Modelling of air resistance during drying of wood-chips

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Abstract: The objective of this study was to investigate the parameters that affect the drying process of wood chips at low air flow conditions. This objective was determined by measuring the air pressure resistance being produced by wood chips by examining different variables such as: air flow rate, air velocity, wood chip size, bulk density, bulk height and porosity. The air flow resistance was measured inside a 3 meter high cylindrical air duct constructed at University of Hohenheim. Physical properties of two different Spruce wood chip fractions were analyzed and their characteristics were considered on fitting the model expression. The analysed model expresses the physical behaviour of air flow resistance. Statistical analyses show high correlation of air speed versus air flow resistance. The model could be used for determination of drying conditions with low air mass flow. The height of bulk density according air mass flow generated or the necessary air mass flow needed for transporting air through the bulk height.

Keywords: Air mass flow, drying, pressure difference, woodchip.

1. INTRODUCTION

Globally there is increasing interest in biomass use as fuel and the potential on substituting fossil fuels is a rising awareness. For instance in Germany large quantities of wood are produced on a regular basis from fruit – industry. The fresh mass of trimming timber amounts to approximately 1 t/ha whereas every 12 to 15 years about 4 t/ha of clearing timber can be harvested from fruit plantations. As this particular kind of biomass has been neglected for energetical use, less is known about its potentials and constrains. Drying of biomass is an energy and cost intensive process which needs to be applied before using wood chips as fuel (Jirjis, 1995; Fyhr and Rasmuson, 1997; Bux, Bauer et al., 2001). The quality of wood chips depends strongly on moisture content. Artificial drying with drying temperatures of 50 – 100 °C requires high investment costs and energy consumption. Therefore drying techniques with low investment costs and energy consumption are desirable. Solar timber dryers might be a method to overcome the existing drying problems with low investment costs and energy consumption (Arnaud and Fohr, 1989; Gigler, Van Loon et al., 2000; Bux, Bauer et al., 2001). Main issue is the development and construction of a solar dryer for wood chips from fruit – industry and short rotation plantations. Since the fundamental research on requirements for production of high quality wood chips with natural convections is missing, research program within the "Regional 2010" of North Rhine – Westphalia, Germany was addressing this issues.

The objective of this study was to investigate the parameters that affect the drying process of wood chips at low air flow conditions or natural convection. The main focus was to monitor the pressure drop of the air passing through wood chips by examining different variables namely: air flow rate, air velocity, wood chip size, bulk density, bulk height and porosity.

2. MATERIALS AND METHODS

2.1 Raw material

Picea abies known as Spruce tree is an evergreen coniferous found in northern temperate and boreal regions. Spruce wood chips were used as raw material in this study to investigate the parameters that influence the drying process at low air flow conditions or natural convection. Two groups of wood chip material were provided from EUSÄKO Sägewerksmaschinen. Spruce wood chip materials were chopped with screw hackers (Laimet HP 21) and wood chips with 20 -30 mm and 55 – 60 mm size were generated (Fig. 1).

Fig. 1 Spruce wood chip groups used for air flow resistance determination.

Moisture content of the Spruce wood chips was determined with the oven method to around 70 % d.b. Wood chips were stored at room temperature of 18 – 20 °C until experiments took place.

2.2 Physical properties

Porosity was measured with a porosity apparatus adapted at University of Hohenheim according Mohsenin, (1980) (Fig. 2).

Fig. 2 Porosity apparatus adapted according Mohsenin, 1980

The principle of this device was measuring the void space inside the bulk material according pressure difference between the two containers as following:

$$\varepsilon = \frac{P_1 - P_2}{P_2} \cdot 100$$

where: ε porosity in %, P1 pressure in empty container and P2 equilibrium pressure between full and empty container in Pa.

Other important physical properties of Spruce wood chips such as moisture content, bulk density, solid density, coefficient of static friction in different surfaces, and static and dynamic angle of repose were measured according standard methods and literature (Mohsenin, 1980; Deutsches Institut für Normung e.v., 2005; Sirisomboon, Kitchaiya et al., 2007) (Bahnasawy, 2007) (Sirisomboon, Kitchaiya et al., 2007; Garnayak, Pradhan et al., 2008) (Table 1).

Table 1. Methods used for analyzing physical properties of Spruce wood chip.

Property	Symbol	N*	Units
Moisture content	MC	5	% d.b.
Bulk density	ρ_b	5	kg/m³
Solid density	ρ_s	6	kg/m³
Static friction	µ	4	-
Iron sheet		4	-
Perforated iron sheet		4	-
Stainless steel		4	-
Aluminium		4	-
Wood		4	-
Plexiglas		4	-
Rubber		4	-
Angle of repose			
Static	θ_s	4	°
Dynamic	θ_d	4	°

*N number of repetitions.

2.3 Experimental procedure

Air pressure drop experiments were conducted in a cylindrical air duct at University of Hohenheim (Fig. 3). The air duct height was 3 m with inside diameter of 480 mm, air output tube was 1.7 m long with 84 mm inside diameter. The air input height was 700 mm. A radial ventilator with 0.43 kW power was installed on the top. The radial ventilator was operated via a frequency converter in order to achieve the desired air velocity and air mass flow.

The air was sucked from bottom tube (air input) passing through wood chip bulk and blowing at top apparatus (air output) where air velocity and air mass flow were measured via Vortex sensor VA40

(Höntzsch Instrument). Two capacitive humidity and temperature sensors TFD 128 (Conrad Electronic) were installed in bottom and top of apparatus. Four digital manometer sensors GMSD 2 BR (Greisinger electronic GmbH) were installed along the height of apparatus at each meter starting from point zero (P_0) at bottom to point (P3) at top of wood chip bulk.
Mechanical Betz manometer was installed for measuring differential pressure drop from P_0 to P_3 and comparison of digital measuring data (Pa) with mechanical measuring data (mmH_2O column). The data were collected via a Data Acquisition Unit (HP-Agilent 34901A) and displayed on a laboratory computer.

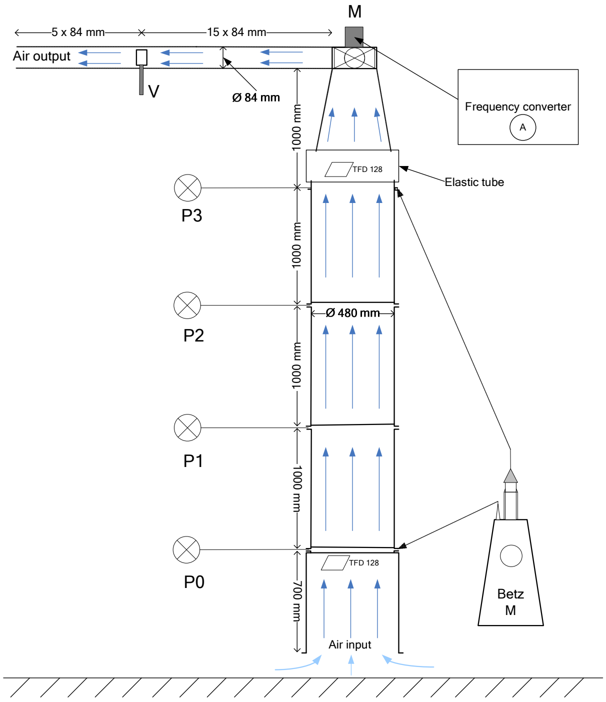

Fig. 3 Equipment used for measuring ail flow resistance of Spruce wood chips.

The apparatus was manually filled with Spruce wood chips from top at the elastic tube connection point (Fig. 3.) Ten wood chip samples were taken for moisture content determination. All sensors were installed and connected to laboratory computer. The air speed was alternated with the frequency converter from 0.5 – 22 m/s air velocity in air output tube. Three repetitions were done for each group of Spruce wood chips. Air speed and air mass flow were recorded at air output tube with 84 mm inside diameter. Therefore, following calculations were done in order to determine the air velocity and air mass flow inside the apparatus with 480 mm inside diameter.
Air velocity inside apparatus:

$$V = \frac{v \cdot a}{A}$$

where: V air velocity in apparatus (m/s), v air velocity in output tube (m/s), a inside area of output tube (m^2), A inside area of apparatus (m^2).
Air mass flow inside apparatus:

$$AM = A \cdot V \cdot 3600$$

where: AM air mass flow (m^3/h).

The digital manometer sensors were recording air pressure drop at each meter of apparatus with an interval of 4 s while the air speed was gradually increasing. Simultaneously differential air pressure drop was manually registered from Betz manometer after air velocity change. Data were than further analyzed with Excel, Origin pro 8, and Matlab software and the most suited model was selected according statistical analyses (Matthies, 1973; Gottschalk and Scholz, 2008).

3. RESULTS AND DISCUSSION

3.1 Physical properties

Table 2 shows physical properties of Spruce wood chips with 30 and 50 mm size. Moisture content before test was 41.7 % d.b. for 30 mm size and 65.8 % d.b. for 50 mm size.

Table 2 Physical properties of Spruce wood chips.

Property	Symbol/Unit	30 mm	50 mm
Moisture	MC % d.b	41.7±6.0	65.8±13.8
Porosity	ε %	0.72±0.01	0.75±0.01
Bulk density	ρ_b kg/m³	241.3±4.6	212.9±5.2
Solid density	ρ_s kg/m³	489.5±6.4	444.3±5.5
Static friction	μ -		
Iron sheet	-	0.27±0.03	0.20±0.03
Perforated iron sheet		0.24±0.00	0.22±0.01
Stainless steel	-	0.29±0.01	0.20±0.01
Aluminium	-	0.34±0.01	0.31±0.00
Wood	-	0.29±0.01	0.20±0.01
Plexiglas	-	0.23±0.00	0.17±0.01
Rubber	-	0.48±0.01	0.45±0.01
Angle repose			
Static	θ_s °	42.3±2.1	43.0±1.8
Dynamic	θ_d °	34.2±3.0	31.7±1.6

Porosity was smaller for wood chip size 30 mm than for 50 mm, 0.72 % and 0.75 % respectively. Smaller porosity means less void spaces between the materials which lead to a higher air resistance through bulk density. Porosity is a parameter that influences the bulk density as well. For instance bulk density was higher for wood chip size 30 mm than 50 mm. Solid density shows same trends like bulk density even though solid density is not influenced by porosity.

Static friction, which is the ratio of force required to start motion over a surface divided by the weight of object show highest value on rubber surface and lowest on Plexiglas. It was observed that Spruce wood chips with 30 mm size had higher values of static friction than 50 mm size on all analyzed surfaces. Static angle of repose for both size fractions was higher than dynamic angle of repose. There were no large differences of static or dynamic angle of repose between wood chip sizes.

3.2 Air flow resistance

The air flow resistance for Spruce wood chip is depicted in Figure 4. Air flow resistance was higher for wood chips with 30 mm size than with 50 mm. For instance at 0.5 m/s air velocity, maximal air flow resistance (h 3) for 30 mm wood chips was about 1200 Pa and about 800 Pa for 50 mm wood chips.

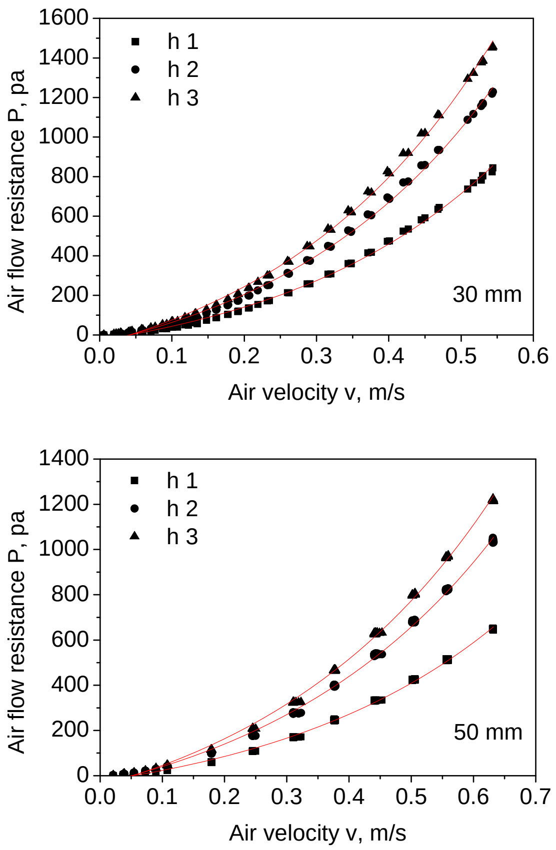

Fig. 4 Air flow resistance of Spruce wood chips with 30 mm and 50 mm size.

Air flow resistance was highest at the first meter of bulk height. This means that wood chip materials are more compact in this segment, resulting in higher bulk density and lower porosity.
Air flow resistance increases with increase of air velocity. The statistical analyses shows that the correlation between air velocity and air flow resistance could be expressed via a power equation.

$$\Delta P = h \cdot C \cdot \frac{1}{\varepsilon^4} \cdot v^{2-n}$$

where: ΔP air flow resistance in Pa, h height of bulk material in m, ε porosity in bulk material in %, v air velocity in m/s and C, n are model constant.
The model constant and r^2 - adjusted are shown in Table 3.

Table 3 Statistical Coefficients

	h		
30 mm	1	2	3
C	759.4	559.6	443.2
n	-9.7	-13.8	-16.87
r^2	0.992	0.991	0.993
50 mm			
C	516.3	412.7	324.1
n	-6.32	-13.79	-14.65
r^2	0.991	0.990	0.992

The model designed from Matthies (1973) expresses the physical behaviour of the system.
Maximal air mass flow generation was higher for wood chips with size 50 mm than 30 mm, 410 m^3/h and 360 m^3/h respectively (Fig. 5). Since the porosity was higher for wood chips with 50 mm size more air was able to pass through bulk material and higher air velocity was achieved for the same ventilator power of maximal 0.43 kW used.

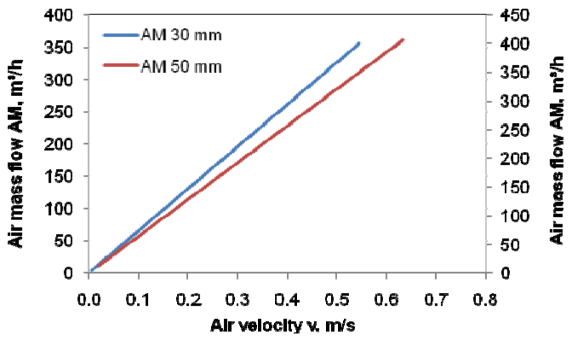

Fig. 5 Air mass flow in Spruce wood chip bulk material with 30 and 50 mm size.

4. CONCLUSIONS

Physical properties are important parameters for characterization of wood chip product. The gathered information was essential for selecting the model of air flow resistance. The selected model expresses the physical behaviour of air mass flow vs. air velocity. The model could be used for determination of drying conditions with low air mass flow. This could either be done by adapting bulk height according to air mass flow generated or by adjusting the air mass flow needed for transporting air through the bulk height.

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