Holz als Roh- und Werkstoff 56 (1998) 355–358 © Springer-Verlag 1998

Cork hygroscopic equilibrium moisture content

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This work is related to the establishment of the curves of cork moisture content in hygroscopic equilibrium (HEM curves), which allow to predict the moisture content of cork planks, one of the most important parameters in cork trading and processing. HEM curves for 20 °C and 40 °C based on an empirical model related to experimental data, were mathematically treated in order to set a series of curves in steps of 5 °C. These curves were transformed in a more usual display of the hygroscopic equilibrium moisture content, for the most common temperature and humidity ranges and tested against experimental data using two cork types.

Hygroskopische gleichgewichtsfeuchte von kork

In diese Arbeit wurden Sorptionskurven für das hygroskopische Gleichgewicht (HEM-Kurven) von Kork erstellt. Sie ermöglichen die Vorhersage der Feuchte als eines der wichtigsten Parameter bei Herstellung und Vertrieb von Korkplatten. HEM-Kurven bei 20 °C und 40 °C wurden aufgrund empirischer Daten erstellt und mathematisch behandelt, so daß eine Serie von Kurven im Abstand von 5 °C erhalten wurden. Diese Kurven wurden umgewandelt in die übliche Darstellung der Gleichgewichtsfeuchte für die gebräuchlichsten Termperatur- und Feuchtebereiche und anschließend anhand experimenteller Daten an zwei Korktypen geprüft.

1 Introduction

Portugal and Spain produce more than 75% (ca. 55% of total production area) of the world's cork. The industry of these two countries transforms about 90% of all cork produced worldwide. The moisture content of cork materials is one of the most important parameters for trading and technological processing and therefore it is of importance to be able to predict this value. Its relation with temperature and relative humidity (RH) is a method commonly used for timber. Although there are graphics of the hygroscopic equilibrium moisture content (HEM curves) for several wood species (e.g Kollmann, 1968), a complete set of graphics covering the usual range of environmental conditions was never established for cork materials, and only limited studies about HEM curves on specific cases have been reported (Adrados, 1994; ICTM, 1993).

The cork moisture content, when removed from the tree, is very high (up to 50%), decreasing quickly once its inner part is in contact with air; it is supposed that after ten days this content decreases till 14% (standard definition for commercial dry cork) (Adrados, 1994). Besides these values for raw cork, it is also important to obtain data on boiled cork, for cork stoppers manufacture, whose wastes are very important for cork agglomerates production, and also for virgin cork.

At present, after extraction from the tree, cork is piled up in the field, where it remains waiting for a buyer. As its price is related with the batch quality and weight, the seller piles it up in such a way that it prevents loss of water. On the other hand, the buyer tends to buy cork as late as possible, in order to allow a greater weight loss. This delay (to buy) can promote the infestation of cork by microorganisms which can be in the origin of anomalous tastes and smells in the beverages which came in contact with the cork stoppers.

Cork HEM curves provide a quick method for the evaluation of cork moisture relating it to the temperature and relative humidity of air. By being able to establish this value, cork can be commercialized on the basis of dry weight or of a known moisture content value, and it will be possible to promote the trust between seller and buyer, with the advantage of a faster commercial transaction, a decrease in financial costs due to raw material immobilisation and a decrease in technical problems (infestations). On the other hand, for industry the quick evaluation of the moisture content can decrease production costs.

A partial study was carried out by Adrados (1994) for cork plancks, and experimental data were fitted to mathematical models which allow the interpolation of the results. The variation of cork moisture content when relative humidity increases, at up two given temperatures (20 °C and 40 °C) was analysed using non-linear regression techniques and it was concluded that the following empirical model was the one that best fitted the experimental data:

$$M = \frac{P_1}{\frac{P_2}{H} - 1} + \frac{P_3}{\frac{P_4}{H} + 1}$$

where

M = cork moisture content (%)
H = air relative humidity (%)
P_i = determined parameters.

2 Plotting of HEM curves

The only isotherms available to date were plotted for 20 °C and 40 °C and are the basis for interpolation and extra-

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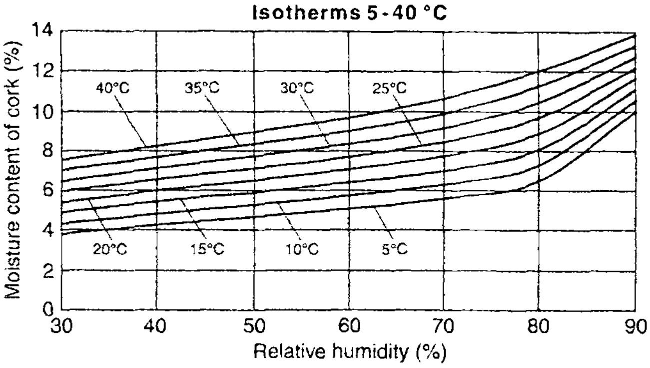

Fig. 1. Cork planks isotherms for hygroscopic equilibrium moisture content
Bild 1. Isothermen der hygroskopischen Gleichgewichtsfeuchten von Korkplatten

polation calculations in order to obtain isotherms for other temperatures.

The ranges for these mathematical treatment were 20–90% RH and 5–40 °C, in steps of 5 °C. It was accepted as valid that intermediate isotherms would fall in intermediate values.

By interpolation the 30 °C isotherm was plotted, passing along the intermediate points between the 20 °C and 40 °C isotherms. Consequently 25 °C and 35 °C isotherms were plotted. Considering that the distance between isotherms is constant for the same temperature difference, 5 °C, 10 °C and 15 °C isotherms were plotted. These interpolation and extrapolation methods lead to Figure 1.

3 HEM curves confirmation

In order to confirm these interpolated and extrapolated curves, some experimental tests were carried out, for the determination of the cork plancks moisture content after conditioning and stabilization at specific air temperature and humidity conditions, to find if the experimental values fall within the range of uncertainty of the curves, calculated using Adrado's equation with the four P_i parameters

Table 1. P_i values and standard deviations for the empirical model
Tabelle 1. P_i-Werte und Standardabweichungen des empirischen Modells

Parameters	$T = 20$ °C	$T = 40$ °C
P_1	0,92 ± 0,79	0,317 ± 0,16
P_2	105,6 ± 10,47	95,68 ± 2,41
P_3	7,78 ± 1,84	6,05 ± 1,43
P_4	11,84 ± 8,49	19,6 ± 7,25

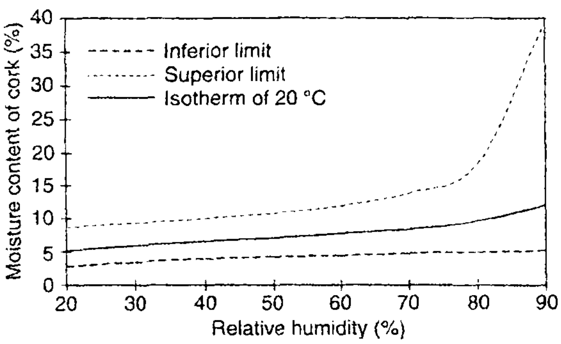

Fig. 2. Limits of the 20 °C isotherm
Bild 2. Grenzen der 20 °C-Isotherme

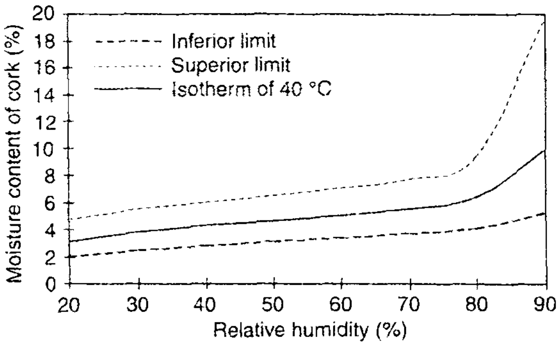

Fig. 3. Limits of the 40 °C isotherm
Bild 3. Grenzen der 40 °C-Isotherme

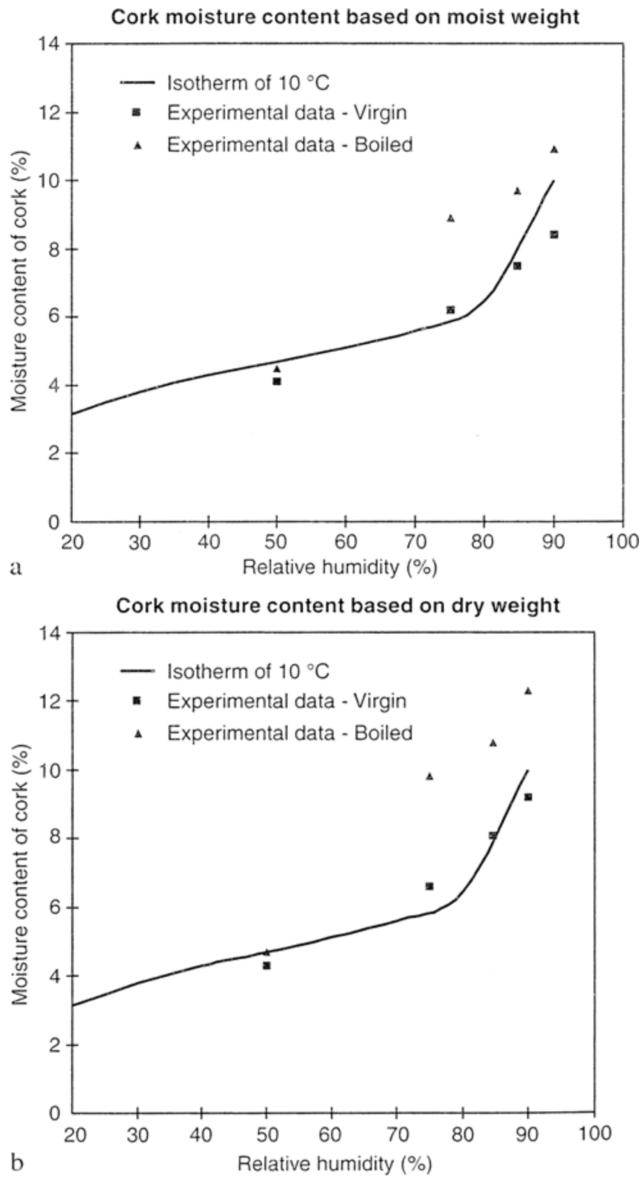

Fig. 4a, b. Isotherm and experimental results for 10 °C; **a** based on moist weight; **b** based on dry weight
Bild 4a, b. Berechnete Isotherme und experimentelle Ergebnisse bei 10 °C; **a** bezogen auf Feuchtgewicht; **b** bezogen auf Trockengewicht

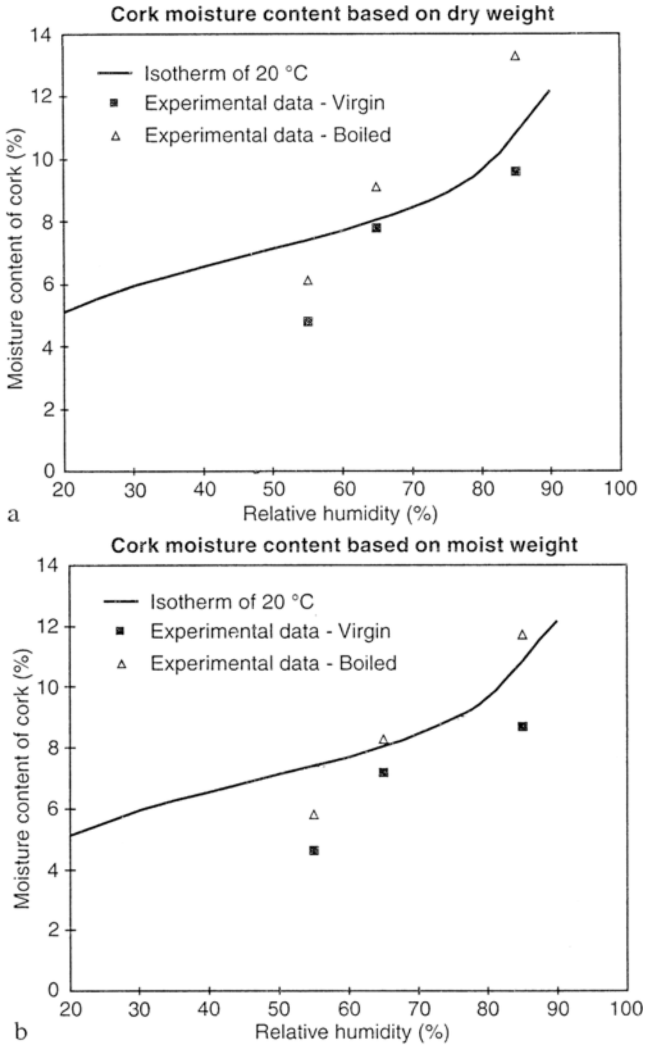

Fig. 5a, b. Isotherm and experimental results for 20 °C; **a** based on moist weight; **b** based on dry weight
Bild 5a, b. Berechnete Isotherme und experimentelle Ergebnisse bei 20 °C; **a** bezogen auf Feuchtgewicht; **b** bezogen auf Trockengewicht

whose values and standard deviations are shown in Table 1, for the two given temperatures (20 °C and 40 °C).

Considering $P_{i\,max}$ and $P_{i\,min}$ values (e.g. $P^{20}_{1\,max} = 0,92 + 0,79$ and $P^{20}_{1\,min} = 0,92 - 0,79$) according to its position on the equation in order to obtain the superior ($P_{1\,max}, P_{2\,min}, P_{3\,max}, P_{4\,min}$) and inferior ($P_{1\,min}, P_{2\,max}, P_{3\,min}, P_{4\,max}$) limits. These results are shown in Figs. 2 and 3.

For the range of 20–80% RH, the uncertainty is ca. 1–3% for cork moisture content. Tests were carried out for the determination of cork moisture content, in two types of cork (boiled reproduction cork and virgin cork) using at least 5 test specimens, according to the Portuguese standard NP 1044 (equiv. to the International standard ISO 2386), where cork moisture content is calculated by the following equation:

$$M = \frac{m_1 - m_2}{m_1 - m_3} \times 100$$

where

M – cork moisture content (%),
m_1 – mass of the vessel with cork before drying,
m_2 – mass of the vessel with cork after drying,
m_3 – mass of the vessel

with the cork moisture content related to the moist cork weight. As there are differences and usually the moisture

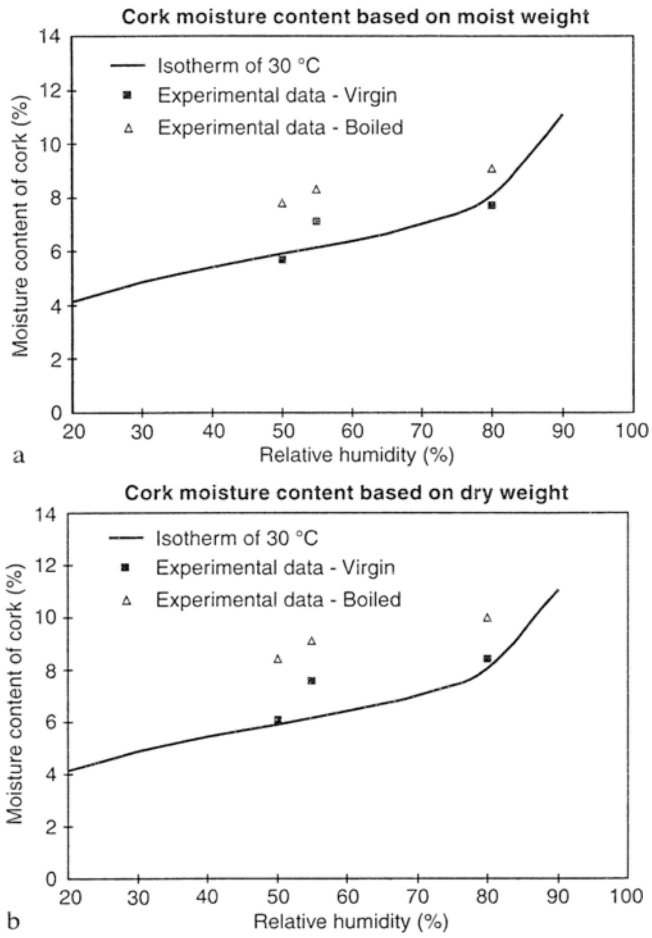

Fig. 6a, b. Isotherm and experimental results for 30 °C; **a** based on moist weight; **b** based on dry weight
Bild 6a, b. Berechnete Isotherme und experimentelle Ergebnisse bei 30 °C; **a** bezogen auf Feuchtgewicht; **b** bezogen auf Trockengewicht

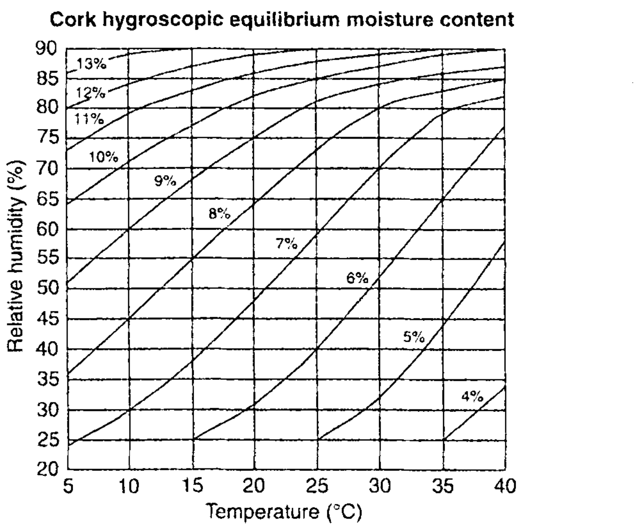

Fig. 7. Cork hygroscopic equilibrium moisture content curves
Bild 7. Hygroskopische Gleichgewichtsfeuchten von Korkplatten

content is related to dry weight (e.g. for wood), the cork moisture content was calculated based on either the moist weight or the dry weight of cork. The moisture content of two cork types was determined for the following conditioning conditions, more representative of environmental average conditions:

$T = 10\ ^{\circ}\mathrm{C}: \ \mathrm{RH} = 50\%; 75\%; 85\%; 90\%;$

$T = 20\ ^{\circ}\mathrm{C}: \ \mathrm{RH} = 55\%; 65\%; 85\%;$

$T = 30\ ^{\circ}\mathrm{C}: \ \mathrm{RH} = 50\%; 55\%; 80\%.$

The results are graphically shown in Figs. 4 to 6. Cork isotherms plotted as is usual for wood (RH.vs.Temperature), derived from Fig. 1, are shown in Fig. 7.

4
Conclusions

These HEM curves are more or less closely related to the experimental data, depending on the moisture content determination basis and on the cork type. Overall the curves appear to be representative for the set of results of moisture content of boiled and virgin cork, related either to dry or moist weight. Boiled cork has usually greater moisture content, for the same conditioning conditions than virgin cork. The curves appear to represent a superior moisture content limit for virgin cork when based on moist weight and an inferior limit for boiled cork.

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