CHAPTER 1.

PROJECT DESCRIPTION

1.1 Introduction

Heat and mass transfer in wood is a topic which has been studied for a long time. Wood is an anisotropic, porous material with complicated and varied structure from species to species. Drying of moist wood is a complicated process involving simultaneous and coupled heat and mass transfer phenomena (Stanish et al. 1986). Therefore theoretical modeling for such phenomena can be a tough task. Numerous studies have contributed to this topic in the past 30 years (Kamke & Vanek 1994). Heat and mass transfer processes have developed from empirical models to theoretical models, and from one-dimensional models to two or three-dimensional models with improvement of experimental designs and computer techniques. Simulating processes using theoretical models give insight into the nature of heat and mass transfer in wood, which will help the wood industry to dry lumber more efficiently.

Most research in modeling found the same result, which is the importance of the parameters used in the models. Agreement between models and experiments does not depend on model complexity, but rather on the number of material parameters employed and the effort put in the evaluation of their numerical values (Hukka 1997). Physical and mechanical properties of wood are structure dependent, and this relationship has been studied. Most of the material properties used in models are empirical, which have limited applications. But material properties built up from theoretical wood structure models can be extrapolated over a wide range of applications. Modeling physical phenomena, such as heat and mass transfer, based on the micro- and macro-scale structure observation offers that possibility.

"The ultimate goal of any field of research is to know the subject so thoroughly that predictions can be made in the full confidence that they will be correct" (Bramhall 1979). However, in practice, any single research is restricted to only a small aspect of the entire field. For instance, some investigators (Comstock 1971, Pang 1997) were interested in diffusion for the mass transfer process, and some (Maku 1949, Khattabi & Steinhagen 1992) were interested in conduction for the heat transfer process. Heat conduction in wood is one of the most important problems in utilizing woods, for instance, drying of wood, heating of a log in veneer mills, and hot pressing in plywood manufacturing, etc. It was found in the literature that most values of thermal conductivity of wood were empirical values. Variations among different research results limited their applications. The complicated structure of wood causes the anisotropic characteristics of its physical properties. Some properties show significant differences in the longitudinal vs. transverse directions. Some phenomena show significant anisotropy in radial and tangential directions, such as shrinking and swelling. Thermal conductivity in the three anatomical directions has been studied empirically, but no theoretical analysis for the difference between directions has been done.

This project focused on heat conduction in wood. A mathematical model for a two-dimension heat conduction process was set up and solved. Thermal conductivity was the most significant parameter used in the heat conduction model. In the first part of the project geometric models based on the macro- and micro-structure observations are set up for theoretically deriving the thermal conductivity of wood. Validation tests followed to examine the ability of geometric models to predict thermal conductivity values. A 2D heat conduction model was developed and solved by using the theoretical thermal conductivities derived. Evaluation of model output can demonstrate the capability of theoretical values to predict heat transfer mechanism in wood. The anisotropic material properties effect on heat transportations was examined.

Investigating the possibility of setting up a model on the basis of macro- and micro-scale structure observation will hint at a connection between wood anatomical structure database and a physical or mechanical model. Modeling of a complicated phenomenon is usually solved by using enough physical assumptions, which makes application limited. However, model predictions can provide scientists with a more complete knowledge of the physical mechanisms and insight for operational controls in industry.

1.2 Project objectives

The goal of the project was to develop geometric models for theoretically deriving the heat transfer parameter of wood -- thermal conductivity, in order to estimate the values over a wide range and allow their use in heat transport models. In order to achieve this general objective, the following specific objectives were pursued:

- Examine differences in heat transfer related anatomical structures in the two directions -- radial and tangential;
- Develop and evaluate geometric models for estimating thermal conductivities in the two directions over a wide range;
- Investigate structural effects on the anisotropic material properties of wood;
- Develop and experimentally validate a two-dimensional transient, anisotropic heat conduction model for wood drying;

This project included theoretical and experimental investigations on the structure effects on heat transportation in wood.

1.3 Scope and Limitation

This study estimated the heat transfer property -- thermal conductivity -- based on the wood anatomical structure observations and experimentally evaluated model estimations. This project proposes an initial scheme for geometric modeling. Therefore only three representative species were studied and tested, two softwood species -- southern yellow pine (*Pinus spp*.) and Scots pine (*P. sylvestris*), and one hardwood species -- red maple (*Acer rubrum*). More species with significantly different anatomical structure can be modeled in the way demonstrated in this project for the future studies.

Only a two-dimensional heat conduction model was developed in this project without being mass transfer coupled. This simplification is made to fulfill the objectives of this study. The objective is to investigate the ability of using the theoretical thermal conductivity values derived from the geometric models to predict the temperature distributions.

1.4 Rationale and Significance

The geometric model for estimating material properties from basic wood structure is a practical and reliable method. This study employed structure observations and electric analogous circuit theory in the model development for material property estimations. Testing the possibility of this approach will yield other applications for wood material property investigations other than thermal conductivity as studied here.

Theoretical model estimations provide complete and consistent values for the parameters studied. It has an advantage over empirical values, which are limited to applications and vary with test conditions. The geometric models developed in this project can be used as a connection for wood anatomical structure databases and the heat and mass transfer modeling databases in the future.

Software used in the project for solving models is the advanced *Mathematica* software (Wolfram Research, Inc.). It contains many built-in solvers that can perform sophisticated and difficult tasks and is very versatile for programming. Powerful results presentation makes it the best choice for engineering research. *Mathematica* also makes it easy to publish on-line. Any model programmed in this software can be easily accessed on-line and results can be dynamically outputted to public users. One of the sub-objectives in this study is to introduce *Mathematica* software into wood research.

1.5 Organization of the Dissertation

The dissertation is divided into two parts for two theoretical models developed in this project.

The first part developed geometric models for estimating thermal conductivity values of wood. In this chapter, anatomical structure of the three species are examined under the Scanning Electron Microscope (SEM) and Environmental Scanning Electron Microscope (ESEM). Some anatomical structure parameters are measured by image analysis software. Results are analyzed with a couple of statistical models in SAS software. Difference in structure within and between the species are discussed. Then geometric models are built up based on results obtained from anatomical structural observations. The geometric models are different for the two transverse directions (radial and tangential), and for softwood and hardwood species. A geometric model for wood with moisture content above the FSP is also discussed. This is distinguished from original geometric models by adding a free water component to the models. Theoretical values for the two thermal conductivities are derived from geometric models and thermal resistance models. A program for heavy calculations is written in *Mathematica* software. Tables for the wide range of values estimated for thermal conductivities with the change of latewood percentage and moisture content in wood are given for all the three species. In conclusion, validation tests for model estimates are performed on the three species.

The second part developed a two-dimensional anisotropic, transient heat conduction model for heat transfer in wood. In this part, a simple mathematical model with assumptions is set up based on the "Energy Conservation Law". The model is then solved by the finite difference method in *Mathematica*. With the model solved, a simulation is run on the special conditions to examine the anisotropic material property effects on heat transportation in wood. Then the validation tests for model predictions are performed. Results are discussed and sensitivity studies are done on certain parameters.

Finally, chapter 4 summarizes the research and discusses possibilities for improving models in the future.

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