Designing Two-Phase Devices for Performance

What Physics Rewards. What It Punishes.

Performance is not optimized — it is allocated.
Every constraint spends margin somewhere.
If you don’t know where, physics will decide for you.

Geometry & Sizing

Performance starts with cross-section.

- **Cross-section is the highest-value asset.**
- **Thickness beats width. Every time.**
- **Short paths outperform clever spreading.**

Punishments

- **Heat spreading does not replace vapor area.**
- **Minimum envelopes do not produce high performance.**
- **Late packaging changes always cost margin.**

Reality check
A 20–30% hit in thickness commonly changes the governing limit.

Flattening & Forming

Flattening is a trade, not a win.

- **Contact improves.**
- **Vapor and liquid-return margin shrink.**
- **Wick damage is real.**

Punishments

- **Flattening does not increase capacity.**
- **Round-tube assumptions lie once you flatten.**

Rule
Flattened height ≤50–60% of OD is where vapor transport and wick effects take over.

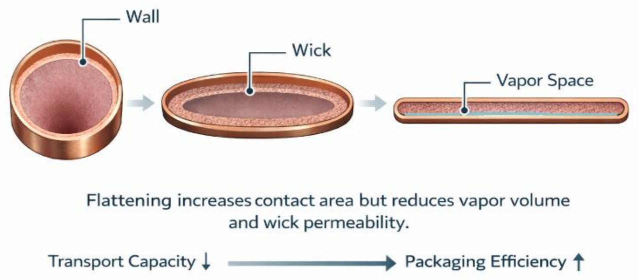


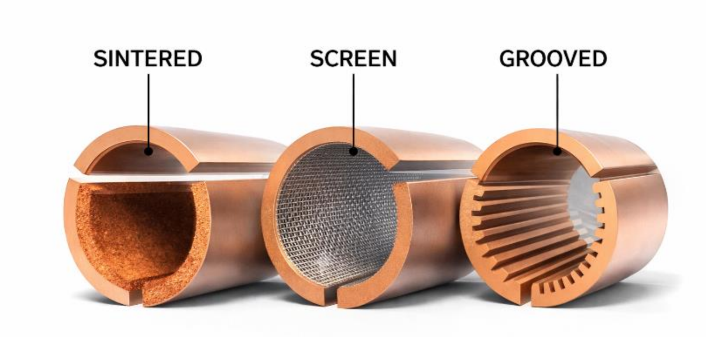
Figure 2-X. Geometry-driven **tradeoffs in flattened heat pipes**.

Progressive flattening improves packaging and interface contact but reduces vapor volume and effective wick permeability, limiting maximum heat transport.

Wick & Liquid Return

Capillary limit kills more designs than anything else.

- Orientation matters — even when you wish it didn’t.
- Capillary pressure without flow margin still fails.



Punishments

- Ideal wick properties do not survive reality.
- Manufacturing, bending, and forming reduce permeability.

Truth
In real hardware, the capillary limit is often the governing limit.

Vapor Space & Transport

Vapor space is not optional.

- Vapor cross-section sets capacity.
- ΔP rises fast with flattening and bending.

Punishments

- Vapor space treated as leftover volume disappears first.
- Transport limits dominate long, thin, flat geometries.

Truth
Long + thin + flat becomes vapor-limited. Always.

Bending & Routing

Every bend spends margin.

- Bends ovalize tubes.
- Wicks distort.
- Vapor area shrinks.

Punishments

- Straight-tube performance does not survive routing.
- Stacked bends behave like restrictions.

Rules

- $R \geq 5\times OD$ → minimal penalty
- $R \geq 3\times OD$ → measurable penalty
- $R < 3\times OD$ → expect degradation

- **Bends within ~5×OD compound losses**
- **Bends near the evaporator are high risk**

Length & Aspect Ratio

Length eats capillary pressure for lunch.

- **Transport penalties scale faster than length alone.**
- **Capillary head is finite — length consumes it directly.**

Punishments

- **Short-device data does not extrapolate.**
- **Condenser area does not save long evaporators.**

Truth
If L/OD looks uncomfortable on the drawing, it already is.

Heat Input & Evaporator

The hottest square centimeter sets the ceiling.

- **Heat input is non-uniform unless proven otherwise.**
- **Total watts is a distraction.**

Punishments

- **Sizing by average power fails.**
- **Trading transport margin for evaporator resistance backfires.**

System Reality

Most systems are not heat-pipe-limited.

- **Airflow, fins, and interfaces often dominate ΔT.**
- **Component optimization ≠ system performance.**

Punishment

- **Chasing small two-phase gains while ignoring airflow is theater.**

Final Rule

Vapor cross-section sets capacity.
Liquid return sets robustness.
Everything else is tuning.

Break these rules and the device may still work —
but it will not be a high-performance solution.