fixings.

Wood drying is an indispensable operation in wood processing. It is a highly energy-intensive process and accounts for nearly three-fourths of the total energy requirement in the entire wood processing chain. In India, wood drying is mostly carried out using steam-heated kilns, where only about 45% of the input heat is utilized for water evaporation, while the rest is lost through transmission and venting losses (Pandey and Jain, 1992). Steam consumption for drying wood ranges from 1.66 to 4 kg per kg of water removed in a steam-heated kiln, whereas in electrically heated kilns, 2 to 4 kWh of electricity is consumed for each kilogram of water evaporated from the wood (Sharma et al., 1980). Other drying methods, such as solar kiln drying, have their own advantages and disadvantages. The major drawback of using a solar kiln is the significantly longer drying time, as solar energy is available only during the daytime. Consequently, solar energy–based industrial operations are forced to stop at night.

Among these options, vacuum drying is one of the advanced alternatives available to the wood industry in India. It is considered to be a much faster technique approximately five times quicker than conventional methods such as steam-heated kiln drying, and the quality of vacuum-dried wood is generally better. Vacuum drying of wood is an advanced technology developed by the Forest Research Institute, Dehradun. It is also a cleaner method, as there are no emissions to the environment compared with traditional steam-heated kilns.

2. Vacuum Drying:

Vacuum drying is an advanced method of timber drying compared to conventional techniques for many species under different environmental and economic conditions. It can reduce drying time by 8 to 12 times and is more energy-efficient than conventional drying. Vacuum drying is based on the principle that the boiling point of water decreases substantially when the atmospheric pressure over it is reduced. For example, if the pressure is lowered from the normal 101 KN/m^2 to 20 KN/m^2, the boiling point of water is reduced from 100°C to 60°C.

This method came into existence in the 1960s. In its early use, wood was placed in a cylinder similar to an autoclave used for preservative treatments. The wood was heated up to 100°C either by steaming or by immersion in boiling water. When the steam supply was shut off or the boiling water was drained, a vacuum was applied to the wood, causing some of its moisture to boil off rapidly. The vacuum alone does not cause drying; the latent heat of evaporation is essential. As soon as the specific heat available from the fall in temperature of the wood and the moisture within it is used up, the drying process stops.

Many studies on vacuum drying have shown that it significantly shortens drying time, especially for thick lumber, and the resulting drying quality is generally good. Vacuum drying is often used for high-value species or large-dimension lumber.

Bulk flow and diffusion are the two major forms of water transport inside wood. Generally, free water bulk flow (FWBF) governs moisture movement when the moisture content (MC) is above the fibre saturation point (FSP), while diffusion controls moisture movement when MC is below FSP. Limited information is available on water vapour bulk flow (WVBF), which is driven by total pressure differences and is strongly dependent on the gas permeability of wood. In vacuum drying, a total pressure difference exists within the wood, causing water vapour to move from the centre toward the surface. Understanding WVBF is essential when water movement is no longer governed solely by diffusion.

It is well documented that permeability affects the rate of vacuum drying and that wood is far more permeable in the longitudinal direction than in the transverse direction. The ratio of longitudinal to transverse permeability in hardwoods is usually more than 30,000 (Chen, 1997). Therefore, significant differences in moisture transport between these directions are expected.

There is still some controversy regarding various aspects of the vacuum drying process, such as whether water actually boils inside the wood. Uncertainty remains about whether most moisture is transferred in vapour or liquid form and about the role the total pressure difference plays as a drying force in vacuum drying.

3. Principle and Working of Vacuum Drying Process

Vacuum kilns dry timber in an airtight chamber where the air pressure is maintained below normal atmospheric pressure. Under these conditions, the boiling point of water is reduced, which increases the rate of evaporation at the wood surface and creates temperature and total pressure gradients that favour the movement of moisture through the thickness of the wood. Drying wood in oxygen-free or oxygen-reduced environments also offers additional advantages, particularly the partial or complete prevention of discoloration.

In vacuum drying, wood is placed inside an airtight chamber, and application vacuum pressure by using vacuum pump to removes the air to create low pressure. Under this low pressure, water inside the wood evaporates at much lower temperatures, usually around 50°C to 60°C. In cyclic vacuum drying, the wood is first heated for some time using hot air. Once the wood reaches the desired temperature, a vacuum is applied again. Drying continues until the moisture removal becomes very slow. When this happens, the cycle of heating and vacuum is repeated until the wood is fully dried in the range of 8 % to 12 % moisture content.

The main difference among various continuous vacuum drying kilns lies in the method used to heat the wood. In the superheated steam and air–steam mixture method, fans circulate superheated steam or an air–steam mixture through lumber stacked on stickers (convective heating). In the hot platen method (no stickers), heat is applied directly to the wood by contact (conductive heating). High-frequency vacuum drying, on the other hand, uses a radio-frequency heating field. Rapid changes in the direction of the electric field cause the dipolar water molecules in the wood (no stickers) to oscillate millions of times per second, resulting in heating due to molecular friction and a subsequent rise in temperature and vapour pressure inside the wood (heat transfer by electromagnetic radiation).

4. Advantages of vacuum drying

The operating characteristics of the vacuum drying process offer significant advantages in terms of productivity, quality, and energy consumption. These factors are discussed below.

Productivity

Vacuum drying is faster than conventional processes for three main reasons:

- Operating under vacuum lowers the boiling point of water, resulting in more rapid surface evaporation (the boiling point of water at 101.3 kPa is 100°C, whereas at 12.3 kPa it is 50°C).
- The effective hydraulic conductivity of the material (the ease with which water circulates through the wood) increases at lower pressure, resulting in greater internal mass transfer (movement of water inside the wood) under vacuum.
- The vacuum process reduces resistance to mass transfer at the surface during evaporation.
- Vacuum drying with superheated steam can be up to five times faster than conventional drying. Hot platen drying can be up to ten times faster, and high-frequency drying up to twenty-five times faster. The rate varies depending on product dimensions and species. Drying times cannot be determined precisely because they depend on factors such as initial moisture content, target moisture content, the characteristics of the wood being dried, and especially the desired final quality. This applies to all drying methods.

Quality

Vacuum drying creates an environment that is highly favourable to producing quality dried wood. Because the boiling point is lower under vacuum, the process operates at relatively low temperatures. Wood is stronger at lower temperatures, reducing the likelihood of checks and splits. Vacuum drying also improves internal water movement, decreasing the severity of moisture gradients and reducing internal stress.

Some vacuum drying systems (such as platen and high-frequency units) allow for the application of a constant top load (top restraint), which minimizes warping during drying. Drying in an oxygen-free or oxygen-reduced atmosphere also reduces chemical discoloration caused by oxidation of natural compounds in the wood.

Energy

Shorter drying times and lower temperatures reduce heat loss from vacuum drying chambers. Because the system is fully enclosed, there is no need to introduce and heat fresh air during the process, unlike in conventional drying. Laboratory tests have shown that the energy consumption of vacuum dryers is generally lower than that of conventional dryers.

However, lower energy consumption does not necessarily mean lower operating costs. The type and cost of the energy source must be considered. For superheated steam, air–steam mixture, and platen technologies, the heat may come from electricity, fossil fuels, or wood residues. High-frequency vacuum drying systems depend entirely on electricity.

5. Vacuum Drying Methods

The Forest Research Institute has developed two different types of vacuum drying methods:

a. Vacuum Press Drying Method

b. Convection Vacuum Drying Method

A. Vacuum Press Drying Method

Vacuum press drying is an efficient technology for the rapid drying of wood. It is faster than conventional drying because the boiling temperature of water in the wood is reduced under low pressure, resulting in rapid moisture evaporation. The use of hollow aluminium platens for heat transfer through conduction, as in the vacuum press dryer (VPD), is considered more efficient than convection vacuum drying because drying can take place continuously.

A vacuum press dryer (VPD) consists of a rectangular steel chamber with a rubber-sheet roof. The chamber is connected to a liquid ring-type vacuum pump. Hollow aluminium platens are placed inside the chamber and are connected to an electric water boiler. When a vacuum is created inside the chamber, the rubberised roof presses the aluminium platens from the top, as shown in Fig. 1.

Research carried out by Kumar et al. (2018) on vacuum press drying of Melia composita and Eucalyptus tereticornis examined drying under two conditions: above boiling point (ABP) and below boiling point (BBP). The results showed that Melia wood reached equilibrium pressure with the VPD pressure almost immediately, whereas Eucalyptus reached equilibrium slowly, achieving it only at later stages of drying when cracks and checks had progressed toward the core. The drying rate was higher for Melia than for Eucalyptus under both drying conditions. For Melia, the ABP drying rate was higher than the BBP drying rate; however, for Eucalyptus, the ABP drying rate did not differ significantly from the BBP rate.

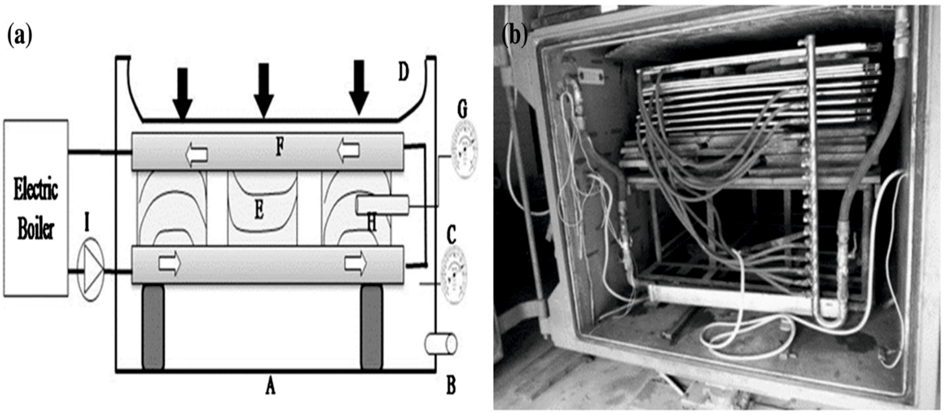

Figure 1 (a) Diagrammatic representation of the VPD. The different components are the rectangular steel tank (A), vacuum pump (B), vacuum gauges (C, G), rubberised roof (D), wood stacked between two aluminium platen (E), aluminium platen (F), brass pipe placed at wood core and connected with a pressure gauge (G) at the other end, brass pipe inserted to wood core (H), motor circulating hot water between boiler and aluminium platen (I). (b) Shows image of the VPD

B. Convection Vacuum Drying Method:

A convection heating based vacuum kiln for timber drying has been installed at the Wood Seasoning Discipline, Forest Products Division, Forest Research Institute, Dehradun. The vacuum kiln consists of a vacuum cylinder with an inner diameter of 121.92 cm (4 feet) and a length of 152.40 cm (5 feet), made of tested mild steel (MS) plates of 12 mm thickness. One end of the cylinder is closed with a dish end, while the other is fitted with a quick-door arrangement equipped with a rubber gasket, flanges, and a nut–bolt tightening system.

The vessel is fitted with an outer ducting system for air circulation. It is connected to a 3 HP water ring–type vacuum pump. A pressure gauge is mounted on top of the vessel, and a thermohygrometer with an internal probe measures the temperature and relative humidity inside the chamber. A fully reversible electric fan of 45.72 cm (1.5 feet) diameter is installed to create an airflow of at least 1 m/s across the length of the wood stack. The fan blades are made of aluminium. Three heaters, each of 0.5 kW capacity, are installed in front of the fan blades to generate heated airflow inside the vessel. The vessel is thermally insulated externally with a 2.54 cm thick glass wool layer covered by an aluminium sheet.

Research by Upreti et al. (2013) was conducted on Pinus roxburghii using twenty samples of thicknesses 1.27 cm (0.5 inch), 2.54 cm (1.0 inch), and 3.81 cm (1.5 inch), each with a uniform length of 76.2 cm (30 inches) and width of 10.16 cm (4 inches). Three levels of absolute vacuum 260 mm Hg, 200 mm Hg, and 150 mm Hg were applied during each drying cycle, achieved within 5, 10, and 15 minutes respectively. The vacuum was maintained for 15 minutes after the pump was switched off. The temperature inside the kiln was maintained at 50°C.

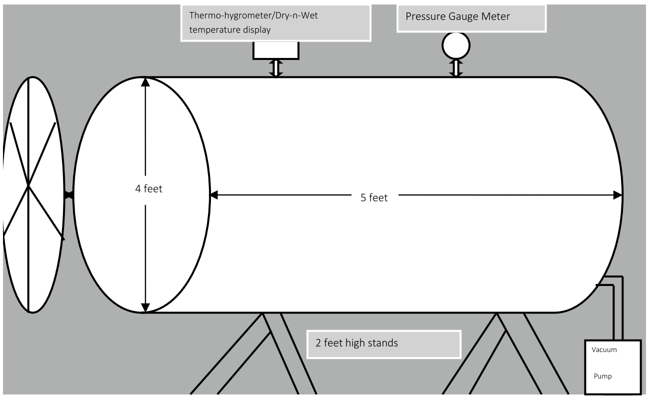

Figure 2: Diagrammatic representation of Convection Vacuum Drying K

The results showed that for 2.54 cm thick samples, the vacuum kiln required only 30.5 hours to reduce the moisture content from 27% to 12.6%, a significantly shorter duration compared to steam-heated kilns. Steam-heated kilns typically require 5 to 7 days to season this species to a final moisture content of 8–12%.

Figure 3 : Vacuum Dryer installed at wood Seasoning Discipline, Forest Products Division, FRI, Dehradun. (Vacuum Drying Technology patent by Dr. Nirmal Kumar Upreti, Wood Seasoning Discipline, Forest Products Division, Forest Research Institute, Dehradun. Patent Number: 349042)

Further studies by Upreti et al. (2015) on Cedrus deodara and Dalbergia sissoo also produced comparable outcomes. C. deodara, categorized as Class C refractory (non-refractory), has a fibre saturation point (FSP) of 21.5%. When dried in steam-heated kilns, it follows Schedule III and needs about 8–10 days to bring 2.54 cm planks down to a moisture content of 8–12%. Under vacuum kiln conditions, however, the same 2.54 cm planks were dried from an initial moisture content of 24.5% to 12% in just 13.63 hours at an absolute vacuum level of 200 mm Hg.

For Dalbergia sissoo, the findings indicated that Shisham belongs to Class B refractory (moderately refractory) with an FSP of 20.9%. Using Schedule IV in steam-heated kilns, seasoning of 2.54 cm planks to a moisture range of 8–12% typically requires 12–15 days. In contrast, the vacuum kiln achieved drying from an initial moisture content of 70.9% to a final 12% in only 92 hours under an absolute vacuum of 200 mm Hg. These results clearly highlight the superior efficiency of vacuum drying compared with conventional steam-heated kiln drying for this species.

6. Conclusion

Vacuum kiln drying has strong potential to transform the timber industry in India. Its major advantages faster drying, improved dimensional stability, reduced defects, and better overall quality make it far superior to conventional steam-heated kilns. With drying times often reduced by up to five times and energy use generally lower due to enclosed operation and lower temperatures, vacuum drying offers clear benefits for furniture, construction, packaging, and handicraft sectors that require high-quality seasoned wood. Studies on species like Pinus roxburghii, Cedrus deodara, and Dalbergia sissoo clearly demonstrate its effectiveness in reducing drying duration without compromising quality.

Looking ahead, vacuum kiln drying has significant scope for wider adoption, especially among MSMEs and modern wood processing clusters seeking efficient, better quality of dried wood and reliable drying technology. There is also potential for further research on optimizing drying schedules for different species, improving kiln design for energy savings, and scaling the technology for industrial use. Overall, vacuum drying presents a valuable opportunity to enhance value addition, reduce wood wastage, and support the growth and modernization of India's wood industry.

References : Contact author at Puruk@icfre.org

Wood Drying, ISPM-15 Heat Treatment, and Thermal Modification Techniques: A Comprehensive Overview

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Introduction:

Wood has served humanity for millennia, yet it remains a technically challenging material because of its intimate relationship with moisture. Whether used in construction, furniture, packaging, or engineered products, wood must be processed so that moisture no longer undermines its stability or performance. As a naturally hygroscopic material, wood constantly exchanges moisture with the surrounding environment, and every change in moisture affects its physical and mechanical properties. This characteristic means that before any significant application, wood must undergo controlled drying. Depending on its intended use, it may also need heat treatment under ISPM-15 guidelines or further thermal modification to improve durability and stability.

The journey from freshly harvested timber to a dimensionally stable, durable, and high-performance material involves several heat-based operations that build upon one another. Drying reduces the moisture content; ISPM-15 heat treatment sanitizes the wood for international trade; and thermal modification transforms its chemical structure to enhance performance. These processes collectively demonstrate how traditional knowledge and modern technology converge to produce sustainable and environmentally friendly wood products for global markets.

Understanding Wood Moisture, the Need for Drying, and the Role of Heat-Based Treatments

Freshly harvested wood contains large amounts of water, both as free moisture in cell lumens and as bound moisture held within the cell wall. The point at which only bound water remains—known as the fiber saturation point (FSP)—generally lies between 25 and 30 percent moisture content. Drying below this level triggers shrinkage and substantial changes in the wood's physical and mechanical properties. Because moisture strongly influences dimensional stability, structural behaviour, and biological susceptibility, controlling moisture becomes the first and most essential step in preparing wood for any meaningful application.

Drying stabilizes wood by reducing its tendency to warp, swell, or shrink in service. As moisture decreases, the wood becomes lighter, more workable, and more receptive to adhesives and finishes. Just as importantly, fungi and insects require moisture to survive and proliferate; well-dried timber therefore offers far better natural resistance to biological degradation. These fundamental improvements make drying a cornerstone of wood processing, regardless of the species or end-use.

The significance of moisture control extends beyond conventional uses of timber. It also underpins the global movement of wood packaging materials, where the risk of transporting insect pests across borders poses a serious phytosanitary concern. To mitigate this, international regulations under ISPM-15 require that wood packaging—such as pallets, crates, and dunnage—be subjected to heat treatment so that the core of the wood reaches 56°C for at least 30 minutes. The effectiveness of this treatment depends directly on how heat penetrates the wood, and moisture plays a critical role in that process. Wet or green wood heats much more slowly and unevenly, while properly dried or partially dried wood responds more predictably. Thus, a sound understanding of wood–water relations enhances not only the efficiency of drying but also the reliability and compliance of ISPM-15 heat treatment in commercial settings.

The chemistry of moisture in wood also influences the performance of thermally modified timber. Thermal modification takes the principles of drying much further by heating wood to temperatures between about 160°C and 240°C in oxygen-limited conditions. At these temperatures, bound water is not merely removed; instead, the structure of the cell wall polymers begins to change. Hemicelluloses degrade, lignin re-arranges, and accessible hydroxyl groups reduce in number. These transformations greatly decrease the wood's affinity for moisture and result in improved dimensional stability, enhanced resistance to decay, and a darker, more uniform colour. Understanding how moisture moves within the cell wall and how drying stresses develop is therefore essential for designing thermal modification processes that avoid internal cracking, case-hardening, or excessive brittleness.

In this way, the science of wood moisture does not operate in isolation. It forms a foundation that governs the success of traditional drying, the phytosanitary effectiveness of ISPM-15 treatments, and the advanced performance gains achieved through thermal modification. Whether the goal is stabilizing timber for furniture, sanitizing packaging for export, or enhancing durability through chemical transformation, each method ultimately relies on a deep understanding of how water interacts with wood.

Figure 1: Air Drying of wood

Figure 2: ISPM15 Heat-treatment

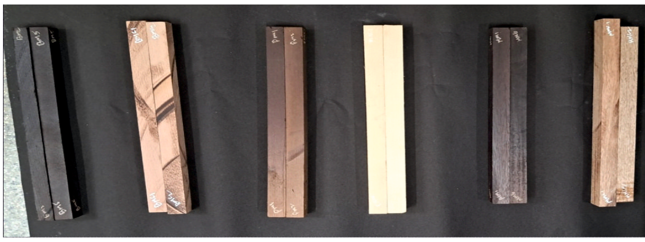

Figure 3: Thermally modified Wood

Drying Methods: From Traditional Practices to Advanced Technologies

Air drying is the oldest drying technique and relies on natural airflow to evaporate moisture. Stacks of timber, arranged with wooden spacers, allow air to pass freely through the pile. Although inexpensive and environmentally friendly, air drying is slow, highly dependent on local climate conditions, and vulnerable to fungal staining in humid regions.

To overcome these drawbacks, conventional kiln drying has become the industrial standard. Kilns provide controlled temperature, humidity, and airflow, allowing operators to tailor drying schedules to the species and thickness of the timber. Well-designed kiln schedules progressively remove moisture while maintaining stress relief through conditioning phases. This form of drying ensures uniformity, speed, and repeatability that air drying cannot match.

High-temperature kilns accelerate the process further by operating above the boiling point of water, but they require careful operation to avoid extreme defects. Dehumidification kilns use a heat-pump or refrigeration cycle to remove moisture from air in a closed system. These kilns are more energy-efficient than traditional kilns and have become popular among small and medium-scale industries.

Vacuum drying represents a more advanced technology, reducing the boiling point of water so that moisture evaporates at lower temperatures. This method is particularly advantageous for thick or high-value hardwoods because it minimizes drying-related defects. Although vacuum systems require higher capital investment, they deliver rapid and high-quality results for difficult-to-dry timber.

Microwave and radio-frequency drying technologies introduce electromagnetic energy to heat wood volumetrically from the inside out. This method drastically reduces drying time and improves uniformity, especially in thick or dense species. However, the need for precise control is crucial, as uneven heating or overheating may lead to scorching, internal fracture, or fire. These systems are currently considered specialized tools within the larger wood-processing industry.

ISPM-15 Heat Treatment and Its Integration with Drying

The increasing global movement of goods has demanded stringent phytosanitary measures for wood packaging materials to prevent the spread of invasive pests. ISPM-15 (International Standards for Phytosanitary Measures No. 15) establishes guidelines for treating wood used in pallets, crates, dunnage, and other packaging components involved in international trade. The most widely adopted method under ISPM-15 is conventional heat treatment, which requires heating the core of the wood to at least 56°C for a continuous period of 30 minutes. This treatment neutralizes pests such as the pinewood nematode, various wood-boring insects, and other quarantine organisms.

Heat treatment, however, is not a drying process. Its primary purpose is sanitation rather than moisture reduction. That said, the operational similarities between drying and heat treatment make it practical for industries to combine both operations within the same kiln. A well-equipped kiln with accurate temperature sensors, reliable data loggers, and uniform airflow distribution can perform heat treatment during or after the drying cycle. This integration significantly enhances operational efficiency, reduces energy consumption, and streamlines production.

In many countries, wood packaging manufacturers routinely use drying kilns for ISPM-15 treatment. The kiln is simply operated at a temperature and duration that ensures the required core temperature conditions. When executed properly, the drying cycle can seamlessly transition into the heat-treatment phase, reducing the need for separate equipment. However, successful implementation depends on careful monitoring of core temperatures, especially in thick sections or species with low permeability. Green or overly moist wood requires longer heating times due to higher thermal inertia, and poorly designed kilns may create uneven heating patterns, resulting in non-compliance. Thus, precise instrumentation and process control are critical.

The integration of drying and heat treatment represents a convergence of efficiency and regulatory compliance. By combining energy expenditure for both processes, manufacturers achieve a more sustainable, cost-effective, and reliable production system for wood packaging material used in global trade.

From Drying to Thermal Modification: Transforming Wood Properties

While drying and heat treatment primarily influence moisture content and biological safety, thermal modification fundamentally changes the chemical composition of wood. In this process, wood is heated to temperatures generally between 160°C and 240°C in an oxygen-limited environment. The absence of oxygen prevents combustion while allowing profound chemical transformations to occur within the cell wall components.

The primary reactions involve the degradation of hemicelluloses, partial condensation and rearrangement of lignin, and reduction of accessible hydroxyl groups. These changes significantly reduce the wood's ability to absorb moisture, leading to enhanced dimensional stability and lower equilibrium moisture content. Fungi, which rely on hemicelluloses as a nutrient source, find thermally modified wood less suitable for colonization, resulting in improved natural durability.

Several commercial systems exist worldwide. The ThermoWood® process from Finland uses steam both as a heat-transfer medium and as a protective atmosphere. The Retification process employs nitrogen, while the Plato® method uses a sequence of hydrothermolysis, drying, and curing. Oil Heat Treatment (OHT) immerses wood in heated vegetable or mineral oils, which act as both heat-transfer mediums and surface sealants that limit oxidative damage. Regardless of the method, all processes rely on strict exclusion of oxygen and controlled heating to achieve desired modifications.

Thermally modified wood is appreciated for its rich, dark colour, enhanced stability, and improved decay resistance. These characteristics make it suitable for high-end interior applications, cladding, decking, and exterior joinery where dimensional stability and durability are essential. However, the process has trade-offs. The degradation of hemicelluloses often leads to a reduction in bending and impact strength. Excessive treatment can cause brittleness or surface checking. Additionally, the darker colour may limit use in applications where a pale, natural wood tone is preferred.

Advances in India: Research and Innovation in Wood Modification

In recent years, India has made notable progress in wood modification research as it seeks to improve the performance of fast-growing plantation species and reduce dependence on imported durable timbers. Institutions such as ICFRE–IWST and ICFRE–FRI have played a leading role in exploring thermal modification, oil-heat treatment, chemical modification, and hybrid techniques.

Indian researchers have paid special attention to using locally available oils such as linseed, neem, and cashew nut shell liquid (CNSL) as environmentally friendly heat-transfer mediums for OHT processes. Studies on species such as Pinus roxburghii, Eucalyptus, Populus, and Acacia indicate remarkable improvements in decay resistance, dimensional stability, and aesthetic appearance. In several cases, thermally modified Indian woods exhibit durability approaching chemically treated wood, making them attractive alternatives in markets that seek non-toxic materials.

Research has also examined issues unique to Indian conditions, such as high ambient humidity, rapid fungal colonization of green timber, and the challenges of modifying species with complex anatomical structures. Parallel developments in radio-frequency and microwave drying at IWST and FRI have demonstrated promising results for reducing drying time in refractory species commonly grown in Indian plantations.

These advancements contribute to India's broader goals of promoting green technologies, supporting the domestic furniture and construction industries, and enhancing the value of indigenous wood resources.

Sustainability Considerations and Environmental Impact

Energy use in wood drying can account for a substantial portion of the overall energy cost in sawmills. Consequently, innovations such as heat-pump drying, solar-assisted kilns, heat recovery systems, and biomass-fired boilers are gaining popularity. Intelligent kiln-control systems powered by machine learning and real-time moisture sensors can further optimize energy consumption while ensuring high product quality.

Thermal modification supports environmental sustainability by providing an alternative to chemical preservatives. Because the process relies solely on heat, without toxic additives, the modified wood remains safe for workers, consumers, and the environment. Its extended service life reduces the need for frequent replacements, thereby lowering the long-term environmental footprint.

In India, growing interest in bioeconomy principles aligns well with thermal modification and advanced drying technologies. By improving the performance of plantation-grown timbers, these techniques support responsible forest management, reduce reliance on tropical hardwood imports, and encourage the use of renewable materials in construction and manufacturing.

Challenges and Future Directions

Despite significant progress, several challenges remain in the industrial application of drying, heat treatment, and thermal modification. Refractory hardwoods continue to be difficult to dry without significant defects. Microwave and radio-frequency systems require precise technical expertise to avoid overheating. Achieving uniform heating during thermal modification remains a challenge, especially in dense or large sections.

Future avenues for innovation include the development of AI-driven prediction models for drying schedules, IoT-enabled kiln automation, carbon-neutral heating systems, low-cost Indian thermal-modification units for small-scale industries, and hybrid techniques that combine steam, oil, and electromagnetic energy. With India's expanding timber and bamboo resource base, research on modified bamboo also presents exciting opportunities for rural development and green construction.

Conclusion

Wood drying, ISPM-15 heat treatment, and thermal modification represent a continuum of interconnected processes that collectively transform raw timber into a stable, durable, and high-performance material. Drying establishes the foundational moisture balance necessary for dimensional stability and efficient processing. Heat treatment ensures phytosanitary compliance for global trade, while thermal modification chemically enhances the wood, improving its durability and environmental performance. Together, these processes integrate traditional knowledge with modern technological innovation, offering sustainable solutions for the wood industry in India and beyond.

As research continues and technologies evolve, these interconnected processes will play an increasingly vital role in producing eco-friendly, high-quality wood products that meet the growing demands of construction, packaging, furniture, and design industries worldwide.

References : Contact author at dubeymk@icfre.org

Package of Practices for Cultivation of Tissue Culture Raised Teak

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Introduction:

Teak (Tectona grandis) is a premier hardwood species native to India, Myanmar, Thailand, and Laos. Known for its durability and aesthetic appeal, it commands high market value and is extensively cultivated in tropical regions. Teak is a large deciduous tree that can reach heights of 30–40 metres. Its golden-brown heartwood darkens with age and emits a leather-like scent when freshly cut.

Teak plantations have deep cultural and economic relevance in India, with the first recorded commercial plantation established in Kerala by Mr. Chatu Menon (1842–1862). Successful teak cultivation depends on factors such as climate, rainfall, soil quality, and superior planting material.

Climate and Soil Requirements

Teak thrives in warm, moist climates with rainfall between 1500–2500 mm. It tolerates temperature ranges from 12°C to 45°C and requires ample sunlight. Ideal soils are well-drained, deep (1 metre), with a pH of 6.5–7.5 and high calcium content. Water stagnation, even briefly, can harm the plants. Lateritic and black cotton soils often restrict growth.

Quality Planting Material

High-quality planting material is critical for maximizing plantation productivity. While seed-derived stumps are traditionally used, their availability is limited. Clonal propagation especially through tissue culture has become popular due to its ability to produce large volumes of disease-free, uniform plants with superior growth and timber quality.

Tissue culture plants are propagated from selected mother trees and initially grown in 10x15 cm polybags. After three months, plants reaching 20 cm in height and a minimum 1 cm collar diameter are field-ready. Alternate options include:

- Net Pot Plants – rooted in 45 cc hycopots
- Baby/Mini Plants – rooted in 10x6 cm polybags

Before field planting, these require secondary hardening in larger bags. To ensure genetic diversity, at least 25% of the planting stock should come from improved Seed Production Areas (SPAs) or Clonal Seed Orchards (CSOs).

Land Selection and Preparation

Ideal sites have good drainage, distinct wet and dry seasons, and minimal shade. Land preparation includes removal of vegetation, roots, and clods, followed by two to three ploughings for aeration. Testing and amending soil for porosity and nutrient content is recommended. Weeds must be controlled rigorously during the first three years to support healthy establishment.

Planting Guidelines

Alignment and Staking: Ensure proper marking of planting locations.

Pit Dimensions : 30 x 30 x 30 cm, filled with native soil and decomposed farmyard manure. Neem cake (50 gm) may be added in termite-prone areas.

Planting Time : Immediately after the first monsoon rains.

Planting Method : Remove polybags carefully, place the plant with intact root ball into the pit, and firm the soil around the base. Moisture retainers like Stocksorb or Jalshakthi can be added if needed.

Maintenance

Watering: Judicious irrigation is essential. Excess watering can result in increased sapwood, heartwood rot, and wind damage. Irrigate weekly during dry spells; avoid during the monsoon. Drip systems are effective in water-scarce areas.

Irrigation schedule: Following irrigation schedule can be maintained for obtaining good growth.

Table 1. Irrigation schedule for teak

Stage	Duration	Normal Soil
First week	Once-daily	1 to 1.5 litres
From the second week to capacity	Once in two days	1 to 1.5 litres depending on the one monthwater draining
Second and third months	Once in three days	1.5 to 2.0 litres depending on the water draining capacity
Fourth to sixth months	Once in four days	2.5 to 3.0 litres depending on the water draining capacity
Seventh to ninth months	Once in four days	3.5 to 4.0 litres depending on the water draining capacity
Tenth to twelfth months	Once in five days	4.5 to 6.0 litres depending on the water draining capacity
Continue upto 3 years	Once in five days	6.0 litres depending on the water draining capacity

Weeding and Soil Working : Weeding is mandatory during the first three years. Year 1: 3 weedings; Year 2: 2weedings; Year 3: 1 weeding. Soil working enhances aeration, moisture retention, and nutrient availability.

Pruning : Start from the third year to remove lower branches, promoting a straight bole and minimizing knots.

Fertilization : Apply 5 kg of farmyard manure per pit at planting. Fertilizer application during the first 5–6 years improves growth.

Following schedules may be practiced for better growth:

Table 2. Irrigation schedule for teak

Duration	Fertilizer / Nutrient
At the time of planting	Keradix (20 ml per pit)
One week after planting	Azospirillum Biofertiliser (20 ml per plant)
Two weeks after planting	Bacillus megatherium (20 ml per plant) + All 19 (19:19:19) – 15g per plant 25cm away from stem
Three weeks after planting	K-solubiliser (20 ml per plant)
One month after planting	19:19:19 Granules / powder – 25g per plant 25cm away from stem
Three months after planting	19:19:19 Granules / powder – 50g per plant + Micronutrients (Water soluble) - 10gm + Neem cake - 250gm + Vermicompost (100g) 25cm away from stem. Good support to stem by soil piling and mulching after saucering and soil working.
Nine months	19:19:19 Granules / powder – 125g per plant + Micronutrients (Water soluble) - 10gm + Neem cake - 250gm + Vermicompost (100g) 30cm away from stem. Good support to stem by soil piling and mulching after saucering and soil working.

One year	19:19:19 Granules / powder – 150g per plant + Micronutrients (Water soluble) - 10gm + Neem cake - 250gm + Vermicompost (100g) 30cm away from stem. Good support to stem by soil piling and mulching after saucering and soil working.
Once in three months in second year	19:19:19 Granules / powder – 200g per plant + Micronutrients (Water soluble) - 20gm + Neem cake - 250gm + Vermicompost (200g) 25cm away from stem. Good support to stem by soil piling and mulching after saucering and soil working.
Once in six months from third year	19:19:19 Granules / powder – 500g per plant + 50 g Urea + Micronutrients (Water soluble) - 50gm + Neem cake - 250gm + Vermicompost (200g) 25cm away from stem
After fifth year – Once in six months	Farm Yard manure (well decomposed) - 2 kg + Neem cake – 250gm

Planting Systems and Spacing

1. Block Planting: High-density monoculture for remote sites. Spacing: 3x3 m or 4x2.5 m. Thinning recommended after canopy closure.
2. Mixed Planting / Agroforestry Models: Agri silviculture, Agri-silvi-horticulture, Silvi horticulture, and Silvi-pasture combinations with crops and trees.
3. Line/Bund Planting: Along boundaries, roads, or canals. Wider spacing required for long-term retention.

Thinning Operations

For a 20–25 year rotation, two thinnings are advised:

First Thinning: At ~9 m tree height to remove poorly formed trees.

Second Thinning: At ~17–18 m height, to retain final density (450–500 trees/ha).

Thinning enhances growth but may induce epicormic branching; early thinning reduces this effect.

Pests and Diseases

- Major Pests: Hyblaea puera (Teak defoliator) and Eutectona machaeralis (Leaf skeletoniser).
- Control: Neem-based sprays, Monocrotophos (0.05–0.075%), or NPV-based biocides.
- Common Diseases: Root rot (*Polyporous zonalis*), Pink disease (*bark flaking*), Powdery mildew (*Olivea tectonae, Uncinula tectonae*).

General practices to be carried out as follows

- Neem extract spraying once a month on leaves till six months.
- Trichoderma application once a month (50 ml per plant) during the first year.
- Neem cake – as prescribed.
- As and when specific insects attack, please contact IFGTB.

Harvesting

Harvesting can be undertaken at 20–25 years. In even-aged plantations, clear felling is practiced. Selective harvesting suits uneven-aged or mixed plantations. Trees meeting market dimensions are harvested accordingly.

Yield Potential

Teak exhibits robust early growth. ICFRE-IFGTB studies show that with intensive management including irrigation and fertilization—rotation periods can be reduced to 20–25 years with higher productivity, particularly in farmlands. Quality of farm-grown teak is comparable to forest teak as per studies by KSCSTE-KFRI.

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Trade statistics- Wood and Wood Products (HS- Code:44)

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Table-1: Statistics of Import and Export of Wood and Wood Products in India during January to March 2025:

S. No.	HS Code	Commodity	Unit	Import (Quantity)	Import (Value in Crore)	Export (Quantity)	Export (Value in Crore)	Trade Balance Quantity (Exp –Imp)	Trade Balance (Value in Crore) (Exp –Imp)
1	4401	Fuel wood, in logs, in billets, in twigs, in faggots or in similar forms; wood in chips or particles; sawdust and wood	(KGs)	1,65,532.00	197.5	117	0.43	-165415	-197.07
2	4402	Wood charcoal (including shell/nut charcoal) whether or not agglomerated	(KGs)	8,68,042.00	44.39	32817	91.04	-835225	46.65
3	4403	Wood in the rough, whether or not stripped of bark or sapwood, or roughly squared	(CBM)	14,18,665.00	2053.97	490	35.51	-1418175	-2018.46
4	4404	Hopwood split poles piles pickets and stack of wood pointed but not cut to lengthwise wooden sticks chip wood	(KGs)	0.00	0	27838	0.36	27838	0.36
5	4405	Wood wool; wood flour	(KGs)	10,25,538.00	2.1	2	0	-1025536	-2.1
6	4406	Railway or tramway sleepers	(KGs)			175	0	175	0
7	4407	Wood sawn or chipped lengthwise, sliced or peeled, whether or not planed, sanded or end- jointed, of a thickness exceeding 6 mm.	(CBM)	7,12,851.00	1039.58	3296	27.89	-709555	-1011.69

8	4408	Sheets for veneering (including those obtained by slicing laminated wood), for plywood or for similar laminated wood and other wood, sawn lengthwise, sliced or peeled, whether or not planed, sanded or end- joined, of a thickness not exceeding 6mm.	(KGs)	20,15,88,195.00	876.88	5253177	67.99	-196335018	-808.89
9	4409	Wood (including strips, frizs for parqt flooring nt assembled) continuously shaped(tonged grooved v-jtd etc) along any edges/facts w/n p	(KGs)	2,24,63,024.00	93.32	595122	39.03	-21867902	-54.29
10	4410	Particle board, oriented strand board (OSB) and similar board (for example, wafer board) of wood or other ligneous materials, whether or not agglomerated with resins or other organic binding substances	(KGs)	1,72,57,291.00	48.28	2492363	14.57	-14764928	-33.71
11	4411	Fiber board of wood or other ligneous materials w/n bonded with resin/other organic substances	(KGs)	6,03,86,789.00	213.65	35001030	144.35	-25385759	-69.3
12	4412	Plywood, veneered panels and similar laminated wood (+).	(CBM)	11,50,045.00	858.19	137992	118.24	-1012053	-739.95
13	4413	Densified wood, in blocks, plates, strips or profile shapes.	(KGs)	13,22,973.00	24.31	392568	6.55	-930405	-17.76
14	4414	Wooden frames for paintings, photographs, mirrors or similar objects.	(KGs)	1,10,577.00	3.74	683285	34.99	572708	31.25
15	4415	Packing cases, boxes, crates, drums and similar packings, of wood; cable-drums of wood; pallets, box pallets and other load boards, of wood; pallet collars of wood.	(NOs)	4,94,300.00	38.01	316897	35.94	-177403	-2.07

16	4416	Casks, barrels, vats, tubs, and other coopers products and parts thereof, of wood, including staves	(KGs)	9,22,830.00	42.35	750	0.04	-922080	-42.31
17	4417	Tool bodies, tool handles, broom or brush bodies and handles, of wood; boot or shoe lasts and trees, of wood.	(KGs)	29,91,999.00	9.31	206096	43.21	-2785903	33.9
18	4418	Builders joinery and carpentry of wood, including cellular wood panels, assembled flooring panels, shingles and shakes(+)	(KGs)	93,12,374.00	97.75	2024905	37.74	-7287469	-60.01
19	4419	Tableware and kitchenware, of wood	(KGs)	72,10,009.00	60.32	4084098	162.46	-3125911	102.14
20	4420	Wood marquetry and inlaid wood; caskets and cases for jewelry or cutlery, and similar articles, of wood; statuettes and other ornaments, of wood; wooden articles of furniture not falling	(KGs)	1,29,797.00	5.07	423527	26.05	293730	20.98
21	4421	Other articles of wood	(KGs)	54,38,219.00	64.08	8884382	370.17	3446163	306.09

Source: Data compilation based on Ministry of Commerce and Industry, Govt. of India

Table-2: Top 10 countries wise Import of Wood and Wood Product in India during January-March 2025

HS Code	Rank	1	2	3	4	5	6	7	8	9	10	Top 10 (Total)	Others	Grand total
4401 (KGS)	**Countries**	LATVIA	VIETNAM SOC REP	SOUTH AFRICA	CHINA P RP	U S A	FRANCE	GERMANY	NEPAL	NETHERLAND	SINGAPORE			
	Import (V)	81.7	71.87	40.65	1.88	0.27	0.25	0.25	0.17	0.16	0.14	**197.34**	**0.14**	**197.48**
	Import (Q)	47792	43185	24045	49861	27	4	27	173	26	294	**165434**	**98**	**165532**
4402 (KGS)	**Countries**	PHILIPPINES	SRI LANKA DSR	INDONESIA	CHINA P RP	VIETNAM SOC REP	BHUTAN	HONG KONG	NETHERLAND					
	Import (V)	26.37	6.45	6.29	2.56	1.2	0.91	0.59	0.01			**44.38**	**0**	**44.38**
	Import (Q)	4330	1081	492	389	275	861401	71	3			**868042**	**0**	**868042**
4403 (CBM)	**Countries**	AUSTRALIA	BRAZIL	URUGUAY	ECUADOR	MALAYSIA	NEW ZEALAND	ARGENTINA	U S A	GHANA	SOUTH AFRICA			
	Import (V)	322.16	238.64	219.79	213.43	191.58	178.97	114.06	88.83	74.26	57.23	**1698.95**	**355.09**	**2054.04**
	Import (Q)	292873	107006	215186	82726	95145	155836	111824	78658	31446	53349	**1224049**	**194616**	**1418665**
4404 (KGS)	**Countries**													
	Import (V)													
	Import (Q)													
4405 (KGS)	**Countries**	VIETNAM SOC REP	CHINA P RP	GERMANY	PERU									
	Import (V)	1.54	0.5	0.05	0.02							**2.11**	**0**	**2.11**
	Import (Q)	876190	140003	9145	200							**1025538**	**0**	**1025538**
4406 (KGS)	**Countries**													
	Import (V)													
	Import (Q)													
4407 (CBM)	**Countries**	GERMANY	U K	BRAZIL	U S A	INDONESIA	TOGO	SWEDEN	MALAYSIA	AUSTRIA	RUSSIA			
	Import (V)	156.61	61.5	59.07	57.53	56.32	54.84	54.37	46.41	41.81	41.03	**629.49**	**410.05**	**1039.54**
	Import (Q)	119309	982	21134	262446	10616	16431	22921	13699	22237	24964	**514739**	**198112**	**712851**
4408 (KGS)	**Countries**	INDONESIA	GABON	VIETNAM SOC REP	TANZANIA REP	CHINA P RP	BRAZIL	NEPAL	MYANMAR	THAILAND	SINGAPORE			
	Import (V)	193.33	177.27	99.64	74.02	61.86	45.29	34.89	25.94	24.69	13.1	**750.03**	**93.32**	**843.35**
	Import (Q)	25701398	28761080	28711475	33495933	3986463	9859809	22495050	9540025	5778588	3675975	**172005796**	**29588195**	**201588195**
4409 (KGS)	**Countries**	INDONESIA	SINGAPORE	CHINA P RP	RUSSIA	ESTONIA	BRAZIL	MYANMAR	UKRAINE	HONG KONG	CHILE			
	Import (V)	33.81	23.12	16.17	12.38	3.13	1.73	0.88	0.67	0.35	0.25	**92.49**	**0.85**	**93.34**
	Import (Q)	11986799	5551160	1347939	2583815	407610	184833	44374	174216	76950	25242	**22382938**	**80086**	**22463024**
4410 (KGS)	**Countries**	THAILAND	MALAYSIA	U ARAB EMTS	GERMANY	BHUTAN	BANGLADESH PR	CHINA P RP	SPAIN	NETHERLAND	U K			
	Import (V)	21.04	6.87	4.42	4.02	3.52	2.11	1.73	0.85	0.81	0.73	**46.1**	**2.19**	**48.29**
	Import (Q)	10338739	2482561	1030273	692228	913922	964432	220956	133598	143950	129977	**17050636**	**206655**	**17257291**

4411 (KGS)	**Countries**	THAILAND	CHINA P RP	VIETNAM SOC REP	MALAYSIA	INDONESIA	NEW ZEALAND	BELGIUM	BANGLADESH PR	GERMANY	TURKEY			
	Import (V)	61.53	41.33	40.2	28.78	15.13	8.74	4.37	4.25	2.64	1.54	**208.51**	**5.14**	**213.65**
	Import (Q)	18781962	7917520	18850447	6810157	4027784	1556386	303502	1023339	382513	87646	**59741256**	**1227352**	**60968608**
4412 (CBM)	**Countries**	VIETNAM SOC REP	NEPAL	CHINA P RP	INDONESIA	RUSSIA	MYANMAR	SINGAPORE	MALAYSIA	KOREA RP	GERMANY			
	Import (V)	394.74	127.3	110.86	99.73	39.63	27.03	24.64	15.6	3.17	2.63	**845.33**	**12.84**	**858.17**
	Import (Q)	175126	871086	56752	18887	8470	4960	7663	2735	1246	224	**1147149**	**2896**	**1150045**
4413 (KGS)	**Countries**	ITALY	GERMANY	CHINA P RP	BELGIUM	KOREA RP	SWEDEN	POLAND	LATVIA					
	Import (V)	7.7	6.32	3.16	2.78	0.76	0.72	0.43	0.1			**21.97**	**0**	**21.97**
	Import (Q)	279848	125602	432484	51003	242140	10588	0	25425			**1167090**	**38052**	**1205142**
4414 (KGS)	**Countries**	CHINA P RP	MALAYSIA	VIETNAM SOC REP	ITALY	U S A	THAILAND	FRANCE	SWITZERLAND					
	Import (V)	2.47	0.97	0.17	0.04	0.04	0.03	0.01	0.01			**3.74**	**0**	**3.74**
	Import (Q)	78780	28326	2064	69	132	584	36	34			**110025**	**552**	**110577**
4415 (NOs)	**Countries**	VIETNAM SOC REP	POLAND	LITHUANIA	SOUTH AFRICA	CHINA P RP	THAILAND	SWEDEN	NETHERLAND	BRAZIL	LATVIA			
	Import (V)	9.32	8.13	3.49	2.87	2.24	1.92	1.84	1.8	1.59	1.13	**34.33**	**3.65**	**37.98**
	Import (Q)	32544	13453	60074	37363	12493	76904	56832	36754	18708	17870	**362995**	**131289**	**494284**
4416 (KGS)	**Countries**	U S A	SPAIN	FRANCE	PORTUGAL	CHINA P RP	U K	AUSTRALIA						
	Import (V)	30.79	4.92	3.74	1.09	0.67	0.66	0.51				**42.38**	**0**	**42.38**
	Import (Q)	757550	52194	57522	21960	1680	22000	9924				**922830**	**0**	**922830**
4417 (KGS)	**Countries**	VIETNAM SOC REP	GERMANY											
	Import (V)	9.25	0.05									**9.3**	**0**	**9.3**
	Import (Q)	2991944	2									**2991946**	**53**	**2991999**
4018 (KGS)	**Countries**	CHINA P RP	INDONESIA	MALAYSIA	THAILAND	GERMANY	ITALY	SLOVENIA	TURKEY	FINLAND	VIETNAM SOC REP			
	Import (V)	35.84	16.98	10.48	7.1	4.96	4.58	3.19	2.65	2.35	1.98	**90.11**	**7.63**	**97.74**
	Import (Q)	3739481	2144421	958926	685250	397072	118203	236929	102522	252726	239257	**8874787**	**437587**	**9312374**
4419 (KGS)	**Countries**	CHINA P RP	RUSSIA	MALAYSIA	VIETNAM SOC REP	THAILAND	HONG KONG	U K	ITALY	INDONESIA	TAIWAN			
	Import (V)	54.34	2.2	1.58	0.61	0.56	0.55	0.19	0.08	0.05	0.04	**60.2**	**0.1**	**60.3**
	Import (Q)	6843490	187981	35564	22417	9554	97337	4296	71	1544	215	**7202469**	**7540**	**7210009**
4420 (KGS)	**Countries**	INDONESIA	CHINA P RP	HONG KONG	MALAYSIA	U ARAB EMTS	THAILAND	SWITZERLAND	U S A	ITALY	FRANCE			
	Import (V)	1.58	1.14	0.71	0.53	0.43	0.35	0.11	0.07	0.04	0.03	**4.99**	**0.05**	**5.04**
	Import (Q)	56205	53902	2697	6396	1243	7474	102	93	50	2	**128164**	**1633**	**129797**
4421 (KGS)	**Countries**	CHINA P RP	MALAYSIA	VIETNAM SOC REP	U K	HONG KONG	RUSSIA	GERMANY	SWITZERLAND	FRANCE	LATVIA			
	Import (V)	59.16	1.36	1.16	0.33	0.31	0.28	0.27	0.2	0.18	0.18	**63.43**	**0.67**	**64.1**
	Import (Q)	5206400	47568	37109	28618	719	35640	1238	560	3412	50850	**5412114**	**26105**	**5438219**

Source: Data compilation based on Ministry of Commerce and Industry, Govt. of India, # V: Values in Crore, ## Q: Quantity in KGs/ CBM/No.s, ### HS code description define in Table-1.

Table-3: Top 10 countries wise Export of Wood and Wood Product in India during January-March 2025:

HS Code	Rank	1	2	3	4	5	6	7	8	9	10	Top 10 (Total)	Others	Grand Total
4401 (KGS)	Countries	France	SAUDI ARAB	BHUTAN	AUSTRALIA	NEPAL	U S A							
	Export (V)	0.28	0.04	0.04	0.02	0.02	0.01					**0.41**	**0**	**0.41**
	Export (Q)	20.13	0	25	14	0	12					**71.13**	**0**	**71.13**
4402 (KGS)	Countries	BHUTAN	SRI LANKA DSR	NETHERLAND	IRELAND	MALDIVES	DOMINIC REP	U ARAB EMTS	U K	DENMARK	NEPAL			
	Export (V)	75.76	8.44	2.85	1.36	0.53	0.45	0.39	0.34	0.31	0.18	**90.61**	**0.44**	**91.05**
	Export (Q)	29948	1287	549	552	125	78	66	88	23	29	**32745**	**72**	**32817**
4403 (CBM)	Countries	SINGAPO RE	CHINA P RP	KOREA RP	U ARAB EMTS	JAPAN	KENYA	QATAR	U S A					
	Export (V)	103.07	28.55	25	20.05	10.07	2.03	0.15	0.03			**188.95**		**188.95**
	Export (Q)	163	155	25	40	14	4	85	3			**489**		**489**
4404 (KGS)	Countries	U ARAB EMTS	SAUDI ARAB	BULGARIA	AUSTRALIA	U S A	MAURITIUS	CANADA	GERMANY	UGANDA				
	Export (V)	0.11	0.08	0.04	0.03	0.03	0.02	0.01	0.01	0.01		**0.34**	**0**	**0.34**
	Export (Q)	22726	100	2	2245	344	360	250	142	30		**26199**	**1639**	**27838**
4405 (KGS)	Countries													
	Export (V)													
	Export (Q)													
4406 (KGS)	Countries													
	Export (V)													
	Export (Q)													
4407 (CBM)	Countries	U S A	U ARAB EMTS	ITALY	SLOVENIA	SAUDI ARAB	RUSSIA	GREECE	MALDIVES	QATAR	BAHARAIN IS			
	Export (V)	10.28	7.22	2.95	2.86	1.17	0.51	0.47	0.42	0.39	0.36	**26.63**	**1.24**	**27.87**
	Export (Q)	456	1465	59	48	432	211	18	156	72	82	**2999**	**297**	**3296**
4408 (KGS)	Countries	CANADA	NEPAL	BANGLADESH PR	CHINA P RP	U S A	U ARAB EMTS	MEXICO	JAPAN	KOREA RP	SPAIN			
	Export (V)	22.24	20.90	8.68	5	2.92	2.37	1.71	0.97	0.79	0.67	**66.25**	**1.74**	**67.99**
	Export (Q)	185507	3998504	869089	53339	17584	17982	8840	7349	9538	7831	**5175563**	**77614**	**5253177**
4409 (KGS)	Countries	U S A	ITALY	BELGIUM	GERMANY	U ARAB EMTS	POLAND	QATAR	BANGLADESH PR	BHUTAN	U K			
	Export (V)	13.68	9.60	5.80	4.64	2.03	1.00	0.86	0.66	0.25	0.19	**38.71**	**0.32**	**39.03**
	Export (Q)	167708	198451	82440	50493	22752	14500	25240	14608	12384	120	**588696**	**6426**	**595122**
4410 (KGS)	Countries	NEPAL	SAUDI ARAB	U S A	SRI LANKA DSR	KENYA	U K	TANZANIA REP	BHUTAN	KUWAIT	ITALY			
	Export (V)	5.75	2.72	1.12	0.83	0.68	0.59	0.55	0.43	0.40	0.38	**13.45**	**1.09**	**14.54**
	Export (Q)	771092	673136	159638	193950	246595	120961	103537	18186	68709	4473	**2360277**	**132086**	**2492363**

4411 (KGS)	**Countries**	U ARAB EMTS	U S A	SRI LANKA DSR	KUWAIT	NEPAL	MALAYSIA	SAUDI ARAB	QATAR	INDONESIA	ISRAEL			
	Export (V)	72.94	15.02	8.80	7.87	4.38	4.15	3.48	3.29	3.24	2.87	**126.04**	**18.27**	**144.31**
	Export (Q)	23009563	571723	2992572	1293443	446619	1280184	521559	459365	1047200	1048321	**32670549**	**2330481**	**35001030**
4412 (CBM)	**Countries**	U ARAB EMTS	SAUDI ARAB	BHUTAN	OMAN	U S A	NEPAL	THAILAND	U K	NETHERLAND	EGYPT A RP			
	Export (V)	29.51	14.7	13.85	6.65	6.12	4.78	4.6	2.58	2.45	2.2	**87.44**	**30.79**	**118.23**
	Export (Q)	6855	3650	106876	2080	3057	1839	1353	337	393	741	**127181**	**10811**	**137992**
4413 (KGS)	**Countries**	U S A	KUWAIT	EGYPT A RP	TANZANIA REP	CANADA	VIETNAM SOC REP	SAUDI ARAB	U ARAB EMTS	NEW ZEALAND	U K			
	Export (V)	2.61	0.69	0.58	0.53	0.39	0.33	0.29	0.29	0.19	0.19	**6.09**	**0.46**	**6.55**
	Export (Q)	32004	22449	14520	83280	50162	17429	51528	32580	25620	88	**329660**	**62908**	**392568**
4414 (KGS)	**Countries**	U S A	NETHERLAND	U K	SPAIN	FRANCE	AUSTRALIA	U ARAB EMTS	CANADA	BRAZIL	BELGIUM			
	Export (V)	21.71	2.83	2.62	1.35	1.24	0.88	0.76	0.46	0.41	0.38	**32.64**	**2.32**	**34.96**
	Export (Q)	3,79,382.00	1,00,198.00	33,694.00	26,688.00	50,790.00	22,514.00	11,880.00	9,396.00	4,690.00	3,964.00	**643196**	**40089**	**683285**
4415 (NOs)	**Countries**	VIETNAM SOC REP	U S A	BELGIUM	CHINA P RP	U K	SWEDEN	FRANCE	SAUDI ARAB	NETHERLAND	GERMANY			
	Export (V)	8.91	7.08	2.62	2.59	2.07	1.83	1.45	1.09	1.08	0.8	**29.52**	**6.38**	**35.9**
	Export (Q)	35229	41596	33846	18169	14442	33816	3576	23887	14645	5616	**224822**	**92075**	**316897**
4416 (KGS)	**Countries**	U ARAB EMTS												
	Export (V)	0.03										**0.03**	**0**	**0.03**
	Export (Q)	504										**504**	**246**	**750**
4417 (KGS)	**Countries**	GERMANY	U S A	DENMARK	NORWAY	KOREA RP	FRANCE	U K	MEXICO	CHINA P RP	JAPAN			
	Export (V)	9.95	4.92	4.58	4.18	2.81	2.69	2.67	1.57	1.21	1.07	**35.65**	**7.58**	**43.23**
	Export (Q)	16804	17067	8081	7696	3986	4210	14022	78578	1723	835	**153002**	**53094**	**206096**
4018 (KGS)	**Countries**	U ARAB EMTS	BHUTAN	NEPAL	U K	U S A	NIGERIA	THAILAND	SRI LANKA DSR	SENEGAL	AUSTRALIA			
	Export (V)	7.41	4.91	4.49	4.45	4.41	1.84	1.8	0.91	0.81	0.65	**31.68**	**6.04**	**37.72**
	Export (Q)	635367	126376	281087	178562	50617	276975	65132	22761	88483	24196	**1749556**	**275349**	**2024905**
4419 (KGS)	**Countries**	U S A	NETHERLAND	U K	CANADA	U ARAB EMTS	GERMANY	FRANCE	POLAND	SOUTH AFRICA	ISRAEL			
	Export (V)	81.04	15.68	12.6	11.32	5	4.41	3.87	3.51	2.53	2.4	**142.36**	**19.98**	**162.34**
	Export (Q)	2078374	552951	198779	211219	124226	143558	81309	87812	66656	56833	**3601717**	**482381**	**4084098**
4420 (KGS)	**Countries**	U S A	GERMANY	MEXICO	SAUDI ARAB	U K	SPAIN	U ARAB EMTS	FRANCE	TURKEY	CANADA			
	Export (V)	13.69	1.92	1.23	1.1	1.09	0.69	0.68	0.67	0.61	0.43	**22.11**	**3.91**	**26.02**
	Export (Q)	202447	41654	17307	15123	10566	13195	12475	5599	16870	16015	**351251**	**72276**	**423527**
4421 (KGS)	**Countries**	U S A	U K	NETHERLAND	GERMANY	AUSTRALIA	SPAIN	FRANCE	SAUDI ARAB	CANADA	ISRAEL			
	Export (V)	183.35	25.53	23.31	15.93	14.83	12.35	11.49	8.45	8.32	8.05	**311.61**	**58.44**	**370.05**
	Export (Q)	4138292	496942	632609	341414	509001	219703	243944	158130	221155	162675	**7123865**	**1760517**	**8884382**

Source: Data compilation based on Ministry of Commerce and Industry, Govt. of India, # V: Values in Crore, ## Q: Quantity in KGs/ CBM/No.s, ### HS code description define in Table-1.

Table-1: Statistics of Import and Export of Wood and Wood Products in India during April to June 2025:

S. No.	HS Code	Commodity	Unit	Import (Quantity)	Import (Value in Crore)	Export (Quantity)	Export (Value in Crore)	Trade Balance Quantity (Exp –Imp)	Trade Balance (Value in Crore) (Exp –Imp)
1	4401	Fuel wood, in logs, in billets, in twigs, in faggots or in similar forms; wood in chips or particles; sawdust and wood	(KGs)	39,489.00	44.03	71	0.35	-39418	-43.68
2	4402	Wood charcoal (including shell/nut charcoal) whether or not agglomerated	(KGs)	4,44,342.00	48.18	25847	74.42	-418495	26.24
3	4403	Wood in the rough, whether or not stripped of bark or sapwood, or roughly squared	(CBM)	18,94,127.00	1997.52	526	12.77	-1893601	-1984.75
4	4404	Hopwood split poles piles pickets and stack of wood pointed but not cut to lengthwise wooden sticks chip wood	(KGs)	3,06,985.00	0.89	12189	0.52	-294796	-0.37
5	4405	Wood wool; wood flour	(KGs)	26,99,292.00	5.77	71018	0.19	-2628274	-5.58
6	4406	Railway or tramway sleepers	(KGs)			0	0	0	0
7	4407	Wood sawn or chipped lengthwise, sliced or peeled, whether or not planed,	(CBM)	6,18,616.00	1085.28	3231	18.77	-615385	-1066.51

		sanded or end- jointed, of a thickness exceeding 6 mm.							
8	4408	Sheets for veneering (including those obtained by slicing laminated wood), for plywood or for similar laminated wood and other wood, sawn lengthwise, sliced or peeled, whether or not planed, sanded or end- joined, of a thickness not exceeding 6mm.	(KGs)	22,37,68,663.00	918.14	4083102	60.34	-219685561	-857.8
9	4409	Wood(including strips, frizs for parqt flooring nt assembled) continuously shaped(tonged grooved v-jtd etc) along any edges/facts w/n p	(KGs)	1,97,98,738.00	94.48	737316	51.81	-19061422	-42.67
10	4410	Particle board, oriented strand board (OSB) and similar board (for example, wafer board) of wood or other ligneous materials, whether or not agglomerated with resins or other organic binding substances	(KGs)	37,21,172.00	13.31	4355617	22.2	634445	8.89
11	4411	Fiber board of wood or other ligneous materials w/n bonded with resin/other organic substances	(KGs)	1,36,18,008.00	69.59	21067684	103.54	7449676	33.95
12	4412	Plywood, veneered panels and similar laminated wood (+).	(CBM)	9,11,527.00	144.65	23669	88.03	-887858	-56.62
13	4413	Densified wood, in blocks, plates, strips or profile shapes.	(KGs)	11,44,394.00	18.05	470381	5.4	-674013	-12.65
14	4414	Wooden frames for paintings, photographs, mirrors or similar objects.	(KGs)	1,68,277.00	3.89	805720	46.04	637443	42.15
15	4415	Packing cases, boxes, crates, drums and similar packings, of wood; cable-drums of wood; pallets, box pallets and other	(NOs)	4,10,805.00	32.88	460863	40.16	50058	7.28
		load boards, of wood; pallet collars of wood.							

16	4416	Casks, barrels, vats, tubs, and other coopers products and parts thereof, of wood, including staves	(KGs)	9,25,184.00	38.77	21200	0.35	-903984	-38.42
17	4417	Tool bodies, tool handles, broom or brush bodies and handles, of wood; boot or shoe lasts and trees, of wood.	(KGs)	29,39,789.00	9.03	141127	43.03	-2798662	34
18	4418	Builders joinery and carpentry of wood, including cellular wood panels, assembled flooring panels, shingles and shakes(+)	(KGs)	99,20,371.00	101.81	1357704	30.25	-8562667	-71.56
19	4419	Tableware and kitchenware, of wood	(KGs)	74,28,291.00	65.85	3954294	157.46	-3473997	91.61
20	4420	Wood marquetry and inlaid wood; caskets and cases for jewelry or cutlery, and similar articles, of wood; statuettes and other ornaments, of wood; wooden articles of furniture not falling	(KGs)	55,817.00	2.91	495335	28.26	439518	25.35
21	4421	Other articles of wood	(KGs)	51,98,365.00	59.33	10521624	428.91	5323259	369.58

Source: Data compilation based on Ministry of Commerce and Industry, Govt. of India

Table-2: Top 10 countries wise Import of Wood and wood Product in India during April-June 2025:

HS Code	Rank	1	2	3	4	5	6	7	8	9	10	Top 10 (Total)	Others	Grand total
4401 (KGS)	Countries	THAILAND	VIETNAM SOC REP	CHINA P RP	U S A	GERMANY	FRANCE	NEPAL	INDONESIA	BELGIUM	SINGAPORE			
	Import (V)	37.11	2.15	1.66	1.24	0.42	0.35	0.28	0.25	0.13	0.12	**43.71**	**0.12**	**43.83**
	Import (Q)	24124	1031	506	505	52	3	271	118	2	234	**26846**	**12605**	**39451**
4402 (KGS)	Countries	VIETNAM SOC REP	SRI LANKA DSR	INDONESIA	CHINA P RP		BHUTAN	HONG KONG	MALAYSIA	THAILAND				
	Import (V)	24.49	10.96	6.47	2.55	1.99	0.87	0.41	0.27	0.14		**48.15**	**0**	**48.15**
	Import (Q)	3907	2137	1450	288	322	436112	44	56	26		**444342**	**0**	**444342**
4403 (CBM)	Countries	AUSTRALIA	MALAYSIA	URUGUAY	NEW ZEALAND	BRAZIL	U S A	PANAMA REPUBLIC	ARGENTINA	PAPUA N GNA	ECUADOR			
	Import (V)	400.34	208.19	167.9	163.09	143	108.22	103.3	102.6	80.72	75.57	**1552.93**	**442.34**	**1995.27**
	Import (Q)	579244	90833	177834	158357	55992	99670	34239	109105	18306	29952	**1353532**	**540175**	**1893707**
4404 (KGS)	Countries	CHINA P RP												
	Import (V)	0.89										**0.89**	**0**	**0.89**
	Import (Q)	306984										**306984**	**1**	**306985**
4405 (KGS)	Countries	VIETNAM SOC REP	GERMANY	CHINA P RP	PERU	AUSTRALIA	U S A							
	Import (V)	5.2	0.26	0.21	0.07	0.02	0.01					**5.77**	**0**	**5.77**
	Import (Q)	2594670	37615	65492	700	543	272					**2699292**	**0**	**2699292**
4406 (KGS)	Countries													
	Import (V)													
	Import (Q)													
4407 (CBM)	Countries	GERMANY	U S A	INDONESIA	U K	BRAZIL	RUSSIA	TOGO	MALAYSIA	SWEDEN	CHINA P RP			
	Import (V)	137.34	63.01	61.76	59.33	57.88	55.24	53.47	50.18	50.1	45.42	**633.73**	**449.89**	**1083.62**
	Import (Q)	205287	17348	11625	11495	22938	57596	11336	14078	20134	6837	**378674**	**239471**	**618145**
4408 (KGS)	Countries	INDONESIA	GABON	VIETNAM SOC REP	CHINA P RP	NEPAL	TANZANIA REP	BRAZIL	MYANMAR	THAILAND	KENYA			
	Import (V)	183.33	152.94	101.61	75.67	61.6	43.76	38.61	36.29	36.03	23.48	**753.32**	**92.95**	**846.27**
	Import (Q)	25124494	24949905	27726411	6542931	44073835	19868450	12238140	11120232	6882848	14667575	**193194821**	**30573528**	**223768349**

4409 (KGS)	**Countries**	SINGAP ORE	RUSSIA	INDONESIA	CHINA P RP	ESTONIA	TURKEY	BRAZIL	BOLIVIA	MYANMAR	MALAYSIA			
	Import (V)	25.35	24.98	20.4	16.22	2.75	1.41	0.63	0.53	0.49	0.36	**93.12**	**1.36**	**94.48**
	Import (Q)	6337498	4659979	6680027	1228412	504552	55919	76702	46907	20310	29155	**19639461**	**159271**	**19798732**
4410 (KGS)	**Countries**	MALAY SIA	SPAIN	GERMANY	CHINA P RP	THAILAND	BANGLADESH PR	BHUTAN	TURKEY	RUSSIA	BELGIUM			
	Import (V)	2.92	2.31	2.28	1.79	0.99	0.86	0.76	0.46	0.41	0.28	**13.06**	**0.24**	**13.30**
	Import (Q)	965354	351292	387963	382967	366250	442762	246896	37960	113740	45094	**3340278**	**380894**	**3721172**
4411 (KGS)	**Countries**	CHINA P RP	THAILAND	GERMANY	BELGIUM	VIETNAM SOC REP	MALAYSIA	TURKEY	SLOVENIA	NEW ZEALAND	ITALY			
	Import (V)	32.67	16.8	4.63	2.46	2.42	2.38	1.14	1.05	1.01	0.98	**65.54**	**4.06**	**69.60**
	Import (Q)	5933762	4509086	592194	244624	625794	431398	141425	137970	337598	204491	**13158342**	**459666**	**13618008**
4412 (CBM)	**Countries**	NEPAL	VIETNAM SOC REP	CHINA P RP	INDONESIA	RUSSIA	MYANMAR	SRI LANKA DSR	SPAIN	KOREA RP	HONG KONG			
	Import (V)	58.33	34.35	26.85	11.77	2.74	2.55	1.64	1.45	1.3	0.96	**141.94**	**2.65**	**144.59**
	Import (Q)	489287	15403	397328	4343	477	482	629	263	602	156	**908970**	**2557**	**911527**
4413 (KGS)	**Countries**	CHINA P RP	GERMANY	BELGIUM	ITALY	CAMEROO N	NETHERLAND	KOREA RP	RUSSIA	U ARAB EMTS	SWEDEN			
	Import (V)	4.31	4.12	3.26	2.88	1.06	0.9	0.74	0.33	0.2	0.12	**17.92**	**0.11**	**18.03**
	Import (Q)	440973	69329	73890	76396	53446	14610	265540	132415	5390	1880	**1133869**	**10525**	**1144394**
4414 (KGS)	**Countries**	CHINA P RP	MALAYSIA	BELGIUM	UNSPECIFIE D	THAILAND	SPAIN	ITALY	INDONESIA	NETHERLAND	SWITZERLA ND			
	Import (V)	2.03	1.37	0.11	0.11	0.09	0.09	0.04	0.01	0.01	0.01	**3.87**	**0.01**	**3.88**
	Import (Q)	128984	33711	1542	1568	738	632	402	453	158	21	**168209**	**68**	**168277**
4415 (NOs)	**Countries**	VIETNA M SOC REP	LITHUANIA	LATVIA	THAILAND	SOUTH AFRICA	CHINA P RP	SWEDEN	CANADA	GERMANY	POLAND			
	Import (V)	10.23	5.26	3.14	3	2.1	2.06	1.77	0.74	0.71	0.62	**29.63**	**3.24**	**32.87**
	Import (Q)	36404	88992	52166	40656	27472	4058	13284	105300	4497	4749	**377578**	**33226**	**410804**
4416 (KGS)	**Countries**	U S A	U ARAB EMTS	SPAIN	FRANCE	PORTUGAL	U K	CHINA P RP	BELGIUM					
	Import (V)	30.58	2.11	2.08	1.6	1.42	0.51	0.27	0.19			**38.76**	**0**	**38.76**
	Import (Q)	801968	41160	1653	43820	13791	19000	2892	900			**925184**	**0**	**925184**
4417 (KGS)	**Countries**	VIETNA M SOC REP	GERMANY	CHINA P RP										
	Import (V)	8.13	0.66	0.24								**9.03**	**0**	**9.03**
	Import (Q)	2844522	27741	67509								**2939772**	**16**	**2939788**

4018 (KGS)	**Countries**	CHINA P RP	INDONESIA	GERMANY	THAILAND	MALAYSIA	ITALY	MYANMAR	SLOVENIA	LITHUANIA	TURKEY			
	Import (V)	38.11	14.47	13.03	10.55	9.73	3.53	2.37	2.31	1.48	1.41	**96.99**	**4.83**	**101.82**
	Import (Q)	3907983	1922684	1114322	1198278	1017760	67447	159863	168319	32029	45129	**9633814**	**286557**	**9920371**
4419 (KGS)	**Countries**	CHINA P RP	RUSSIA	MALAYSIA	VIETNAM SOC REP	THAILAND	ITALY	INDONESIA	U K	SINGAPORE	U ARAB EMTS			
	Import (V)	57.98	4.23	1.77	1.04	0.46	0.11	0.07	0.07	0.05	0.03	**65.81**	**0.03**	**65.84**
	Import (Q)	6930509	410511	38220	37133	9885	100	697	337	558	150	**7428100**	**191**	**7428291**
4420 (KGS)	**Countries**	INDONESIA	MALAYSIA	THAILAND	HONG KONG	CHINA P RP	U K	U S A	PHILIPPINES	VIETNAM SOC REP	NEPAL			
	Import (V)	0.82	0.75	0.48	0.29	0.2	0.12	0.12	0.03	0.03	0.02	**2.86**	**0.03**	**2.89**
	Import (Q)	34514	9468	2822	949	4449	187	882	173	1285	769	**55498**	**299**	**55797**
4421 (KGS)	**Countries**	CHINA P RP	BELGIUM	MALAYSIA	SWITZERLAND	RUSSIA	VIETNAM SOC REP	GERMANY	ECUADOR	HONG KONG	NETHERLAND			
	Import (V)	53.18	1.62	0.98	0.89	0.72	0.43	0.42	0.4	0.16	0.13	**58.93**	**0.38**	**59.31**
	Import (Q)	5018207	42704	28653	3047	71280	7894	15409	6571	571	847	**5195183**	**3182**	**5198365**

Source: Data compilation based on Ministry of Commerce and Industry, Govt. of India, # V: Values in Crore, ## Q: Quantity in KGs/CBM/No.s, ### HS code description define in Table-1.

Table-3: Top 10 countries wise Export of Wood and wood Product in India during April-June 2025:

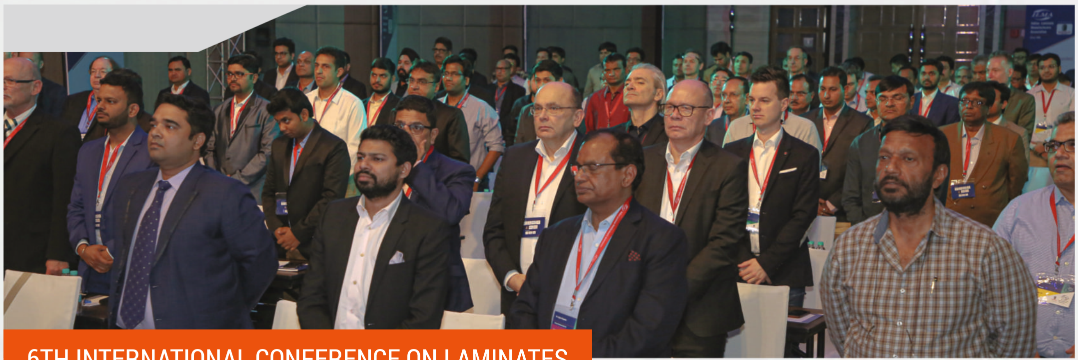
HS Code	Rank	1	2	3	4	5	6	7	8	9	10	Top 10 (Total)	Others	Grand Total
4401 (KGS)	Countries	AUSTR ALIA	BAHARAIN IS	BANGLADESH PR										
	Export (V)	0.33	0.01	0.01								**0.35**	**0**	**0.35**
	Export (Q)	31	0	2								**33**	**18**	**51**
4402 (KGS)	Countries	BHUTA N	SRI LANKA DSR	NETHERLAND	IRELAND	DOMINIC REP	MALDIVES	U K	EGYPT A RP	GERMANY	NEPAL			
	Export (V)	60.1	7.41	3.62	1.24	0.45	0.45	0.34	0.31	0.27	0.17	**74.36**	**0.05**	**74.41**
	Export (Q)	17406.06	821.04	263.6	316.4	52.15	64.12	77	28	83	3.12	**19114.49**	**11**	**19125.49**
4403 (CBM)	Countries	SINGAP ORE	HONG KONG	CHINA P RP	SPAIN	SRI LANKA DSR	SAUDI ARAB	NETHERLA ND	MALDIVES	AUSTRALIA	U S A			
	Export (V)	5.42	4.3	1.92	0.27	0.24	0.17	0.11	0.1	0.08	0.06	**12.67**	**0.08**	**12.75**
	Export (Q)	131	64	52	29	3	61	100	27	19	1	**487**	**39**	**526**
4404 (KGS)	Countries	U ARAB EMTS	U K	U S A	NEPAL	MALAYSIA	CANADA	NETHERLA ND	TAIWAN					
	Export (V)	0.17	0.14	0.1	0.04	0.02	0.01	0.01	0.01			**0.5**	**0**	**0.5**
	Export (Q)	4073	3359	1802	2169	29	197	23	59			**11711**	**478**	**12189**
4405 (KGS)	Countries	DJIBOU TI	ETHIOPIA	TANZANIA REP										
	Export (V)	0.09	0.09	0.01								**0.19**	**0**	**0.19**
	Export (Q)	35000	35000	1000								**71000**	**18**	**71018**
4406 (KGS)	Countries													
	Export (V)													
	Export (Q)													
4407 (CBM)	Countries	U S A	U ARAB EMTS	RUSSIA	IRAQ	SAUDI ARAB	CROATIA	COSTA RICA	ITALY	KUWAIT	MALDIVES			
	Export (V)	5.32	4.94	1.36	1.29	1.22	1.17	1.12	0.73	0.48	0.38	**18.01**	**0.76**	**18.77**
	Export (Q)	203	1580	343	132	485	26	27	39	91	120	**3046**	**185**	**3231**
4408 (KGS)	Countries	CANAD A	NEPAL	U S A	BANGLADE SH PR	CHINA P RP	U ARAB EMTS	SPAIN	VIETNAM SOC REP	ITALY	MEXICO			
	Export (V)	17.04	17.03	8.52	6.55	4.23	2.39	1.23	0.58	0.5	0.4	**58.47**	**1.84**	**60.31**
	Export (Q)	162669	2949902	65420	744034	40066	28323	5762	65250	1360	4005	**4066791**	**16311**	**4083102**
4409 (KGS)	Countries	U S A	BELGIUM	ITALY	GERMANY	U ARAB EMTS	PHILIPPINES	BHUTAN	NEPAL	JAPAN	SINGAPORE			
	Export (V)	30.59	7.9	6.56	4.86	0.84	0.37	0.21	0.16	0.06	0.05	**51.6**	**0.21**	**51.81**
	Export (Q)	400242	104750	100830	52066	35133	13885	10598	13664	2723	1213	**735104**	**2212**	**737316**
4410 (KGS)	Countries	NEPAL	ISRAEL	SAUDI ARAB	U S A	KENYA	BHUTAN	KUWAIT	SRI LANKA DSR	CANADA	BAHARAIN IS			
	Export (V)	6.13	4.05	2.74	2.52	1.19	0.77	0.76	0.75	0.7	0.49	**20.1**	**2.09**	**22.19**
	Export (Q)	579345	1402726	795090	398762	346988	25812	135792	177751	76335	104960	**4043561**	**312056**	**4355617**

4411 (KGS)	**Countries**	U ARAB EMTS	U S A	KUWAIT	MALAYSIA	SAUDI ARAB	NEPAL	SRI LANKA DSR	BHUTAN	MEXICO	QATAR			
	Export (V)	40.35	13.98	7.17	5.22	4.92	4.63	4.12	3.33	2.77	2.65	**89.14**	**14.36**	**103.50**
	Export (Q)	12549946	571194	1199294	1474242	819183	472708	1337974	124317	277952	414222	**19241032**	**1826692**	**21067724**
4412 (CBM)	**Countries**	U ARAB EMTS	BHUTAN	SAUDI ARAB	U S A	NEPAL	THAILAND	U K	NETHERLAND	OMAN	BAHARAIN IS			
	Export (V)	15.92	14.55	12.61	5.89	4.04	3.08	3.08	2.7	2.49	2.35	**66.71**	**21.29**	**88**
	Export (Q)	4096	5539	3294	1420	1577	922	498	384	771	635	**19136**	**4533**	**23669**
4413 (KGS)	**Countries**	U S A	U ARAB EMTS	CONGO D. REP.	VIETNAM SOC REP	NEW ZEALAND	KUWAIT	GUYANA	NIGERIA	SAUDI ARAB	U K			
	Export (V)	1.35	0.83	0.81	0.5	0.38	0.34	0.2	0.2	0.19	0.15	**4.95**	**0.43**	**5.38**
	Export (Q)	39187	77546	123900	26332	51240	10776	35100	27820	29899	365	**422165**	**48216**	**470381**
4414 (KGS)	**Countries**	U S A	U K	NETHERLAND	FRANCE	U ARAB EMTS	SPAIN	GERMANY	AUSTRALIA	JAPAN	TURKEY			
	Export (V)	31.47	6.16	1.35	1.04	0.82	0.75	0.66	0.59	0.42	0.33	**43.59**	**2.47**	**46.06**
	Export (Q)	546943	73180	44524	34070	13395	21033	14538	9766	3842	6555	**767846**	**37874**	**805720**
4415 (NOs)	**Countries**	VIETNAM SOC REP	U S A	ROMANIA	U K	FRANCE	NETHERLAND	CHINA P RP	BELGIUM	TURKEY	SWEDEN			
	Export (V)	8.68	7.84	3.79	1.83	1.82	1.65	1.62	1.53	1.31	0.95	**31.02**	**9.2**	**40.22**
	Export (Q)	34969	76479	10036	18486	8819	13780	7518	14461	3461	18393	**206402**	**254461**	**460863**
4416 (KGS)	**Countries**	GERMANY	U ARAB EMTS	NEPAL										
	Export (V)	0.14	0.13	0.07								**0.34**	**0**	**0.34**
	Export (Q)	4080	11550	5370								**21000**	**200**	**21200**
4417 (KGS)	**Countries**	GERMANY	NORWAY	U S A	CHINA P RP	CZECH REPUBLIC	DENMARK	NETHERLAND	U K	KOREA RP	MEXICO			
	Export (V)	8.25	7.76	5.34	3.06	2.91	2.55	1.64	1.62	1.23	1.1	**35.46**	**7.45**	**42.91**
	Export (Q)	10395	7126	29581	3294	3001	2531	1867	4653	1126	53295	**116869**	**24258**	**141127**
4018 (KGS)	**Countries**	NEPAL	BHUTAN	U K	NIGERIA	U S A	U ARAB EMTS	COSTA RICA	MALAYSIA	MALDIVES	ITALY			
	Export (V)	5.94	5.64	4.27	2.74	2.27	0.94	0.73	0.7	0.52	0.45	**24.2**	**6.04**	**30.24**
	Export (Q)	266065	96751	167147	403325	39949	29376	38226	7481	8391	12750	**1069461**	**288243**	**1357704**
4419 (KGS)	**Countries**	U S A	U K	NETHERLAND	FRANCE	POLAND	SWEDEN	CANADA	GERMANY	U ARAB EMTS	SOUTH AFRICA			
	Export (V)	84.67	10.22	8.16	7.24	5.66	4.28	3.6	3.15	3.13	2.63	**132.74**	**24.73**	**157.47**
	Export (Q)	2145550	218646	284106	157296	138775	87429	99598	89146	96233	74565	**3391344**	**562950**	**3954294**
4420 (KGS)	**Countries**	U S A	CANADA	MEXICO	U K	SAUDI ARAB	FRANCE	MALAYSIA	CHINA P RP	SINGAPORE	SPAIN			
	Export (V)	17.37	1.32	1.08	1	0.8	0.78	0.52	0.48	0.45	0.43	**24.23**	**4.01**	**28.24**
	Export (Q)	303718	43571	18350	9862	13822	5790	7625	6698	1797	8018	**419251**	**76084**	**495335**
4421 (KGS)	**Countries**	U S A	GERMANY	U K	NETHERLAND	FRANCE	AUSTRALIA	CANADA	SPAIN	POLAND	U ARAB EMTS			
	Export (V)	239.7	23	22.8	18	17.77	14.23	12.04	10.85	10.66	5.57	**374.62**	**54.21**	**428.83**
	Export (Q)	5379446	489295	424013	459706	415632	444288	325384	220356	301589	141725	**8601434**	**1920190**	**10521624**

Source: Data compilation based on Ministry of Commerce and Industry, Govt. of India, # V: Values in Crore, ## Q: Quantity in KGs/CBM/No.s, ### HS code description define in Table-1.

www.ilma.org.in

INDIAN LAMINATE MANUFACTURERS ASSOCIATION



6TH INTERNATIONAL CONFERENCE ON LAMINATES

Strength of Unity

Indian Laminate Manufacturers Association (ILMA) is nonprofit making organization of manufacturers of Decorative and Compact laminates or high pressure laminates, Particle Boards, Plywood and Pre-lam (Short Cycle Laminates). It is the only registered association of the laminate industry at national level and we are proud to complete 20years since 1998. More than140 manufacturers of Laminates of India are the registered members of ILMA.

ILMA is a place where companies collaborate to get more opportunities to grow their business. ILMA is a symbol of Indian Laminate Manufacturer's unified commitment to provide seamless & world-class decorative surfaces. ILMA assembles its manufacturers on a unified platform & voices out its fair opinions. It unanimously provides a healthy competition, creating great opportunities by using different strategies and combining the views of the manufacturers.

Key Achievements

1. Organized six International Conference on Laminates between 2010 to 2018
2. ILMA Institute of Technology to enhance production capabilities of members employees
3. Restrict import of low quality laminate
4. Study on Cleaner Production
5. Launch of Technical book on laminate
6. Catalogue shows at National and International Level
7. Launch of awareness video on Laminate application
8. Networking with members for raw materials, production, market and government policy related issues
9. Export incentive benefits to laminate exporters
10. Support to PM Cares fund during pandemic

Upcoming Events

1. 7th International Conference on Laminates during Delhi wood March 2021
2. Catalogue show at Interzum, Germany 2021
3. Online technical workshop on production and environment aspects during October 2020.
4. Environment clinic with Pollution control board (December 2020)

FOR REGISTRATION
Contact us on +91 9904125666/ +91-79-400 53443
Write to us at ilma@live.in
Join us on Facebook.com/ilma.org.in
Visit our Website www.ilma.org.in

REACH OUT TO US AT
INDIAN LAMINATE MANUFACTURERS ASSOCIATION
Regd. Office:
301, ILMA, Shubham Complex, Nr. Vastrapur Lake, Opp. Sanjeevani Hospital, Vastrapur, Ahmedabad, Gujarat, INDIA 380015.

भारतीय वानिकी अनुसंधान एवं शिक्षा परिषद्
Indian Council of Forestry Research and Education
(पर्यावरण, वन एवं जलवायु परिवर्तन मंत्रालय, भारत सरकार, की एक स्वायत्त निकाय)
(An Autonomous Body of Ministry of Environment, Forest and Climate Change, Govt. of India)
पी.ओ. मल्लेश्वरम/P.O. Malleswaram, बेंगलुरु/Bengaluru – 560 003

Ministry of Environment, Forest & Climate Change

LiFE Lifestyle For Environment

ICFRE-Wood Industries Committee of India (ICFRE-WINCOIN)

(formed vide Notification No.F.No.36-5/2022-ICFRE dated 23rd Dec, 2022)

MEMBERSHIP APPLICATION FORM

1. Name of the Organization to be printed on Membership Certificate			
2. Address to be printed on Membership Certificate			
3. Correspondence Address, if different from 2. above.			
4. GST No. of the Organization at 1. above			
5. Name of Head of Organization			
6. Contact details: **Land line number & STD:**		**Fax No:**	
Mobile No.:		**Email:**	
7. Details of erstwhile IPIRTI Membership, if any.(Please enclose copy of earlier Membership certificate)		**Year of Membership :**	
		Membership Type: Associate/SSI/MSI/LSI/Life Membership	
8. Membership Required, **Please choose one**		Associate/SSI/MSI/LSI/Life Membership	
For the financial year:		**If Renewal, then year of commencement :**	
9. Structure of Organization: **Please tick one**		Public Ltd./Private Ltd/Partnership/Proprietary Concern	
10. Registered as (Please enclose copy of Registration Certificate)		Large Scale / Medium Scale /Small Scale Industry or any other:	
11. Products Manufactured			
12. Installed Capacity			
13. Annual Production			
14. Whether BIS Licensee			
15. Total no. of employees		No. of Technical Persons	
16. Details of application fee paid		**D.D.No./Transaction Id:**	
Issuing Bank/Branch		**Amount:**	**Date:**
(DD to be drawn in favour of The Director, IWST CORPUS FUND, payable at Bangalore; Please see overleaf for Bank account details and fee structure of ICFRE-WINCOIN)		**Seal and Signature of Authorized Signatory**	
17. Any other details		**18. For further Information please contact** **Secretariat ICFRE-WINCOIN,** **Institute of Wood Science & Technology** **P.O. Malleshwaram, Bengaluru- 560 003 (India)** **Email: dir_iwst@icre.org**	

दूरभाष/Phones:कार्यालय/Office: 080-23341731(निदेशक/Director);080-22190100, 200(सामान्य/General)
फैक्स/FAX: 0091-80-23340529, ईमेल-/e-mail: dir_iwst@icfre.org, वेबसाईट/Website: http://iwst.icfre.gov.in

Details of Membership Type (Category) and Membership fees are as under:

Membership Category	Membership Fee
(i) Life Membership SSI:	(i) Rs.1,20,000/- + 18% GST (In one lumpsum or in 4 instalments of Rs.30,000+18%GST payable half-yearly)
(ii) Life Membership MSI/LSI:	(ii) Rs.2,40,000/- + 18% GST (In one lumpsum or in 4 instalments of Rs.60000+18%GST payable half-yearly)
(iii) Annual Member SSI	(iii) Rs.12,000 + 18% GST for Small Scale Industries / units
(iv) Annual Member MSI/LSI : Manufacturers of panels from wood and other lignocellulosic materials	(iii) Rs.24,000 + 18% GST for 1" year and thereafter for renewal Rs.18,000+ 18% GST every year for Medium/ Large Scale Industries / Units
Associate Member : Other manufacturers like machinery, resins and chemicals etc	Rs. 6000/- per year +18% GST

Benefits for industrial members of "ICFRE -WINCOIN":

a) Technical support services related to processing and production of wood & wood-based products.
b) Provide solutions to common problems of the industries and their needs through regional workshops/meetings.
c) Arranging Training and Education for the candidates sponsored by the industries through regular short term vocational courses as well as specially conducted courses as per the request of sponsors.
d) Preference in providing well educated and trained production workforce to the wood & wood based industries.
e) Focus will be given to problems and needs of the industries in R&D projects.
f) Undertaking sponsored projects given by the industry for their process and product development.
g) Enlighten the members as well as non-members for the Wood and Wood based Industries regarding the significant achievements and other important events conducted in the Institute.
h) Formulation of specifications for the new products developed by the industry and issue of draft amendments to existing standards.
i) Undertaking sponsored projects given by the factory for their process and product development.

The membe rship fees may be paid through Demand Draft/Online to the following account :-

The Director, 'IWST-Corpus Fund'
A/c No. 64013600791
State Bank of India
(03295)-Yeshwanthpur (Bengaluru)
Tumkuru Road, Near APMC Yard, Yeshwantpur,
Bengaluru-560 022, Karnataka
IFSC Code: SBIN0003297

आई सी एफ आर ई - काष्ठ विज्ञान एवं प्रौद्योगिकी संस्थान
ICFRE - INSTITUTE OF WOOD SCIENCE & TECHNOLOGY
(भारतीय वानिकी अनुसंधान एवं शिक्षा परिषद)
(Indian Council of Forestry Research & Education)
(पर्यावरण, वन और जलवायु परिवर्तन मंत्रालय, भारत सरकार का एक स्वायत्त निकाय)
(An Autonomous body of Ministry of Environment, Forest & Climate Change, Govt. of India)
डाकघर मल्लेश्वरम/P.O. Malleswaram, बेंगलुरु/Bengaluru – 560003

सं/No:16-214/2023-24/IWST/EXTN/Incubation Centre/436(a) दिनांक/Dated: 17.01.2024

GUIDELINES FOR REGISTRATION AT INCUBATION CENTRE OF ICFRE-IWST

About ICFRE-Institute of Wood Science and Technology (IWST), Bengaluru

ICFRE-IWST is a premier research Institute under Indian Council of Forestry Research and Education (ICFRE) with specialized mandate to work on the research aspects of wood science and technology. In order to promote innovation and entrepreneurship among students, faculty and stakeholders, ICFRE-IWST has established Incubation Centre for wood products under the guidance of expert scientists of ICFRE-IWST.

Vision

To nurture the culture of invention and entrepreneurship in the wood products among students, faculty, stakeholders and community inventors.

Mission

i. To focus on invention by identifying problems and providing solutions that would be commercialized into venture development.
ii. Product development would be prime focus by normalizing resources.

Objectives

i. Identifying areas, proof of concepts to prototype modules and translating them into product development.
ii. Conducting hackathons and wood camps to engage and develop interest among students, faculty, stakeholders and community inventors.
iii. To inculcate generation of Intellectual Property Rights (IPRs) among students, faculty, stakeholders and community inventors.

Incubation Space

ICFRE-IWST has full-fledged Incubation Centre with 250 sq.mt. work space with modern wood working machineries to assist the inventors and entrepreneurs. Institute also host IT Cell and library to access the knowledge in the field of wood science and technology. ICFRE-IWST host Wood Properties and Processing (WPP) Division and Plywood and Panel Product Technology Division with experienced wood scientists and technical officers to guide and assist students, faculty, stakeholders and community inventors on their invention ideas into business model.

Fields of incubation

i. Wood and bamboo based products
ii. Engineered wood
iii. Wood polymer composites
iv. Wood modification
v. Wood and lignocellulose panel products
vi. Forest Protection
vii. Tissue Culture
viii. Forest management and certification

Process of Registration and Operationalization

Interested students, faculty, stakeholders, community inventors and entrepreneurs who like to work in the Incubation Centre of ICFRE-IWST on wood products shall register by submitting duly filled necessary data in Registration Form enclosed. The applicants shall pay ₹10,000/- (Rupees Ten Thousand only) as a deposit amount to ICFRE-IWST.

The incubation after registration has to sign a Memorandum of Association with IWST and bear cost of material required for developing prototypes, charges for machine usage and meet any other financial obligations as agreed in the Memorandum of Association.

REGISTRATION FORM TO WORK IN ICFRE-IWST INCUBATION CENTRE

PHOTOGRAPH

PERSONAL INFORMATION		
1.	**Name:**	
2.	**Contact Number:**	
3.	**E-mail Id:** ✉	
4.	**Postal address:**	

BUSINESS INFORMATION		
1.	**Name of the business:**	
2.	**Which topic is most aligned with your idea?**	
3.	**How long you have been working in your business idea?**	
4.	**Any progress so far made?**	
5.	**Any prototype model developed (if applicable)?**	
6.	**How would your business idea contribute to improve life using business as a force for good things?**	

Signature of the applicant

Federation of All India Timber Merchants, Saw Millers & Allied Industries

Head Office: Federation of Karnataka Timber Merchants & Saw Millees, White Pearl, Flat 201, Bangalore 560026.

e-mail: contact@timberfederation.in

Website: www.timberfederation.in

Sri Naval Kedia, President
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Mob: 9830200497

Sri D Ramakrishna, Hony. General
e-mail: dwararamakrishna@gmail.com
Mob: 9440176081

Zonal Offices:

East: "Diamond Prestige", Room No. 409, 41A,
AJC Bose Road, Kolkata - 700017 (WB).
033 - 22640073 / 74

West: "Timber Bhawan", Room No. 409, Plot No. 47,
Sector 8, Gandhidham, Kutch - 370201 (Gujarat).
02836 230676

North: C/O Mahalaxmi Lumbers Pvt. Ltd, 1/57A,
WHS Timber Market, Kirti Nagar, New Delhi-110015.
011 - 41009111

South: Timber Yard, Aryapuram, Rajahmundry - 533101
Andhra Pradesh.
0883 - 2464949

Central: C/O United Timbers, New Timber Market, Fafadih,
Raipur - 492009.
8770862991

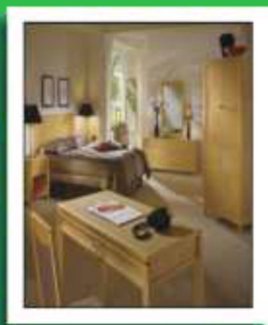
FEDERATION OF INDIAN PLYWOOD & PANEL INDUSTRY (FIPPI)

REGISTERED UNDER THE SOCIETIES REGISTRATION ACT XXI OF 1860, REGN. NO. S/2985/1968-69 DT. 4.1.1969

Part of FIPPI Achievements

With great efforts of Federation of Indian Plywood & Panel Industry (FIPPI), an Apex representative body of Plywood / Panel / Other Allied products including Furniture and Wood / Bamboo Working Machinery Manufacturers in India alongwith close cooperation with various Ministries and Premier Institutes through Agro and Farm Forestry and other Captive Plantation programme, the dying woodbased industry is again reviving in the country to produce various standard products like Veneer, Plywood, Panelboard, Particleboard, MDF, Laminates etc. which are internationally accepted. Further with great pursuance of the President and Senior Executive members of FIPPI we are highlighting and representing the crucial issues confronting the Plywood & Panel Industry. FIPPI also publishes quarterly Journal Indian Wood & Allied Products highlighting the development taking place in India and abroad, market profile, world timber market report, statistics, international exhibition and conferences, articles, write-ups etc.

FIPPI is cordially inviting all plywood / panel / bamboo / Laminates and other allied products manufacturers to become active member for the strengthening the platform of FIPPI and working for the development of the industry which is Internationally recognized by ITTO, FAO, European Union, IWPA, BIS, MoEFCC, Ministry of Commerce & Industry, BIS, FICCI, CII and other renowned Organizations.



FEDERATION OF INDIAN PLYWOOD & PANEL INDUSTRY (FIPPI)

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At AIPM, we are dedicated to unlocking the full potential of Agroforestry for a sustainable future. Together with farmers, governmental bodies like IWST and IPIRTI and influential industry leaders, we're shaping a greener tomorrow. Our member companies are at the forefront of integrating agroforestry with modern manufacturing, creating durable, eco-friendly products that benefit people, communities and the planet.

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Sustainable & Durable:

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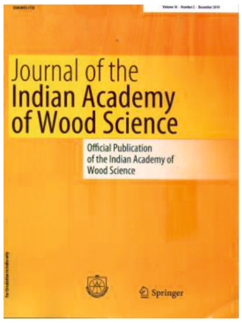
AIPM

ASSOCIATION OF INDIAN PANEL BOARD MANUFACTURERS

THE INDIAN ACADEMY OF WOOD SCIENCE

Working Office: Institute of Wood Science & Technology Campus,
P.O. Malleswaram, Bengaluru-560 003 (India)
E-Mail: iaws.india@yahoo.com Website: http://www.iaws.org.in

The Indian Academy of Wood Science was founded in 1968 to advance the knowledge of wood science & technology and covers in its activities all the aspects related to wood, cellulose and their products such as logging, saw milling, wood working, plywood, fibre boards, particle boards, improved and composite woods, cellulose and cellulose based sciences and industries and allied fields. The Academy runs a Journal called "Journal of the Indian Academy of Wood Science". In addition to this, it also organises seminars and workshops. During some annual meetings, lectures from eminent scientists are also arranged. The Academy has joined hands with Springer, an internationally reputed publishing house, for bringing out the journal fully online for wider international readership. Authors may submit the manuscript of their research papers online following the Springer publication link http://www.editorialmanager.com/jiaw



APPLICATION FOR MEMBERSHIP

To,

The General Secretary
Indian Academy of Wood Science
Institute of Wood Science & Technology Campus
P.O. Malleswaram, Bangalore-560 003 (India)

Sir,

I wish to become a member of the Indian Academy of Wood Science and give below the necessary particulars for enrolling as "Corporate Member/Institutional Member/Individual Member" (as the case may be). Necessary remittance of Rs.* .... is made by a Demand Draft/Cash, which may please be acknowledged. I agree to abide by the constitution of the academy and agree to the code of ethics contained therein.

Place: ……………………..   (Signature of the Applicant)

Date: ……………………..

1. Name of applicant in full (in block capitals)	
2. (a) Date of Birth, (b) Age (in case of individuals only)	
3. Academic and professional qualifications (in case of individuals only)	
4. Present employment/how engaged and brief history of previous career in case of individuals (separate sheet may be attached, if necessary)	
5. Brief description of general activities in case of Corporate, Institutional Members	
6. Address to which communications should be sent including phone, fax & e-mail	

* *Demand Draft should be drawn in favour of 'Indian Academy of Wood Science' and payable at Bangalore.*

Membership Type	Annual Fee	Life Time Fee
Indian :		
Corporate	N. A.	Rs. 100,000
Institutional	Rs. 2,000	N.A.
Individual	Rs. 500	Rs. 5,000
Foreign :		
Corporate	N. A.	US $ 2,500
Institutional	US $ 50	N.A.
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