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Water vapour transmission properties of linseed oil paint

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Abstract. Linseed oil paint has been in use in indoor and outdoor decorating for a long period of time. It is not easy to date the first findings but there are signs of using linseed paint at least in V-IX century in some areas of Afghanistan and during the renaissance period in Europe. It is also known as a good preservative material for wood. Indoor finishing materials considerably influence the indoor climate (temperature, RH, ventilation rate) because of their moisture buffering ability. Moisture buffering occurs because of the sorption and diffusion properties of materials (wood, plaster, gypsum board etc.). As paint is a cover for those materials, the knowledge about material water vapour transmission properties is essential for evaluating hygrothermal properties of boarders and the co-action of paint and substrate (plaster). There could be products with different properties referred to as 'linseed oil paint'.

In the current study six handmade paints with different recipes including two primers and two commercial paints were under investigation. As for interior works, one layer of paint could be used as well therefore the samples were covered with both – one and two layers of paint. The thickness of paint layers varied from 0.8 and 6.2 μm for one-layer primers, from 11.3 to 26.9 μm for one-layer paints and from 17.8 to 40.7 μm for two-layer paints. Water vapour transmission properties were determined by using EVS-EN ISO 7783 standard.

Water vapour diffusion equivalent air layer thickness s_d was estimated as 0.1 and 0.2 m for 1-layer primers, 0.2 to 0.9 m for 1-layer paints and 0.4 to 0.9 m for 2-layer paints. The information gathered from the experiment enables to get an overview of the different properties of 'the same product" and use the data in hygrothermal calculations.

Key words: linseed oil paint, water vapour transmission, water vapour permeation coefficient, water vapour diffusion equivalent thickness, water vapour resistance factor.

INTRODUCTION

The study focuses on water vapour transmission properties of different linseed oil paints.

Linseed oil paint has been in use in indoor and outdoor decorating for a long period of time. It is not easy to date the first findings but there are signs of using linseed paint at least from V–IX century in some areas of Afghanistan (History of Linseed oil Painting…; Secrets of Bamiyan Buddhas.).

Linseed oil paint was used for interior works in the XVI century in painting art and room decorating earlier as can be read from Theophilius tractate 'Schedula Diversarum Artium' (Using of linseed oil …).

Also, it is known as the oldest timber paint for outdoor use in Central Europe in the Renaissance period already. The oldest written data about outdoor use of paint in Sweden and Finland indicate that linseed oil as a binder in different mixtures was used already in XVI century. In the 1950–60s alcyd paints were taken into intensive use but oil paints did not disappear and today they have made comeback (Kaila, 1999).

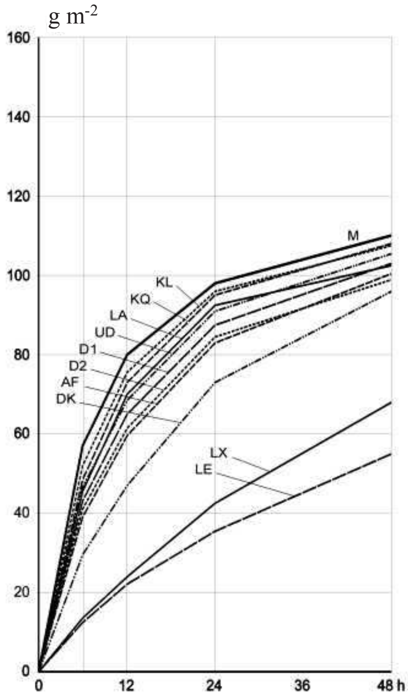
Natural and traditional paints are quite popular in the restoration of buildings and in designing new interior as well. Compared with frequently used traditional paints like casein paint and egg tempera, and commercial alcyd paint, linseed oil paint has water vapour transmission rate more or less equal to alcyd paints (Ruus et al., 2011).

Linseed oil is also known as a good preservative material for wood.

Besides temperature, relative humidity (RH) is one of the key parameters of indoor climate and can be determined by measuring indoor moisture generation, air-change rate, and the release or uptake of moisture by hygroscopic surface materials as well as moisture flow through structures (Kurnistki et al., 2007.)

There is a need for deeper and more exact information about the the behaviour of indoor paints as a part of wall in diffusion calculations and coating of hygroscopic materials offering moisture buffering values (MBV).

The influence of different paints depending on time was studied by Minke (2006). It can be seen (Fig. 1) that on silty loam substrate the lime (KQ), casein and cellulose glue paint (KL) only slightly reduce the absorption (after a sudden increasing RH from 50–80%), whereas double latex (LX) and single linseed oil (LE) coating can reduce absorption rates to 38% and 50% respectively.



M – Silty loam without coating;
KQ – 2x Lime paint;
KL – 2x Chalk cellulose glue paint;
LE – 1x Double-boiled linseed oil;
D2 – 2x Biofa dispersible paint
LA – 1x Biofa glaze with primer;
AF – 2x Acrylic paint;
DK – 2x Synthetic dispersion paint exterior;
LX – 2x Latex;
UD – 2x Dispersion paint without solvent;
D1 – 2x Dispersion paint for interio.

Figure 1. Influence of coatings on 1.5 cm-thick one-side exposed loam plasters at temperature of 21 °C (Minke, 2006).

The influence of coating on vapour diffusion thickness could depend on using or not using the primer under paint (primer + 2 layers of paint) and on the base material also (Ramos et al, 2010). Using primer for vinyl paint increased S_D (RH = 54%) value 7.1 times on base material of gypsum board, 4.4 times for gypsum plaster and 1.5 times for gypsum + lime plaster.

Brachaczek (2014) proposed statistical models for the optimization of the recipe configurations for silicone coatings. Combining the analysis of physical parameters determining the quality of the coatings (hydrophobicity, resistance to wet scrubbing and the ability to diffuse water vapour through the coatings), the results enabled the selection of the optimal ranges of values for the analysed factors, from a physical as well as an economic point of view.

In the study paint samples as non-self-supporting systems were prepared. Thickness and water vapour transmission rate were estimated to get an idea about the differences. Afterwards numerical values derived for the water vapour permeation coefficient δ_c, water vapour diffusion equivalent thickness, s_d and water vapour resistance factor μ for different linseed oil paints and primers.

MATERIALS AND METHODS

In the current study six handmade paints with different recipes including two primers and two commercial paints were under investigation. Standard EVS-EN ISO 7783:2011 was followed in the testing procedure. Standard methodology was chosen for making results comparable and more clearly understandable.

As for interior works, one layer of paint could be used also therefore samples with both, one and two paint layers (three test pieces of each) were studied.

Recipes used for handmade paints are the following:

I – primer: varnish 0.2 l, turpentine 0.2 l, zinc oxide ~100 g, titanium dioxide ~100 g, chalk 80 g;

II – paint: varnish ~0.30 l, zinc oxide ~50 g, titanium dioxide ~200 g, kaolin 50 g;

III – paint: varnish 0.25 l, titanium dioxide ~175 g, zinc oxide 25 g, kaolin 75g;

IV – paint: varnish 0.25 l, red pigment (iron oxide) ~200g, kaolin 25 g;

V – primer: varnish 0.2 l, turpentine 0.2 l, titanium dioxide 100 g;

VI – paint: varnish 0.16 l, titanium dioxide 200 g, zinc oxide 100 g.

Another group is presenting commercial paints:

X – commercial paint of large enterprise;

XI and XII – commercial paint from a small enterprise;

XII – has some defects – includes pieces.

Turpentine was used as a solvent for primers. For both primers the amount of solvent was equal with binder. Traditional recipe for one primer (mixture I) was modified by increasing amount of solid powder part twice. That enables to satiate the substrate surface not just cover. Another primer (mixture V) was made on the basis of a traditional primer recipe.

Mixtures II, III, IV are VI present different recipes of paints in use. Mixtures II, III and IV have similar proportions of liquid binder as varnish and solid powder as pigment plus filler (approx. 0.1 l liquid + 100 g of solid). In the recipe VI the proportion is approx. 0.1 l of liquid and 200 g of solid powder.

The samples with one-layer paints were dried for 5 and two-layer paints for 8 days in the room with natural air circulation and air temperature of 20 ± 2 °C and relative humidity of 35 ± 5%. From each sample three test pieces were cut out. 36 paint test pieces in total and three for carton as substrate were tested in RUMED 4101 climate chamber affording RH of 20–95%, with accuracy of ± 2–3% and temperature of 0–+60 °C with accuracy of ± 0,5 °C (Fig. 2).

Air temperature was maintained at 23 °C and relative humidity at 50% in the climate chamber (according to standard methodology). In the vessel the relative humidity was kept at 93% using ammonium dihydrogen phosphate ($NH_4H_2PO_4$) saturated solution. The test pieces were weighed once a day until weight loss speed was stabilizing using Mettler PC440 Delta Range weight, providing test area of 0.5–400 g and accuracy of 0.01 g not exactly meeting standard requirements. The accuracy of 0.01 g is suitable for pieces with areas 50 cm^2 and larger. In the current study the testing area was 42 cm^2. An interval of 24 hours was chosen for linseed oil paint which is known as a material with low water vapour permeability. In all cases the change of mass was higher than 50 mg as described in the standard procedure.

Figure 2. Test pieces sealed on vessels.

The thickness of the coating was estimated with micrometer. The total thickness of substrate plus coating and carton were measured. Thickness of paint was calculated.

Water vapour transmission rate of the coating can be expressed with the formula

$$\frac{1}{V} = \frac{1}{V_{cs}} - \frac{1}{V_s} \tag{1}$$

$$V = \frac{V_{cs} \cdot V_s}{V_s - V_{cs}} \tag{2}$$

where: V – water-vapour transmission rate, g (m^2 d)$^{-1}$; V_{cs} – water vapour transmission rate of the substrate plus coating, g (m^2 d)$^{-1}$; V_s – water-vapour transmission rate of the substrate, g (m^2 d)$^{-1}$.

The water vapour permeation coefficient of the coating δ_c, (g (m d Pa)$^{-1}$) can be found using the formula:

$$\delta_c = \frac{V \cdot d}{\Delta_{pV}} \qquad (3)$$

where: d – thickness of coating, m; Δp_V – the water-vapour partial pressure between two sides of the coating, Pa.

Water vapour diffusion equivalent thickness s_d, (m), can be calculated with the formula

$$s_d = \frac{\delta_a \cdot \Delta_{pV}}{V} \qquad (4)$$

where: δ_a – water vapour permeation coefficient of the air at standard temperature and pressure 0.016 g (m d Pa)$^{-1}$

Water vapour resistance factor μ (–), can be calculated with the formula

$$\mu = \frac{s_d}{d} \cdot 10^6 \qquad (5)$$

RESULTS AND DISCUSSION

The thickness of carton was 28.6 ± 0.7 μm. Water-vapour transmission rate for carton was 627.6 ± 104.8 g (m^2 d)$^{-1}$. Water vapour transmission rate for paint layers was calculated with the formula 2 (see Table 1). The water vapour permeation coefficient of air δ_a = 0.016 g (m d Pa)$^{-1}$ was used in the calculations.

Three test pieces is the minimum amount required in standard but causes too large variability in results and it makes comparison difficult. The data presented in Table 1 gives some overview of possible values and variability of data.

Table 1. Thickness of coating and water vapour transmission rate of linseed oil paint

Sample	One-layer coating		Two-layer coating	
	d, μm	*V*, g (m^2 d)$^{-1}$	d, μm	*V*, g (m^2 d)$^{-1}$
I	6.2 ± 3.4	90 ± 58.5	15.7 ± 7.1	55.4 ± 8.4
II	11.3 ± 7.4	27.3 ± 7.5	33.3 ± 7.8	33.7 ± 14.5
III	19.0 ± 4.4	29.5 ± 11.6	40.7 ± 9.1	24.9 ± 21.4
IV	12.2 ± 4.9	43.8 ± 14.4	32.0 ± 4.0	27.9 ± 7.2
V	0.77 ± 0.7	209,1 ± 2.7	7.5 ± 6.1	101.2 ± 4.1
VI	26.9 ± 23.3	20.3 ± 6.7	39.8 ± 20.4	21.9 ± 14.0
X	12.6 ± 3.3	73.2 ± 37.8	17.8 ± 6.7	46.9 ± 29.0
XI	15.5 ± 2.7	82.1 ± 63.8	24.9 ± 1.4	42.6 ± 16.9
XII	17.0 ± 9.2	83.1 ± 35.7	29.2 ± 9.8	53.2 ± 49.3

The thickness of one-layer samples was from 0.77–26.9 μm on average. For two layers thickness of 7.5–40.7 μm was measured. The thickness of traditional primers (V) was under 1 μm for one-layer and 7.5 μm for two-layer samples. The difference occurred probably because liquid mixture was absorbed by porous surface.

According to the average it can be seen that traditional primer has also the highest water vapour transmission rate – 209.1 for one-layer and 101.2 g (m^2 d)$^{-1}$ for two layers.

Paint having proportionally the largest solid powder content ratio (sample VI) gives almost highest results in thickness (26.9 and 39.8 μm) and lowest in water vapour transmission rate 20.3 and 21.9 g (m^2 $d)^{-1}$.

Paints with the same recipe and technology (XI and XII) seems to give similar results, but in most cases variability seems to be higher for the paint with defects.

As the variability of results is large, *t-test* was chosen to analyse the results of water vapour transmission rate as a first result derived from the measurements.

T-test ($P < 0.05$) shows that one-layer paints sample V (traditional primer) has statistically significant difference compared to all others. Sample VI has also statistically significant difference compared to others. For example compared with Sample II $P = 0.04$. For other samples differences can be seen in some cases: I–II $P = 0.04$, I–IV $P = 0.02$, III–IV $P = 0.03$, XII–IV $P = 0.02$.

Using *t-test* for two-layer paints indicated that Sample V has statistically significant difference from other paints except Sample XII, where variability is too large to show any difference. The primer with modified recipe (Sample I) differs from other paint samples like II ($P = 0.01$), III, IV and VI.

The classification given in the mentioned standard (EN ISO 7783-2 2001) determines that most samples are classified as medium II class (medium) V = 15–150 g (m^2 $d)^{-1}$ and only one-layer primer (sample V) is in class I (high) > 150 g (m^2 $d)^{-1}$. Water-vapour partial pressure between two sides of the sample Δ_{pV} was calculated at 2 °C and saturated water vapour pressure of 2,643 Pa (Hutcheon & Handegord, 1984) and found to be (0.93–0.5)*2,643 = 1,136.5 Pa.

The water vapour permeation coefficient of the coating δ_c (g (m d $Pa)^{-1}$), water vapour diffusion equivalent thickness s_d (m) and water vapour resistance factor μ (m) were calculated with the help of the formulas 3, 4, 5 for each test piece and the results are presented in Table 2 and Figs 3–5.

The maximum and minimum values calculated are used hereby to present the range of values. For Water vapour resistance factor μ values are rounded to the nearest 100.

Table 2. The water vapour permeation coefficient of the coating δ_c (g (m d $Pa)^{-1}$,), water vapour diffusion equivalent thickness, s_d (m) and water vapour resistance factor μ (–) for samples of linseed oil paint

Sample	δ_c *10^{-7} g (m d $Pa)^{-1}$	s_d, m		μ, –
		One-layer	Two layers	
I	3.4–9.2	0.16–0.26	0.31–0.35	17,400–46,600
II	2.3–13.1	0.60–0.75	0.45–0.62	12,200–70,000
III	4.2–12.0	0.52–0.70	0.58–1.20	13,300–38,100
IV	3.8–9.0	0.37–0.49	0.60–0.73	17,800–42,000
V	1.0–8.3	0.09	0.18	19,300–39,100*
VI	3.3–7.7	0.78–1.00	0.66–1.13	20,800–48,400
X	4.6–8.9	0.21–0.32	0.32–0.53	18,000–35,000
XI	4.8–16.9	0.17–0.32	0.38–0.52	9,500–33,100
XII	7.7–20.7	0.20–0.27	0.25–0.54	7,700–20,900

*only two-layers have been taken into account.

The water vapour permeation coefficient of the coating δ_c g (m d Pa)$^{-1}$ (Fig. 3) and water vapour resistance factor μ (–) (Fig. 5), which are material properties, have to be similar not depending whether they are estimated by one or two layers. In some cases (Sample II, IV, V) μ-value has clearly lower value for two layers. That is probably because of substrate adsorption and indicates that micrometer is not the best tool for measuring the thickness of paint layer and calculation based on the application rate recommended in the standard is more reliable.

It is exceptional that s_d values for two layers have to be twice as much as for one layer paint (Fig. 4). Actually, it can be seen very clearly only on traditional primer s_d = 0.09 for one layer and 0.18 m for two layers. Compared with the sample VI, the paint with the highest percentage of solid powder (s_d = 0.66–1.13 m), the difference is clearly noticeable.

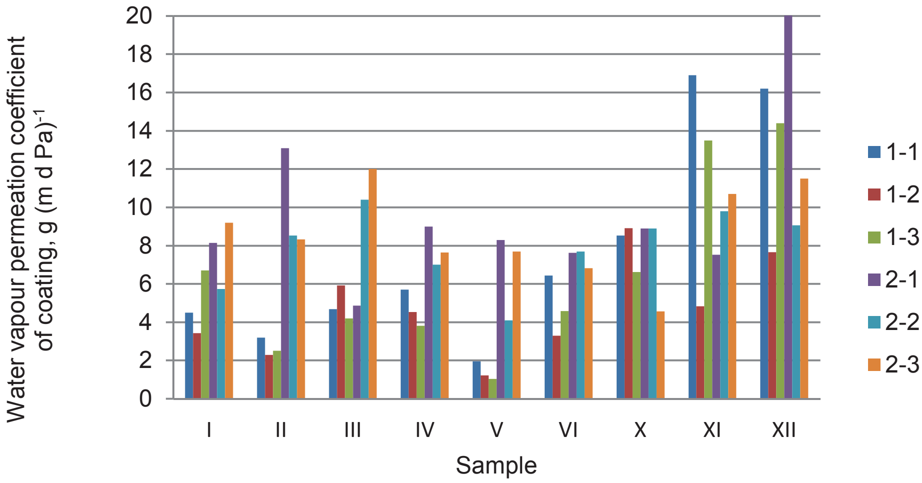


Figure 3. The water vapour permeation coefficient of the coating δ_c (g (m d Pa)$^{-1}$).

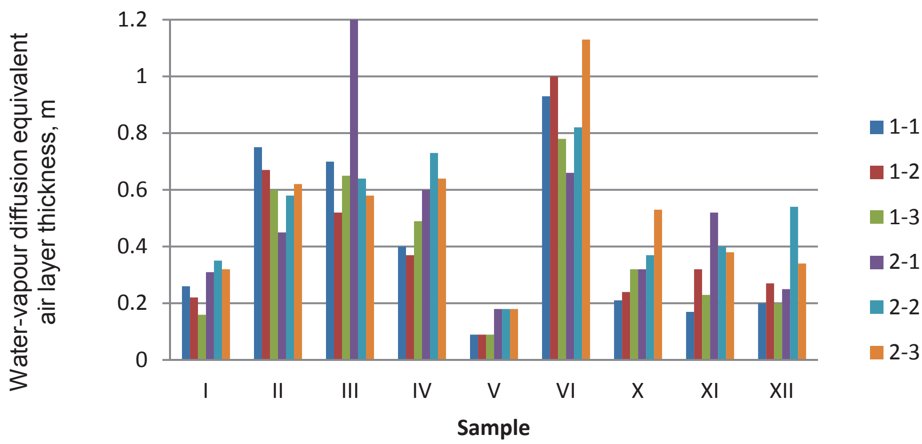


Figure 4. Water vapour diffusion equivalent thickness s_d (m).

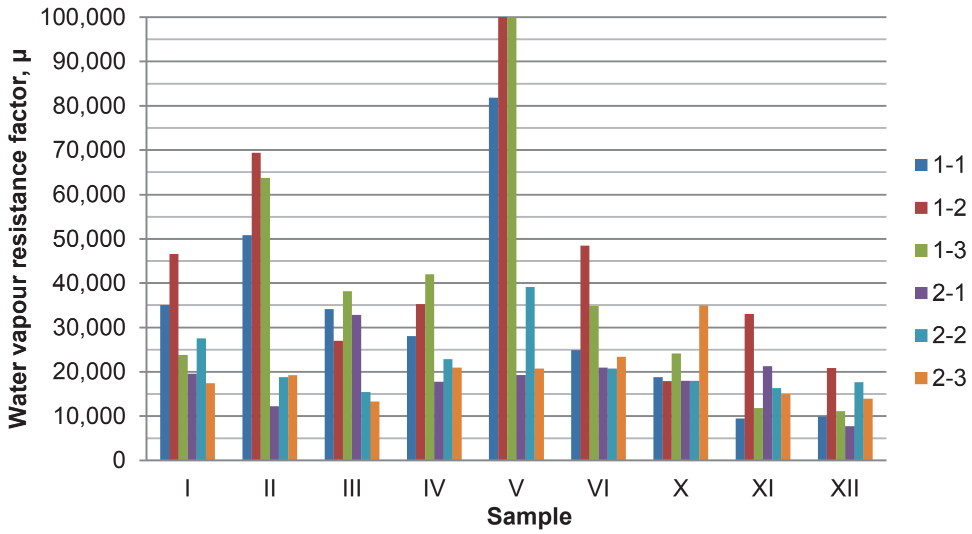


Figure 5. Water vapour resistance factor μ (–).

From the data presented in Table 2 s_d values are most reliably usable, while vapour permeation coefficient and water vapour resistance factor can be more tested with a larger number of test pieces to reduce the variability. For comparison in standard EVS EN ISO 10456:2008 presenting hygrothermal properties of building materials and products next values are can be found: emulsion paints s_d = 0.1 m, gloss paints s_d = 3.0 m and vinyl wallpaper s_d = 2.0 m.

CONCLUSIONS

Today energy efficiency or hygrothermal calculations are becoming more and more detailed and are performed with computer software enabling monthly, daily or hourly data based modelling. For the calculations of such accuracy, a detailed input of material data is needed.

The information gathered from the experiment enables to get an overview of the different properties of 'the same product' and use the data in hygrothermal calculations.

In the current study the data is presented in two ways:

1) thickness and water vapour transmission rate i.e .practical values giving an overview of the real situation,

2) material parameters for diffusion calculations in building physics.

Three test pieces is a minimum amount required in standard but causes too large variability of results and makes comparison difficult. In the further studies more test pieces have to be used.

The results of the water vapour permeation coefficient of the coating δ_c, water vapour diffusion equivalent thickness, s_d and water vapour resistance factor μ could be useful in hygrothermal calculation.

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