WOOD CONSOLIDATION:
Influence of liquid surface tension on its penetration into wood

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Introduction

Today, the consolidation of wood is primarily performed with synthetic consolidants, which, as a result of their better properties, have reduced the usage of natural consolidants, such as waxes and oils. Due to its ease of use, consolidation with high molecular polymer solutions is the most widely used. Because consolidation efficiency is proportionate both to the amount of consolidant (polymer) in the wood and to its distribution therein, it is very important that the consolidant solution penetrates readily into a wooden structure. Consequently, it is essential to find the right balance between the penetration ability of the consolidation solution and adjustable parameters given by theoretical equations (e.g. Darcy´s law). Namely, those are parameters related to penetrating liquid, wood structure and experimental conditions. This work is focused to deeper discussion of the influence of liquid surface tension and contact angle on liquid-wood interface on liquid penetration into wooden capillary system. Theoretical aspects will be demonstrated on practical work: addition of surface active agents to wood consolidation system.

$$Q = \frac{KA}{L} . \frac{1}{\nu\rho} . \Delta P$$

Darcy´s law

1. Parameters of the wood

Coefficient of wood permeability K [m^2], length of sample in the flow direction L [m], cross-sectional area to flow A [m^2] represents parameters connected to wooden sample.
Depends on anatomic structure:

- tree specie, location in trunk (sapwood, heartwood)
- geometry of the artifact
- moisture content
- degree of deterioration

2. Parameters of the penetrating liquid

Kinematic viscosity ν [mm^2.s^{-1}] and liquid density ρ [kg.m^{-3}] are connected to penetrating liquid and depends on:

- molecular weight of the consolidant
- polarity
- its concentration in the solution

3. Ways of consolidation

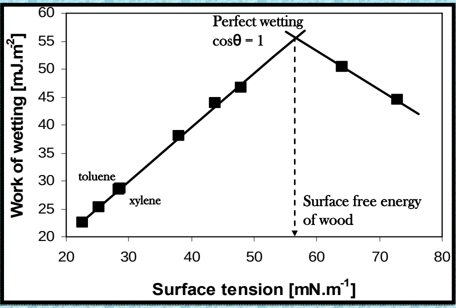
Pressure gradient ΔP [Pa] is given by impregnation method and may be caused by capillary or external pressure. External pressure is applied, when the wood is impregnated under reduced or high pressure. Capillary pressure is the cause of impregnation by immersion under atmospheric pressure, by brushing and spraying. This work is further focused to consolidation by capillary action. Capillary pressure Pc is described by Young-Laplace's equation: there the parameter surface tension on liquid-air interface γ_{LG} and cosine of contact angle θ is wetting angle refer to wetting properties.

Young-LaPlace equation combined with Darcy´s law

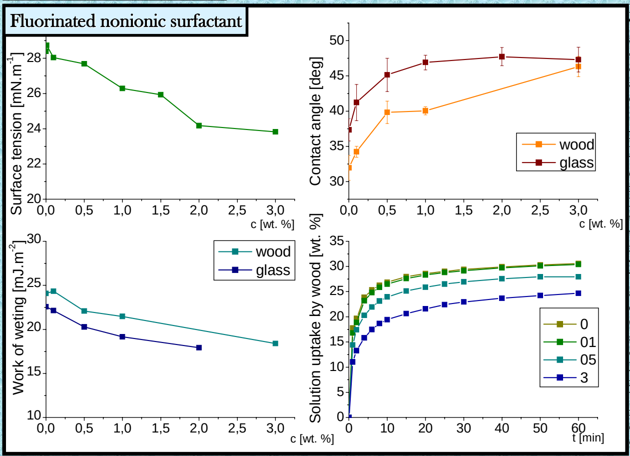
$$P_c = \frac{2\gamma_{LG}\cos\theta}{r} \Rightarrow Q = \frac{2KA}{r\upsilon\rho L} . \gamma_{LG} . \cos\theta$$

Work of wetting

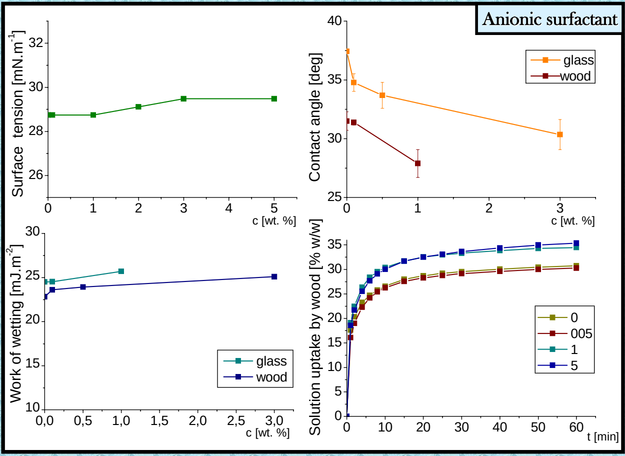
According to this equation, higher is the work of wetting W_W better is the penetration of liquid into wood. When the contact angle on liquid-wood interface drops to zero, the cosine of theta reaches its maximal value (cosθ = 1). This case is referred as perfect wetting and ensures highest value of wetting work. Value of liquid surface tension at which the perfect wetting occurs depends on surface free energy of support (wood in this case). With further decrease of liquid surface tension contact angle remains zero, wetting force decreases. Liquid penetration into wood capillary system would be unfavorable with further decrease of liquid surface tension. Thus, the best penetrating liquid would have surface tension equal to value of surface free energy of wood, which occurs as a breaking point in the Graph (approximately 56 mN.m^{-1}). Many solvents for polymeric consolidants have surface tension of about 30 mN.m^{-1}. The way how to modify a penetrating liquid is an addition of surface active agent into solution. Their addition should lead to contact angle reduction and facilitate a penetration of liquid through wooden capillaries. They are generally set up of two groups: one part, which ensures its partial solubility in the medium, another which is insoluble and provides its associative behavior.

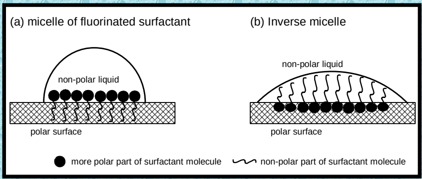


Results of impregnation



Experimental
The Du Noüy method was used to measure surface tension of 15 wt. % toluene solution of Paraloid B72 (copolymer of ethylmethacrylate with methylacrylate, Rohm and Hass company). X-axis gives weight concentration of surfactant in solution (Nonionic surfactant Zonyl FSN 100, DuPont; Anionic surfactant Borchi Gen 0650, Borchers). Sessile drop shape analysis was used to determine the contact angle on a quartz plate (which have comparative surface free energy as wood, but which surface is more homogeneous) and directly on the surface of the wood samples. Paraloid concentration in the solution being 30 wt. % in order to minimize penetration into the wood. Work of wetting was calculated according to equation $W_W = \gamma_{LG}.\cos\theta$. Penetration of Paraloid solutions into the wood was achieved by capillary action in its lengthwise direction for 60 minutes. The experiment was performed subsequently: The samples were placed in a consolidant solution reservoir, in which the level of the observed liquid reached a maximum height of 2 mm above the sample base. The intake of the polymer solution was measured for ten samples of wood, and determined by the increase in sample weight over time.





Fluorosurfactants addition lead to surface tension decrease, which was accompanied by increase of liquid contact angle with increasing concentration of surfactant in the solution. This refers to worse wetting force and thus worse penetration ability of the solution with increasing surfactant concentration, which was experimentally proven. This is given by the structure of surfactant: this surfactant is composed of fluorinated chain which is the hydrophobic part of surfactant and alkyl chain, which is the hydrophilic part, this surfactant creates analogical micelles as which are formed in water medium. Extremely non-polar part of fluorinated chain concentrates on liquid-air interface, while alkyl chain forms the more polar part, which ensures partial solubility in the medium. Contrariwise, anionic surfactant addition lead to slight increase of surface tension as well as to contact angle degrease. It referred to better penetration abilities of that solutions which was experimentally proven. Anionic surfactants thus form different micelles than fluorinated surfactants: they form so-called inverse micelles, where polar part of the molecule is excluded from the solution to form surface layer, while non-polar part is soluble in the medium.

Conclusion

Our results showed that, while addition of such surfactant decreases the surface tension of a solution, it indicates poorer wettability of wood surface and consequently poorer penetration performance of the solution. If surface tension enhances, it refers to better wetting properties which resulted to better penetration of such solution. Fluorosurfactants have negative impact on wood wettability as well as on solution penetration into wooden microstructure. The same behaviour was observed with addition of surfactants based on dimethylsiloxanes. Anionic surfactants, here presented by Borchi Gen 0650, slightly increased surface tension of solution which resulted in better wetting force and consequently better penetration into wood. Anionic surfactants probably form in toluene medium inverse micelles. The same impact was observed after addition of surfactant based on poly(oxylethylene) group. Better penetration might thus be improved by addition of surfactnats which are able to form inverse micelles in toluene medium.