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EFFECTS OF NANO-SILVER ON GAS AND LIQUID PERMEABILITY OF PARTICLEBOARD

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Effects of 200 ppm aqueous dispersion of silver nano-particles on gas and liquid permeability of particleboards is studied here. Nano-silver was added at two levels of 100 and 150 milli-liters/kg dry weight wood particles and compared with control boards; all other manufacturing variables remained constant. Gas permeability values were measured at 7 different vacuum pressures in a single run and correlation of each was analyzed with two liquid permeabilities as 1st drop time and 50-mm-lowering time; both liquid permeabilities were measured using Rilem test tube. Results showed that 100 ml/kg made permeability decrease by about 90% which is due to better heat-transfer to the center layer of the mat making better polymerization of resin. Also, all 7 vacuum pressures nearly presented the same permeability values except the vacuum pressure at the first water column height due to high fluctuations at the beginning of each run. 50-mm-lowering liquid permeability is recommended for estimation of gas permeability of particleboards because of its higher correlation.

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Keywords: Gas and Liquid Permeability; Nano-Silver; Particleboard; Vacuum Pressure.

1. Introduction

Hot-presses are usually considered a bottle-neck for nearly all wood-composite manufacturing factories (Doosthoseini, 2001). Minimum pressing time of a particleboard primarily depends on heat transfer, which in turn varies with thickness, press temperature, closing rate, and mat moisture distribution. When high internal steam pressures are involved, presstimes necessary to prevent blows depend on such factors as resin type, density, press temperature, and total MC (Lehmann et al., 1973). Based on non-heat-conductivity nature of wood, several methods have so far been created to shorten presstime, saving time and energy. Still, except where controlled by high internal pressures or excessive moisture contents, the time required to maintain centerline temperatures varies only slightly. Also, final pressure, although a good indicator of minimum presstime within a board type varies considerably (Lehmann et al., 1973). However, for urea-formaldehyde (UF) resin, there is a limitation of MC level (Papadopoulos, 2006).

Heat-conductive property of nano-metal-particles (Taghiyari, 2011; Taghiyari et al., 2011; Taghiyari et al., 2012; Taghiyari, 2012) might be used to transfer the heat from platens to the core of the mat more efficiently and rapidly, and eventually decrease heat-gradient across the wood-particle mat. The present study is, therefore, aimed at finding its effects on gas permeability at 7 different vacuum pressures, as well as on two liquid permeabilities. The correlation between gas permeability at each vacuum pressure with the two liquid permeabilities were also analyzed. In order to assess the possibility of using this process on an industrial scale, nano-silver-boards were manufactured at industrial dimensions at the Iran-Choob factory using the same machines and equipment of commercial particleboards.

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2. Materials and methods

Particleboard Production

Particleboards were made in Iran-Choob factory, Ghazvin, Iran. Boards were 16 mm in thickness, 0.7 g/cm^3 in density. Chips were comprised of poplar spp. Temperature of hot-press plates were fixed at 200°C. Specific pressure of plates was 25 kg/cm^2; total nominal pressure of the plates was 200 kgf. Dimensions of the boards produced on industrial scale were 530 × 130 × 1.6 cm. Urea-Formaldehyde (13%), plus 1% ammonium chloride (NH_4Cl) as hardener, was used as the resin. 200 ppm nano-silver suspension was made using electrochemical technique in collaboration with Jafr Sorkhe Fajr Co. (Ltd.) and added to the resin before mixing the resin with wood particles; pH and viscosity of the resin were kept constant for all treatments in the present study. Nano-silver was used at two levels of 100 and 150 ml/kg wood particle, based on the dry wood basis of wood particles; therefore, there were three treatments of: 1- control, 2- 100 ml of NS/kg, and 3- 150 ml of NS/kg. Boards were kept at the warehouse for two months before gas and liquid permeability tests were done.

Nano-silver Suspension Production

A 200 ppm aqueous dispersion of silver nano-particles was made using an electrochemical technique in collaboration with Jafr Sorkhe Fajr Co. (Ltd.). The size range of silver nanoparticles were from 10 to 80 nm. The pH of the suspension was 6 – 7; two kinds of surfactants (anionic and cationic) were used in the suspension as stabilizer; the concentration of the surfactants was three times the nano-silver particles. The nano-silver suspension was added at two levels of 100 and 150 ml/kg based on the dry weight of wood particles.

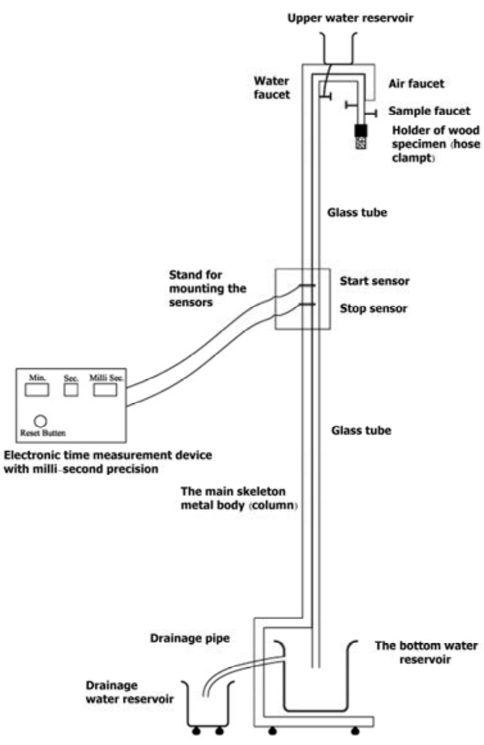

Fig. 1. The overview of the gas permeability apparatus (USPTO Pub. No. 2010/0281951 A1) equipped with single-storey milli-second precision electronic time measurement device (Taghiyari & Efhami, 2011).

Table 1. Vacuum pressures at starting and stopping points for each of the 7 measuring heights.

Code of the 7	Height of the 7	Height of the 7	Starting point	Stopping point

Water Columns	Water Columns at Starting Point (cm)	Water Columns at Stopping Point (cm)	vacuum pressure (minus milli-bar)	vacuum pressure (minus milli-bar)
Gas 1	149.5	139.5	155	146.5
Gas 2	134.5	124.5	141.5	132
Gas 3	119.5	109.5	126.5	117
Gas 4	104.5	94.5	112	101.5
Gas 5	89.5	79.5	97.5	86.5
Gas 6	74.5	64.5	82	72
Gas 7	59.5	49.5	66.5	56

Gas Permeability Measurement

Longitudinal gas permeability measurement was carried out by an apparatus designed and built by the author (Taghiyari & Efhami, 2011) (Fig. 1) equipped with 7-storey automatic-time-measurement device with milli-second precision. Falling-water volume-displacement method was used to calculate specific longitudinal gas permeability values based on the microstructure porosity of wood (Siau 1971, Taghiyari et al. 2010). 20 specimens were randomly cut at scattered locations from the boards of each treatment by a hole-saw. Diameter of specimens was 17 mm. For each specimen, gas permeability values were measured at 7 different water-column heights, that is 7 different vacuum pressures, in a single run. Internal diameter of the glass tube was 13 mm. Water level was 15 cm above the starting sensor of the first time-measurement device (Gas 1). Connection between the specimen and holder was made fully air-tight. A pressure gauge with milli-bar precision was connected to the whole structure to monitor pressure gradient (ΔP) and vacuum pressure at any particular time as well as height of water column. Vacuum pressures at starting and stopping points for each of the 7 different heights are listed in Table 1.

Three measurements were taken for each specimen. Superficial permeability coefficient was then calculated using Siau's equations (Siau, 1995) (equations 1 and 2). The superficial permeability coefficients were then multiplied by the viscosity of air (μ=1.81×10^{-5} Pa s) for the calculation of the specific permeability ($K=k_g\,\mu$).

(Equation 1) $$k_g = \frac{V_d C L (P_{atm} - 0.074\bar{z})}{tA(0.074\bar{z})(P_{atm} - 0.037\bar{z})} \times \frac{0.760mHg}{1.013\times10^6 Pa}$$

(Equation 2) $$C = 1 + \frac{V_r(0.074\Delta z)}{V_d(P_{atm} - 0.074\bar{z})}$$

***Where*:**

k_g = longitudinal specific permeability (m^3 m^{-1})
$V_d = \pi r^2 \Delta z$ [r = radius of measuring tube (m)] (m^3)
C = correction factor for gas expansion as a result of change in static head and viscosity of water.
L = length of wood specimen (m)
P_{atm} = atmospheric pressure (m Hg)
$\bar{z}$ = average height of water over surface of reservoir during period of measurement (m)
t = time (s)
A = cross-sectional area of wood specimen (m^2)
Δz = change in height of water during time t (m)
V_r = total volume of apparatus above point 1 (including volume of hoses) (m^3)

Liquid Permeability Measurement

Liquid permeability was measured using Rilem test method II.4 (Fig. 2) according to Rilem Commission 25, PEM, Test Method 1154 by International Union of Laboratories and

Experts in Construction Materials, Systems, and Structures; penetration tests were conducted under laboratory conditions according to ASTM E-514. Two times were measured: 1- The time the first drop of water falls off the bottom surface of the specimen; 2- The time the level of water in Rilem tube lowers by 50 mm in the tube (that is, 6.6 CC of water). Correlations between each of the 7 gas permeability times were separately calculated with the-first-drop time, as well as 50-mm-lowering time.

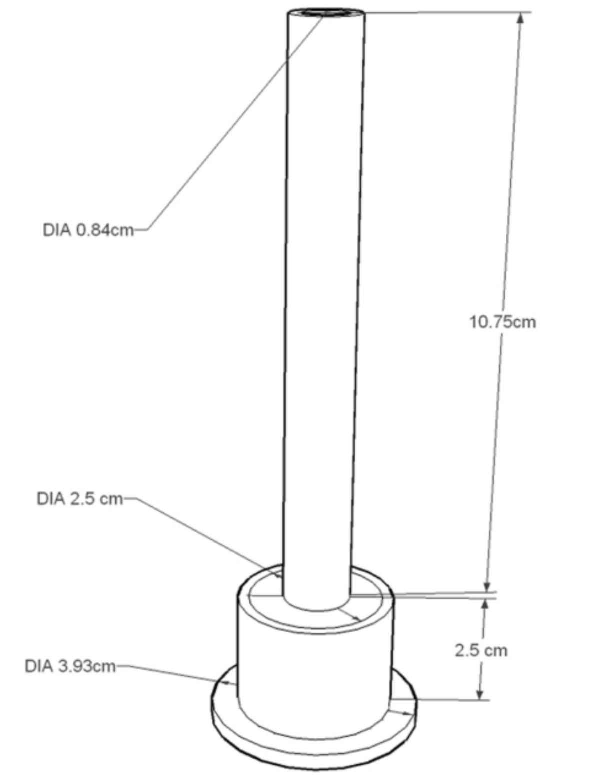

Fig. 2. Liquid permeability measurement apparatus (Rilem).

Statistical Analysis

Analysis of variance (ANOVA) was conducted using SAS software program, version 9.1 at 99% confidence level. Regression analysis was done using SPSS 16 software. Hierarchical cluster analysis, including dendrogram and using Ward methods with squared Euclidean distance intervals, was done by SPSS/16.

3. Results

Gas Permeability

Results showed that specific gas permeability values were the lowest in 100 ml/kg boards, and highest in control specimens. Nano-silver particleboards at 100 ml/kg level showed about 90% decrease, and at 150 ml/kg level showed about 20-30% decrease (depending on the vacuum pressure) in comparison to control particleboards. Specific gas permeability value for control, 100 ml/kg, and 150 ml/kg particleboards at the third water column height (Gas 3) were measured to be 0.022, 0.002, and 0.015 ($\times 10^{-13}$ m^3 m^{-1}) respectively.

Specific gas permeability values showed nearly the same values for all 7 different water column heights (Figures 3, 4, and 5). The highest consistency between different heights was seen in 100 ml/kg boards, and the lowest in control particleboards.

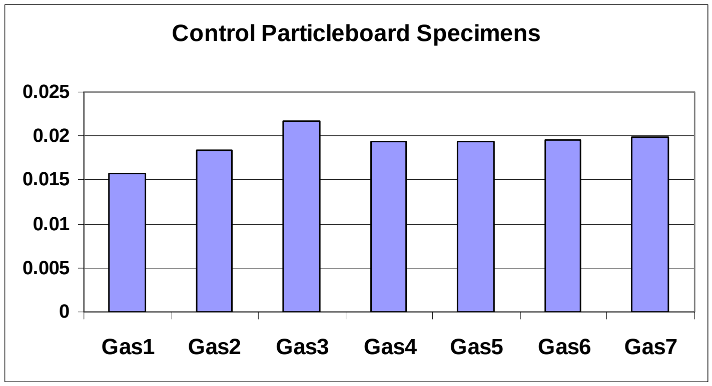

Fig. 3. Specific gas permeability values for control particleboards specimens at 7 different vacuum pressures (× 10^{-13} m^3 m^{-1})

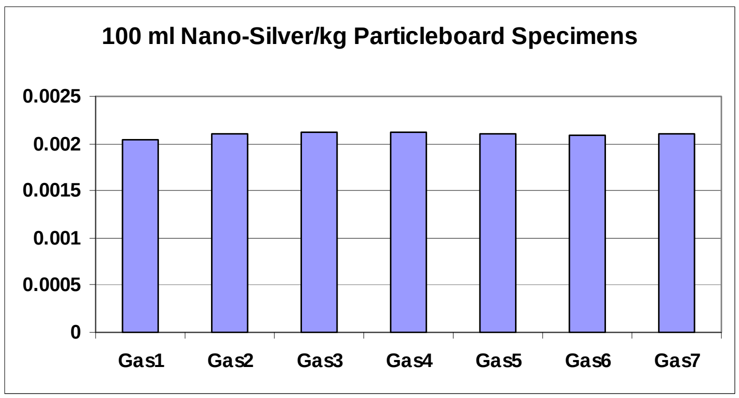

Fig. 4. Specific gas permeability values for 100 ml nano-silver/kg particleboards specimens at 7 different vacuum pressures (× 10^{-13} m^3 m^{-1})

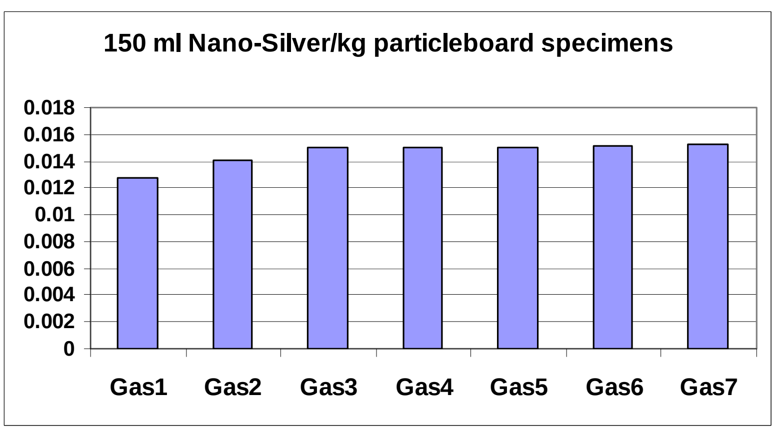

Fig. 5. Specific gas permeability values for 150 ml nano-silver/kg particleboards specimens at 7 different vacuum pressures (× 10^{-13} m^3 m^{-1}).

Liquid Permeability

1st drop time was lower than 50-mm lowering time in all 3 treatments of control, 100 ml/kg, and 150 ml/kg (Fig. 6). The lowest 1st-drop liquid permeability time was found in control specimens (110.6 s), and highest in 100 ml/kg (902.1 s). Also, the lowest 50-mm lowering time was found in control specimens (331.5 s), and the highest in 100 ml/kg specimens (2,428.6 s).

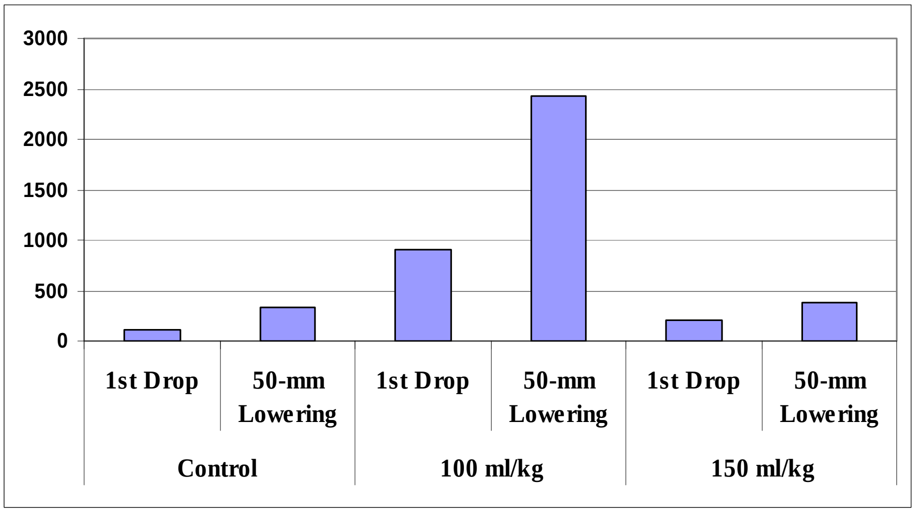

Fig. 6. The two liquid permeability times for the three treatments of control, 100 ml/kg, and 150 ml/kg (s)

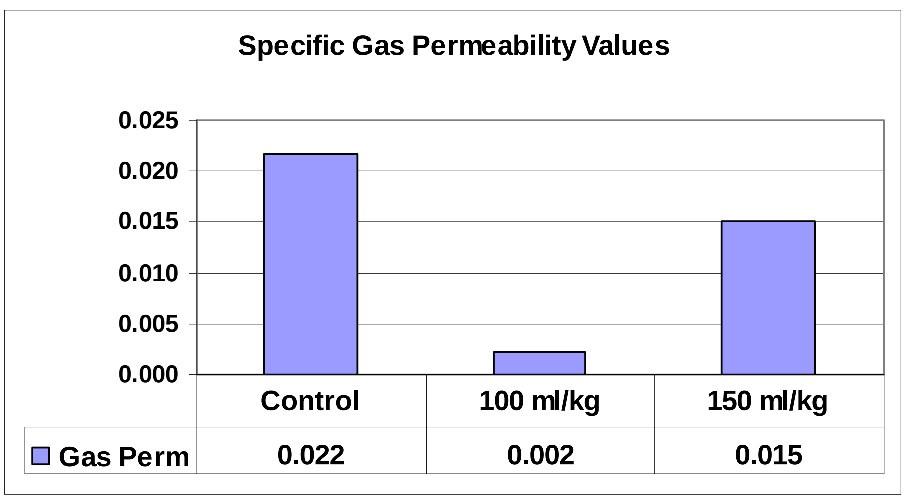

Fig. 7. Specific gas permeability values of the three treatments of control, 100 ml/kg, and 150 ml/kg at the third vacuum pressure (Gas 3) (× 10^{-13} m^3 m^{-1})

4. Discussion

All 7 water column heights, that made 7 different vacuum pressures, made nearly the same specific gas permeability values; therefore, it may be concluded that water column height does not significantly affect specific gas permeability. The only height showing different specific gas permeability value was the first height (Gas 1). The reason may be traced to the vacuum shock when sample faucet (Fig. 1) is turned open; the sudden drop of water in the water column makes a vacuum shock and consequently vacuum pressure changes instantly. Therefore the permeability value calculated based on the first height may not be considered authentic although it may show a high correlation with the other water column heights (Table 2). As the water column continues to drop in the glass column, the sudden shock fades out and vacuum pressure gauge shows a constant vacuum pressure decreasing gradually as the water level in the glass water column continues to drop steadily. This makes the other 6 water column heights consistent with each other showing authentic specific gas permeability for each specimen.

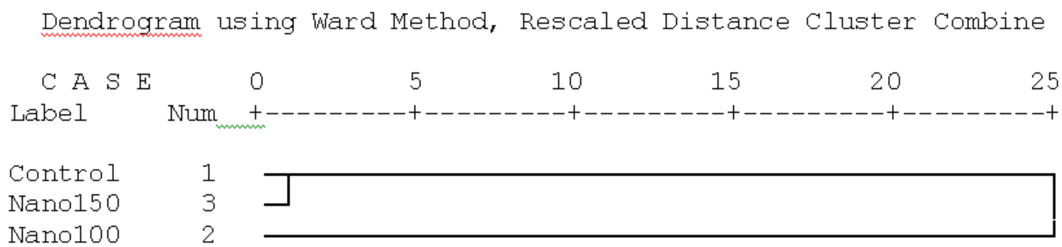

Fig. 8. Cluster analysis of the three treatments (control, 100 ml/kg, and 150 ml/kg) based on the seven gas permeability and the two liquid permeability values

Table 2. Regression analysis of the 7 gas permeability time values of different water column heights with liquid permeability time values (1st drop and 50-mm-lowering) .

Gas and Water Permeabilities	Gas 1	Gas 2	Gas 3	Gas 4	Gas 5	Gas 6	Gas 7
1st Drop	0.883 ** (+)	0.885 ** (+)	0.889 ** (+)	0.886 ** (+)	0.876 ** (+)	0.866 ** (+)	0.875 ** (+)
50-mm Lowering time	0.950 ** (+)	0.948 ** (+)	0.950 ** (+)	0.949 ** (+)	0.937 ** (+)	0.932 ** (+)	0.935 ** (+)
Gas 1	**1**	0.998 ** (+)	0.998 ** (+)	0.998 ** (+)	0.991 ** (+)	0.991 ** (+)	0.990 ** (+)
Gas 2		**1**	0.999 ** (+)	0.999 ** (+)	0.991 ** (+)	0.992 ** (+)	0.990 ** (+)
Gas 3			**1**	1.000 ** (+)	0.992 ** (+)	0.992 ** (+)	0.991 ** (+)
Gas 4				**1**	0.994 ** (+)	0.995 ** (+)	0.993 ** (+)
Gas 5					**1**	1.000 ** (+)	1.000 ** (+)
Gas 6						**1**	1.000 ** (+)
Gas 7							**1**

** Statistically significant at the 1 % level.
Gas 1 – 7: The 7 water column heights for measuring gas permeability representing the 7 vacuum pressures
(+) Positive correlation

Liquid permeabilities showed nearly the same increasing or decreasing trend as in gas permeability in all treatments. Correlation analysis of each vacuum pressure with the two liquid permeabilities showed high R-square, but the greatest correlations were found for the third vacuum pressure that is Gas 3 (Table 2). Therefore, this vacuum pressure, in other words this water column height, is recommended for further measurement and reports on gas permeability of particleboards.

Gas and liquid permeability values in the three treatments are quite compatible with lower water absorption and thickness swelling (Taghiyari et al., 2011). Heat conductivity of nano-silver particles made better polymerization of resin in the center and surface layers of the mat causing better bonds occur among wood particles ending up in a more consistent matrix of resin-wood particles. This has eventually made less space available for fluid (gas and water) to transfer or penetrate through the boards and consequently less permeability (Fig. 7), as well as less water absorption and thickness swelling, were found in nano-silver particleboards. In the meantime, 100 ml/kg particleboards showed lower gas and liquid permeabilities than 150 ml/kg boards; this shows better bonds were formed through the mat in 100 ml/kg, consequently it may be concluded that more nano-silver amount than 100 ml/kg may cause over-heating in the mat causing de-polymerization of the bonds probably occur in the surface layers of the mat. Cluster analysis of the three treatments showed that 100 ml/kg treatment was clustered quite differently from the other two treatments (control and 150 ml/kg) (Fig. 8). Cluster analysis of physical and mechanical properties showed that control treatment was clustered differently than the two other treatments having nano-silver (Taghiyari et al., 2011). It can then be concluded that the effects of nano-silver content on physical-mechanical properties may be different than that on gas and liquid permeabilities.

5. Conclusion

Heat-conductivity property of nano-silver particles makes better transfer of heat to the center layer of composite mat and therefore better polymerization occurs which in turn ends up in less fluid transfer through the wood particle-resin matrix. In fact, this decrease in fluid transfer is the root-reason for decrease in water absorption and thickness swelling (Taghiyari et al., 2011).

High consistency between gas permeability of the 7 different vacuum pressures, that is the different 7 water columns, shows vacuum pressure does not significantly affect specific gas permeability values; still, it may be concluded that in falling water displacement volume method, water column should at least be 25 cm above the first starting sensor of the milli-second time-measurement device of gas permeability apparatus. Lower than 25 cm does not give enough time for the sudden shock to be faded out and therefore the time registered may not be authentic for specific gas permeability calculations using formula 1 and 2.

As to the high significant correlations between gas permeability at different vacuum pressures with both 1st drop and 50-mm-lowering times, it may be concluded that gas permeability gives a suitable criterion for water absorption and thickness swelling.

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