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

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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: $j_v = -\delta_p \nabla p_v - \delta_T \nabla T$

- 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)

- 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
**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 \( \delta_T \): > 0, = 30 \cdot \delta_p
- interstitial condensation: 149 g/m²day

→ potentially large influence, verification is required
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’

![Graph showing vapour flow vs. vapour pressure difference](image)
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Achilles heel: inclusion of liquid transport

Liquid transfer does not play a sizeable role

- cup measurements: equal dry and wet cup permeabilities
  → liquid transfer cannot be used in the modelling of vapour flows

Uneven thermal diffusion

- small at negative $\Delta p_v$
- large at positive $\Delta p_v$
  → contrary to expectation

Other error must be there

- RH sensor deviations

Graph:

- original measurements
- expected isothermal flow

Vapour flow [kg/m²s] vs vapour pressure difference [Pa]
**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

\[
RH_{\text{act}} = RH_{\text{mea}} + 2.5 + 7.5 \left( \frac{RH_{\text{mea}} - 49}{74 - 49} \right)
\]
Corrected results: no more thermal diffusion

RH correction changes vapour pressure differences

- corrected curve crosses origin (0 Pa $\Delta p_v$ & 0 kg/m$^2$s 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 = \( j_v = -D_p \nabla \rho_v - \varepsilon D_p \nabla T \)
- ‘important thermal diffusion’: large ‘thermal flows’ measured
- thermal diffusion factor \( \varepsilon \): complex measurement technique
  \((j_v & \rho_v \text{ profile} & \ T \text{ profile} \text{ for (non)isothermal experiments})\)

Vapour diffusion measurements for Gotland sandstone

<table>
<thead>
<tr>
<th></th>
<th>isothermal</th>
<th>non-isothermal</th>
</tr>
</thead>
<tbody>
<tr>
<td>RH level</td>
<td>65-85</td>
<td>65-95 %RH</td>
</tr>
<tr>
<td>diffusion</td>
<td>1.5 (10^{-7})</td>
<td>7.2 (10^{-7}) kg/m²s</td>
</tr>
<tr>
<td>( \nabla \rho_v )</td>
<td>0.13</td>
<td>0.53 kg/m⁴</td>
</tr>
<tr>
<td>( \nabla T )</td>
<td>-</td>
<td>260 K/m</td>
</tr>
<tr>
<td>( D_p )</td>
<td>1.2 (10^{-6}) m²/s</td>
<td>( \varepsilon ) = 3.2 (10^{-4}) kg/m³K</td>
</tr>
<tr>
<td>( \nabla p_v )</td>
<td>1.8 (10^4)</td>
<td>7.8 (10^4) Pa/m</td>
</tr>
<tr>
<td>( \delta_v )</td>
<td>8.5 (10^{-12})</td>
<td>9.2 (10^{-12}) kg/msPa</td>
</tr>
</tbody>
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→ 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: