Moisture movement in wood

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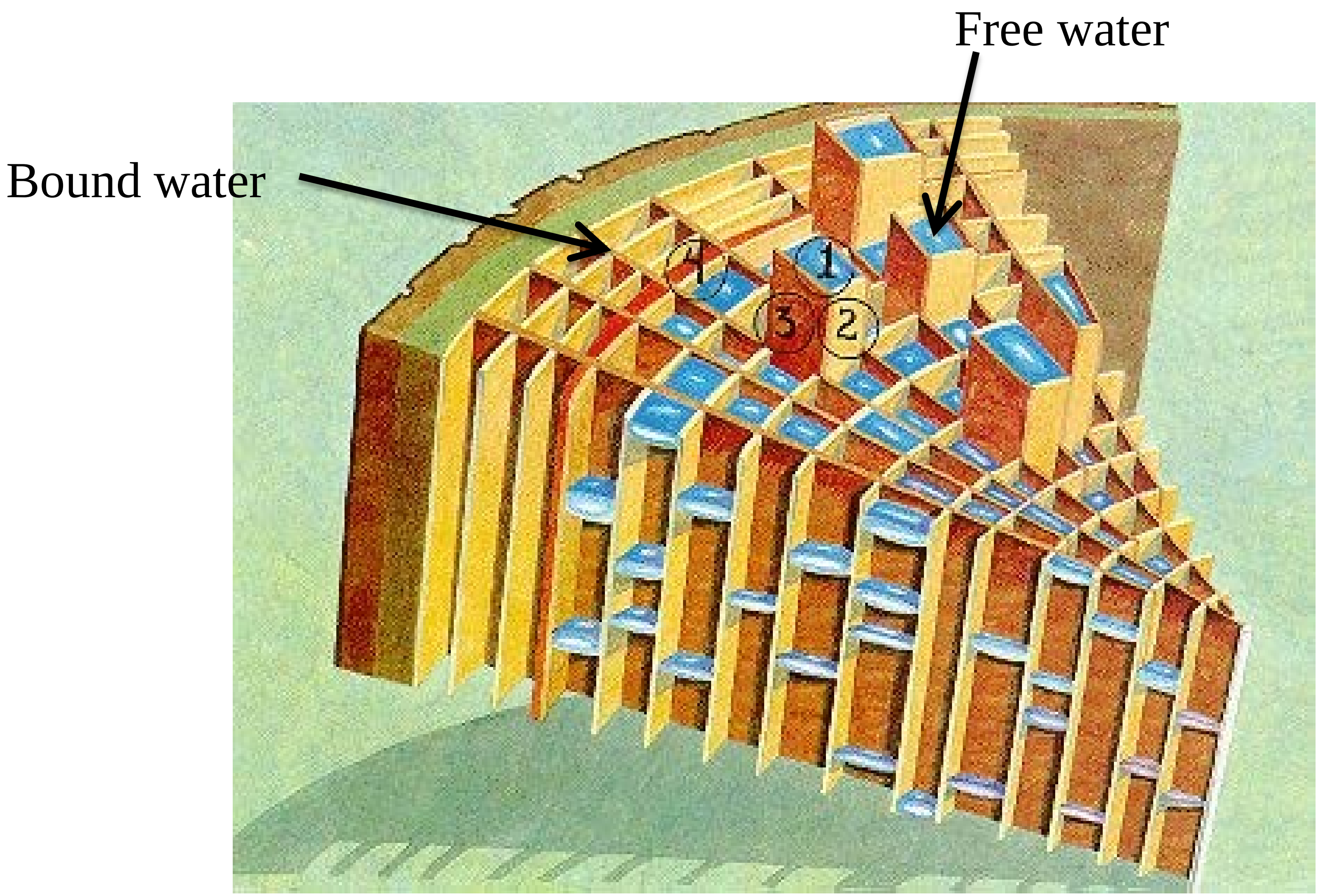
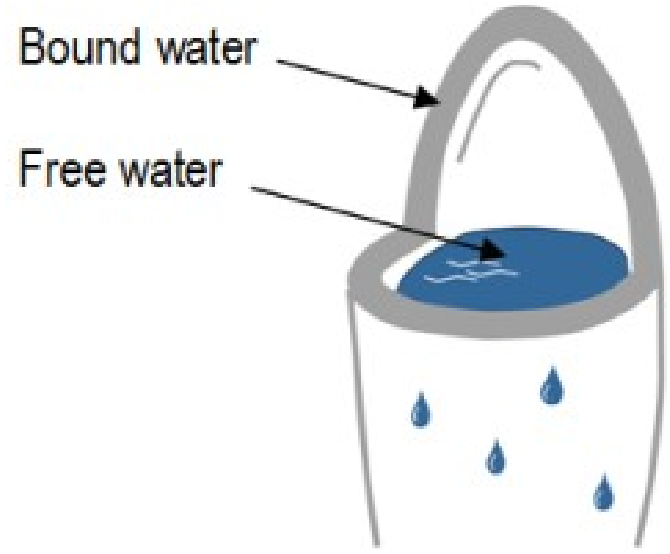

Free water
Bound water
1
2
3
4

Water in wood

As free liquid water and water vapour in the cell cavities

As hygroscopic bound within the cell walls (intermolecular attraction within cell walls)



Hygroscopic water

A hygroscopic material adopts the moisture content of the surrounding climate and strive for equilibrium

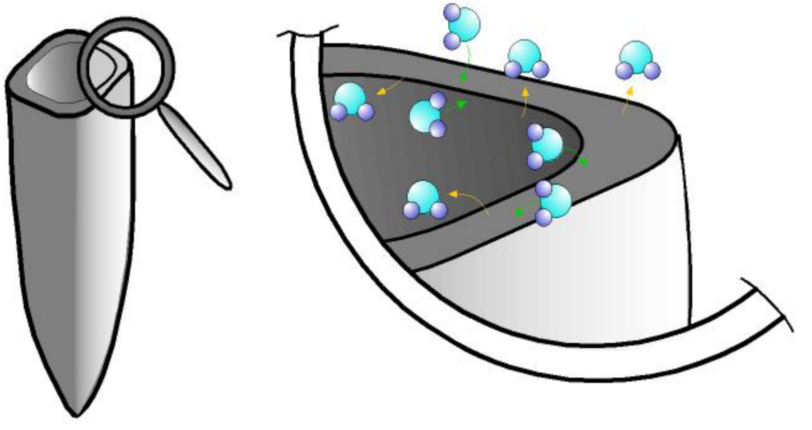
- Bricks, which are hygroscopic, have the ability to bind 30 litres of hygroscopic water/m^3 material.
- Wood has the capacity to bind 5 times more!
- Paper, hair, bread are other materials.

30 L water/m^3

150 L water/m^3

Hygroscopic materials strive to reach equilibrium with the surrounding air. As the climate changes the moisture content in wood will also change. To reach equilibrium the climate need to be stable for a long time.

The ***exchange of moisture*** between the hygroscopic bound moisture in wood and the air is in the form of ***vapour***.



Equilibrium air/wood:

When the same amount of water molecules collects and emits by the cell wall.

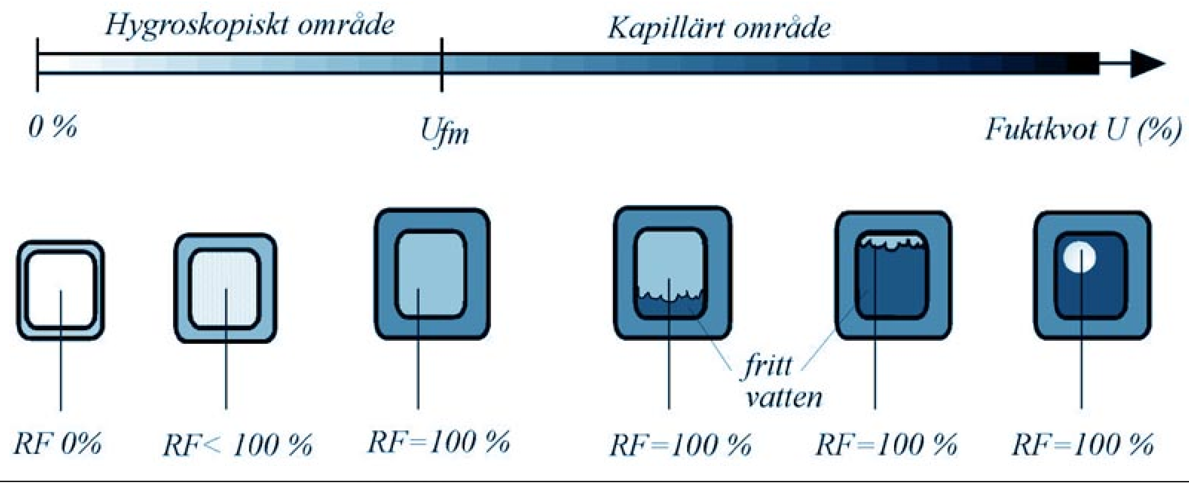
Capillary bindings weaker than hygroscopic bindings
→ Easier to break … less energy
→ Capillary water departs first !!

Fibre saturation point FSP

Empty lumen - no free water. Cell walls fully saturated.

As the drying proceeds water will disappear from the cell walls - the wood starts to shrink.

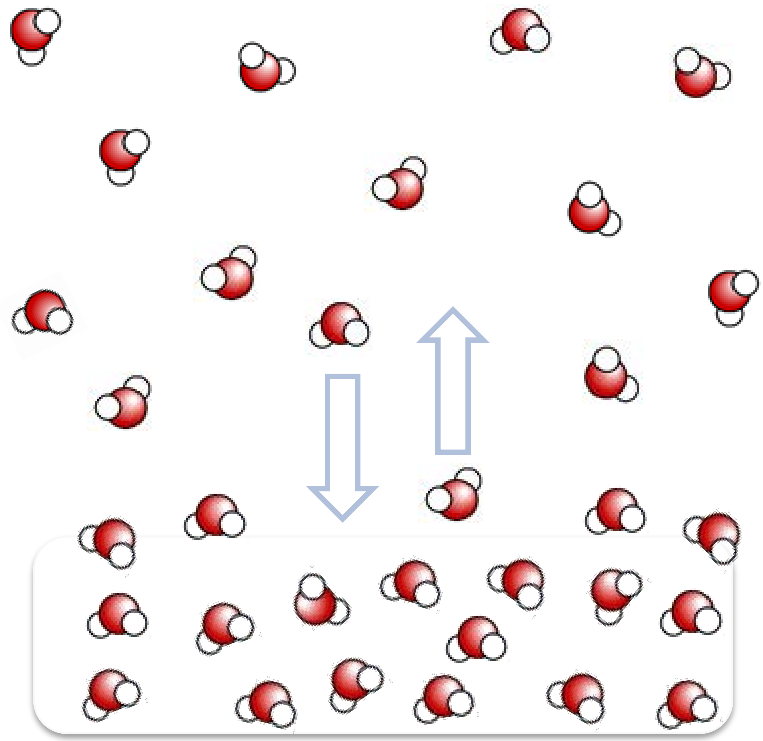
¨FSP ~ 30%



MSP

EMC

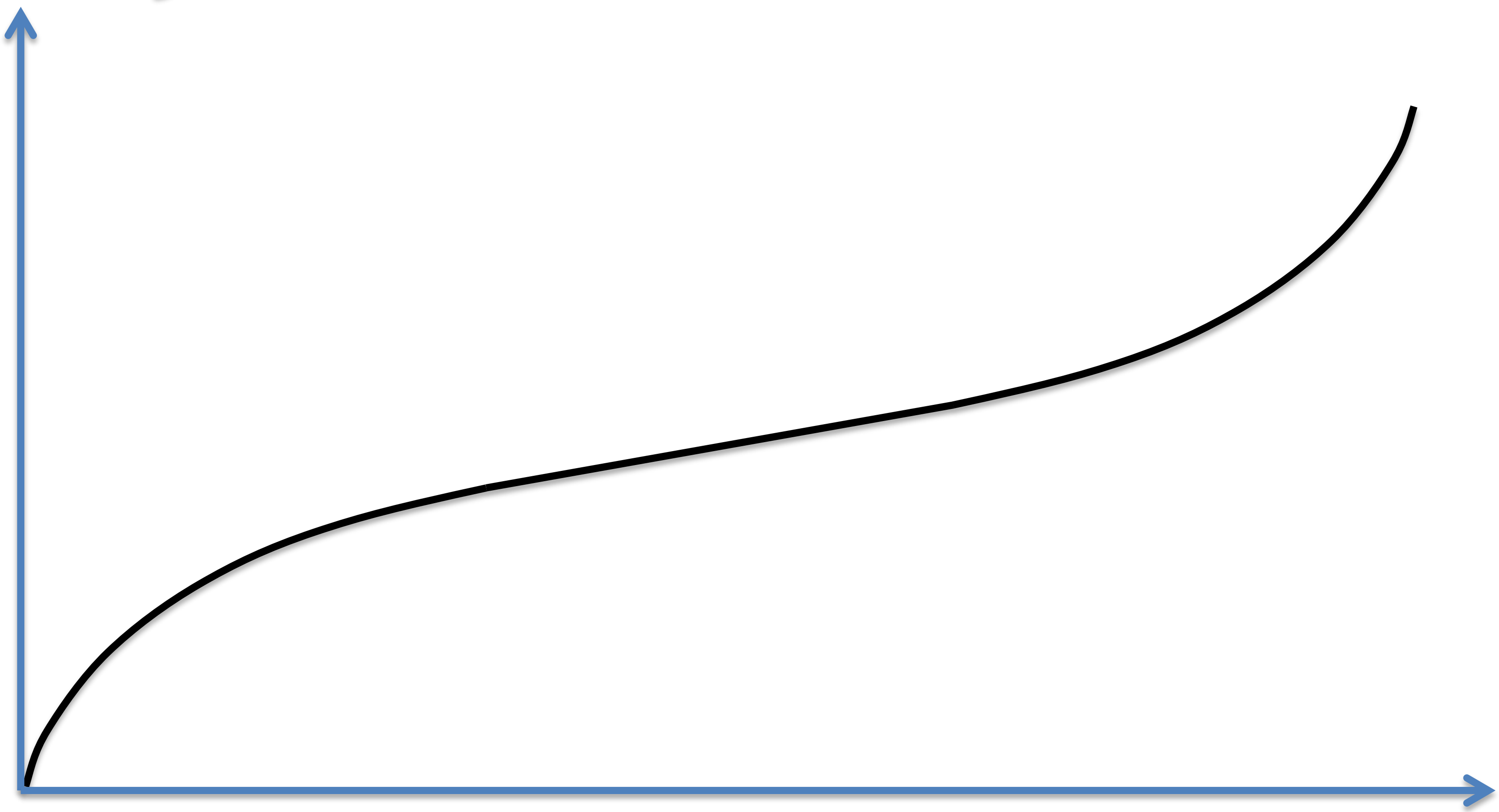
Relative humidity in air



Equilibrium moisture content in wood

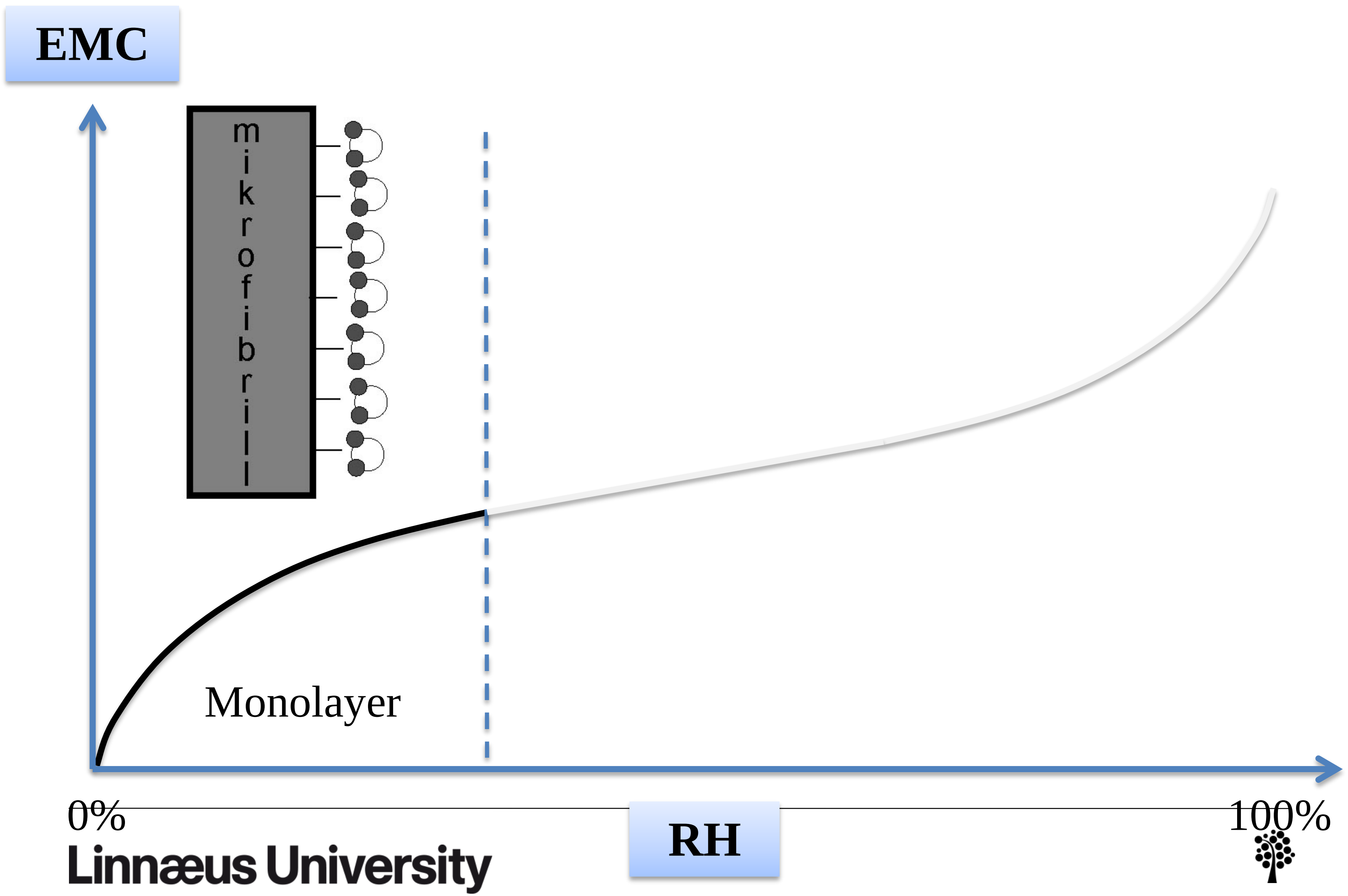
Sorption isotherms

EMC } Equilibrium moisture content

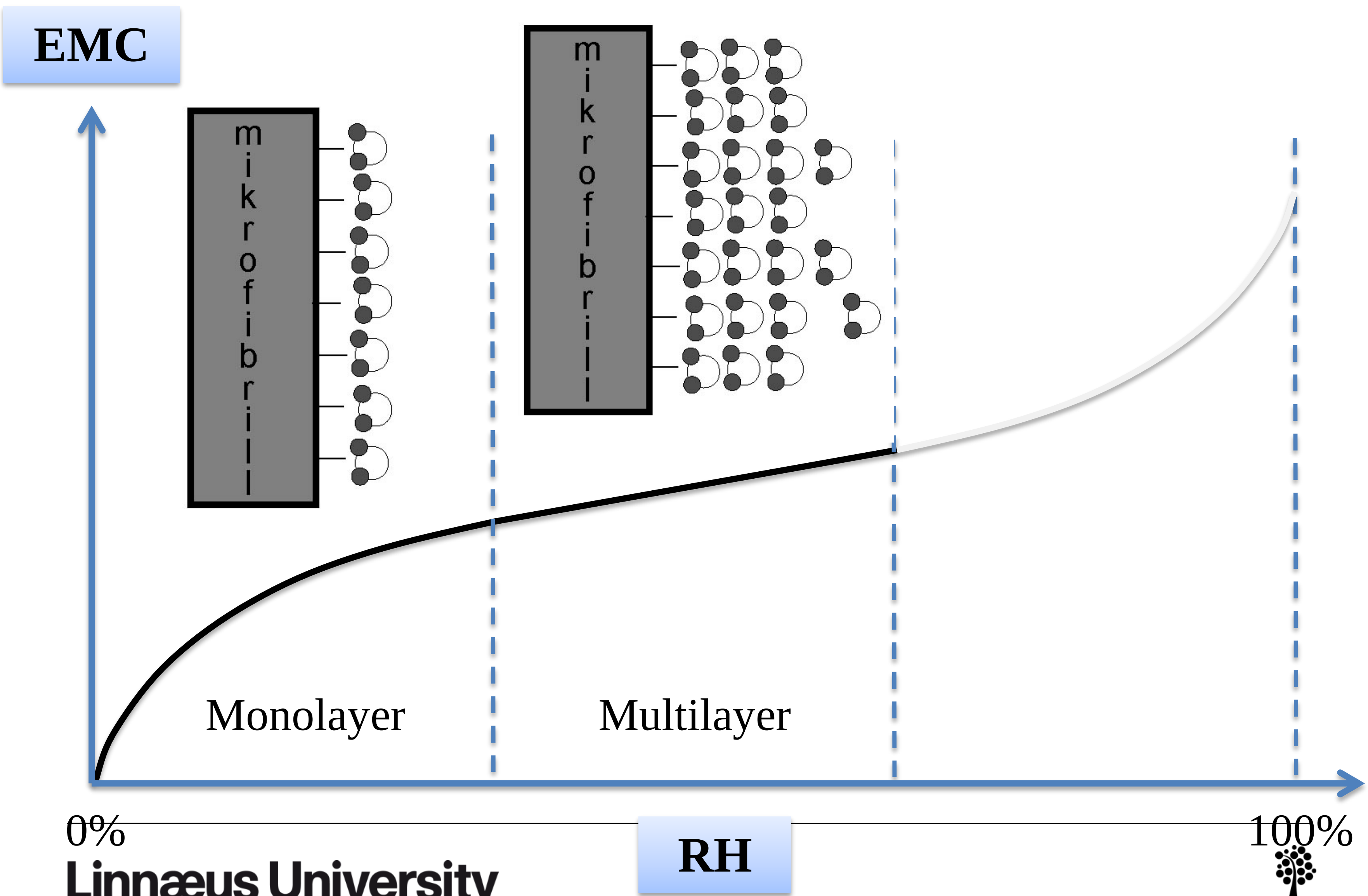


RH } Air relative humidity

BET isotherm (*Brunauer–Emmett–Teller*)

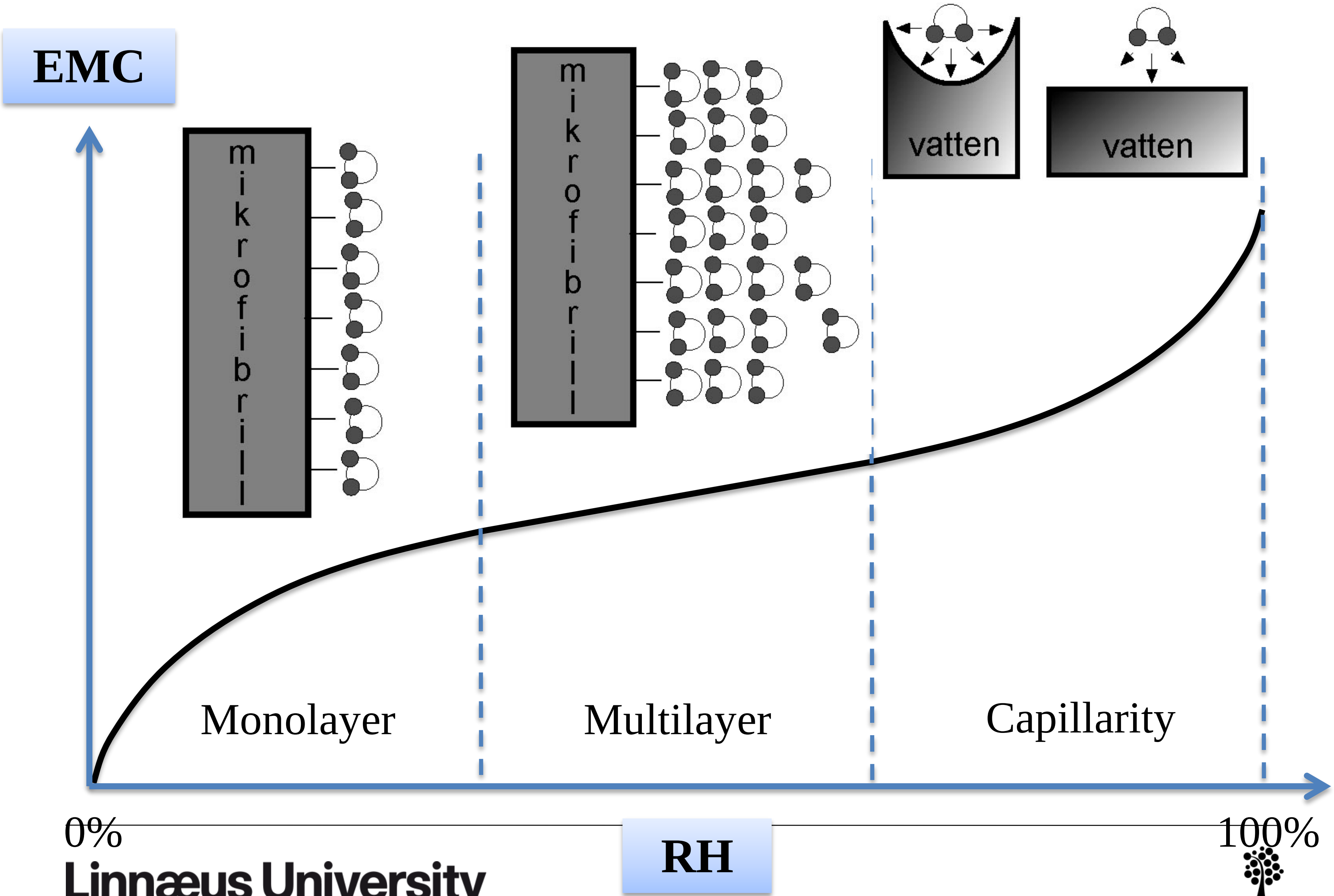


BET theory

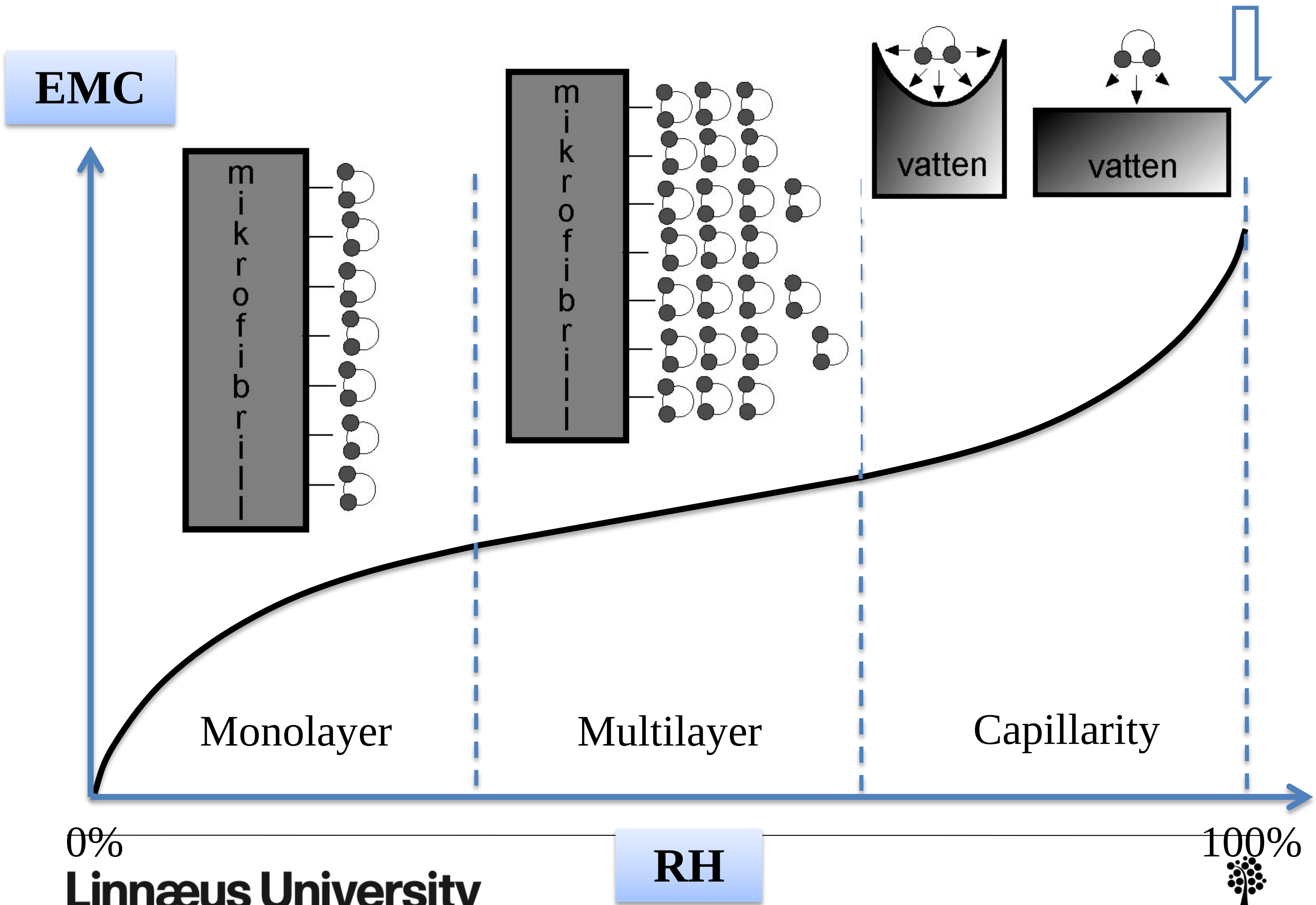


EMC
m i k r o f i b r i l l
m i k r o f i b r i l l
Monolayer
Multilayer
0%
100%
RH

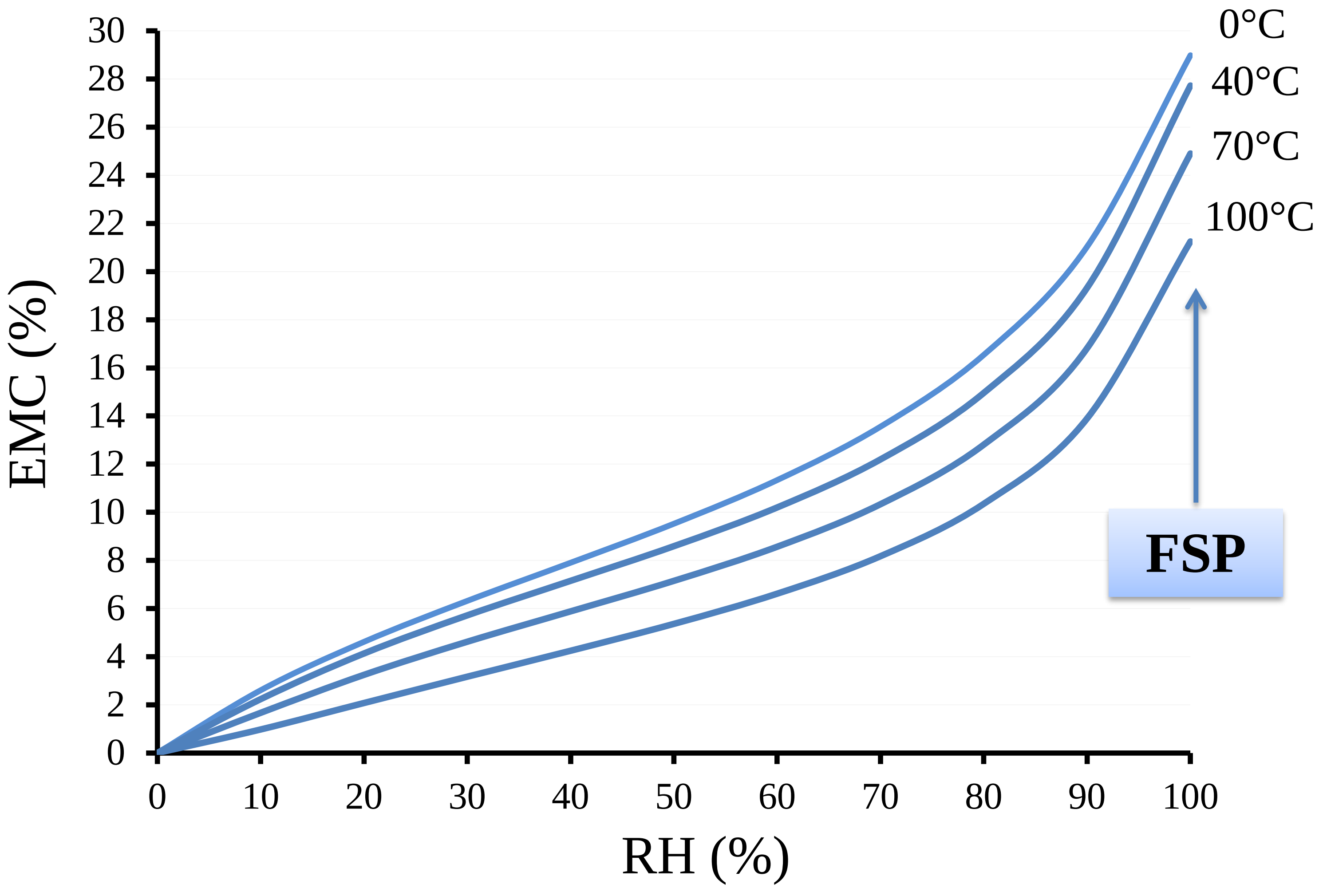
BET theory


EMC
mikrofibrill
mikrofibrill
vatten
vatten
Monolayer
Multilayer
Capillarity
0%
100%
RH

BET theory


FSP
EMC
mikrofibrill
mikrofibrill
vatten
vatten
Monolayer
Multilayer
Capillarity
0%
100%
RH

EMC depends on temperature

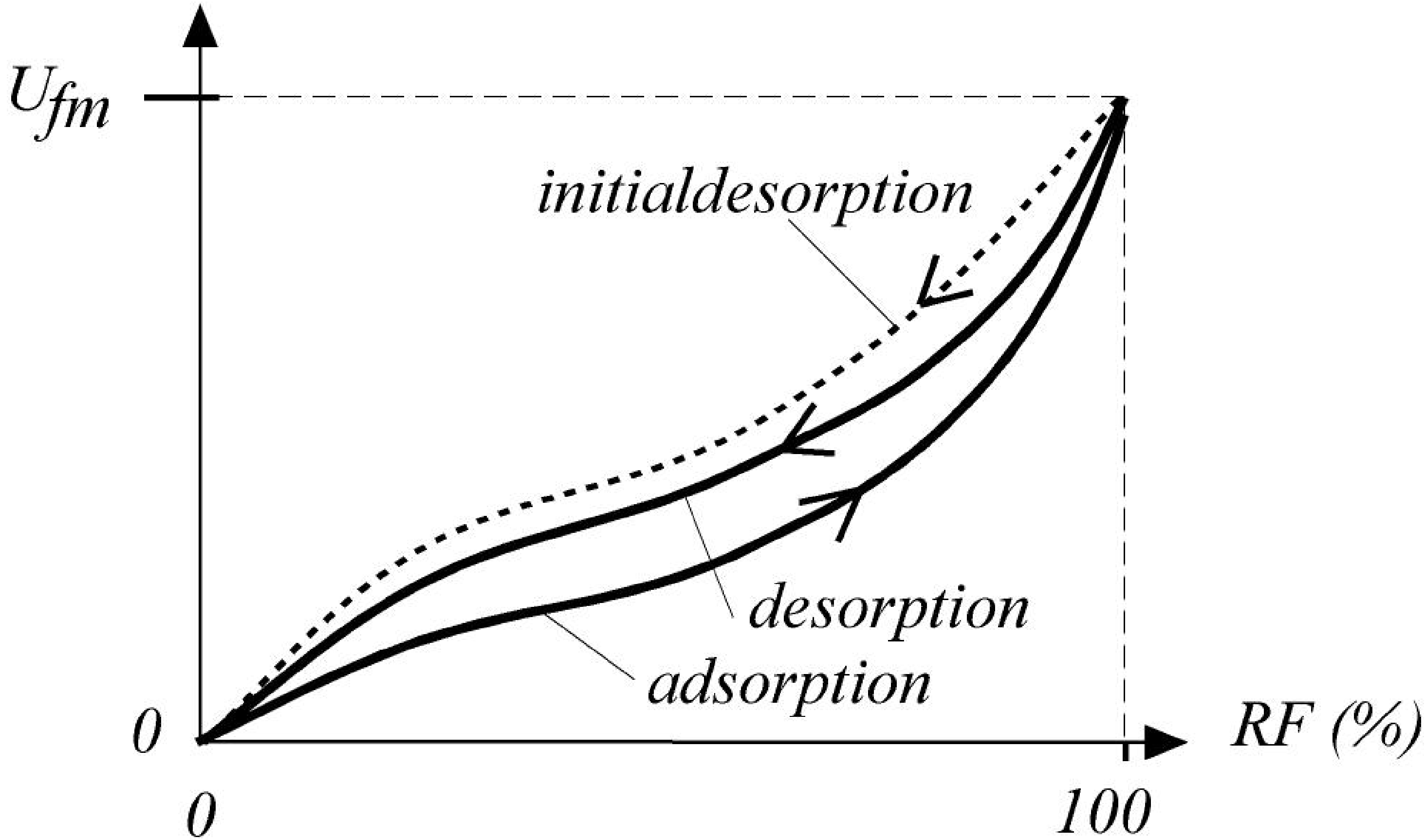


*Hailwood AJ, Horrobin S (1946) Absorption of water by polymers: analysis in terms of a simple model. T Faraday Soc B 42:84–102

Hystereses

Difference in desorption and adsorption

Also dependent on wood story. Dried at high T => lower EMC.

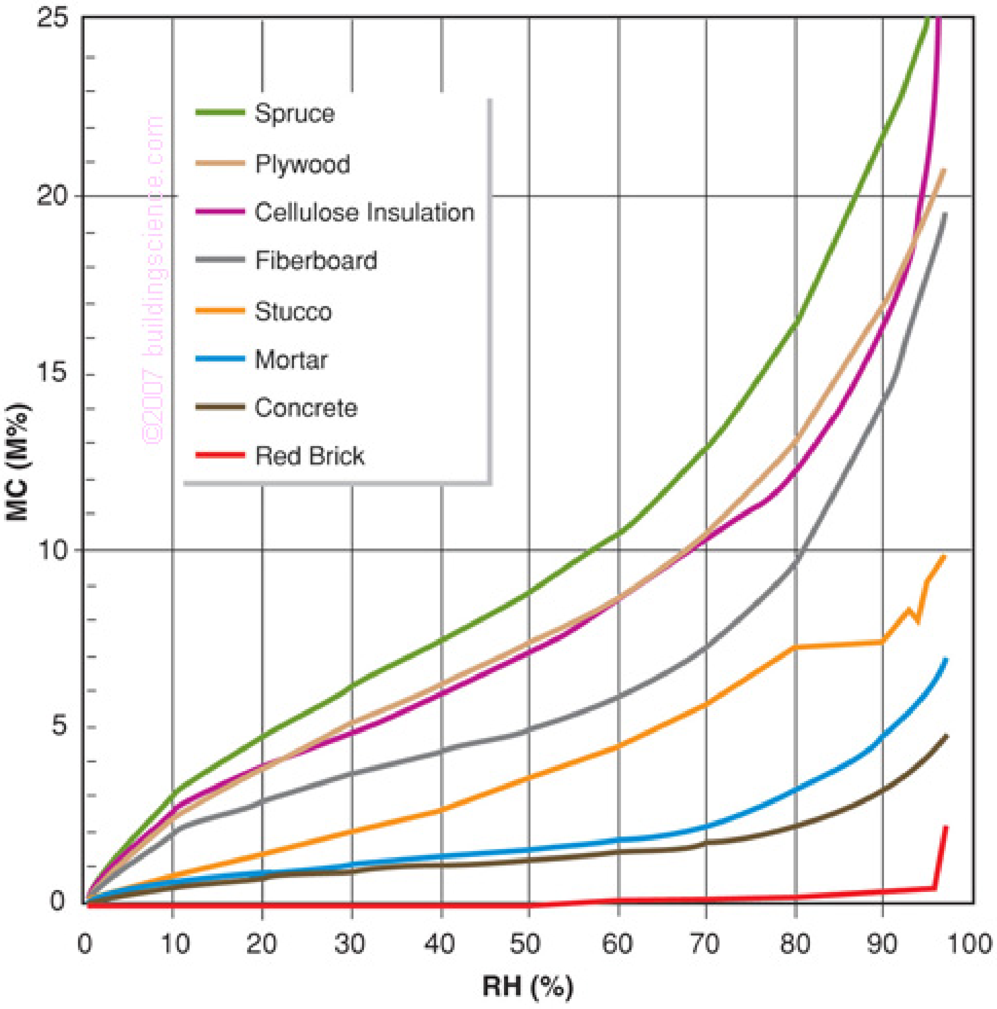


Moisture content of wood in equilibrium with stated temperature and relative humidity

Temperature		Moisture content (%) at various relative humidity values																		
(°C	(°F))	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%	55%	60%	65%	70%	75%	80%	85%	90%	95%
−1.1	(30)	1.4	2.6	3.7	4.6	5.5	6.3	7.1	7.9	8.7	9.5	10.4	11.3	12.4	13.5	14.9	16.5	18.5	21.0	24.3
4.4	(40)	1.4	2.6	3.7	4.6	5.5	6.3	7.1	7.9	8.7	9.5	10.4	11.3	12.3	13.5	14.9	16.5	18.5	21.0	24.3
10.0	(50)	1.4	2.6	3.6	4.6	5.5	6.3	7.1	7.9	8.7	9.5	10.3	11.2	12.3	13.4	14.8	16.4	18.4	20.9	24.3
15.6	(60)	1.3	2.5	3.6	4.6	5.4	6.2	7.0	7.8	8.6	9.4	10.2	11.1	12.1	13.3	14.6	16.2	18.2	20.7	24.1
21.1	(70)	1.3	2.5	3.5	4.5	5.4	6.2	6.9	7.7	8.5	9.2	10.1	11.0	12.0	13.1	14.4	16.0	17.9	20.5	23.9
26.7	(80)	1.3	2.4	3.5	4.4	5.3	6.1	6.8	7.6	8.3	9.1	9.9	10.8	11.7	12.9	14.2	15.7	17.7	20.2	23.6
32.2	(90)	1.2	2.3	3.4	4.3	5.1	5.9	6.7	7.4	8.1	8.9	9.7	10.5	11.5	12.6	13.9	15.4	17.3	19.8	23.3
37.8	(100)	1.2	2.3	3.3	4.2	5.0	5.8	6.5	7.2	7.9	8.7	9.5	10.3	11.2	12.3	13.6	15.1	17.0	19.5	22.9
43.3	(110)	1.1	2.2	3.2	4.0	4.9	5.6	6.3	7.0	7.7	8.4	9.2	10.0	11.0	12.0	13.2	14.7	16.6	19.1	22.4
48.9	(120)	1.1	2.1	3.0	3.9	4.7	5.4	6.1	6.8	7.5	8.2	8.9	9.7	10.6	11.7	12.9	14.4	16.2	18.6	22.0
54.4	(130)	1.0	2.0	2.9	3.7	4.5	5.2	5.9	6.6	7.2	7.9	8.7	9.4	10.3	11.3	12.5	14.0	15.8	18.2	21.5
60.0	(140)	0.9	1.9	2.8	3.6	4.3	5.0	5.7	6.3	7.0	7.7	8.4	9.1	10.0	11.0	12.1	13.6	15.3	17.7	21.0
65.6	(150)	0.9	1.8	2.6	3.4	4.1	4.8	5.5	6.1	6.7	7.4	8.1	8.8	9.7	10.6	11.8	13.1	14.9	17.2	20.4
71.1	(160)	0.8	1.6	2.4	3.2	3.9	4.6	5.2	5.8	6.4	7.1	7.8	8.5	9.3	10.3	11.4	12.7	14.4	16.7	19.9
76.7	(170)	0.7	1.5	2.3	3.0	3.7	4.3	4.9	5.6	6.2	6.8	7.4	8.2	9.0	9.9	11.0	12.3	14.0	16.2	19.3
82.2	(180)	0.7	1.4	2.1	2.8	3.5	4.1	4.7	5.3	5.9	6.5	7.1	7.8	8.6	9.5	10.5	11.8	13.5	15.7	18.7
87.8	(190)	0.6	1.3	1.9	2.6	3.2	3.8	4.4	5.0	5.5	6.1	6.8	7.5	8.2	9.1	10.1	11.4	13.0	15.1	18.1
93.3	(200)	0.5	1.1	1.7	2.4	3.0	3.5	4.1	4.6	5.2	5.8	6.4	7.1	7.8	8.7	9.7	10.9	12.5	14.6	17.5
98.9	(210)	0.5	1.0	1.6	2.1	2.7	3.2	3.8	4.3	4.9	5.4	6.0	6.7	7.4	8.3	9.2	10.4	12.0	14.0	16.9
104.4	(220)	0.4	0.9	1.4	1.9	2.4	2.9	3.4	3.9	4.5	5.0	5.6	6.3	7.0	7.8	8.8	9.9			
110.0	(230)	0.3	0.8	1.2	1.6	2.1	2.6	3.1	3.6	4.2	4.7	5.3	6.0	6.7						
115.6	(240)	0.3	0.6	0.9	1.3	1.7	2.1	2.6	3.1	3.5	4.1	4.6								
121.1	(250)	0.2	0.4	0.7	1.0	1.3	1.7	2.1	2.5	2.9										
126.7	(260)	0.2	0.3	0.5	0.7	0.9	1.1	1.4												
132.2	(270)	0.1	0.1	0.2	0.3	0.4	0.4													

Forest product and wood handbook

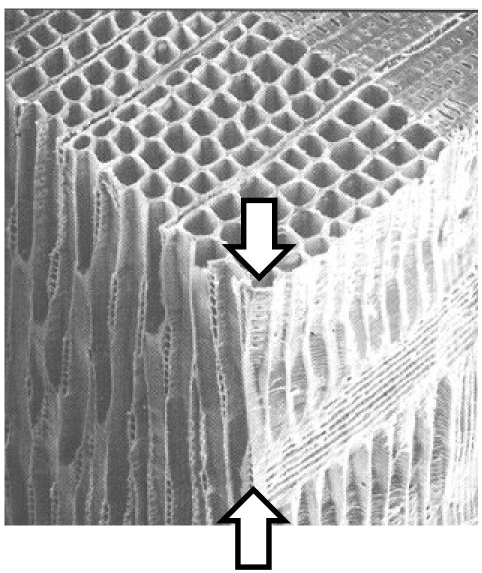
The EMC depends on the material



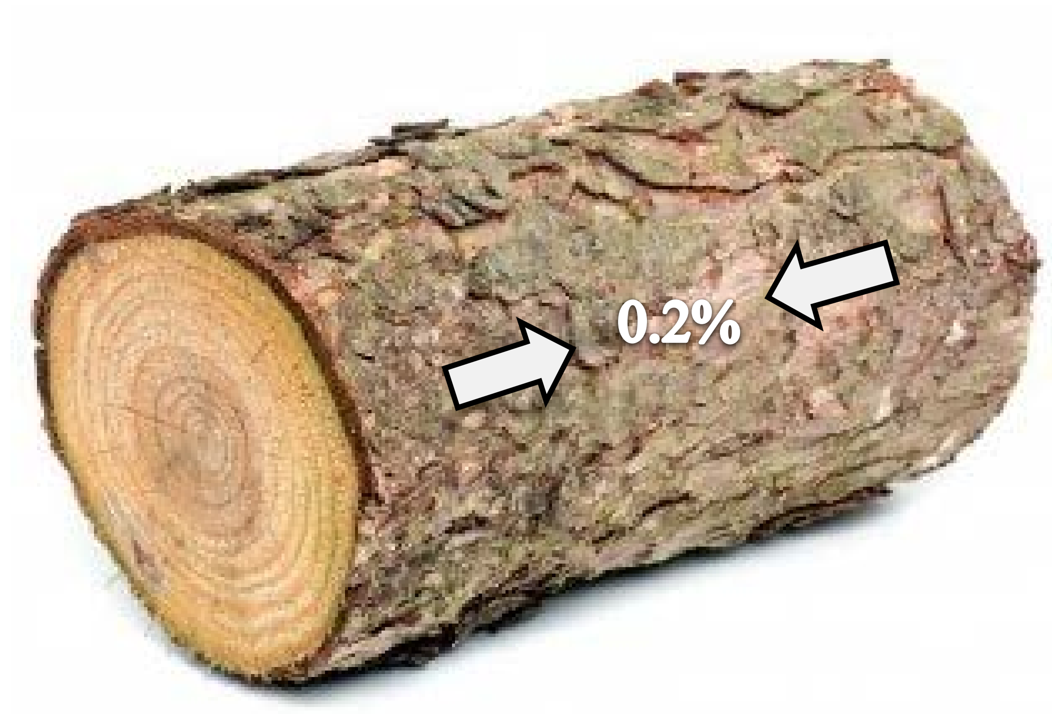
DE

Longitudinal shrinkage

Approximate shrinkage for pine at 0% MC

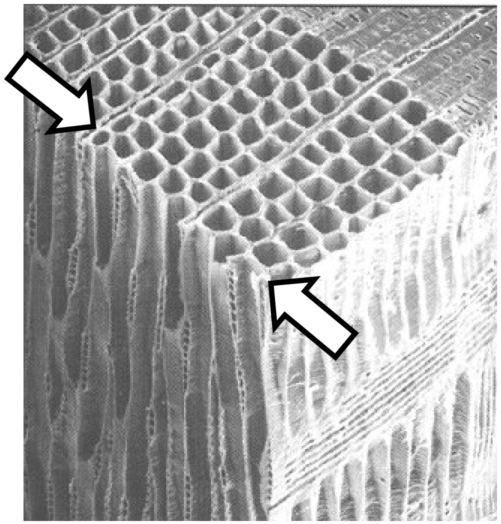


Shrinkage = 0.2%



Tangential shrinkage

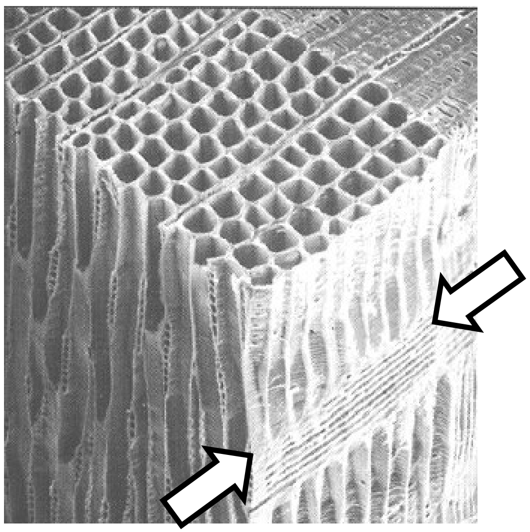
Approximate shrinkage for pine at 0% MC



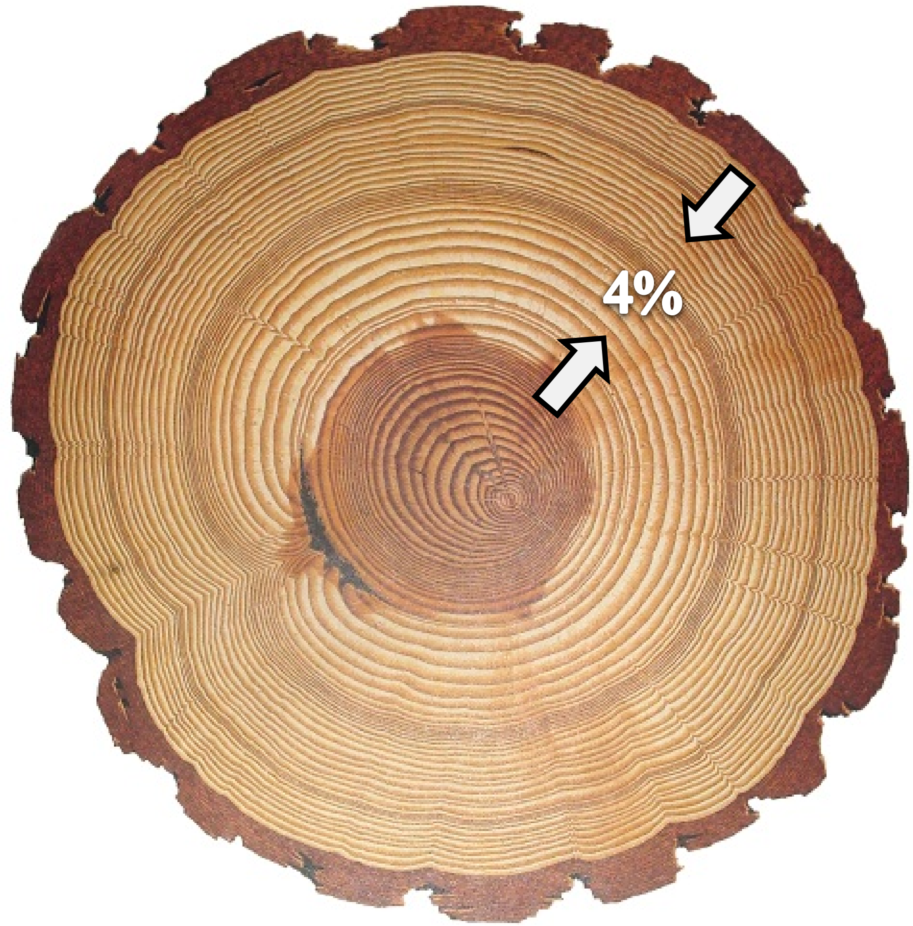
Shrinkage = 7%

Radial shrinkage

Approximate shrinkage for pine at 0% MC

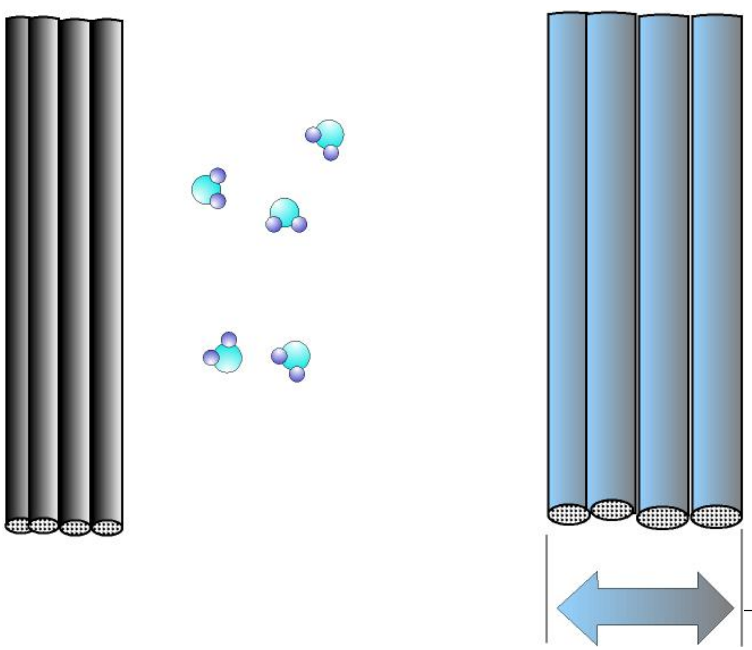


Shrinkage = 4%

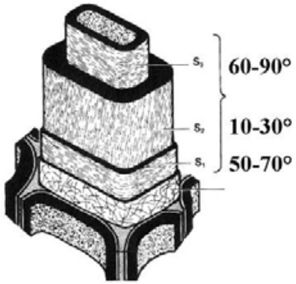


Shrinkage-fibril angle

Larger shrinkage across fibre direction => water molecules bound between the fibrils in the cell walls

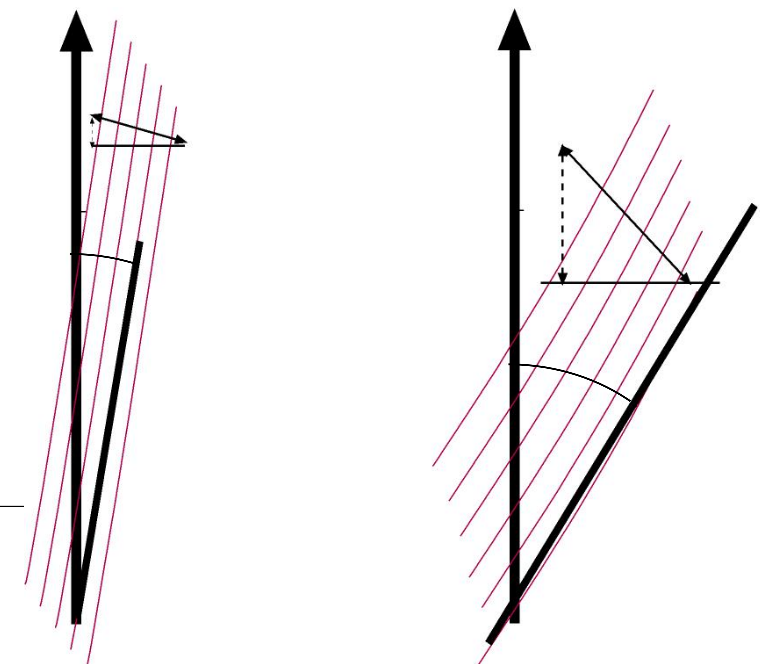


Thick S_2layer decides the strength and properties of the cell.



Since the fibril angle in S_2layer normally small - the shrinkage longitudinally small.

small fibril angle ⇨ small axial shrinkage
big fibril angle ⇨ big axial shrinkage



Shrinkage and swelling values

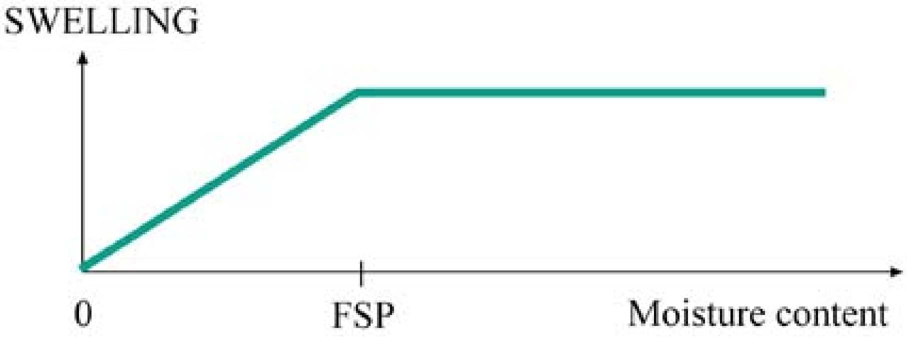
Shrinkage value from FSP to MC=0% => β.

β_{tan}, $\beta_{rad,}$ β_{long}

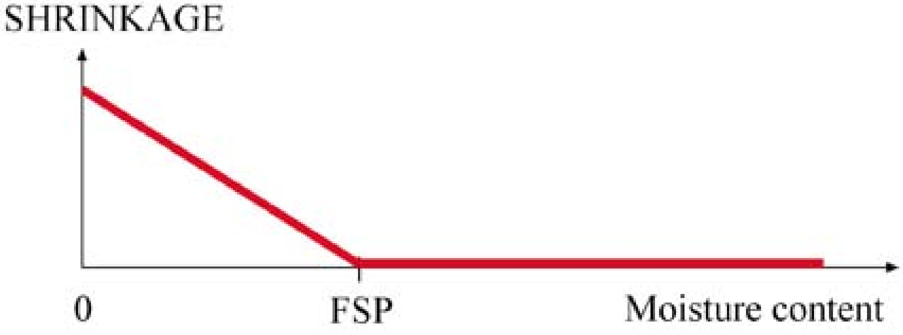
Swelling value from MC=0% to FSP => α

α_{tan}, $\alpha_{rad,}$ α_{long}

Wood is hygroscopic which means it exchanges water from the surrounding air

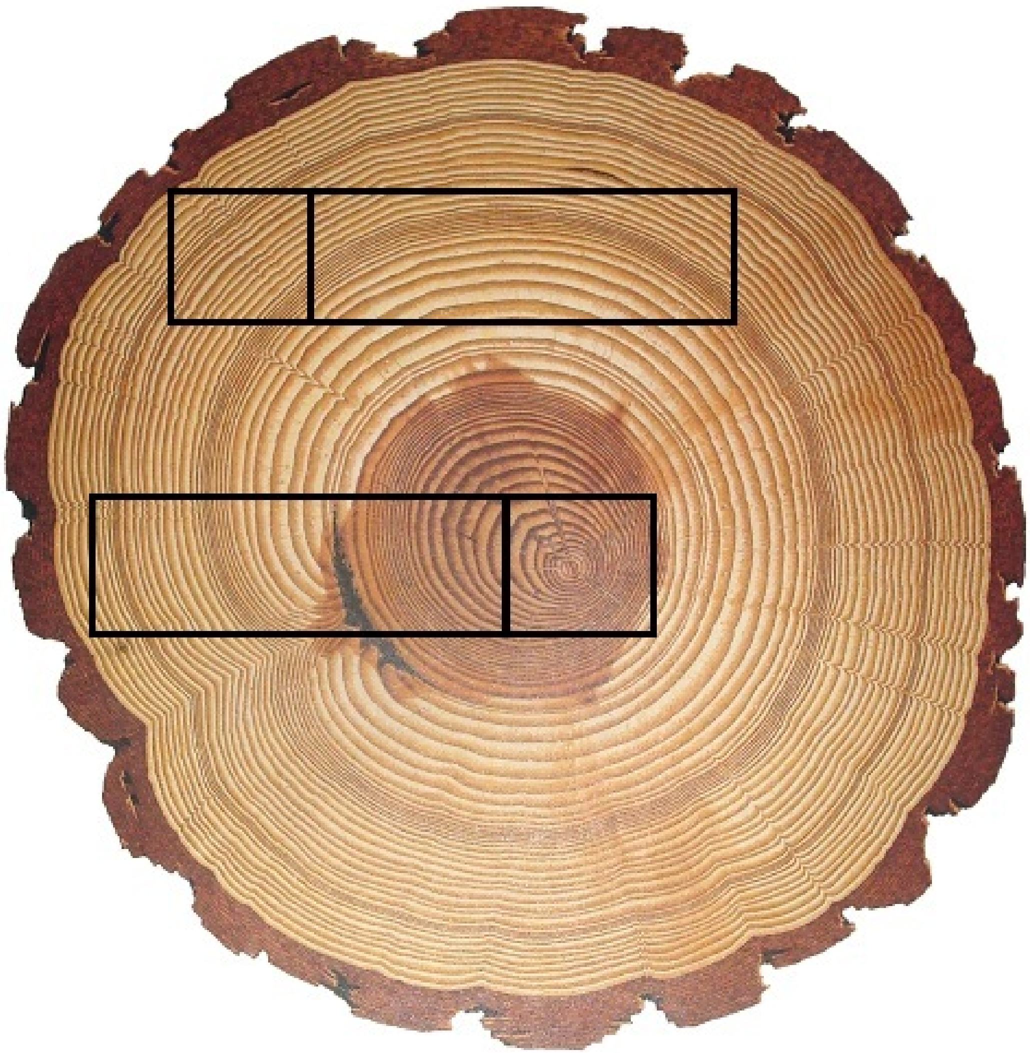


During absorption wood swells until it reaches FSP



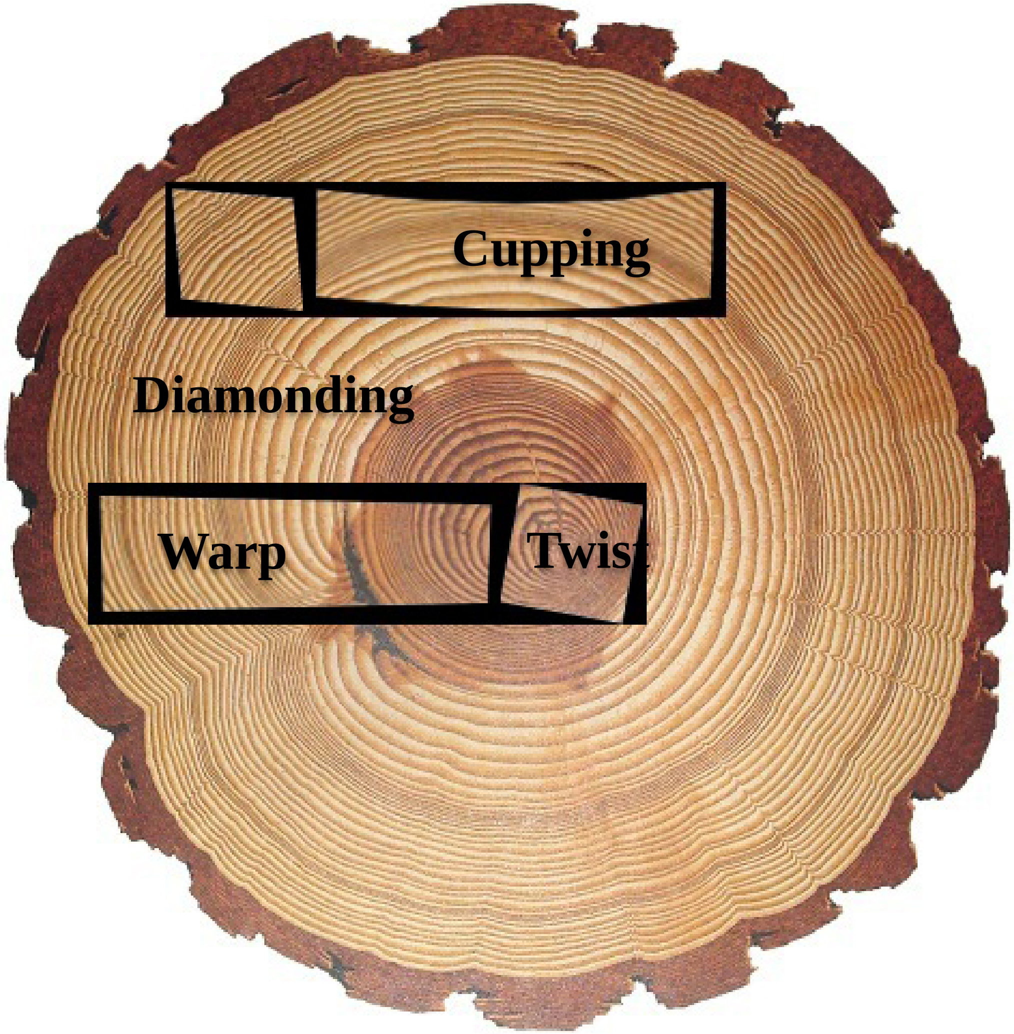
During desorption wood starts to shrink below FSP

Sawn wood before drying



Green wood

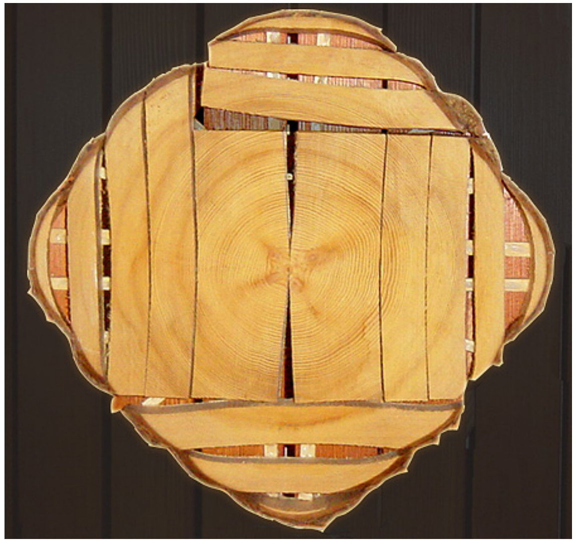
Sawn wood after drying



Dried wood

Anisotropic shrinkage

Sawing around



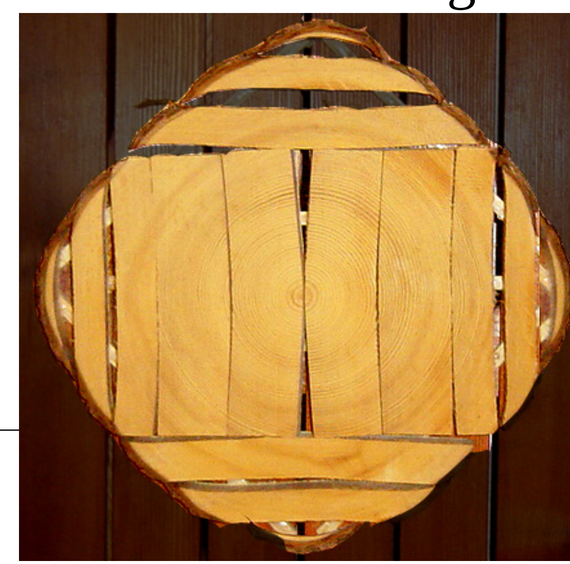
Quarter sawing

DE

Sawing through

Star sawing

Block sawing

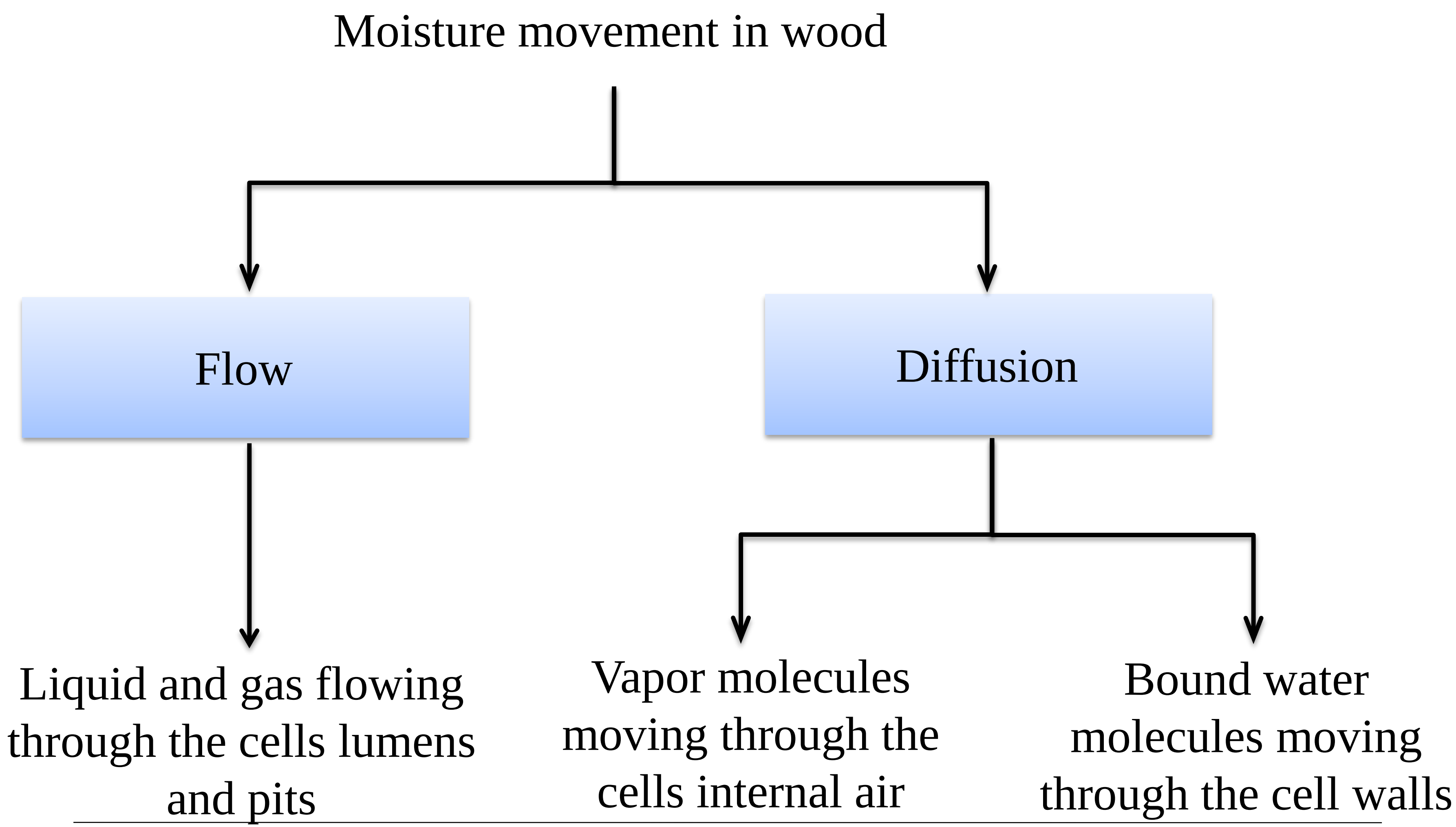


Dimensional stabilization

Refers to mechanical or chemical treatments or modification that reduce the tendency of wood to shrink or swell with surrounding moisture change

1. Laminating like plywood
2. Treating with water resistance substances
3. Reduce hygroscopicity of wood
4. Fiber bulking
5. Cross linking of cellulose chain of fiber so that their separation by water is minimized

Moisture movement in wood

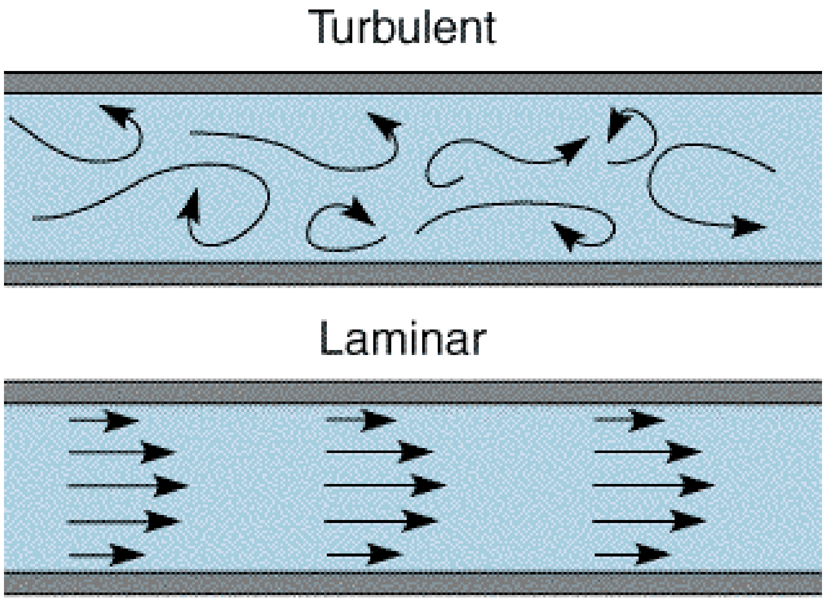


The theory of flow and diffusion

Flow

Darcy's law
for volume flow

$$Q = K \frac{A\,\Delta P}{L}$$



Q = Flow volume rate [m^3/s]

K = Permeability [$m^2/Pa.s$]

A = Cross sectional area [m^2]

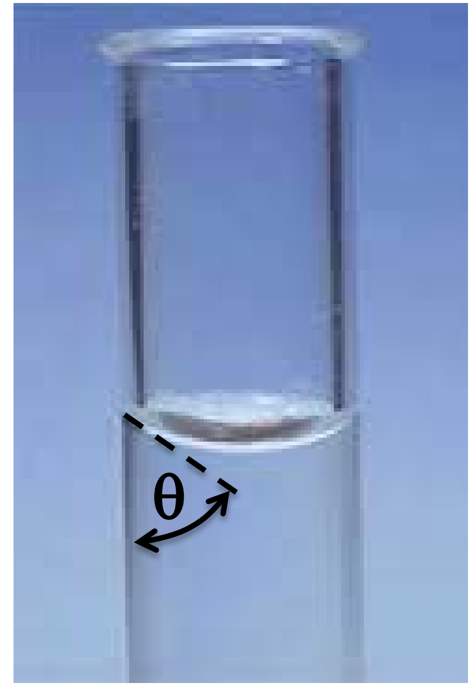
L = Length in the direction of the flow [m]

ΔP = Pressure difference [Pa]

Water surface tension

Young–Laplace equation
for capillary pressure

$$\Delta \boldsymbol{P} = \frac{\mathbf{2}\,\boldsymbol{\gamma}\,\boldsymbol{cos}(\theta)}{\boldsymbol{r}}$$



ΔP = Capillary pressure difference [Pa]

γ = Surface tension [J/m^2]

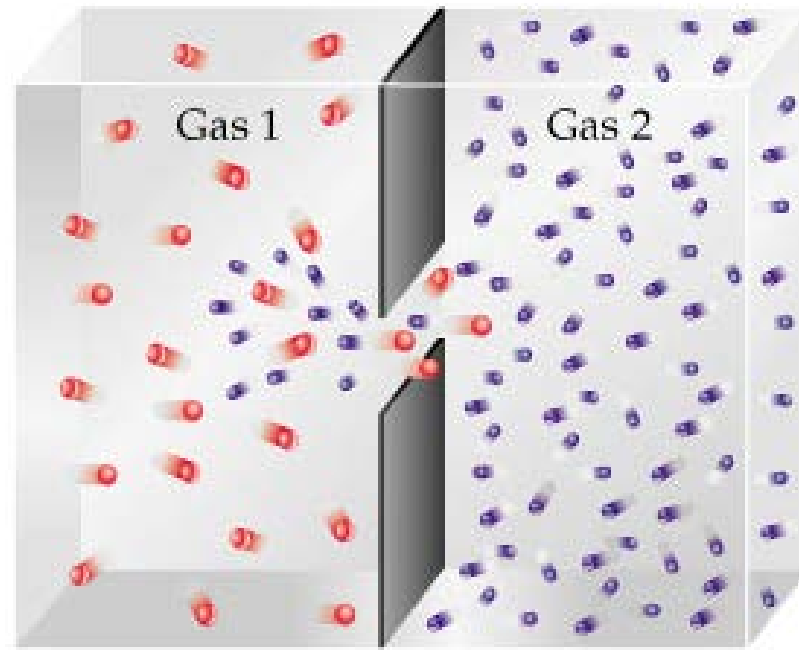
θ = Contact angle [rad]

r = Capillary radius [m]

Diffusion

Fick's law
of diffusion

$$m = D\,\frac{A\,\Delta C}{L}$$

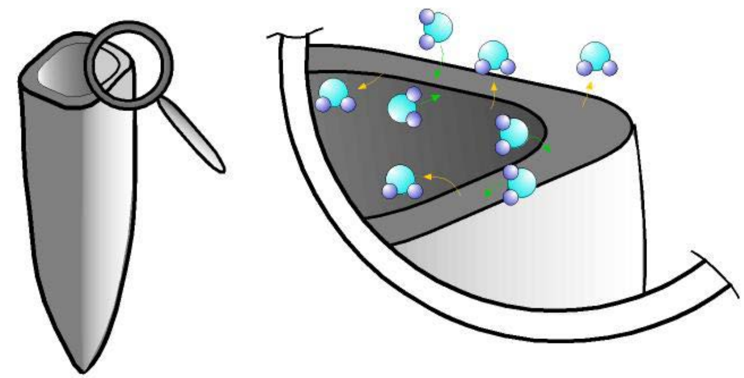


- m = Mass flow rate [kg/s]
- D = Diffusion coefficient [m^2/s]
- A = Cross sectional area [m^2]
- L = Length in the direction of the flow [m]
- ΔC = Difference in mass concentration [kg/m^3]

Diffusion

Fick's law
of diffusion

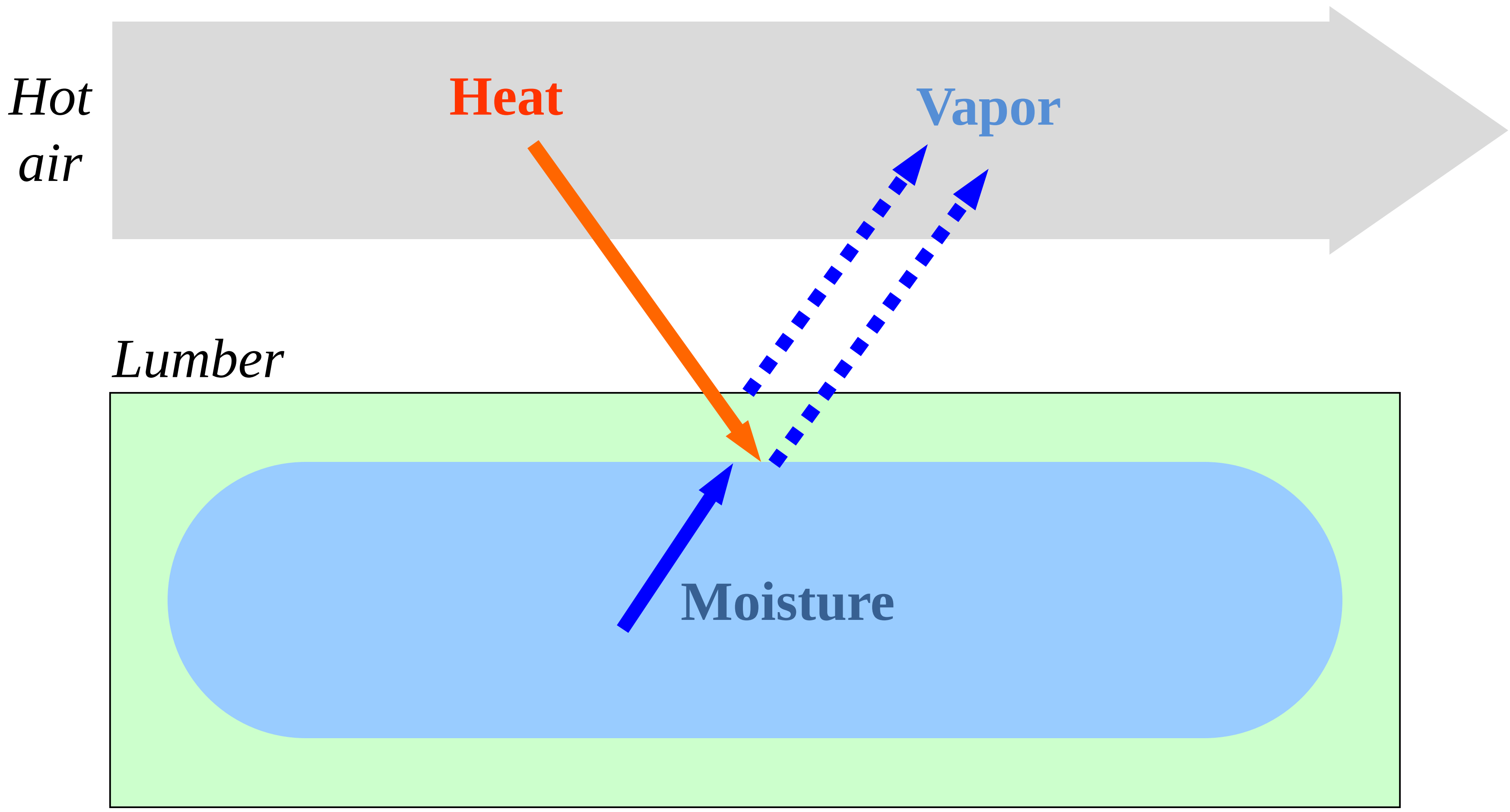
$$m = D\,\frac{A\,\Delta C}{L}$$



Fick's law of diffusion is also valid for bound water

Wood drying

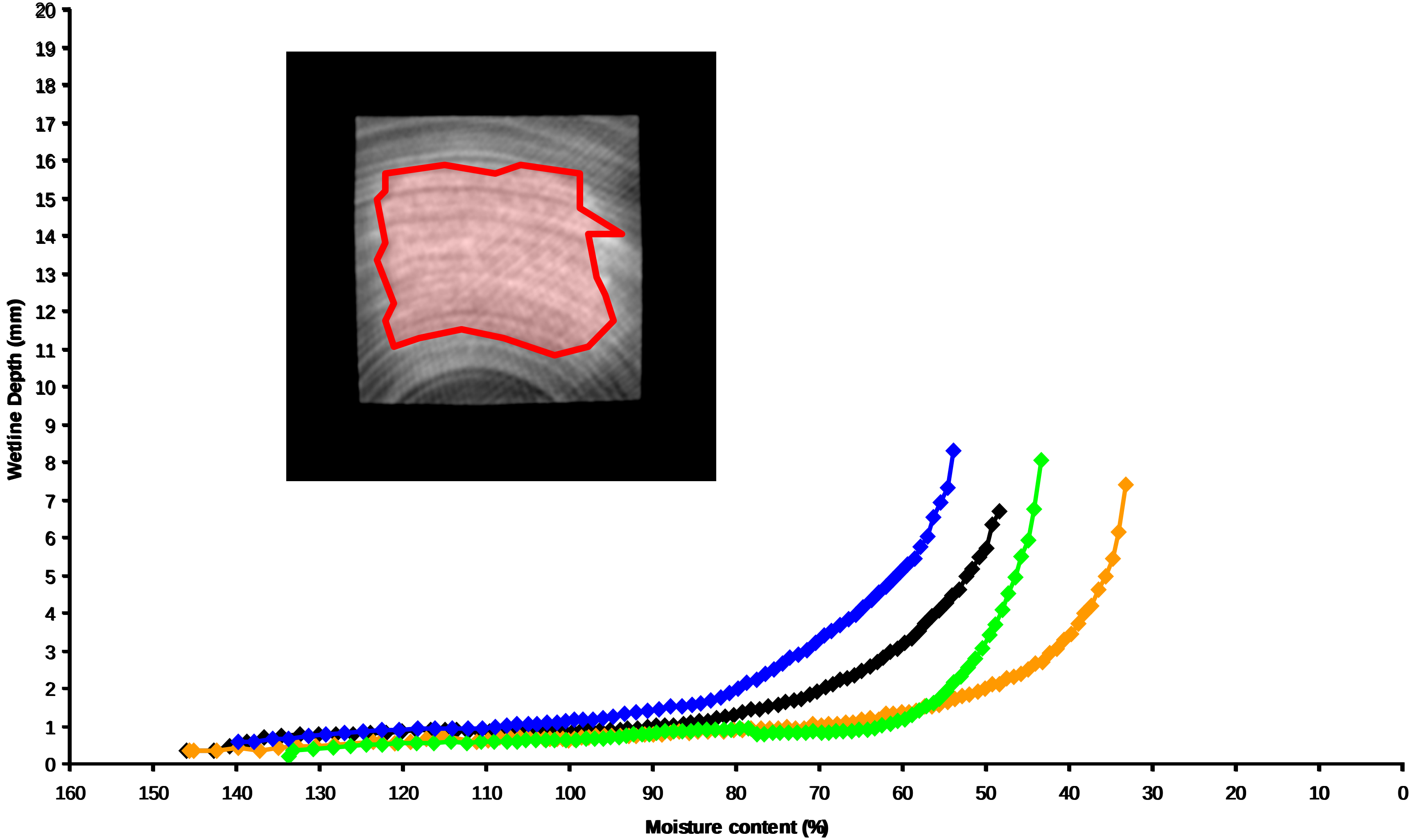
Drying mechanism



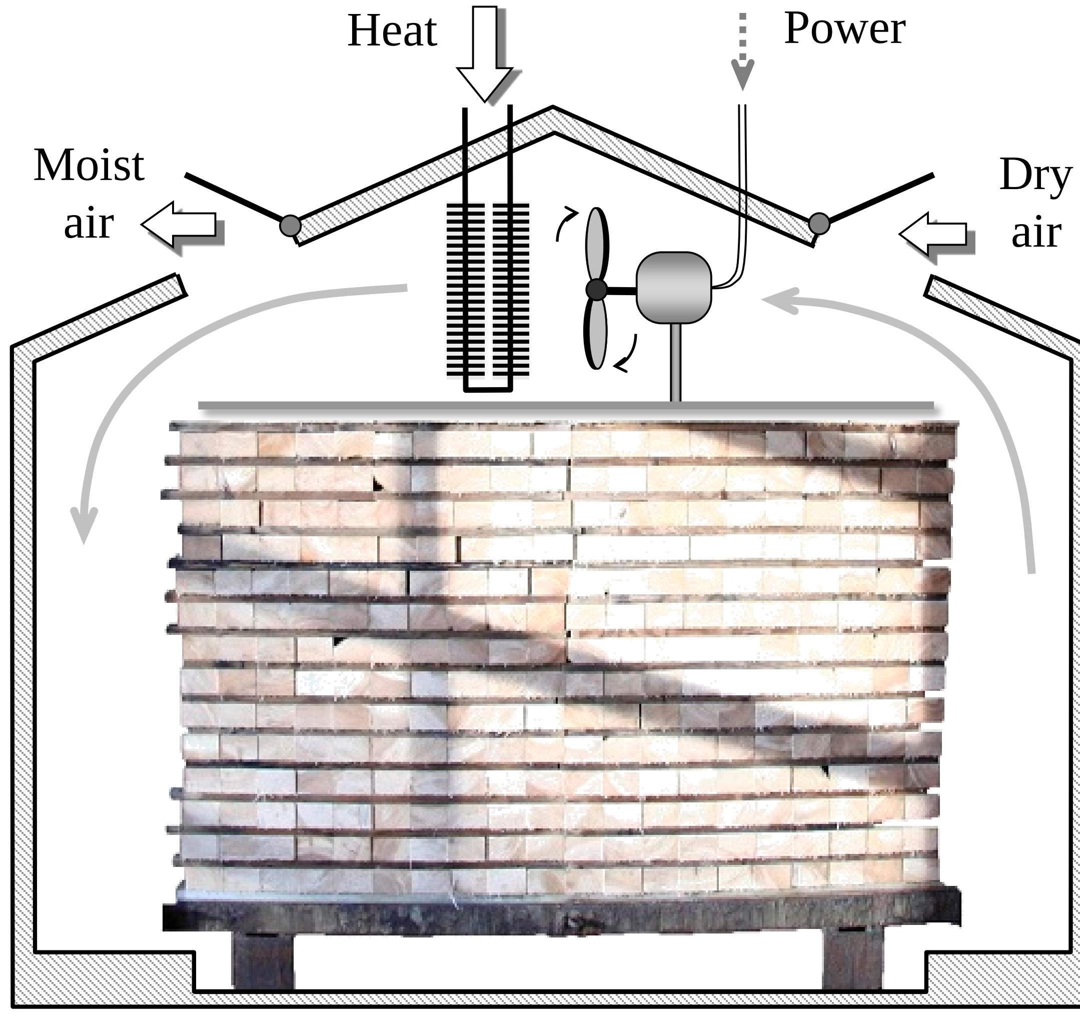
Drying of wood can be considered as a three-stage process:

1. **Heat and mass transfer controlled regime** = wetline remains close to surface and water is drawn to the surface through capillary forces
2. **Transition regime** *(*from *ca*. 50% avg. MC) = wetline recedes when continuous fluid columns become broken
3. **Diffusive regime** = no capillary network active

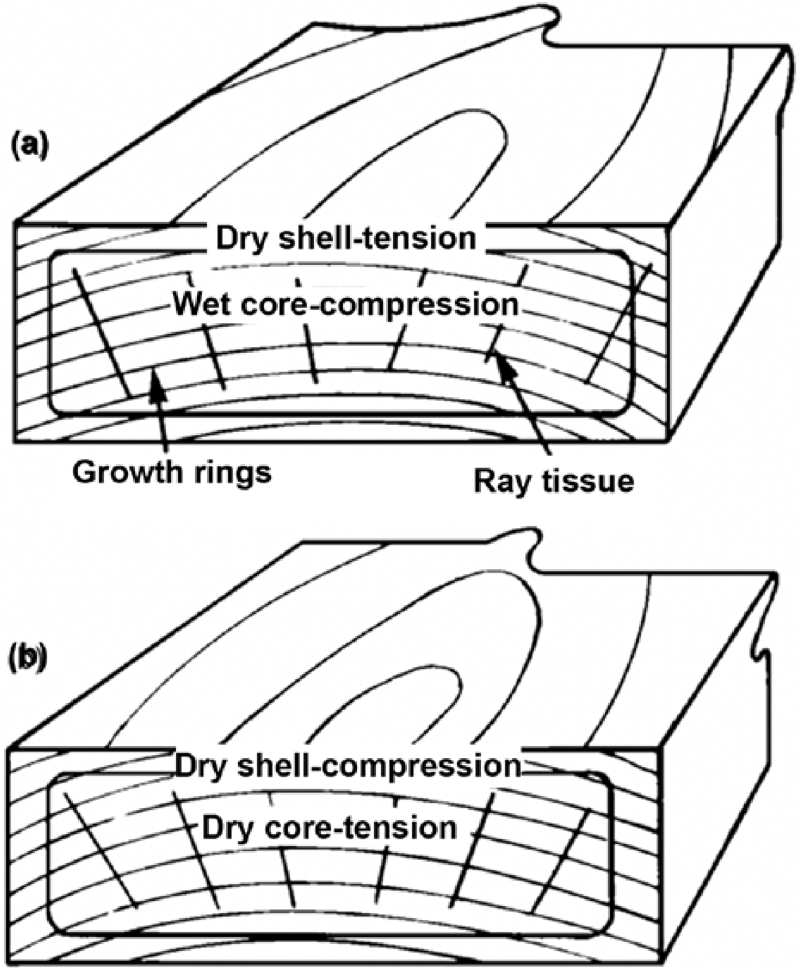
Water-soaked Radiata Replicates
Wetline depth

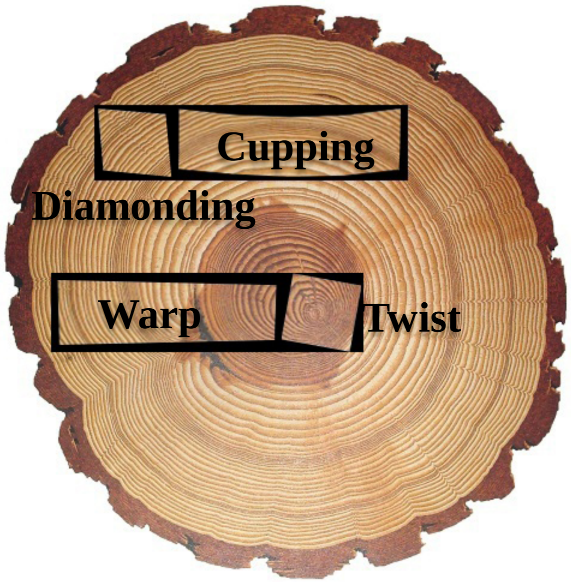


Source: G Scheepers, T Moén, T Rypstra (2007) Liquid water flow in Pinus radiata during drying. Holz als Roh- und Werkstoff. 65(4): 275-283


Heat
Power
Moist
air
Dry
air

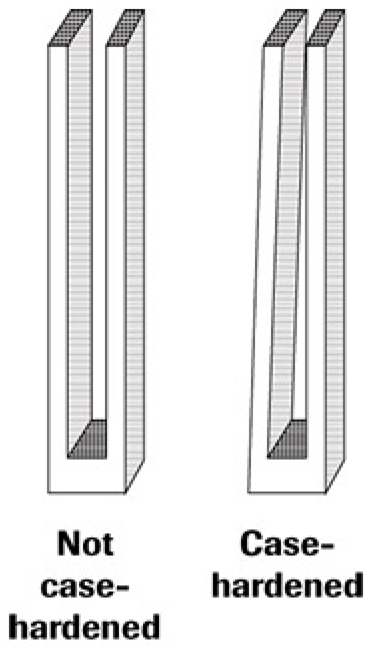
Drying stresses

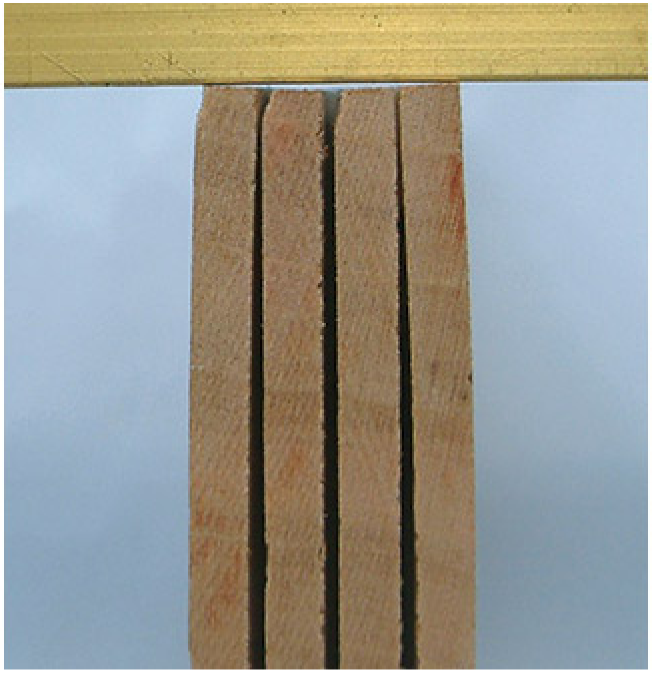




Honeycombing

Source: Forest product and wood handbook

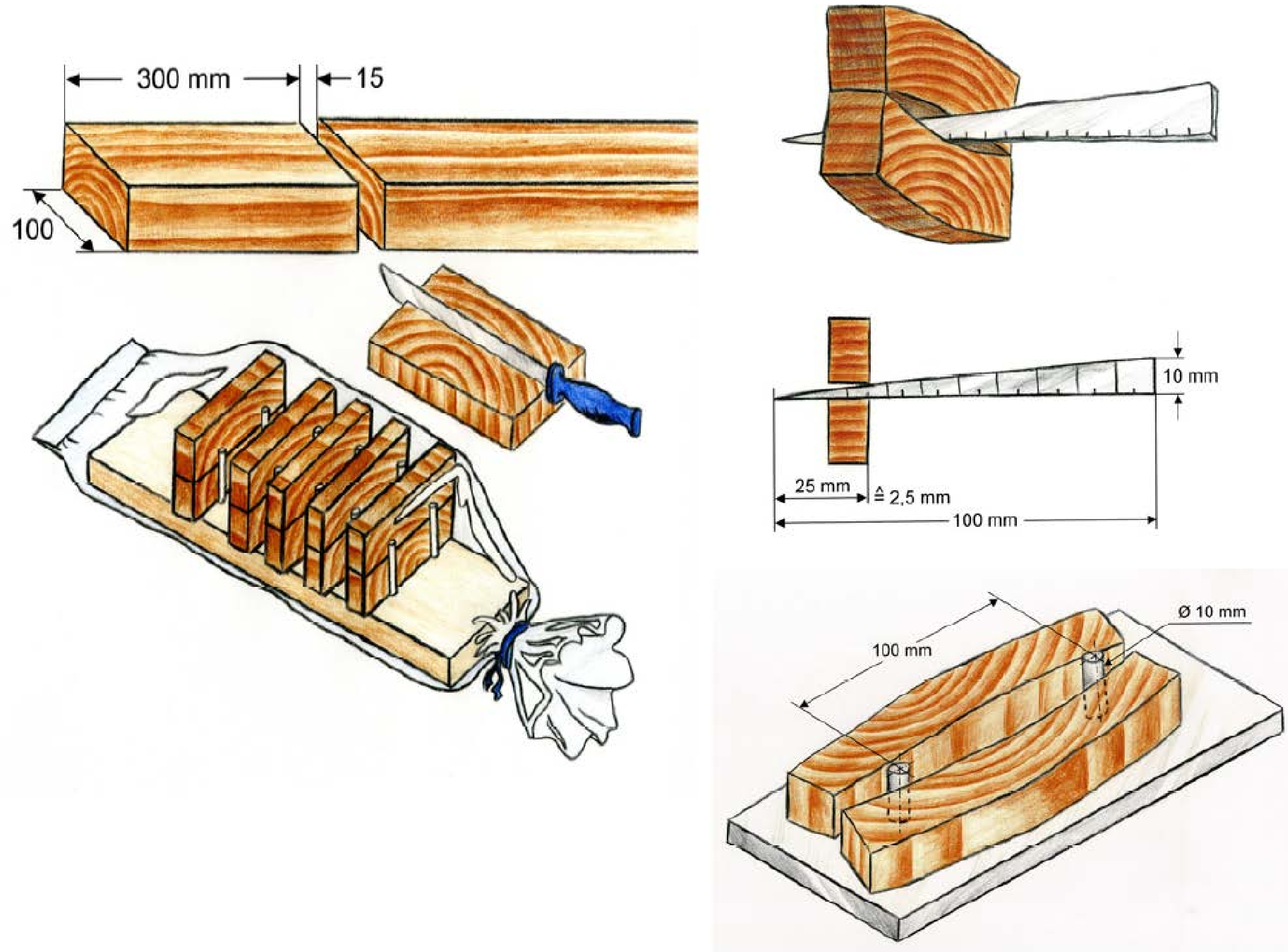




•Residual internal stress between the shell and the core is called **case hardening**.

•If a narrow slice is cut into the shape of a tuning fork, the tines will curve inward if case hardening is present.

•Case hardening can be reversed or eliminated at the end of the kiln cycle.



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Reading material

Morén, T., Virkestorkningens grunder, Valutec AB 2007. 97 pages