DVS measurement of water vapour sorption by Pine wood

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Introduction

Wood is an important natural resource that is used around the world for building and construction. Since it is a versatile material from renewable sources, it is likely to continue to play a significant role in construction in the future. As such, different woods must be well characterised and their properties understood in various climatic conditions. Atmospheric changes may vary over the course of hours or years, leading to rapid or more gradual changes in structural properties. Wood is also a renewable fuel, from which energy may be extracted. However, the combustion process used to release this energy must be optimised for the moisture content of the wood, in order to maximise the energy output and minimise potentially polluting effects. Thus, understanding the mechanisms of water sorption inside wooden fuels is also an important area of research.

As a biological material, wood is also susceptible to parasite infection, mould and fungus growth and natural decay processes [1] unless properly preserved. Such preservation processes may involve the treatment of wood to make it less sorbing, preventing transport of water through the material by sealing the surfaces. Dynamic Vapour Sorption (DVS) measurements can play a vital role in assessing the suitability of types of wood for construction or fuels, or assess its susceptibility to natural decay. In this application note, we demonstrate the use of the Hiden Isochema IGAsorp to deter-mine the specific water sorption properties and mechanisms of a common wood, Scotch pine.
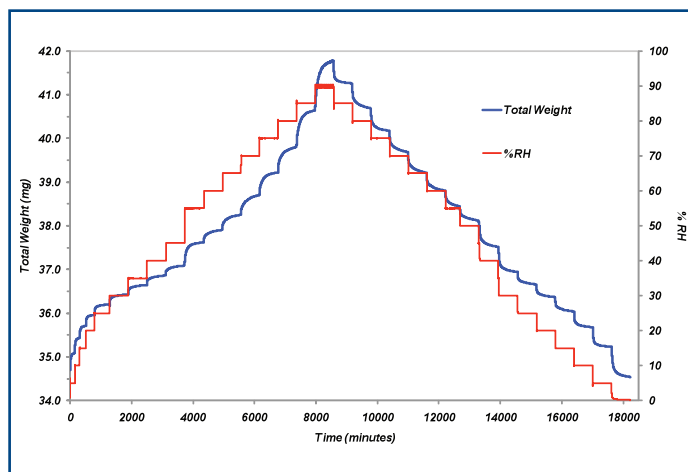

Figure 1: Kinetic Profile for DVS Isotherm

Materials and Experimental Procedure

Due to its biological nature, wood is a hygroscopic material capable of sorbing and desorbing water according to the humidity of the surrounding atmosphere. This moisture-responsive property is believed to be caused primarily by the interaction between polar hydroxyl- chemical groups in the cell walls and water [2], yet the magnitude of the response to external humidity changes and the sorption kinetics will depend upon the type of wood in question and its surface morphology.

This study examined Scotch pine (Pinus Sylvestris) wood in bulk and splintered form, using a gravimetric IGAsorp instrument to perform isothermal vapour sorption measurements. All the reported measurements were performed using a standard IGAsorp instrument [3] with a refrigerated water bath to thermostat the sample chamber. The measurements involved changing the relative humidity (%RH) of the chamber atmosphere by combining streams of dry (0% RH) and vapour-saturated (100% RH) nitrogen, controlled by RH sensor feedback and mass-flow controllers, while accurately maintaining experimental conditions such as temperature, total gas flow rate, pressure and balance stability. 37.143 mg of sample was initially dried in-situ for 24 hours under a stream of dry nitrogen at 25°C, until its mass stabilised at 34.690 mg. A sorption and desorption isotherm was then determined in steps of 5 %RH (compared to the minimum control increment of 1 %RH for high resolution scanning) up to a relative humidity of 95 %RH. The IGAsorp's intelligent real-time analysis software monitored the kinetic mass response of the sample until the mass reached 99 % of the predicted asymptotic uptake. It then automatically advanced onto the next isotherm step and continued the measurement. Throughout the measurement, the temperature was maintained at 25°C ± 0.1°C.
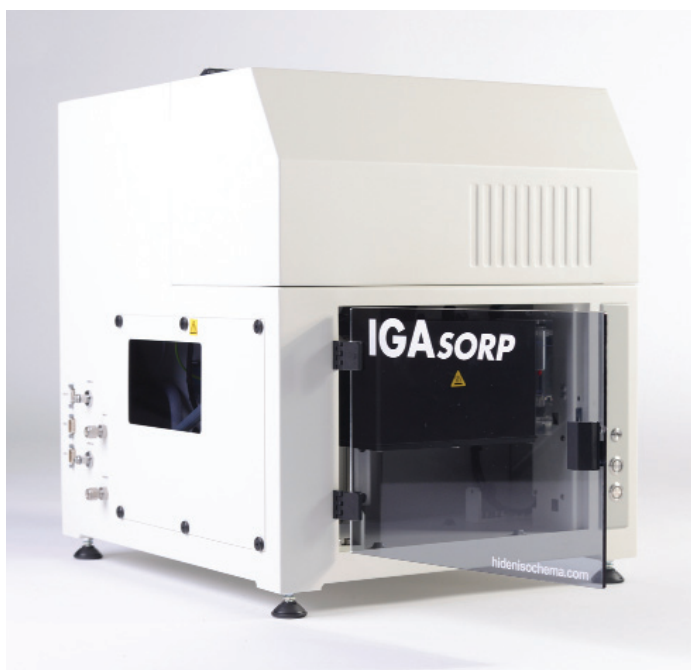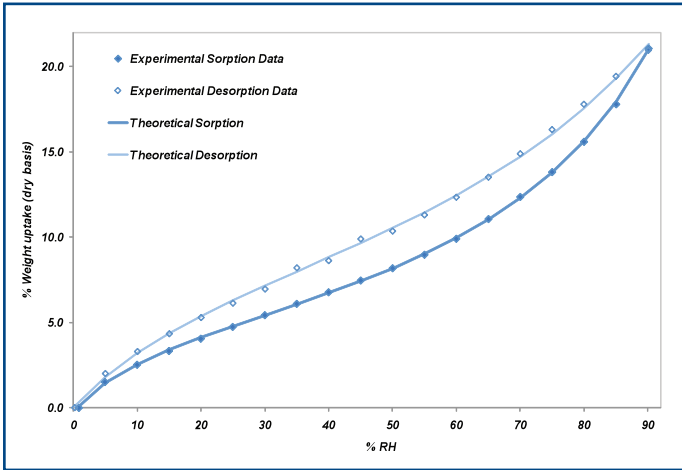
Figure 2: Sorption and desorption isotherms showing experimental data and theoretical fits.

Results and Discussion

A full kinetic profile of the sorption and desorption isotherms is shown above in Fig. 1. The time taken for the wood to reach 99% of predicted moisture sorption equilibrium at each isothermal point is relatively constant at around 400 minutes. The isothermal data can be plotted as weight % uptake against %RH, as shown in Fig. 2. The equilibrium weight % uptake at each isotherm point is the predicted asymptotic uptake calculated from each fitted kinetic mass response.

The data were subsequently fitted using the Hailwood-Horrobin (HH) [4] and Dent [5] models, which are widely used to fit moisture sorption data in wood and other such porous materials. The latter of these two models is derived from the Brunauer, Emmett and Teller (BET) method [6], which is a well known approach to surface area determination while the former is a first principles approach. Both models assume two separate mechanisms of water sorption, primary and secondary types. The primary sorption occurs due to interaction of the water with the hydroxyl cellular structures within the wood, which provide primary sorption 'sites'. Secondary sorption occurs because of interaction with the moisture already sorbed, and is thus a
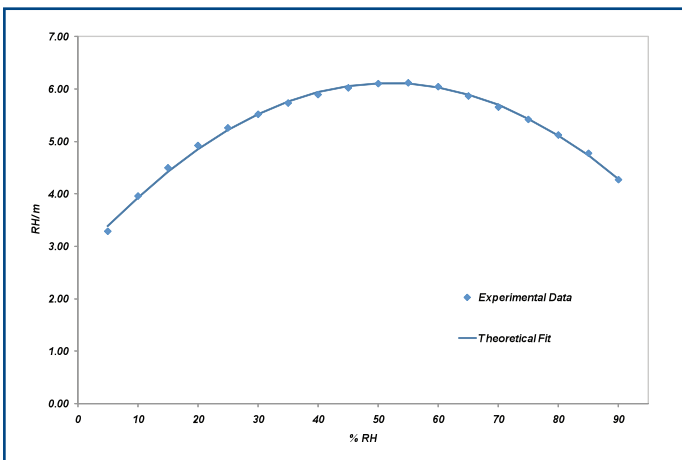
much weaker interaction than that of primary sorption. BET theory assumes that the secondary sorption energetics are identical to the interaction of non-sorbed molecules, whereas the HH and Dent models deviate from this assumption in the case of water sorption. HH theory predicts that plotting the ratio of the relative humidity to the uptake, (RH/m), against %RH, where RH is denoted HR below, will result in a parabola. This plot is shown in Fig. 3 and may be modelled by the following equation [2]

$$\frac{H_R}{m} = A + B(H_R) + C(H_R)^2 \tag{1}$$

where m is the mass uptake (wt.%) and A, B and C are material dependent constants.
The constants A, B and C used for fitting the HH theory to the experimental data then allows the determination of a number of physical properties. The property most relevant to many fields, including building and constructions applications, is the molecular mass of dry wood per sorption site; this will give a comparative indication of the susceptibility of the wood to physical changes due to moisture uptake. This measure, W, may then be calculated from the constants A, B and C in equation 1 thus:
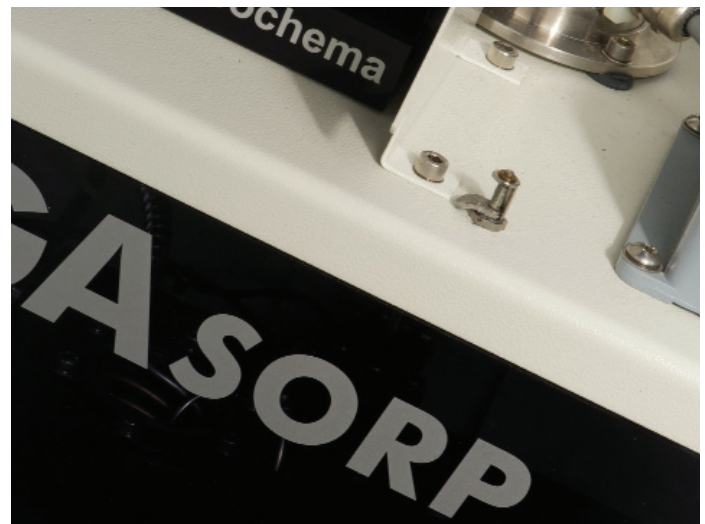
$$W = 1800\sqrt{B^2 + 4AC} \tag{2}$$

Using this measure, further information may be determined by deconvoluting the HH model into primarily and secondarily sorbed layer contributions, m1 and m2 respectively, for each humidity step thus:

$$m = m_1 + m_2 = \frac{1800}{W}\left(\frac{K_1 K_2 (H_R)}{100 + K_1 K_2 (H_R)}\right) + \frac{1800}{W}\left(\frac{K_2 (H_R)}{100 - K_2 (H_R)}\right) \tag{3}$$

where K1 and K2 are calculated from the constants A, B and C as follows:

$$K_1 = 1 + \frac{B\sqrt{B^2 + 4AC}}{AC} \tag{4}$$

$$K_2 = \frac{50\left(\sqrt{B^2 + 4AC} - B\right)}{A} \tag{5}$$

Figure 3: %RH/m vs %RH plot from sorption data, used for HH theory fitting.
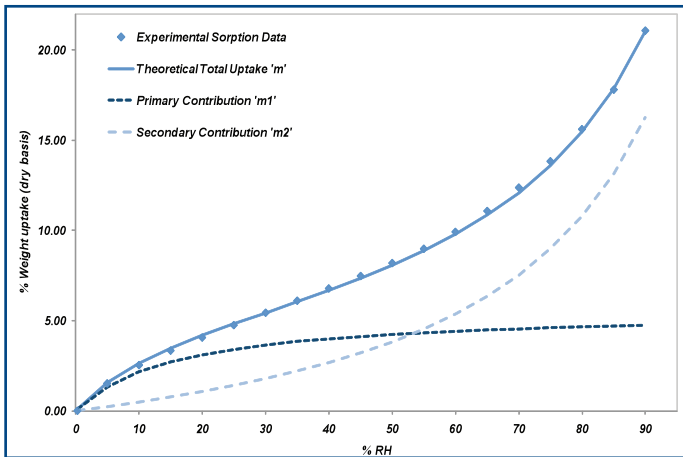
Figure 4: Primary and secondary sorption contributions to total moisture uptake.

The sorption contributions for primary and secondary sorption sites can then be assessed as a function of %RH, as shown in Fig. 4. Clearly, this shows that moisture is initially sorbed onto primary sites, limited by the number of hydroxyl- sites with which to bond, while subsequent sorption is simply due to interaction between the water vapour and the sorbate.

Conclusion

This study has demonstrated the use of the Hiden Isochema IGAsorp to determine the moisture sorption isotherms for Scotch pine (Pinus Sylvestris). The IGAsorp is a fully automated system which allows the accurate and efficient determination of dynamic vapour sorption isotherms and equilibrium kinetics in materials. The recorded data closely fit those predicted by Hailwood-Horrobin theory. This validates

the properties subsequently determined from the theoretical data produced; material constants which were used to model the extent of primary and secondary sorption effects within the material. Such properties can give an insight into the suitability of the wood for use as a building and construction material, a fuel, and its susceptibility to natural decay processes which rely upon the presence of moisture.

References

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