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Thermal diffusion of water vapour in porous materials: true or false ?

Introduction

Background

Thermal diffusion

Overview, example

Significant ?

Peuhkuri, overview

Extension

Potentials

Conclusion

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• Background

Durability & thermal water vapour diffusion

Moisture conditions strongly affect durability

- metal corrosion, mould growth, wood rot, hygric stresses, ...

→ *correct assessment of moisture required*

Diffusion is significant transport mechanism

- moisture buffering of interior enclosure, evaporative cooling of roofs, interstitial **condensation** in building components

→ *correct evaluation of diffusion is needed*

Driving forces: vapour pressure & temperature ?

- some authors: Fick & vapour pressure as sole driving force
- some authors: diffusion also driven by temperature gradient

→ *disagreement on diffusion driving forces*

Experimental investigations on thermal diffusion

Proponents thermal diffusion: $j_v = -\delta_p \nabla p_v - \delta_T \nabla T$

- Kumaran 1987, Galbraith et al 1998, Peuhkuri et al 2008, ..
- measure vapour flow under combined vapour pressure and temperature gradients

→ *important diffusion (warm to cold): $\delta_T > 0$, $\delta_T = 5$ to $50 \cdot \delta_p$*

Opponents thermal diffusion: $j_v = -\delta_p \nabla p_v$ *(Fick)*

- Galbraith et al 1998, Thomas 1999, Glass 2007, Baker 2009
- perform measurements along similar experimental principles

→ *no consistent nor significant evidence for thermal diffusion*

Objective: critical analysis to resolve contradictions

→ *it will be shown here that all proponent studies are **flawed***

- ***Example***

Effect thermal diffusion on interstitial condensation

Insulated wall: brick, mineral wool, gypsum board

-10 °C
200 Pa

20 °C
1200 Pa

- interstitial condensation at brick/insulation

Opponents thermal diffusion: $j_v = -\delta_p \nabla p_v$ *(Fick)*

- interstitial condensation: 76 g/m²day

Proponents thermal diffusion: $j_v = -\delta_p \nabla p_v - \delta_T \nabla T$

- thermal permeability δ_T: > 0, = $30 \cdot \delta_p$
- interstitial condensation: 149 g/m²day

→ *potentially large influence, verification is required*

- ***Peuhkuri***

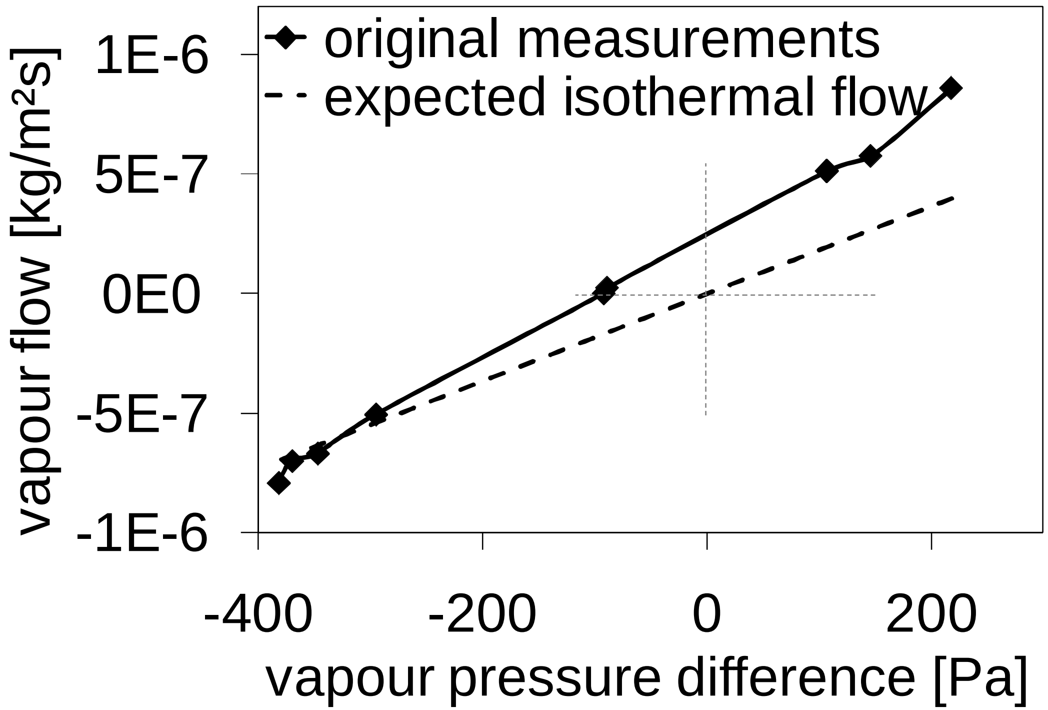
Thermal diffusion: original measurement results

Flow deviates critically from expected isothermal flow

- measurements: *cup set-up with constant T-gradients*
- regression: *fitting:* standard diffusion and thermal diffusion and **liquid** capillary **transfer**

→ *'other transport than the vapour pressure driven alone'*

→ *'temperature gradient itself is driving the moisture from warm to cold'*



- ***Peuhkuri***

Achilles heel: inclusion of liquid transport

Liquid transfer does not play a sizeable role

- cup measurements: equal dry and wet cup permeabilities

→ *liquid transfer can not be used in the modelling of vapour flows*

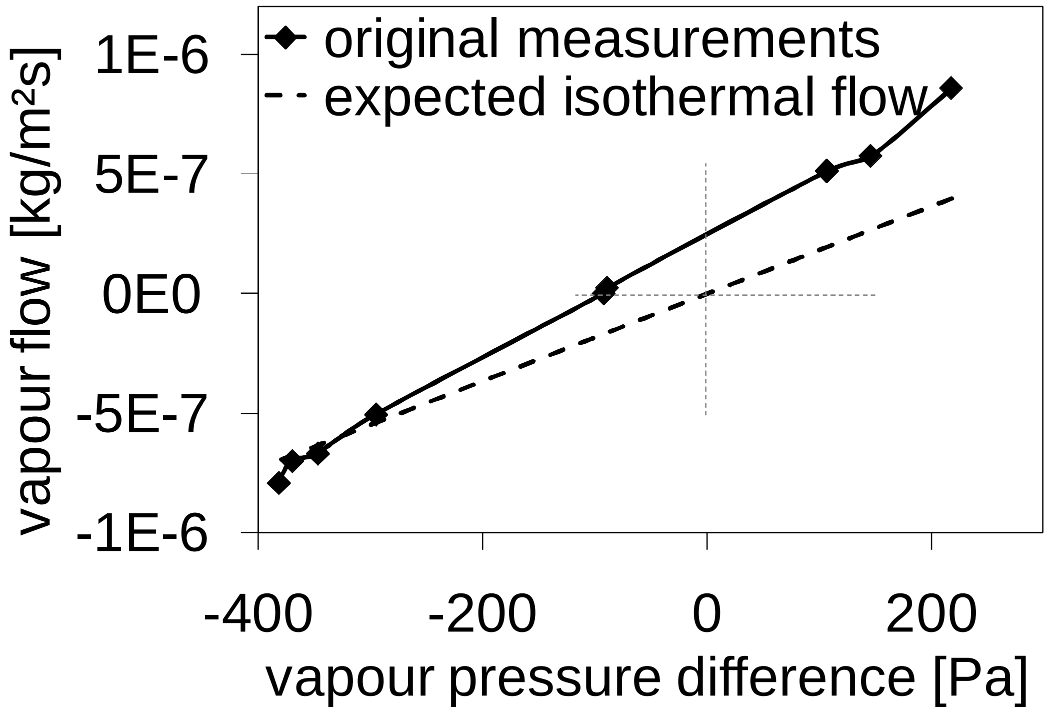
Uneven thermal diffusion

- small at negative Δp_v
- large at positive Δp_v

→ *contrary to expectation*

Other error must be there

- RH sensor deviations



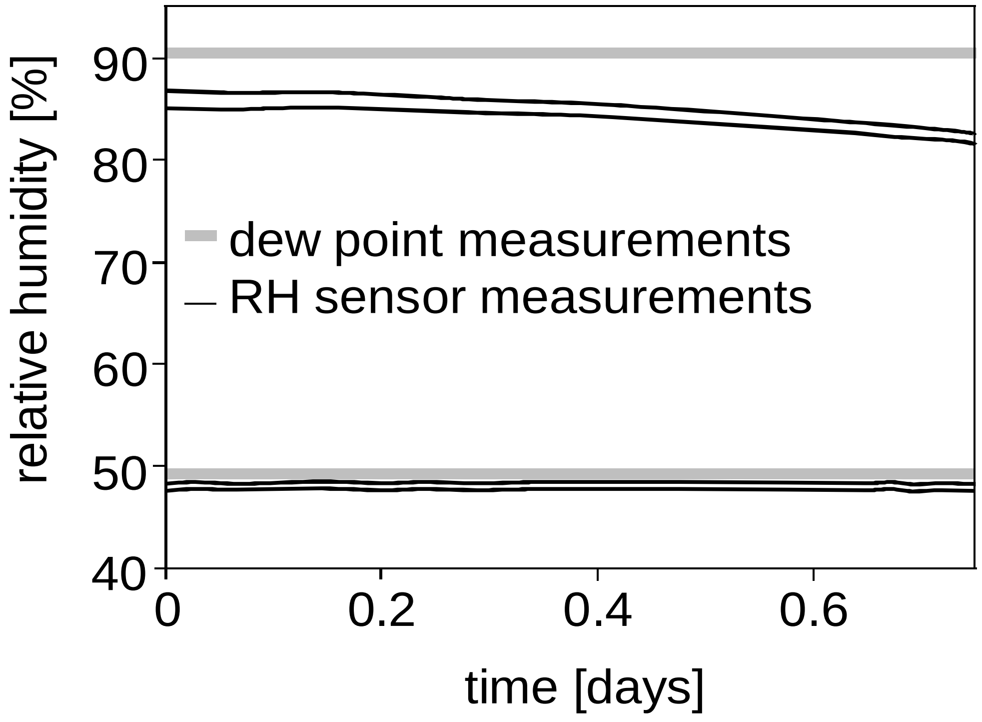
Confrontation: RH sensors & dew-point

PhD of Peuhkuri shows errors RH measurements

- low RH: RH sensors underestimate with approx. 2-3 %
- high RH: RH sensors underestimate with approx. 7-15 %

Correction for RH results

- $$RH_{act} = RH_{mea} + 2.5 + 7.5\left(\frac{RH_{mea} - 49}{74 - 49}\right)$$



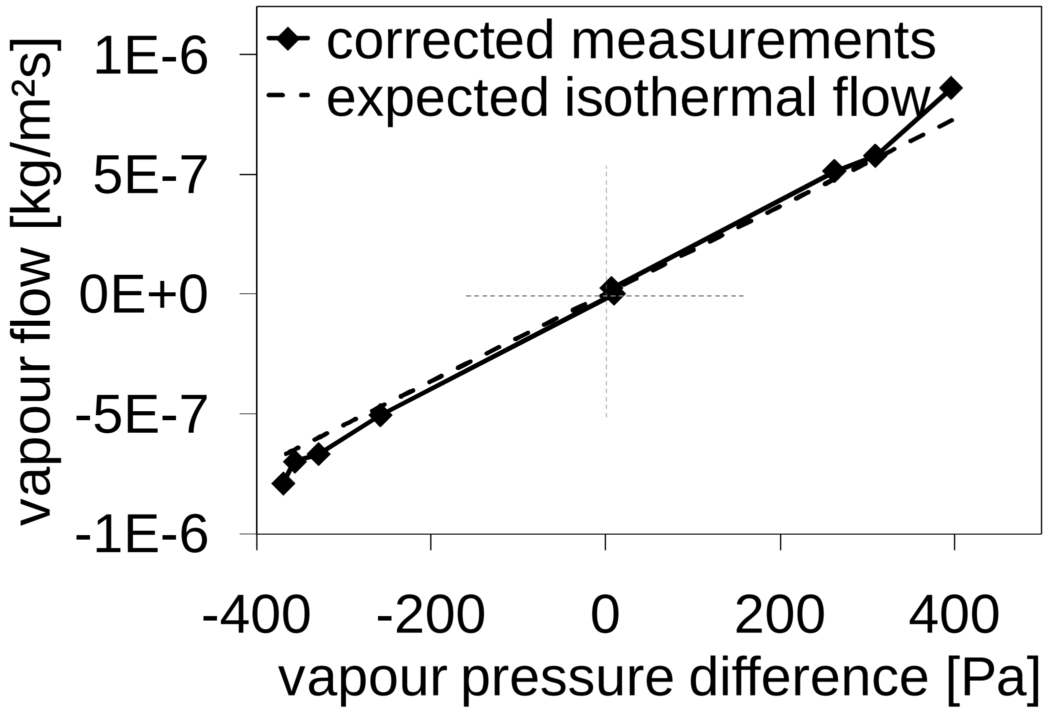
• *Peuhkuri*

Corrected results: no more thermal diffusion

RH correction changes vapour pressure differences

- corrected curve crosses origin (0 Pa Δp_v & 0 kg/m²s flow)
- corrected curve agrees with expected isothermal diffusion
- no consistent nor significant evidence for thermal diffusion

→ *no evidence for driving force other than the vapour pressure*



Other proponent studies: similar falsification

Galbraith et al (1998), Kumaran (1987), ... equally flawed

- original analysis: supported 'existence of thermal diffusion'
- corrected analysis: eliminates support for thermal diffusion

→ removes all contradiction with opponent investigations

Thermodynamics give 'small & negative' thermal diffusion

Small magnitude of thermal diffusion, thus insignificant effect

→ thermal diffusion is not critical for most building issues

Other potentials: parasitic thermal diffusion

Qin et al (2008), ... : diffusion = $j_v = -D_\rho \nabla\rho_v - \varepsilon D_\rho \nabla T$

- ‘important thermal diffusion’: large ‘thermal flows’ measured
- thermal diffusion factor ε: complex measurement technique *(j_v & ρ_v profile & T profile for (non)isothermal experiments)*

Vapour diffusion measurements for Gotland sandstone

	isothermal	*non-isothermal*	
RH level:	65-85	65-95	%RH
diffusion:	$1.5\ 10^{-7}$	$7.2\ 10^{-7}$	kg/m²s
$\nabla\rho_v$:	0.13	0.53	kg/m⁴
∇T:	-	260	K/m

→ $D_\rho = 1.2\ 10^{-6}$ m²/s & ε = $3.2\ 10^{-4}$ kg/m³K

∇p_v:	$1.8\ 10^4$	$7.8\ 10^4$	Pa/m
δ_v:	**$8.5\ 10^{-12}$**	**$9.2\ 10^{-12}$**	**kg/msPa**

→ **vapour pressure** more suitable as transport potential

Thermal diffusion: true or false ?

Similar measurement principles, contradictory experimental results

'Proponents' and 'opponents' on occurrence thermal diffusion

→ disagreement on temperature gradient as driving force

Proponent investigations are shown to be flawed (different errors)

Correction eliminates support for existence thermal diffusion

→ thermal diffusion is not critical for most building issues

Vapour pressure is best potential (non)isothermal vapour diffusion

Other transport potentials result in parasitic thermal diffusion

→ unnecessary complication of model and measurement

Thank you for your attention

Questions and/or comments ?

More information:

Janssen H, 2011. *Thermal diffusion of water vapour in porous materials: fact or fiction ?* International Journal of Heat and Mass Transfer, 54, 1548-1562.