Gottschalk, Klaus and Scholz, Volkhard

Thermodynamic model for wood chip storage

Moisture content significantly influences the storability of wood chips. Other factors are mass loss due to microbial metabolic processes and the development of pathogenic moulds causing hygienic problems if the contamination of the pile exceeds critical quantities. The drying process of the wood chips in the pile largely depends on particle size and particle size distribution. A thermodynamic model of the drying processes shows the development of temperature and moisture content in piles of different heights.

Keywords
Model wood chip drying, wood chip storage

Abstract
Landtechnik 64 (2009), no. 5, pp. 322 - 325, 5 figures, 1 table, 3 references

It becomes important to gain solid bio fuel from arable land as an alternative for farmers to grow woods for combustion. Pre-drying the wood augments the heat value and prolongs the storability. Because renewable energy sources are in competition to fossil fuel it is necessary to develop technologies to process the material for better value return [3].

Poplar has been harvested from test fields, cut to wood chips (**figure 1**) and experimentally dried with forced heated air. Based on the temperature profiles within bulk materials of different particle size variants a thermodynamic model can calculate proceed of the drying process. With this model the temperature and moisture content of wood chips in bulk of different particle sizes (coarse - 24 mm, middle - 14 mm, fine - 8.5 mm) can be calculated along the bulk height and time.

Model of heat and mass transfer

On homogenous air flow through the bulk of wood chips heat and mass transfer takes place between the particles and the passing air. The heat and mass can transfer in both directions between the particle and the air. Particle moisture and air humidity change during the mass transfer, while particle temperature and air temperature change during the heat transfer. The transfer directions are depending on the 'driving forces'. These 'forces' are water potential differences and temperature differences. On the surfaces (= boundary between particle and air) of the drying particles moist is assumed, since the moisture is diffusing through the material to the surface as long water potential differences exist. The thermodynamic laws are valid during the interaction of the particle surfaces to the air:

- While a temperature difference between the surface and the air exists, a certain amount of heat is interchanged.
- While a partial vapour pressure difference between the moist surface and the humid air exists, water evaporates.
- The transfer equations are integrated along the air flow path passing the individual particles.

The problem is reduced to a one-dimensional air flow model through the homogeneous bulk. The bulk is divided into a number of layers. The thickness of the layers is equal to the particles diameters. The heat and mass (water) balance equa-

Fig. 1

Wood chips; size: medium, separated. Photo: ATB

tions are set up in the model. Additionally the heat and mass transfer laws of the boundary layer theory are applied. Finally the state equations for humid air are used. The system of the equations is discretized using the finite difference method (FDM). The equations are calculated for each time step along the air flow stream line crossing the layers.
When setting the balance equations the following physical laws are used:

- heat balance, equ. (1)
- heat transfer, equ. (2)
- mass balance, equ. (4)
- mass transfer, equ. (5)
- enthalpy of the evaporation, right hand term of equ. (1)
- pressure head loss within the porous bulk, equ. (7)
- air flow velocity (air flow rate)

By this set the temperature of the air, humidity of the air, temperature of the wood chips and the moisture of the wood chips are calculated transient in the time domain along the height. Some simplifications are taken: (1) the bulk is homogeneous, i.e. the particle size distribution is equal, (2) the heat and mass transfer are taken place on discrete layers of the porous bulk material, (3) the boundary conditions at the air inlet and outlet are constant, (4) the bulk height is constant, (5) the physical properties are constant (which means that height and mass loss are neglected).

The system of equations is:

$$\frac{dj_Q}{dz} = -c_K \rho_K \frac{dT_K}{dt} + \eta - \frac{dj_m}{dz} \cdot (r_0 + c_{pD} \cdot T_K)$$

(heat conservation) (1)

$$\lfloor j_Q \rfloor_{Oberfl} = \alpha\,(T_K - T_L)$$

(heat transfer, surface - air) (2)

$$\frac{dj_Q}{dz} = \frac{\dot{m}_L}{A} \cdot \left[c_L \frac{dT_L}{dz} - r_0 \frac{dx}{dz} \right]$$

(heat transport, layer - layer) (3)

$$\frac{dj_m}{dz} = -\rho_K \frac{du}{dt}$$

(mass conservation) (4)

$$[j_m]_{Oberfl} = k(x_K - x)$$

(mass transfer, surface - air) (5)

$$\frac{dj_m}{dz} = \frac{\dot{m}_L}{A} \frac{dx}{dz}$$

(mass transport, layer - layer) (6)

with

T_K	K	abs. temperature of particle
T_L	K	abs. temperature of air
j_Q	$J \cdot s^{-1} \cdot m^{-2}$	heat flux density
j_m	$kg \cdot s^{-1} \cdot m^{-2}$	mass flux density
α	$J \cdot s^{-1} \cdot m^{-2} \cdot K^{-1}$	heat transfer coefficient
c_K	$J \cdot kg^{-1} \cdot K^{-1}$	spec. heat capacity of particle
c_L	$J \cdot kg^{-1} \cdot K^{-1}$	spec. heat capacity of air
u	$kg \cdot kg^{-1}$	water content of particle
x	$kg \cdot kg^{-1}$	humidity (of air; abs.)
x_K	$kg \cdot kg^{-1}$	humidity (of air; abs.) at surface temperature
η	$J \cdot s^{-1} \cdot m^{-3}$	heat flux density induced by biol. process
z	m	height axis of bulk
A	m^2	surface area of particle
$\dot{m}$	$kg \cdot s^{-1}$	mass flux
t	s	time

The evaporation process is described by the last term in equ. (1). The heat and mass transfer takes place inside the finite boundary layer for the passing heat and vapour between particle surface and air (using the heat transfer coefficient α and the mass transfer coefficient k). Free convective air flow is initiated as long temperature differences inside the bulk (between the layers) and temperature differences bulk to air exist. The air flow is limited by the pressure head loss (equ. 7) of the bulk material.

Experimental investigations

Poplar (var. *Japan* 105) and willow (var. *Salix Viminalix*) were growing on test fields of the institute ATB. Fresh harvested poplar has been cut using a shredder with two different settings to coarse particles of middle sizes (ca. 20 mm) and fine particles of small sizes (ca. 10 mm). Samples were separated using a grader to get 3 classes (coarse, middle and fine) of almost homogeneously sized samples. Therefore, samples of poplar with 5 sizes (non separated and separated) and 1 willlow sample for comparison have been prepared (**table 1**).

For the drying tests environment air has been heated to constant temperature of 20 °C and transported to the drying chamber. The airflow was regulated by using a frequency converter to control continuously the revolution speed of the fan. The drying chamber was divided into 6 compartments with boxes of equal sizes (0.42 m × 0.52 m × 1.4 m) = 0.305 m³, with ground area of 0.22 m² each. All boxes were ventilated with the same regulated air flow. Due to different flow resistances for each individual bulk of the 6 variants, different air flow rates or flow velocities developed in the boxes.

The air flow resistances of the bulks with the parameters α and β depending on air velocity w passing through the bulk material are calculated with

$$\frac{\Delta p}{h} = \alpha \cdot w^{\beta}$$

(pressure head loss Δp in the bulk divided by height h (7)

see also **table 1**.

Tab. 1

Physical properties of wood chips

	Poplar non separated		Poplar separated		
	coarse g	fine f	coarse fg	middle fm	fine ff
Average particle size [mm]	19.50	9.30	23.70	13.60	8.5
Bulk height [m]	1.10	1.25	1.05	1.18	1.25
Fresh mass f.m. [kg]	58.05	68.40	56.09	58.37	55.31
Bulk density dry[1] [$kg \cdot m^{-3}$]	89.04	116.31	89.38	81.16	84.77
Dry matter[2] d.m. [%]	48.50	46.70	50.90	51.00	47.8
Porosity [-]	0.74	0.66	0.74	0.76	0.75
Loss [%]	47.40	33.70	47.80	48.80	40.2
Air rate [$x10^{-6}$ $m^3 \cdot s^{-1} \cdot kg^{-1}$]	115.00	51.50	650.00	700.00	210
Air velocity through bulk [$m \cdot s^{-1}$]	0.01-0.02	0.005-0.010	0.07-0.10	0.09-0.10	0.02-0.03
α[3]	900.00	1000.00	300.00	550.00	1500.00
β[3]	1.43	0.87	1.74	1.43	0.75

[1] after drying experiment; [2] before drying experiment; [3] according to equ. (7)

Results

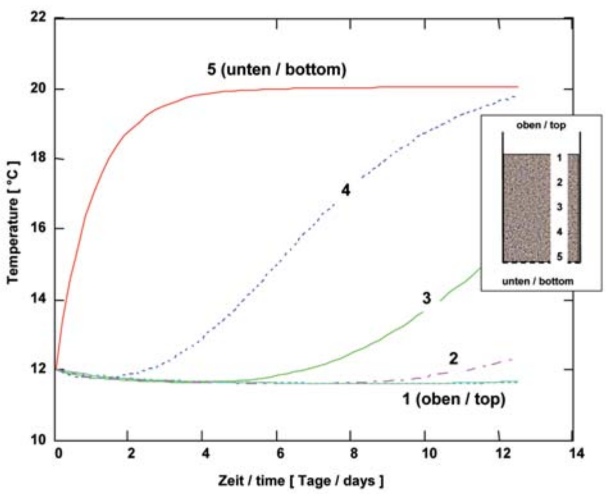
The drying time for separated coarse wood chips was 7 days reaching final moisture content of 10 % (d.b.). For separated middle sized wood chips the drying time was 15 days while the bulk surface left moist. Drying of the fine separated chips did not reach the wanted final moist content of 12 % or lower. The best result was obtained for separated coarse (almost homogenously sized) wood chips.

The results of the measurements were used to adapt the model parameters. Acceptable agreements of the measurements and the model calculations could be reached for the different size variants (**figure 2** to **figure 4**). The experimental result of one example for middle sized chips is shown in **figure 5**. An acceptable agreement could not found for separated fine chips. The reason is that the boundary conditions do not yet allow defining time variant conditions in the model for this example.

Conclusions

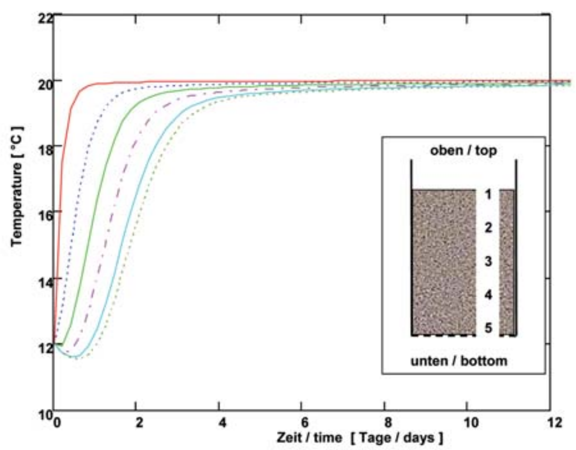
The 'optimal' final moisture content for wood ship to be storable is assumed as 20 % (d.b.), [1; 2]. This could be reached below during the experimental drying time for coarse sized wood chips (**figure 2**). Almost homogenous coarse sized wood chips with only low additives of fine particles could reach best conditions for air flow through the bulk at highest drying velocity.

Fig. 2



Temperature in wood chips bulk, model; chip size: coarse, non separated

Fig. 3



Temperature in wood chips bulk, model; chip size: coarse, separated

Calculations with the model allow simulating the drying process. Aligning the parameters from experimental results gives acceptable agreement to the calculated results.

Literature Books are signed with ●

[1] Gürtner, M.: Energie aus dem Wald. Fachtagung „Energetische Nutzung von Biomasse", Forum für Zukunftsenergien e. V., Landtechnik Weihenstephan, TU München, Band 12 Freising, 27.-28.4.1992, 1992, S. 190–192

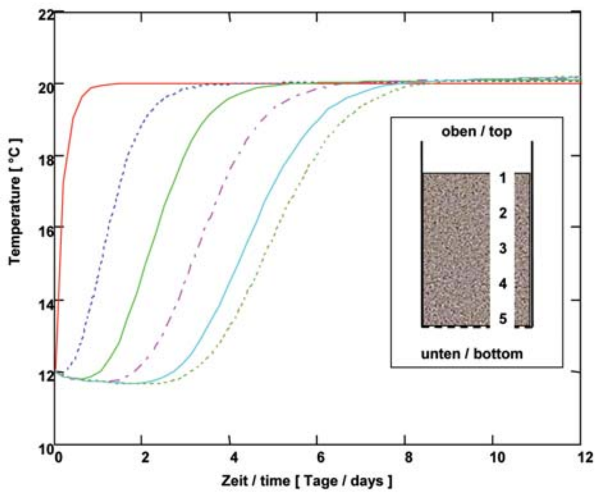
[2] ● Ebert, H.-P.: Heizen mit Holz in allen Ofenarten. Ökobuch Verlag, Staufen i.Br., 1989

[3] Scholz, V., C. Idler und W. Daries: Energieverlust und Schimmelpilzentwicklung bei der Lagerung von Feldholz-Hackgut. Bornimer Agrartechnische Berichte, Heft 39, 2005

Authors

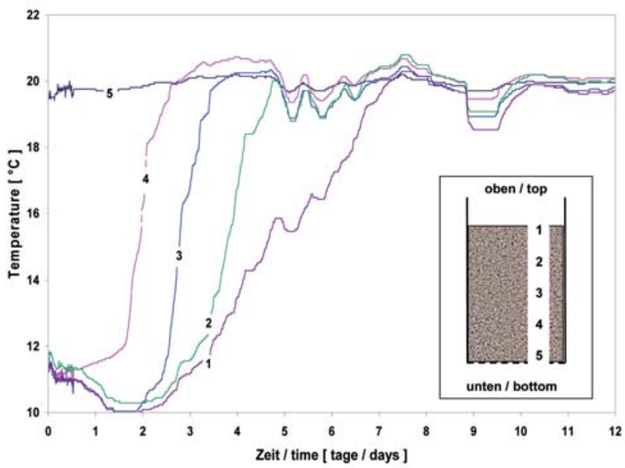
Prof. Dr.-Ing. Klaus Gottschalk and **Dr.-Ing. Volkhard Scholz** are Senior Scientists at Leibniz-Institut für Agrartechnik Potsdam-Bornim e.V. (ATB), Max-Eyth-Allee 100, 14469 Potsdam, Germany,
E-Mail: kgottschalk@atb-potsdam.de

Fig. 4



Temperature in wood chips bulk, model; chip size: medium, separated

Fig. 5



Temperature in wood chips bulk, experiment; chip size: medium, separated