

SZENT ISTVÁN UNIVERSITY

**Study of the drying of the wood as an energy plant and some measurement
questions of the drying**

Thesis

István Seres

Gödöllő

2003

INTRODUCTION FOR THE DRYING MODELING

This research was carried out to model the drying process of willow wood stems during forced drying. In the bulk model a pile of stems is used during the drying, where the pile can be modeled as pile of cylinders. Field measurements with this kind of piles were carried out, too. To model the drying process, the changes of the moisture content and moisture distribution of a stem in a given environment has to be calculated first.

For the diffusion equation some numerical solving methods will be presented and after analyzing the differences between them, the best one for this model the finite difference method will be chosen. Some possible boundary condition will be taken into consideration for the finite difference method to get the most real value for the boundary against the time with different circumstances.

From this result the properties of the whole pile can be calculated. As a result of the drying process the $M(t)$, $Rv(t)$, $\Theta(t)$ and $Ta(t)$ parameters as a function of the time will be presented. With these functions the drying process of the whole pile can be described and after validation of this model to the measured data, the model can be used to simulate the very long drying process during relatively short time. These calculations can help to develop the used technology, which is more efficient, to dry whole stems or chips, help to calculate the optimum size of the pile, which is the optimum wind speed during the forced drying, etc. In this report only drying process of the stems will be considered.

THE PARTIAL DIFFERENTIAL EQUATION SYSTEM (PHYSICALLY BASED MODELL)

First the physical principles of the drying process were taken into the account. On this basis four balance equations were developed. The heat and mass balance of the wood, and the heat and mass balance of the air.

Mass balance of the wood for one stem (Diffusion equation)

$$\frac{\partial C}{\partial t} = \text{div}(D \cdot \text{grad}C)$$

Mass balance of the drying air:

$$G \cdot \frac{\partial H}{\partial x} = -\rho_b \cdot \frac{\partial M}{\partial t}$$

This equation shows that the water evaporated from the wood causes an increase of the air humidity.

The energy balance of the wood:

$$\rho_b \cdot (c_p + c_w \cdot M) \cdot \frac{\partial \Theta}{\partial t} = \rho_b \cdot \Delta H(\Theta) \frac{\partial M}{\partial t} + U \cdot (T - \Theta)$$

These equations shows, that the changing of the internal energy of the wood equals to the heat loss by of the evaporation and the heat transfer from the air.

The energy balance of the air:

$$\rho_a \cdot (c_a + c_v \cdot H) \cdot \frac{\partial T}{\partial x} = \rho_b \cdot \frac{\partial M}{\partial t} c_v \cdot (T - \Theta) - U \cdot (T - \Theta)$$

This equations shows, that the changing of the internal energy of the drying air equals the heat loss because of the heating of the evaporated water from the wood temperature to the air temperature and the heat transfer from the air to the wood.

THE SOLUTION OF THE DIFFUSION EQUATION

It can be noticed, that all the last three equations of the partial differential equation system use the quantity of $\frac{\partial M}{\partial t}$, But M can be calculated from the C so the diffusion equation is most important equation for the system. From the diffusion equation the absolute moisture distribution is calculated, from that the average absolute moisture content and finally the relative moisture content.

For solving the diffusion equation some numerical methods were tested:

Solution with the Bessel function

The first solution was developed with the help of the first kind Bessel functions of order zero. The method can be used with uniform initial distribution and the constant boundary value.

The absolute average moisture content was calculated by the following expression:

$$C(t) = C_e + (C_0 - C_e) \cdot \sum_{i=1}^n \frac{4}{\alpha_i^2} \cdot e^{-\frac{D \cdot \alpha_i^2 \cdot t}{R^2}}$$

where α_i -s are the roots of the Bessel function of the first kind of order zero. The mathematical correct solution can be found by setting the value of n to infinite, but our calculations showed, that the value n=30 gives less difference than 1 % (n was tested from 1 up to 150).

The finite element method (MATLAB PDE toolbox)

For the solution of maximum two dimensional partial differential equation (two space dimension + the time dimension), the MATLAB has a PDE toolbox. The toolbox calculates with the finite element method and it calculates the values of the function in a set of triangular grid points at the all time level wanted.

The method was usable for the simulation of the inner part of the wood, but the shrinkage of the sample (e.g. the peel) can not be taken into the account.

The finite difference method.

In this method the derivatives are represented with finite differences. In our case the Crank-Nicholson method was used as presented here:

$$\frac{\partial C}{\partial x} = \frac{1}{2} \left(\frac{C(j+1,i) - C(j-1,i)}{2 \cdot dx} + \frac{C(j+1,i+1) - C(j-1,i+1)}{2 \cdot dx} \right)$$
$$\frac{\partial C}{\partial t} = \frac{C(j,i+1) - C(j,i)}{dt}$$

As it can be seen in the next figure all the three models give more or less the same results for the average moisture content, so the models are quite accurate.

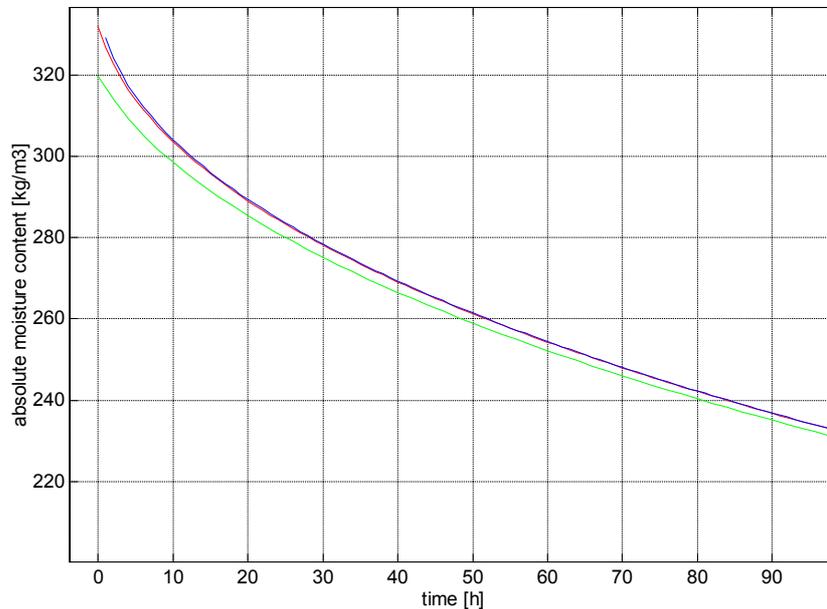


Figure 1. Comparing the different models for the first 100 hours (the lowest one is the Bessel function, then the finite difference and the finite element goes together)

The resistance model

As it can be seen from the measurement data the above mentioned methods are suitable only for the homogenous cylindrical systems e.g. for the stems without peel. This was the reason why another model was developed for the wood with peel.

The resistance of a cylindrical system for the diffusion in radial direction is [3]:

$$\mathfrak{R} = \frac{\ln(R/r)}{D \cdot 2 \cdot \pi \cdot l},$$

where R and r is the outer and inner radius and l is the length of the hollow cylinder. But for a stem the inner radius equals to 0, so this formula can not be used automatically

in this case. Instead of this the average resistance of the stem will be used, for which the next definition was used:

$$\mathfrak{R}_a = \frac{\int_0^R 2r\pi \cdot dr \cdot \frac{\ln(R/r)}{D \cdot 2\pi \cdot l}}{\int_0^R 2r\pi \cdot dr}$$

The integral below is equal to $R^2\pi$, and getting out the constants from the integration above, the next result will be formed:

$$\mathfrak{R}_a = \frac{1}{D \cdot 4\pi \cdot l}$$

This formula is valid for the inside of the stem (for the wood). The peel was considered as a thin plain because of its thickness. So the resistance of the peel:

$$\mathfrak{R}_p = \frac{\Delta d}{D_p \cdot 2R\pi \cdot l}$$

where Δd is the thickness of the peel and R is the average radius of it. So the total resistance of the stem with peel:

$$\mathfrak{R}_t = \frac{\Delta d}{D_p \cdot 2R\pi \cdot l} + \frac{1}{D_i \cdot 4\pi \cdot l}$$

As the capacity of the system is the volume (V), so the time constant of the process is:

$$\tau = \mathfrak{R}_t \cdot V = \left(\frac{\Delta d}{D_p \cdot 2R \cdot l} + \frac{1}{D_i \cdot 4\pi \cdot l} \right) \cdot R^2\pi \cdot l = \left(\frac{\Delta d}{D_p \cdot 2R} + \frac{1}{4D_i} \right) \cdot R^2$$

Knowing the time constant, the average moisture content of the wood against the time can be calculated from the next function:

$$C(t) = Ce + (C0 - Ce) \cdot e^{-\frac{t}{\tau}}$$

BOUNDARY CONDITIONS

For solving the diffusion equation several boundary conditions for the outer boundary layer (to the edge of the wood) were considered. In this chapter the used conditions for the finite difference method from the most simple constant boundary value to the coupled mass and heat transfer.

Solution with constant boundary value

For forced drying, where the air speed is high and the relative air humidity is low, the drying of the boundary layer is a relatively fast process. For a long time process the simplest and fastest way for the calculation to use a constant boundary value for the inner moisture distribution of the wood. The equilibrium moisture content in this case can be read from the sorption isotherm.

Solution with the partition coefficient

If the first few hours are important, when the evaporation is at its maximum, the changing of the air humidity next to the boundary has to be taken into account, which is higher than in the bulk.

The outer boundary condition in this case is:

$$-D \cdot \frac{\partial C}{\partial r} \Big|_{r=R} = k \cdot (\rho_{bo} - \rho_{bu})$$

where ρ_{bo} and ρ_{bu} are the absolute air humidity in the boundary layer and far from the wood (bulk), k is the mass transfer coefficient. The ρ_{bu} is known, the ρ_{bo} can be read from the sorption isotherm, so the boundary condition can be calculated.

Solution with constant flux in the beginning

The outer boundary condition in this case:

$$-D \cdot \frac{\partial C}{\partial r} \Big|_{r=R} = k \cdot (\rho_{bo} - \rho_{bu})$$

$$\Phi_m = k \cdot (\rho_{bo} - \rho_{bu})$$

$$\Phi_h = \alpha \cdot (T_{bu} - T_{bo})$$

In case of limiting heat transfer:

$$\Phi_m \Delta H(\Theta) = \Phi_h$$

In these two equations there are two unknowns (T_{bo} , ρ_{bo}) which can be easily calculated $\Rightarrow \Phi_m = k \cdot (\rho_{bo} - \rho_{bu})$ can be calculated, too.

Considering, that the edge of the wood has moisture enough for the free evaporation, the limiting factor of the process is not the diffusion, and the mass transfer at the boundary to the air, but the coupled mass and heat transfer in the air (The heat capacity of the wood can not supply the energy for the evaporation for a long time, so the energy, needed for the evaporation, has to come from the air).

Combined boundary condition

With the usage of the different boundary conditions different limiting factors were considered for the drying process. When using constant boundary value the diffusion is considered to be the limiting factor. But at the beginning of the process, when the boundary moisture content is high, the diffusion has not a big influence on the speed of the evaporation as there is enough moisture in the boundary layer. In this case the limiting factor is the speed of the mass transfer in the air. If there is almost free evaporation on the surface, the coupled heat and mass transfer has to be taken into the account. This means, that the temperature decrease of the air in the boundary condition can limit the process (when the temperature decrease a lot, the air can be almost saturated just because of this effect, and then the rate of evaporation is very small).

The further improvement of these conditions is the following:

Both the flux and the partition coefficient are calculated, and the rate of the decrease for each model. The limiting factor (and the model for that) has to be used is that one,

where the rate of the decreasing in the average moisture content is smaller. The results of the finite difference model with different boundary conditions but with the same initial conditions are illustrated at the next figure:

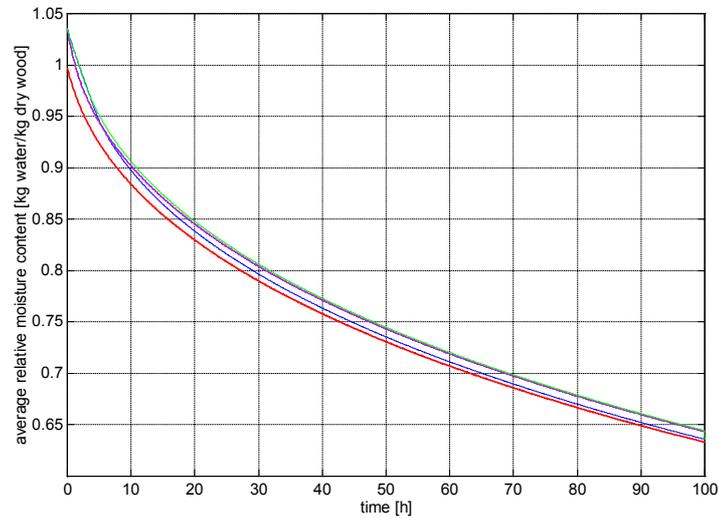


Figure 2. Results of the finite difference model with different boundary conditions but with the same initial values

MEASUREMENTS

To validate the developed model some measurements were carried out. The measurements were done with 3 year old willow stems, a part of them with peel, and the other part without peel.

Moisture content measurement

During the experiment the willow stems were put into an air stream with constant speed, constant air temperature and constant air humidity. These quantities were controlled permanently by an automatic system. The values of these quantities in this experiment were the following:

- air speed: 0.1 m/s,
- relative air humidity: 60 %,
- air temperature: 20 °C.

The relative moisture content on dry basis calculated from the measured data can be seen in fig. 3.

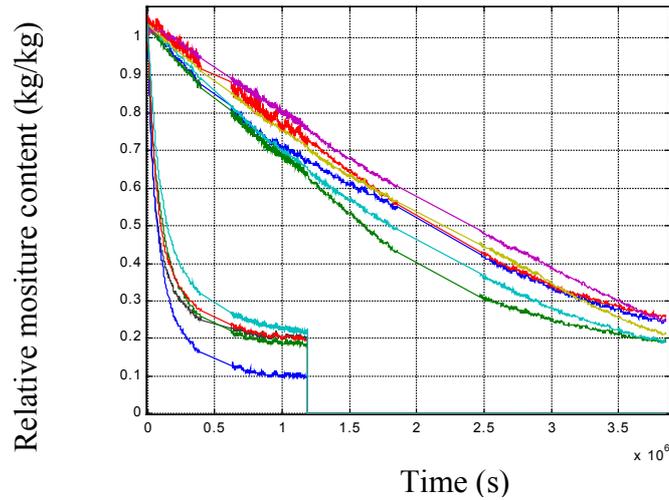


Figure 3. Moisture content on dry base for peeled and unpeeled samples against time
 As it can be seen from the figure 3., the drying curve of the peeled and unpeeled wood is very different, so it is reasonable to deal with them separately.

The model for the unpeeled wood

In this part the moisture dependence of the diffusivity of the unpeeled wood will be presented and on this basis the validation of the finite difference method will be given. As at the beginning of the process there is a constant flux period, and the real diffusion starts later, a shift was introduced to the calculations.

The result of this calculation is plotted in fig. 4.

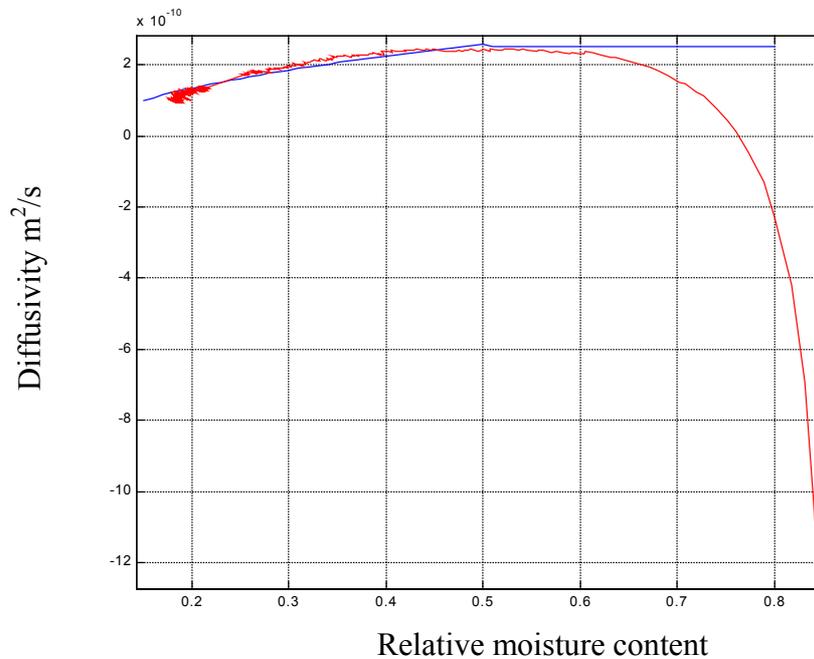


Figure 4. The calculated diffusivity from the measured data against the moisture content

The model for the peeled wood

The evaluation of the measured data from the peeled wood drying was started on the same way, first the time dependence of the dimensionless moisture content was calculated. To achieve the diffusivity of the peel from these data, the two layer resistance model was used.

As the plot of the calculated diffusivity is a kind of exponential function, for modeling that the form was considered as it was advised in the literature. In our case the $\alpha = 0.5$ value gave a fairly good fitting, as it can be seen in figure 5.

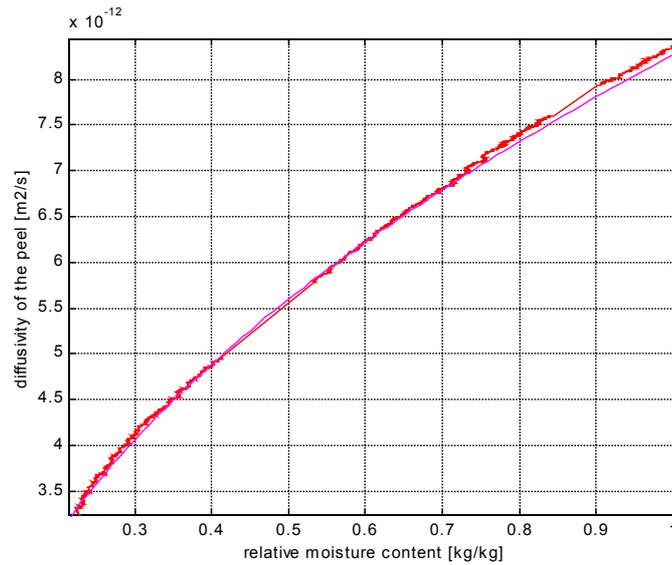


Figure 5. The measured and modeled diffusivity of the peel vs. the relative moisture content

THE BULK MODEL

If the $M(t)$ function is known, the whole model for a bulk can be calculated with the finite difference method, too. The values of the quantities ($M(t)$, $R_v(t)$, $H_v(t)$, $\Theta(t)$ and $T_a(t)$) for the bulk model were calculated under different conditions.

INTRODUCTION FOR THE MEASUREMENT PROBLEMS

Measuring the temperature as a basic physical quantity has great importance in a lot of fields of the practice. It has significance not only for the knowledge of the actual temperature of a matter, but also that the most physical properties of a matter depend on the temperature.

Though some temperature measuring methods are widely used and well known in certain cases the precise measuring of the temperature demands special methods special technical equipments. A very important method from this kind of "scientific" temperature measuring is the use of thermocouple which is the subject of the research activity.

It is well known, that if the two junctions of a thermocouple has different temperature than someone can measure a so called "themovoltage" in the thermocouple. The approximate function of the thermo voltage - that is given in the technical literature - is not proper because it does not fulfill the physical principles concerning to the thermocouple.

This is the reason why the intention of this research is to show the incorrectness of the commonly used approximate functions and after it to give a better approximate function which is in keeping with the physical principles.

PROBLEM WITH THE CLASSICAL APPROXIMATION

We use the next marks:

$U_{AB}(T, T_0)$ is the thermo voltage for a thermocouple which contains of two different metals (A and B), T_0 is the temperature of the reference junction and T is the temperature of the measuring junction.

For the thermo voltage the classical literature gives the next formula:

$$U_{AB}(T, T_0) = \alpha (T - T_0) + \beta (T - T_0)^2 + \gamma (T - T_0)^3 + \dots \quad (1)$$

where α, β, γ are special coefficients determined by the two kind of metal of the thermocouple (A and B) and usually depending on the T_0 reference temperature.

Laws for the thermo voltage

From the literature the next rules are well known:

I. The law of homogeneous metals:

$$U_{AA}(T, T_0) = 0 \quad (2)$$

II. The law of isotherm thermocouple:

$$U_{AB}(T, T) = 0. \quad (3)$$

III. The law of antisymmetry :

$$U_{AB}(T, T_0) = - U_{AB}(T_0, T) \quad (4)$$

IV. The law of successive metals:

$$U_{AB}(T, T_0) = U_{AC}(T, T_0) + U_{CB}(T, T_0) \quad (5)$$

V. The law of successive temperature:

$$U_{AB}(T_1, T_3) = U_{AB}(T_1, T_2) + U_{AB}(T_2, T_3) \quad (6)$$

It is obvious that as these 5 laws are true for the thermo voltage of a thermocouple they have to be true to the approximate function of it, as well. If we examine the approximate function given from the literature in (1) we can notice that the first two laws are true for this function.

But the **law of antisymmetry** will be the next for this (1) function:

$$\alpha (T-T_0) + \beta (T-T_0)^2 + \gamma (T-T_0)^3 + \dots = -\alpha (T_0-T) - \beta (T_0-T)^2 - \gamma (T_0-T)^3 + \dots$$

The odd powers or the term $(T-T_0)$ satisfy the law, but the even powers of the term do not, so this law will not be true for the (1) approximate function.

It is possible to show that the law of successive temperature will not be true for the (1) function as well in a general case.

In the basis of the shown facts we can establish that the approximate function for the thermo voltage of a thermocouple given in the literature do not proper for the principles of the thermocouples from the physics and the practice. That is why I began to research that instead of the (1) approximate function what kind of function would be suitable for the physics and for the measured thermovoltage.

APPLICATION THE THEORY OF THE FUNCTIONAL EQUATIONS

At the basis of (2) - (6) equations it is useful to examine that the theory of the functional equations what sort of solutions give to these equations.

The functional equations given at (5) and (6) have a special "eliminating" property namely the right sides of these equations contain C or T_2 in the sum but the left sides of the equations do not. Examining these kinds of functional equations - the so called Sinzow-equations - we can establish that the thermo voltage function can be produced by the subtraction of two single-variable function (with arguments T and T_0). The antisymmetrical property shown at (4) makes it possible to see that these "two" single-variable functions are the same that is the approaching function for the thermo voltage can be write in the form $f(T) - f(T_0)$.

THE THEORY OF THE ORIGIN OF THE THERMO VOLTAGE

Showing that the approach based on the classical professional literature does not fit the physical principles we look after a new approaching function by using the Fermi-Dirac statistics.

With the help of the energy - spectrum of this statistics it can be show that the Fermi energy of a metal is the even power function of the absolute temperature.

Using the fact that the Galvani voltage between two different metals depends on the difference between their Fermi- energies and that the thermo voltage is the difference between the Galvani voltages at T and T₀ junction temperature, it can be see that the thermo voltage of a thermocouple has the following form:

$$U_{AB}(T,T_0) = U_{AB}(T)-U_{AB}(T_0) = \alpha(T^2-T_0^2) + \beta(T^4-T_0^4)+\gamma(T^6-T_0^6)$$

As checking this form we can examine that equations (2) - (6) are true or not for this form. As a result we can establish that this approaching form fits all of (2) - (6) equations and the physical principles behind them.

THE NUMERICAL CONTROL OF THE APPROACHING FORM

As a further check of the approaching form we examined that this form how fits to the data given by the manufacturer for the thermo voltage of a thermocouple.

During this work we compared the approaching of the classical, commonly used and the new forms.

As summarizing it can be established that the new approaching function which fits the physical principles given at (2) - (6) generally gives better approaching than the forms commonly used.

For example at the temperature range 0 °C - +50 °C what was important for the measuring application the new form gives better approach than even the most special functions given in the classical professional literature.

But if we examine a wider (- 50 °C - +100 °C) temperature range we can see that only the fully special Bodry approaching function gives better approach than the new form.

On the other side the new form gives less difference than 0,3 °C in temperature that is the difference between the thermo voltage and the approaching form is not the main problem in a measuring method, usually the measuring error is much higher than the error from the approaching form.

The results we got and the advanced measuring and computer equipments make possible to use a measuring circuit with thermocouple without stabilized

reference temperature. As an application of the measuring circuit, it was used to measure the temperature of mushroom while it was vacuum-cooling.

ERROR ANALYSIS OF THE THERMOCOUPLE MEASURING CIRCUIT

On the basis of the nonequilibrium thermodynamics the error analysis of a measuring circuit for thermocouples was presented. As a result of investigation it was shown, that the Thermo voltage develops in the regions where the temperature gradient is not zero, and not necessary in the junction regions of the two different metals as it is widely known.

Beside this result it can be established that if someone wants to avoid the measuring errors than temperature gradient must not exist in the regions where the matter is inhomogeneous. This means for example that the junction areas made by soldering or welding have to be isothermal to avoid the developing of false thermo voltage in these regions. The isotherm junctions need proper thermal contacts between the junction and the measured (reference) medium.

Examining the effects of the magnetic field to the thermo voltage it can be say that inside the magnetic field the temperature gradient has to be eliminatable.

THESES

During the research the next theses were established:

1. The differential equation system of a peeled stem for heat and mass transfer were set up, and the numerical representation of the model was elaborated, too. A combined boundary condition was developed, which can describe the process in accordance with the measurement data even in the first, highly moisture phase as well. The difference between the model and the measurement data is less than 3 %, the value of the correlation coefficient is $R = 0,9998$.
2. A two layer diffusion model was set up for the unpeeled wood on the basis of the analogy with the electrical resistance. In the model the inside of the wood was modeled with a resistance, calculated by an improper integral, while the resistance of the peel is calculated as a resistance of a flat plate:

$$\mathfrak{R}_e = \frac{1}{D_b \cdot 4\pi \cdot L} + \frac{d}{D_h \cdot 2R\pi \cdot L}$$

With the help of this resistance the time constant of the exponential function of the drying was determined.

3. For a bulk of wood a numerical model was developed, which can calculate the air temperature, the air humidity, the wood temperature and the average moisture content of the wood in different parts of the bulk. To calculate these values, simulation software was developed. With the help of the software different distributions were calculated for different boundary conditions.
4. It was proved, that the thermo voltage function generally used in the literature for a thermocouple in the form of $U_{AB}(T, T_0) = \alpha (T-T_0) + \beta (T-T_0)^2 + \gamma (T-T_0)^3 + \dots$ is not fit for the basic physical laws.
 - a, With the help of the theory of function equations it was proved, that the function has to be calculated as a subtraction of two, one variable functions, where the two variables are the measured and the reference temperature, that is $U(T, T_0) = f(T) - f(T_0)$.
 - b, With the help of the Fermi-Dirac statistics a new function was set up, which fits for the physical laws as well, in the form of

$$U_{AB}(T, T_0) = U_{AB}(T) - U_{AB}(T_0) = \alpha \cdot (T^2 - T_0^2) + \beta \cdot (T^4 - T_0^4) + \gamma \cdot (T^6 - T_0^6) + \dots$$
 - c, By using the thermo voltage data, provided by thermocouple manufacturers, the developed function was compared with these data, and other approximation functions, available in the literature. Based on these calculations it could be concluded, that the newly developed function gives better approximation in the temperature range of $-50 - +150$ °C, than the some special functions used in the literature.
5. With the help of the non-equilibrium thermodynamics the theory possible measurement errors were considered. Based on these calculations it was shown, that the temperature gradient in the junction zone of the metals can cause measurement

error. Another conclusion of these calculations suggest that in the non-zero temperature gradient regions homogenous material necessary, other ways measurement errors occur.

ACKNOWLEDGEMENT

This research was carried out at the Department of Physics and Process Control, Szent István University, Gödöllő. For the possibility of doing this research the author thanks very much for the Professor of the Department, Professor István Farkas, who was the supervisor of this work.

Professor Gerard Bot and Dr. Wilko van Loon, from the Wageningen University, and Dr. Jörg Gigler from the Research Institute IMAG, Wageningen made a lot for the success of this work too, by providing the possibility of the measurements.

Finally I would like to thank to my colleges, and for my family the lot of help I got during my work.

SUMMARY

Nowadays the environmental protection and the use of the renewable energy resources have greater and greater importance. Among the renewable energy resources the role of the biomass is very important, from which the energy forest can have a bigger role even in Hungary. In case of Hungary joins the EU the agricultural fields with low quality can not produce their products economically, and for them the energy forest is an alternative.

The presented research results are in connection with the wood of the energy forest, too. The wood of the energy forest can not be used immediately because of its high water content. During the research the modeling of the drying of the wood and some measuring methods of the drying were studied. From the measurement problems only the question of the temperature measurement is presented because of the limited size of the thesis, other investigations such as sensor development for the free air convection for natural drying, or optical moisture content measurement are presented in other papers.

During the modeling of the drying of a stem a differential equation system was set up and –in absence of an analytical solution- numerical methods were used for the evaluation. For this purpose the finite element and the finite difference method were considered, and finally the later was chosen. For the numerical solution difference boundary conditions were tested, finally a moisture content dependent, combined boundary condition was developed.

For the wood with peel a two layer resistance model was set up. The numerical models were tested with physical properties from different measurements, and the results of the tests were compared with drying experimental data.

With the use of drying model of a stem a model of a pile was set up, in which the stems in the different parts of the pile could be modeled and average properties for the pile were possible to get.

Research was carried out on the measurement methods of a drying process as well, e.g. optical moisture content or natural air convection measurement but the thesis –because of the limited space- only the results on the temperature measurement are presented as one of the most important parameter of the drying is the temperature. This time the temperature measurement with thermocouple is investigated. I proved, that the thermovoltage function of the thermocouple provided in the literature (and based on the Taylor theory) is not correct, it contradicts to the basic physical principles.

I searched a new approximate function, which agree with the physical principles and the approximation of the function is as good, or better than for the usual functions. During the solution the Sinzow theory of the function equations and Fermi-Dirac statistics for the electron gas in a metal were used. Based on this theory with the help of the potential valley model the new function was developed. I tested that the function agrees all the basic physical principles.

The new function was calculated for the most common thermocouple, the Cu-Ko thermocouple, and from the investigations it had turn out, that this function gives better

approximation in the tested $0^{\circ}\text{C} - 50^{\circ}\text{C}$ or $-50^{\circ}\text{C} - 250^{\circ}\text{C}$ temperature range than the special, physically baseless models.

The cited measurement method was used as an example for measuring temperature distribution inside a mushroom during vacuum cooling.

OWN PUBLICATIONS CONNECTED TO THE TOPIC OF THE THESIS

1. Seres I. - Vincze Gy.: Hőmérséklet mérés termopárral hidegőpont nélkül, MTA-AMB Kutatási és Fejlesztési Tanácskozás, Gödöllő, 1989
2. Seres I. - Vincze Gy.: Hőmérsékletmérés stabilizált referenciapont nélküli termopárral, MTA - AMB Kutatási és Fejlesztési Tanácskozás, Gödöllő, 1992, pp. 346-349.
3. Seres I.: - Vincze Gy.: Termopárral felépített mérőkör mérési hibáinak elemzése, MTA - AMB Kutatási és Fejlesztési Tanácskozás, Gödöllő, 1993 pp. 65-70.
4. Seres I. - Vincze Gy.: Analysis measuring errors of measuring circuit built with thermocouple, Hungarian Agricultural Engineering, 1993/6. szám pp. 42-44.
5. Seres I.: Stabilizált hidegpontról nélküli termoelemes mérőkört vezérlő és kiértékelő program, (MTA - AMB Kutatási és Fejlesztési Tanácskozás, Gödöllő, 1994) pp. 93-98
6. Vincze Gy. - Seres I.: Some Details of Temperature Measuring with Thermocouple without Stabilized Reference Point Advances in Agricultural Engineering Conference, Nyitra, 1994.
7. Seres I.: Wood drying models, TEMPUS Report, Wageningen, The Netherlands, 1997. p. 47
8. Seres I.-Farkas I.-van Loon,W.-Gigler,J.: Fa szárítási modellek, 2. Magyar Szárítási Szimpózium, Gödöllő, 1997. dec. 5, 20. o.
9. Seres I. - Farkas I.: Nyomásesés vizsgálatok fűzfa chips rétegeken, 3. Magyar Szárítási Szimpózium, Nyíregyháza, 1999. Szeptember 22.-23., 38-42. o.
10. Seres, I., Farkas, I, van Loon, W.K.P. and Gigler. J. K.: Air pressure drop measurement through packed bed of willow chips and chunks, Bulletin of Polish Academy of Sciences, Vol. 48, No. 3, 2000, p. 445-454.
11. Gigler JK, Van Loon WKP, Seres I, Meerdink G, Coumans WJ.: Drying characteristics of willow chips and stems. Journal of Agricultural Engineering Journal 2000, 77(4), pp. 391-400.
12. Seres I.-Farkas I.-Font L.: Nedvességtartalom mérése optikai úton, MTA Agrár-Műszaki Bizottság, XXV. Kutatási és Fejlesztési Tanácskozás, Gödöllő, 2001. jan. 23-24. 13. o.
13. Seres, I. - Farkas, I.: Development of a thermovoltage function with thermocouple temperature measurement, Research and Teaching at Department of Physics in Context of University Education, Nitra, 2001. január 26., Proceedings, pp. 65-68.
14. Seres I. - Farkas I.: Temperature measurement and control during quality drying of apple, CAPPT'2001, Peking