

FACTORS INFLUENCING THE MECHANICAL STABILITY OF WOOD PELLETS

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ABSTRACT

One possible way to use waste materials in the wood industry (chip, dust, smaller pieces) is to transform them into pellets. Pellet making requires, however, additional energy which should be as low as possible. Present work examines the possible origins of binding forces and experimental evidences show that also the presence of water on particle surfaces plays a definite role. It also turned out that the water potential curve of timber materials can successfully be used to estimate the relation of compaction pressure to the water tension of the material.

KEYWORDS: Pellet-water contact, sorption isotherm, water potential, pF curve, tension.

INTRODUCTION

The common method for reducing the volume of dust and chip materials is the pelleting facilitating the handling (transport, storage, feeding into heating devices) of the originally loose material considerably. The essence of the pelleting process is the pressing of the properly prepared material by high pressure (~1000 bar). The particle size distribution should be in the range from 0.2 to 1.5 mm and the moisture content varies generally between 10 and 12 %. The density of pellets of good quality amounts to 1050-1100 kg.m⁻³. In order to achieve a proper durability of pellets, pressures at least 1000 bar or above is needed (Kocsis 2015). It is well-known from the practice that the deviation of moisture content upwards or downwards in relation to the common values (10-12 %) will highly decrease the mechanical stability of pellets, i.e., the binding forces among the particles are sharply decreasing. The detrimental effect of higher moisture contents can easily be explained by the fact that much water in the material hinders the compaction of the material. It is not the case, however, at decreasing water content. Therefore this latter case requires explanation.

It is generally assumed that the binding forces among the particles originate from the lignin which is one of the main constituents of wood materials (Andrew 2004; Anon 2009; Demirbas 2001; Dmitry et al. 2013). The lignin is known to be a binding material on the outer surface of

the cell walls which support the above assumption (Escort 2009; Karwandy 2007). But it is not fully clear why a small decrease in moisture content causes a rapid deterioration of binding forces among the particles and with this the loss of durability. It is therefore reasonable to suppose that the water itself may play also a given role in the development of binding forces.

It is also known that molecular forces exert considerable action on water molecules contacting a surface in one or several layers. The highest force and adhesion will be exerted on the first layer of water molecules which may contribute to the binding forces considerably (Brunauer et al. 1938; Dent 1977; Hailwood and Horrobin 1946; Pizzi et al. 1987). A layer of water molecules can appear on the surface of particles only in the case, if the pressure used is somewhat higher than the water potential (tension) of wood material at the given moisture content. Using the theory of wood-water relations, the water potential curve can be constructed and used to check the validity of the above assumption. The aim of present investigation is to solve this problem.

Theoretical consideration

Timber materials are porous and hygroscopic possessing the ability to adsorb and desorb water depending on the environmental circumstances. The water content in wood plays an important role in many aspects. Concerning only our subject, it seems to be well-established that the water content of chips plays a decisive role in the development of bonding forces in the pellet. Wood materials tend to be in equilibrium with the surrounding environment which is changing continuously in its temperature and relative humidity. At equilibrium the partial vapor pressure above the surface is equal to the saturated vapor pressure corresponding to the given temperature.

As mentioned above, the wood is a porous material having capillaries of different diameters. On a liquid-gas interface, due to intermolecular forces, the surface tension phenomenon exists. As a consequence, the water rises in the capillary and over the capillary meniscus, depending on the radius of the capillary, the static pressure decreases which corresponds to a decreased relative humidity over the meniscus. This relationship is described by the Thompson equation as follows:

$$\varphi = \exp\left(\frac{2\sigma\rho_v}{p_v\rho_w r}\right) \quad (1)$$

where: φ – the relative humidity,
 σ – the surface tension of water (0.072 N.m⁻¹),
 p_v – the vapor pressure,
 ρ_v, ρ_w – the density of vapor and water, respectively,
 r – the radius of capillary.

It is interesting to note that the sap in the wood contains soluble nutrients which decrease the surface tension to about 0.05 N.m⁻¹. As an example, a capillary radius $r = 0.36$ nm corresponds to $\varphi = 5\%$ and $r = 100$ nm to $\varphi = 98\%$. It means that in the sorption process capillaries over 100 nm radius cannot be filled with water. That means that the sorption isotherm does not characterize the entire moisture range of a saturated wood sample. An approximate distribution of pore radii for a pine wood is represented in Fig. 1 with the corresponding moisture content (Sitkei 1994).

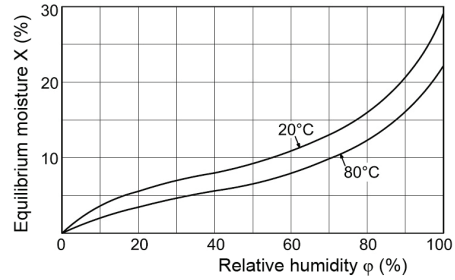
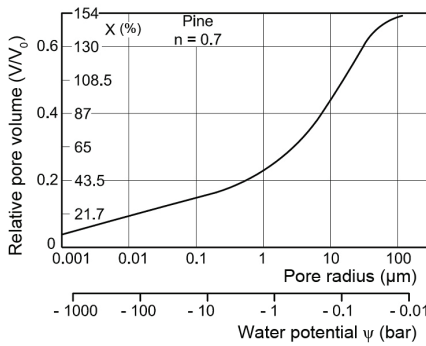


Fig. 1: Relative pore volume of Pinewood as a function of pore radii. The corresponding theoretical water potential values are also given. Fig. 2: The equilibrium moisture content of wood for two different temperatures.

The water taken up in the sorption process is called the hygroscopic water and the corresponding moisture content is the fiber saturation point (Tiemann 1906).

Measurements on the distribution of micro capillaries in wood have shown that most of the capillaries is in the 0.5-1.0 nm range which corresponds to $\phi = 20\%$ and appr. 5% moisture content (Stamm 1946). This low relative humidity means a high driving potential or tension which rapidly decreases with increasing capillary radii. This capillary tension is a real driving force which can be expressed in term of water potential as:

$$\psi = \frac{2\sigma \cos \theta}{r} \tag{2}$$

where: θ – the contact angle to the wall of the capillary tube.

Due to its relative humidity, the surrounding air has also a driving potential or tension given by the following equation:

$$\psi_a = \frac{RT}{m_w} \ln \phi \tag{3}$$

where: m_w – the molecular volume of water ($18 \text{ cm}^3 \cdot \text{mol}^{-1}$),
 T – the temperature ($^{\circ}\text{K}$),
 R – the gas constant ($82 \text{ bar} \cdot \text{cm}^3 \cdot \text{mol}^{-1} \cdot ^{\circ}\text{K}$).

Fig. 2 gives a relationship between the equilibrium moisture content and the relative humidity of air. Therefore, using Eq. (3), the driving potential of the air can be calculated for each equilibrium moisture content. As an example, the air with relative humidity of 90% has water potential or tension of appr. – 140 bar. Using the sorption isotherm given in Fig. 2, the corresponding water potential curves are depicted in Fig. 3.

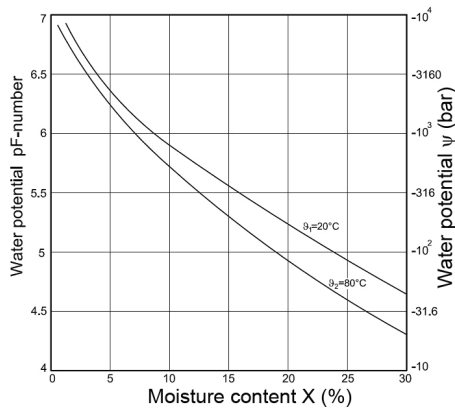


Fig. 3: The pF curve of wood for two different temperatures.

The water potential may have different dimensions depending on the choice of dimensions in Eq. (3). If we choose for $R = 8.314 \text{ kJ}\cdot\text{kmol}^{-1}\cdot\text{K}$ and $m_w = 18 \text{ kg}\cdot\text{kmol}^{-1}$, then the water potential has the dimension kJ/kg . For example, taking 50 % relative humidity, it corresponds to nearly $100 \text{ kJ}\cdot\text{kg}^{-1}$ and 1000 bar tension. Originally in the soil science, for the characterization of water potential the pF -number has been introduced which is the logarithm of the pressure height expressed in cm (Schofield 1935). For instance, $pF=3$ means $1000 \text{ cm} = 1 \text{ bar}$ tension.

MATERIAL AND METHODS

Experimental measurements were conducted using spruce (*Picea abies*) and black locust (*Robinia pseudoacacia*) chips similar to those commonly used for pellet production. The particle size varied between 0.2 and 1.5 mm which was produced by a chipper and screened to the above particle size range. The moisture content of chips has been varied between 5 and 15 %. The pressure in every case was chosen such that the obtained pellet taking out from the die had the required stability. The required pressure at 5 % moisture content amounted to well over 3000 bar. The pressure die had 6.0 mm diameter and length of pellet averaged around 25 mm. The pressing velocity was always $10 \text{ mm}\cdot\text{min}^{-1}$. The pressure die can be heated and regulated to the required wall temperature. A more detailed description of the experimental set-up was given in an earlier article (Kocsis and Csanady 2015).

RESULTS

For each chosen moisture content a series of measurements was conducted to find the minimum pressure giving stable pellets. The obtained minimum pressure was then represented in the previously constructed water potential relationship as shown in Fig. 4.

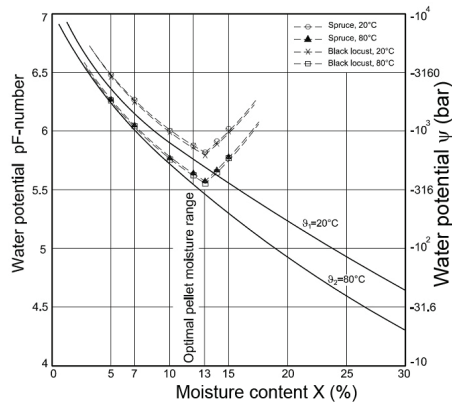


Fig. 4: The measurement results (broken line) and the pF curve of wood (solid line) for two different temperatures.

Because the water potential can be expressed in the common pressure unit, for instance in bar, therefore the required minimum pressure can directly be compared to tension holding the water in the material at the given moisture content.

The obtained results are highly interesting. The measurement points are systematically placed slightly above the water potential curves as a function of moisture content. This means that the required compaction pressure should always be higher than the water holding tension at the given moisture content. Increasing the moisture content above 13 %, the required pressure rapidly increases. In the presence of excessive water the compactibility of the material is worsening and a thicker water layer among the particles decreases the effect of molecular forces.

DISCUSSION

The measurement results clearly indicate that some water may be pressed out from the material to its surface giving an additional binding force among the particles. In the soil science it is well known long ago that a thin water layer, less than 5 or 6 molecular thickness, on the soil particles makes the water immobile due to molecular forces and this water is not available for plants (wilting point). Similar observation was also presented studying water sorption energies (Pizzi et al. 1987). Therefore it may be assumed that also here the thin water layer on the particle surfaces contributes to the binding forces.

The obtained experimental results prove the practical experience that the optimum moisture content for making pellets is in a narrow range between 10 and 12 %. Below and over this moisture range the necessary pressure steeply increases requiring much more compaction energy and additional friction forces for pushing out the pellet from the die.

It is interesting to note, furthermore, that the required minimum pressures for 80°C are somewhat nearer to the water potential curves than for 20°C temperature. The absolute minimum pressure points for both cases, however, are obtained at the same moisture content of 13 %. According to these experiments, in the optimum range of moisture content a compaction pressure of 1000 bar supplies stable pellets with sufficient safety.

CONCLUSIONS

Based on the above theoretical consideration, it can be stated and formulated that hygroscopic materials hold the water by tension. From this statement it follows that the dewatering of a material is possible only by applying a pressure somewhat higher than the tension exerting by the material at a given moisture content. Concerning the pelleting process, the same statement is valid: if the required minimum pressure which ensures a stable pellet is higher than the tension exerted by the material at given moisture content, then some portion of water will be pressed out from the chip particles to their surface. As outlined in the introduction, this thin layer of water may also contribute to the development of bonding forces.

The following main conclusions may be drawn:

- Moisture has also a definite role in the development of bonding forces in pellets;
- The relation of compaction pressure and water tension in the material can conveniently be followed using the water potential curves;
- In order to minimize the energy consumption of pellet making an accurate control of chip moisture content is essential.

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