Monitoring and Control of an Energetically Efficient Wood Drying Process

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Abstract

The paper will describe the monitoring and control system for an energetically efficient wood drying process, using solar energy as heating source, currently being developed under the INETI’s SECMAD project. After a brief presentation of the drying process, objectives and dryer structure, the main physical quantities and control strategies will be focused. Quality control of dried wood and optimization of operational conditions play a major role on the fuzzy control algorithm, resident in a local PC based system. The hardware and software architectures and functionalities of this system will be described. Remote supervision of several such local systems will also be presented.

Keywords: Wood drying, drying control, distributed instrumentation

1 Introduction

Wood drying is the process of reducing moisture content from wood, which is a critical step in the technological fabrication process of wood components, because it interferes in the global quality chain. Green lumber might include a water amount weighting more than the dried wood itself. This leads to water contents values above 100%, since it is measured as the ratio between water and wood weight. Dried lumber has many advantages over green lumber for producers and consumers and drying is required for wood to be used in most products. Removal of excess water reduces weight, thus shipping and handling costs. Proper drying confines shrinking and swelling of wood in use to manageable amounts, under all but extreme conditions of relative humidity or flooding. As wood dries, most of its strength properties increase, as well as its electrical and thermal insulating properties. Properly dried lumber can be cut to precise dimensions and machined more easily and efficiently. Glue, paint, varnish, and other finishes are more effectively applied and maintained over properly dried wood. (Cutter, 1994, Wenghert 1992, Joly et al. 1980).

Current drying methods in industry are the traditional open air, the conventional heated drier kilns, electrical dehumidifying equipment and vacuum drying. Each of these, present some advantages and some drawbacks, in relative comparison, especially when final product quality, time and energy expenditure are concerned (Awadalla et al, 2004).

The main purpose of lumber air drying is to evaporate water as much as possible before end use or transfer to a kiln drier. Air drying can usually proceed until wood moisture content attains 25% to 20%, needing to be followed by another drying methodology if a lower target value is desired. Air drying saves energy costs and reduces required dry kiln capacity, but presents the usual limitations of an uncontrolled process. Drying rates are very slow during the cold winter months. Under hot, dry winds, quality may be degraded as a result of surface shrinking and end splitting, due to severe differential drying. Another drawback of this method is the...
In kiln drying processes, higher temperatures and faster air circulation are used to considerably increase drying rate. Specific drying schedules/profiles have been developed to control temperature and relative humidity in accordance with the moisture content and stress situation within the wood, in order to minimize shrinkage-caused defects and improving quality. Conventional drying is one of the most expensive processes in wood industry, due to the enormous thermal energy expenditure (Joly et al, 1980).

In solar kilns thermal energy comes from solar radiation and can be a reasonable and promising method for almost any wood industry to gain the capacity to dry wood at reduced costs (Awadalla et al. 2004, Greensfelder 1998, Reuss et al. 1997). Known past implementations rarely use control embedded in the drying process, resulting in poor quality and dry time improvements. However, current instrumentation capabilities allow cost effective control solutions.

Under SECMAD project a low cost solution for a controlled solar kiln is being developed. This paper addresses some relevant aspects of the work, focusing on its instrumentation for monitoring and control.

2 Wood drying dynamic and solar dryer structure

To dry wood the surrounding air must be sufficiently dried up to absorb its moisture. This can be accomplished either by ventilating or heating the kiln air. During the first stage of the drying cycle, air easily absorbs the moisture and relative humidity inside the chamber may keep close to 100%, with water often beading on the walls in a based-greenhouse structure. As the process evolves wood moisture expelling is increasingly difficult, mainly by the low diffusion speed of moisture in wood. At a final stage, when all free water has been lost, only cell bonded moisture has left to be extracted. This final stage is more time and energy consuming, since it requires additional energy supply to break the bonds. Quality regards are present in the intermediate and final drying stages. In this process temperature, relative humidity and wood moisture content are the most relevant quantities (Titta et al. 2002, Steinmann 1995, Joly et al., 1980).

In the SECMAD Project, the whole concept of a kiln drier has been reviewed, namely to reduce its cost and enhance solar energy collection (side walls, double ceiling, etc.). The concept uses natural and mechanical ventilation controlled by an instrumentation and control system, accounting for both internal kiln and external environment conditions. Fig. 1 illustrates the drier prototypes’ structure and Fig. 2 shows the ventilation and heating systems, with colours indicating the inside psicrometrics conditions of the air: red arrows give indication of direction of hot and dry air while blue ones indicate the direction of cold and humid air. Green arrows indicate the entrance of outside air, being heated by solar air collector at side wall and ceiling. Moist air is expelled through vents by forced flow, while the fan is turned on. This solar and ventilation dryer is intended to be considerably faster than the traditional open air method and much lesser energy consumption and cost expensive than conventional kilns.

Fig. 1. Solar kiln drier structure models, developed under INETI’s SECMAD Project.
3 Control strategies

One innovative aspect of INETI’s SECMAD project is the inclusion of control instrumentation to optimize operational conditions in solar dryer structure. The main objective of the control is the reduction of drying time, taking into account the restrictions imposed by quality issues, based on a flexible response to the natural change of exterior conditions (solar radiation, and psicrometrics conditions of external air, etc.).

Different control strategies were evaluated in SIMULINK, using a simplified model to simulate the wood drying process (Nogueira 2003, Nogueira 2005), and to estimate the time evolution of interior kiln temperature and humidity and wood moisture. External environment was characterized in terms of solar radiation, temperature and relative humidity, taking into account average daily and annual variations for Portugal. Forced ventilation was the only controlled variable. Model allows adjustments to parameters, mainly to account for different wood types. Specific heat coefficients of wood and water, density, thermal conductivity and moisture diffusion coefficient are the main quantities used in the modelling.

Simulation results pointed out that a fuzzy approach to control gives better results than traditional PID or PI solutions, for this kind of process and for any kind of modelled wood. The fuzzy algorithm used, temperature and humidity differences (between kiln and external environment) and kiln temperature change rate as fuzzy variables, to control the on/off forced ventilation. Regarding quality, a safe upper limit is imposed for the wood moisture time rate, which can also act on (prevent) ventilation. This limit is also a model parameter because it varies with wood type. During natural drying, safe wood moisture time rates can be broken, especially on summer, degrading final quality. With fuzzy control algorithm, drying times of three months and less, in the most favourable conditions, have been predicted, which is another considerable improvement, compared with the six to eight months that natural drying usually takes.
4 Instrumentation functionality and architecture

Wood mills and processors often need to have more than one drier. A networked architecture has been adopted for the instrumentation to address this requirement, consisting in one local system by each drier, responsible for the monitoring and control of the local process, and one supervisor system, located elsewhere, to provide global monitoring of all driers state.

4.1 Local drier system

The local system instrumentation offers monitoring, data logging and control capabilities of the relevant physical quantities, during all the drying period. The distributed nature of these quantities dictates their measurement in several selected points, recommending a distributed structure for the signal acquisition instrumentation (Fig. 4). To shorten the development time of the demonstration prototypes, an option to use off the shelf components, whenever possible, has been adopted.

Present implementation, has two measurement nodes, with the capability to collect up to 32 channels, for collecting the following variables:

- temperature, relative humidity, solar radiation and wind velocity; of the outside environment;
- temperatures and relative humidities in two locations in the solar collector zone;
- temperatures, relative humidities, equilibrium humidity and moisture contents of drying wood, inside of the kiln chamber.

Wood moisture content is measured at the surface and deep inside of the boards, in five locations, to evaluate the moisture gradient and its time rate evolution, as it is of utmost importance (Titta 2002). For these measurements, an electronic circuit has been developed and calibrated, which senses the change of electrical conductance with moisture, outputting a DC voltage. Equilibrium humidity is also measured this way, across a traditional wood flake. Other quantities are sensed by common commercial devices.

Configuration capabilities have been considered, namely in terms of the number and the electrical signal types that are measured (voltage, current, resistance, thermocouples, etc.). Nodes can be added or removed, each one having a modular structure, to dynamically allow the addition or reduction of channels, to provide measurement redundancy and flexibility, to compensate malfunctions or to adapt the system to different end users.

Each node is presently based on National Instruments’ Field Point modules, using a FP1001 for node control and communication, supported on a RS485 connection, wired or wireless. This device is also linked to the other node modules, responsible for the signal conditioning and digitization.

The control node is based on an industrial single board computer, with 128MB of RAM, a hard disk, TCP/IP and serial connections and capabilities to connect to other peripherals (display monitor, keyboard, CD-ROM) that can be present or not.

![Local system architecture](image-url)
The main functions of this control node, besides the coordination of the acquisition task, are the control of the drying process, by an adequate algorithm, and the data logger function to gather the time evolution of relevant physical variables. This data will be used in future analysis for deeper understanding of the drier’s behaviour.

4.2 Moisture content measurement instrumentation

Specific signal conditioning developed for moisture content measurement was developed, because no commercial device was found with an analogue or digital output. Measurement principle is based on AC electrical resistance evaluation, between two points in wood, to prevent electrochemical effects.

Device calibration was an important issue, because the relationship between electrical resistance and moisture content is highly dependent on moisture itself, wood type, porosity and environment conditions (Titta et al 2002). Experimental work was carried out to collect calibration data, in two different situations.

In a first phase, a set of well known electrical resistances were measured both with the developed device and with a traditional equipment dedicated to moisture content evaluation in wood, also based on electrical resistance measurement principle. Traditional instruments generally possess different scales to use with different wood types. The conducted experiments took advantage of this interpretation capability of the electrical resistance for different kinds of wood, allowing the construction of a calibration table for the developed device.

In a second phase, a confirmation of these results for a specific type of wood has been attempted, using a gravimetric method as reference. The time evolution of the weight and the electrical resistance of a pine wood block, subject to drying conditions, have been monitored, respectively with the help of a scale and the developed device. For the moment, results of these experiments showed output circuit dependence with temperature, affecting measurement precision (around 3%). Nevertheless a reasonable agreement with previous ones, for the same type of wood, has been achieved, especially in the lower values range, which agrees with the results from other authors (Titta 2002).

5 Supervisor system

The supervisor system is a PC, connected to the Internet and running the supervision application. It is an option and can be located in accordance with end users’ needs, being able to supervise several driers, each one identified by an unique address on a network architecture illustrated in Fig. 5. The existence of supervision may free local systems of heavy functions, like variables monitoring and operator’s graphical interface, allowing more cost effective local systems.
6 Software application

As the process dynamics is slow, local system doesn’t need any real time operating system and may use a standard one. Currently, Win98SE is used by the local system controller and WinXP by the supervisor. The software applications for both have been developed in Labview. Communication and interaction between the supervisor system and local ones are based on DataSocket programming technology, provided by Labview, simplifying data exchange between computers and applications. Internet and TCP-IP protocol are used without the need of low-level programming (National Instruments, 1999).

6.1 Local application

The local system architecture is based on a one core process responsible for the basic capabilities, as signal acquisition, control, data logging and communication (Fig. 6). This allows each local system to perform its functions autonomously, independent of any supervision presence.

Basic configuration is read from a default settings file or indicated by the operator. Collected data is logged into disk files, organized by physical quantities, containing timestamps and values of all the enabled channels of that physical quantity. In the present implementation, local applications need the identification of the supervisor system address, to be able to answer its requests and communicate with it.

The software application is menu driven and profits from the hardware flexibility, reinforcing the ease of system configurability. Additional processes, communicating by “notifications” (a synchronizing and interaction mechanism in Labview), may be launched by menu options to accomplish other functionalities, when needed. This option increases the flexibility and simplifies the maintenance operations or the addition of future improvements. Configuration change and monitoring are two of such functionalities already implemented in the present version.

Configuration (channels, sample rate, file paths, etc.) can be adjusted at any time, making it possible to adapt the system to malfunctions during operation. No control parameters can be changed but new types of physical quantities can be added by the operator without the need to change the software. Monitoring is also organized by physical quantities and location groups, using data logging files to display previous history, since the beginning of the drying process.

![Fig. 6. Block diagram of main local process](image-url)
6.2 The Supervisor application

Supervisor application is menu driven. Its main function is to inspect the local operations and devices status, including visualization of the evolution profiles of variables, displaying them to users in a graphical interface. Change of acquisition parameters (acquisition sample rate, channels enabling / disabling) is also possible from the supervisor system.

The supervisor and local systems identify each other by their IP addresses. In the current implementation, the supervisor’s main process is similar to the local one described above, without the control functionality. It handles the communication with each local system at a time, exchanging (requesting and sending) information in the form of “raw data” using DataSocket. Data requests works as the data acquisition source and all the other processes, like monitoring, data saving and reconfiguration of local system, are launched in a similar way as in local systems, using notifications to communicate.

7 Results and conclusions

Presently, one experimental prototype of the low cost solar kiln and two industrial prototypes, are being built, respectively at INETI and at industrial partners’ plants. However, software applications have been developed and tested before any physical drier realization was available and instrumentation installed, allowing for the short development time available. This has been carried out substituting the actual physical quantities acquisition with its simulation, integrating the SIMULINK models of, kiln, wood and external environment into LABVIEW programming (National Instruments, 2003).

For the moment, there are no experimental results related with the drying process control. Current implementation just monitors environment variables, using a wired version of the local distributed system, AC powered in each node. Even if this solution represents an improvement regarding a centralized one, system assemblage pointed out the importance of wireless communications for the future. To increase operator’s safety, power supply is also another issue that must be modified, to use low DC voltage power supply either centralized or provided by local batteries. Regarding signal quality, monitoring results indicate that special attention must be paid to improve moisture content measurement precision and accuracy. This achievement can also lead to control improvements, based on new rules accounting with the wood moisture gradient.

The new system, specially developed to be used in wood drying kilns, also presents a great potential in other agricultural drying processes such as the production of dried tomato, dried fruits, drying of pine cones to extract stone pine nuts. This will allow the maximization of added value of the system, by a diversified use according to the season.

8 Acknowledgments

Ineti’s SECMD project has been supported by PRIME, a Public Founding Programme for the the Portuguese Economy Inovation.

9 References


National Instruments, 1999. Integrating the Internet into your measurement system.


