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Escuela de Ciencia e
Ingeniería de los Materiales

Modeling of a vapor chamber using Comsol Multiphysics®

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PROBLEM STATEMENT

- A vapor chamber is a cooling component in microelectronics that efficiently dissipates heat by utilizing a liquid-to-vapor phase change process within a sealed chamber.

- Vapor chambers have been historically reserved to **high power** consumption systems or premium segments.

- Due to their high cost of manufacturing and their exclusivity, vapor chambers are not as demanded as mainstream thermal solutions such as heat pipes or spreaders.

- Since vapor chambers are not commonly employed, the modeling techniques for this thermal solution have not been easily defined for everybody.

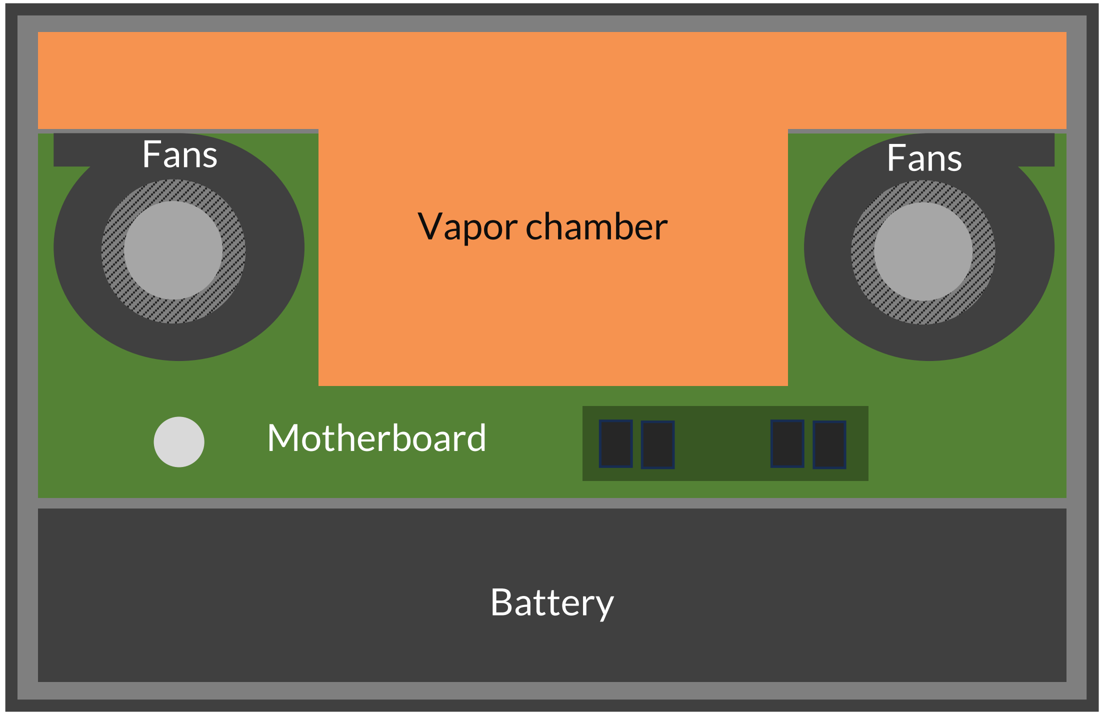


Figure 1. Vapor chamber placed as thermal solution in mobile system

VAPOR CHAMBER WORKING PRINCIPLE

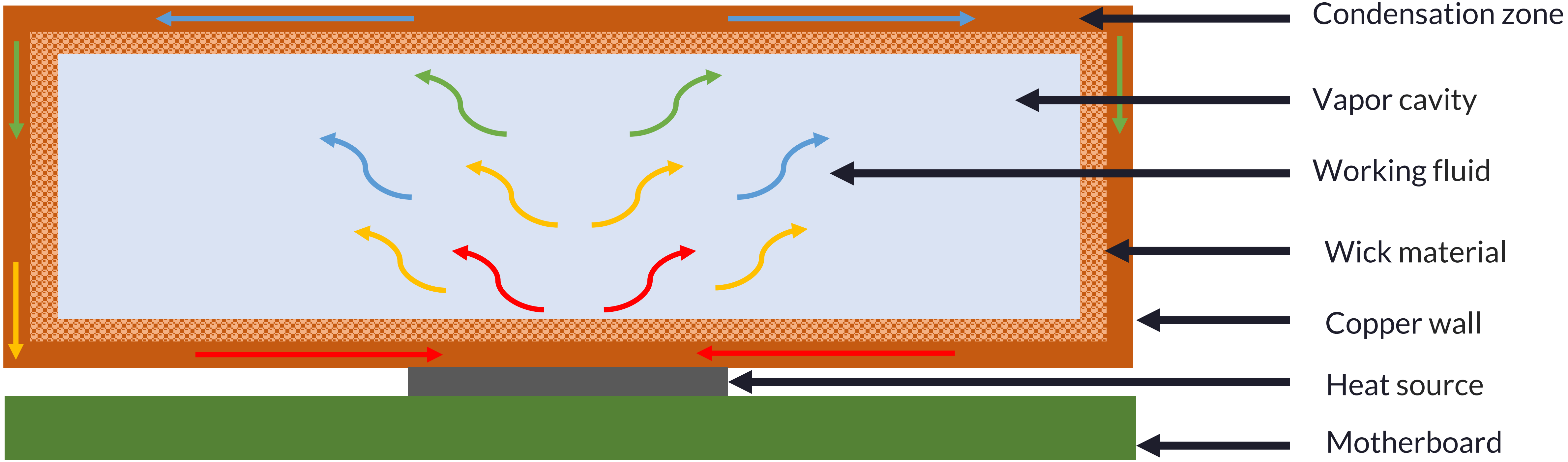


Figure 2. Vapor chamber operation diagram

MATHEMATICAL DESCRIPTION

$$\rho Cpu \cdot \nabla T + \nabla \cdot q = Q$$

Conservation of energy

ρ = material density (kg/m^3)

Cp = specific heat capcity (J/kg K)

u = velocity field in a fluid domain (m/s)

T = temperature (°C)

q = heat flux (W/m^2)

Q = heat source (W/m^3)

$$\rho \frac{\partial u}{\partial t} + \rho u \cdot \nabla u = -\nabla p + \nabla \cdot \left(-\frac{2}{3}\mu[\nabla \cdot u]I + \mu\,[\nabla u + \{\nabla u\}^T]\right) + F$$

Momentum balance

μ = viscosity (Pa.s)

I = identity tensor

F = volumetric external forces applied to the fluid (N/m^3)

MATHEMATICAL DESCRIPTION

$$\vec{q} = -k \cdot \nabla \mathrm{T}$$

$$\vec{q} = -keff \cdot \nabla \mathrm{T}$$

Thermal conductivity

$\vec{q}$ = heat flux vector (W/m^2)

k = conductivity of the material (W/mK)

∇T = temperatura gradient (K/m)

$keff$ varies depending on the porosity od the porous material and the conductivity of the fluid

$$\frac{\rho}{\varepsilon}(u \cdot \nabla)\frac{u}{\varepsilon} = \nabla \cdot \{-p\, I + \frac{\mu}{\varepsilon}\left[\nabla u + (\nabla u)^T\right] - \frac{2}{3}\frac{\mu}{\varepsilon}[\nabla \cdot u] I\} - (k^{-1}\mu + \frac{Q_m}{\varepsilon^2})\, u + F$$

Brinkman equation

p = pressure (Pa)

u = viscosity (Pa.s)

F = volumetric external forces applied to the fluid (N/m^3)

k = permeability (m^2)

Ɛ = porosity

Qm = mass source (kg/m^3)

MODEL CONSTRUCTION

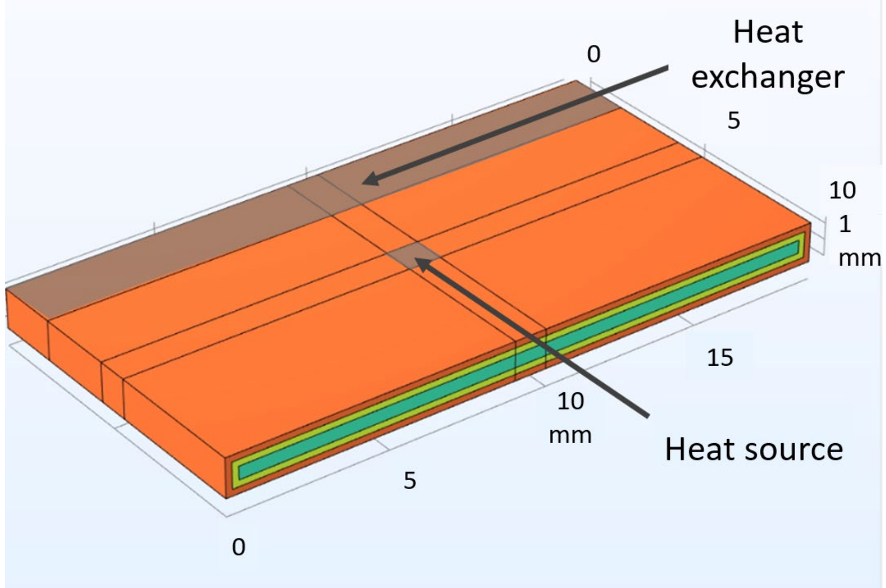


Figure 3. Original dimensions of vapor chamber body

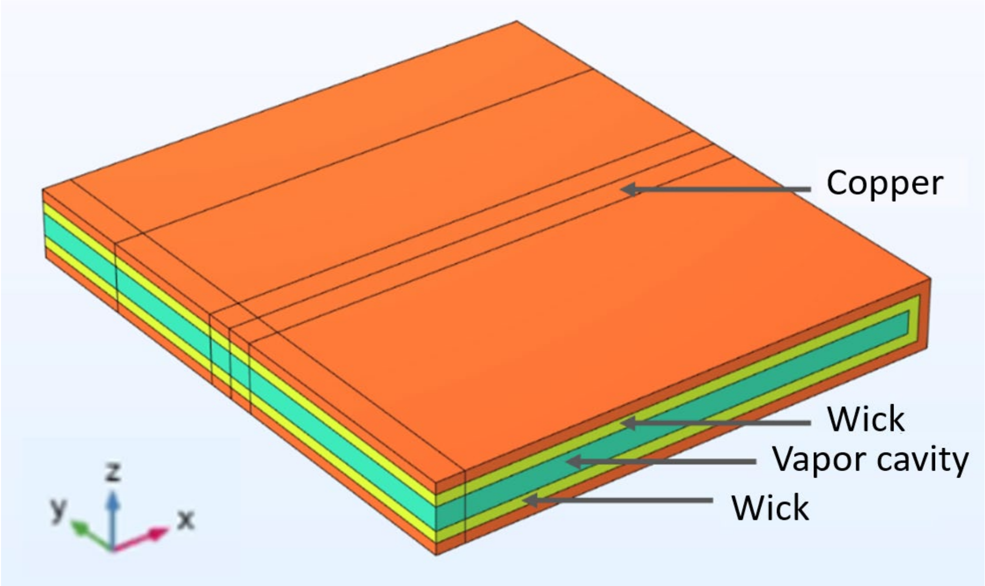


Figure 4. Simplified vapor chamber and its layers

Quantity	Name	Length (mm)	Width (mm)
1	Central body	10.00	19.00
1	Heat source	1.00	1.00
1	Heat exchanger	2.00	19.00

Quantity	Layer	Material	Thickness (mm)
2	Copper walls	Copper	0.2
2	Wick	Copper 68% porosity	0.2
1	Vapor cavity	Water	0.4

MATERIAL PROPERTIES

Copper thermal conductivity: 400 W/mK
Porosity of wick: 68%
Thermal conductivity of working fluid: 0.02 – 0.68 W/mK dependending of temperature
Other working fluids properties:

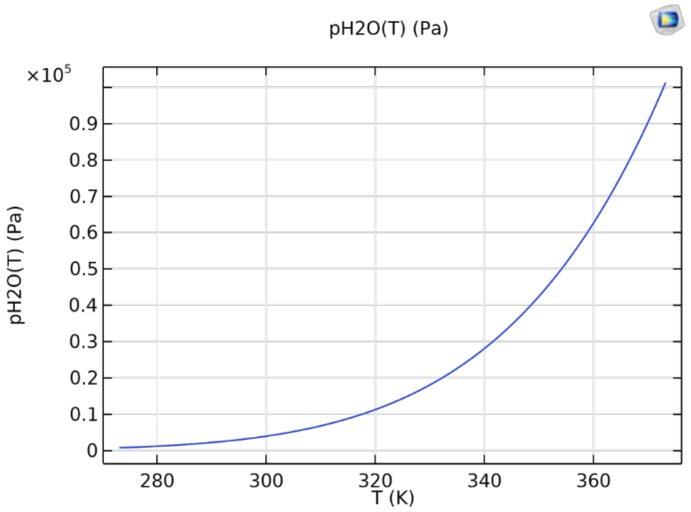


Figure 5. Water saturation pressure as a function of temperature

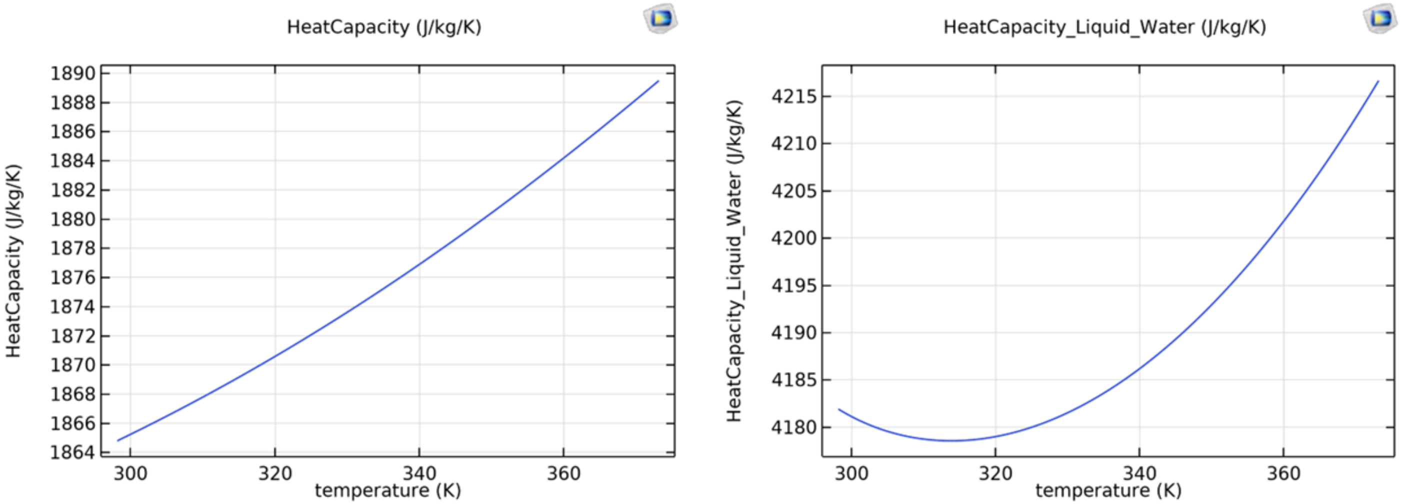
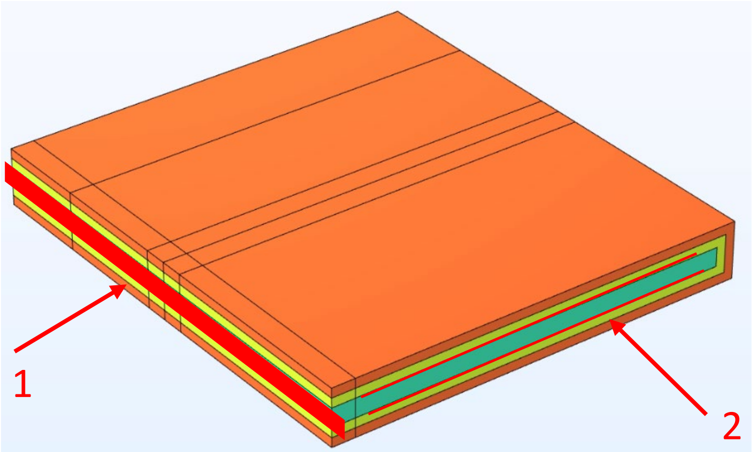


Figure 6. Specific heat of water vapor (left) and liquid water (right) as a function of temperature

BOUNDARY CONDITIONS

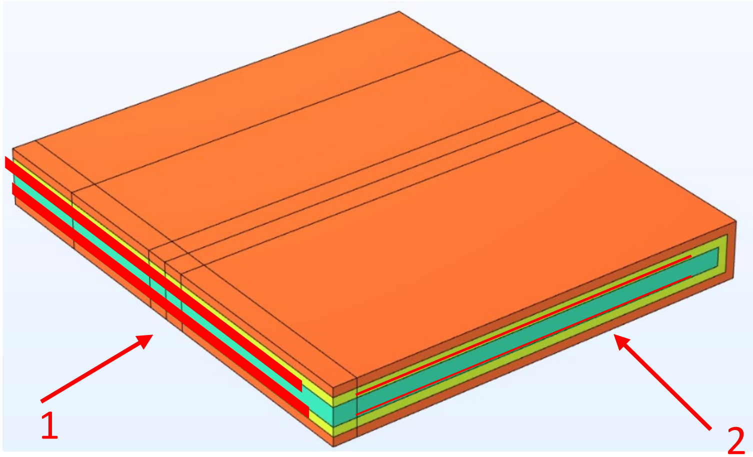
LAMINAR FLOW



1. Wall
No slip
u = 0

2. Inlet
$P = pH2Osat(T)$

BRINKMAN EQUATIONS

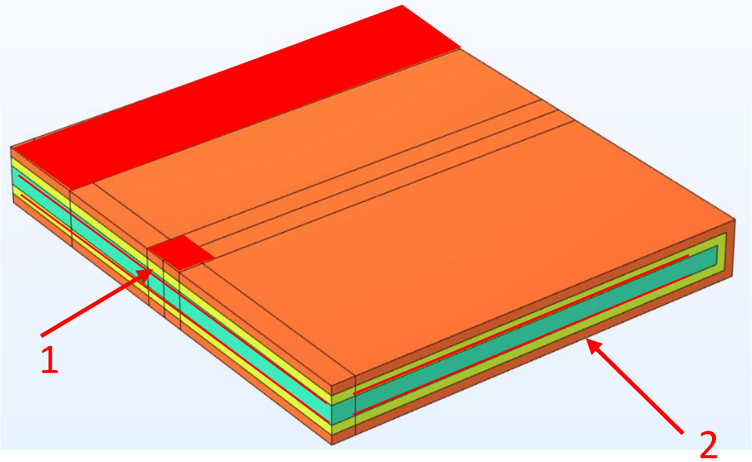


1. Wall
No slip
u = 0

2. Inlet

$$u_l = \frac{u_v\,\rho_v}{\rho_l}$$

HEAT TRANSFER IN POROUS MEDIA



1. The surfaces of the heat exchanger and heat source are defined

2. **Heat source**
(u*spf.nx+v*spf.ny+w*spf.nz)*HeatOfVaporization_water21(T)*spf.rho

MESH

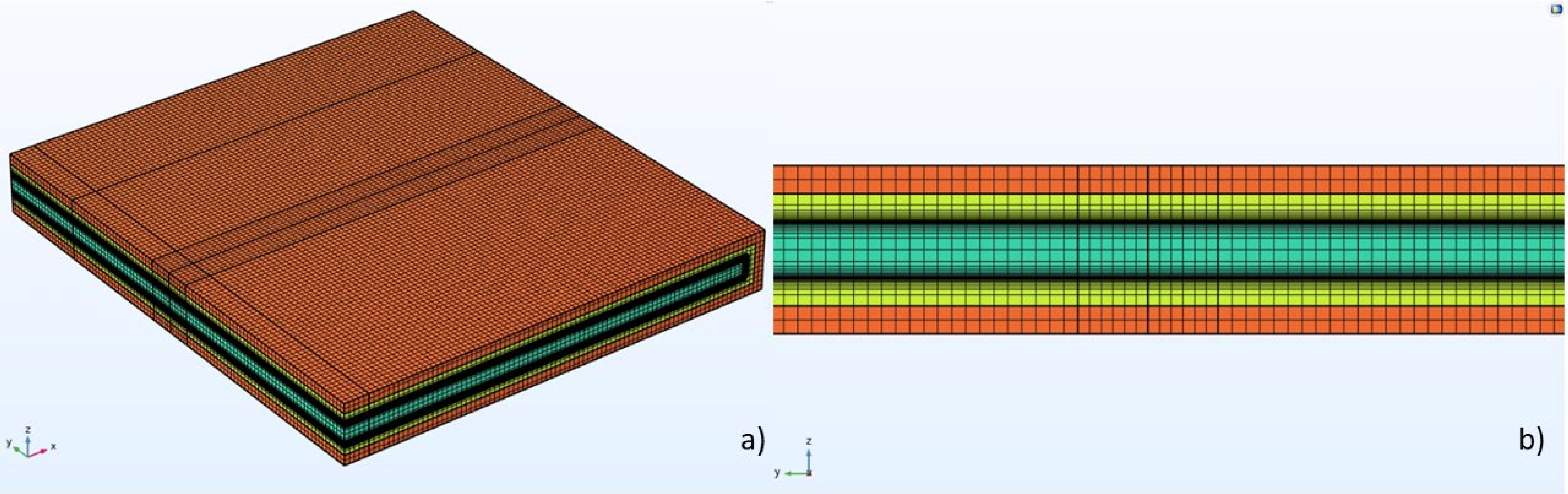


Figure 7. Mesh of the model, a) Isometric view and b) Cross section of the chamber

- Free quadrilateral mesh
- Boundary layer between vapor and porous material
- Sweep function

- Number of elements: 182 172
- Average mesh quality: 0.99
- Min element quality: 0.39

EXPERIMENTAL RESULTS FROM LABORATORY

Initially, it is unknown at what power and heat transfer coefficient to simulate the model since the geometry was simplified

However, the actual vapor chamber test conditions are known
Normalized power 1 W/W
Normalized heat transfer coefficient of 1 (W/m2·K) / (W/m2·K)

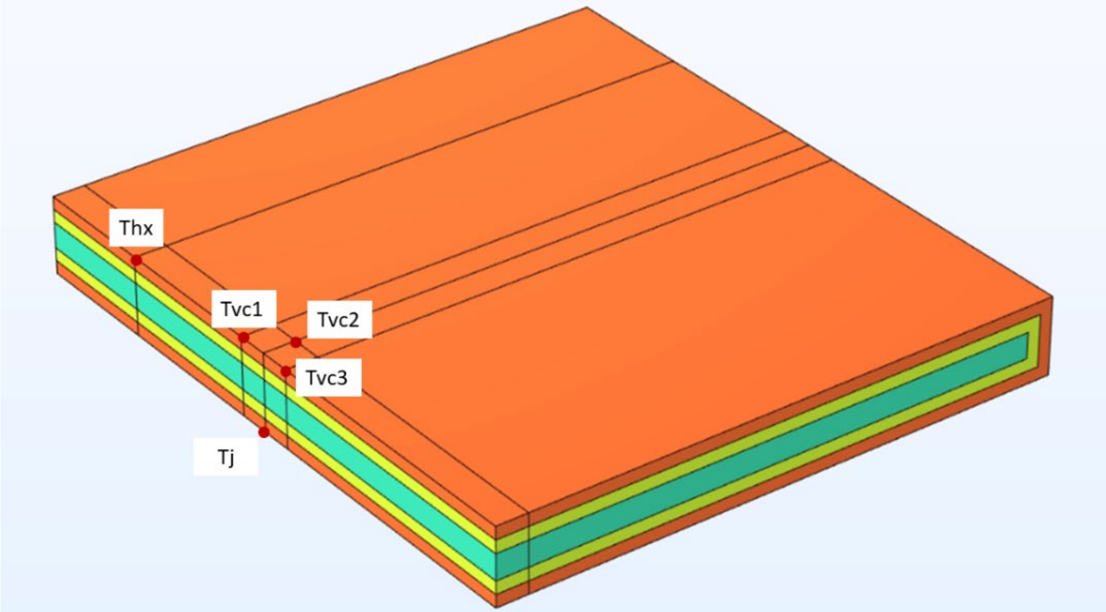


Figure 8. Position of temperature measurement points in the real-life vapor chamber

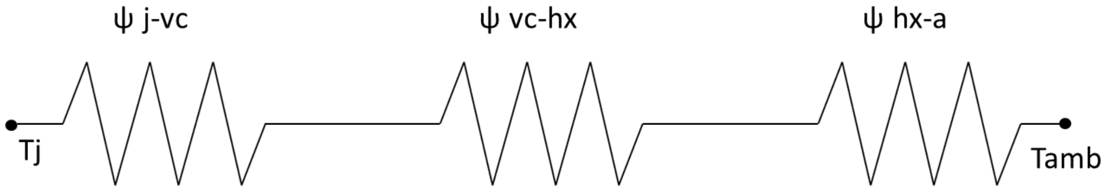


Figure 9. Thermal circuit from the transistor layer to room temperature.

FINAL RESULTS FROM MODEL

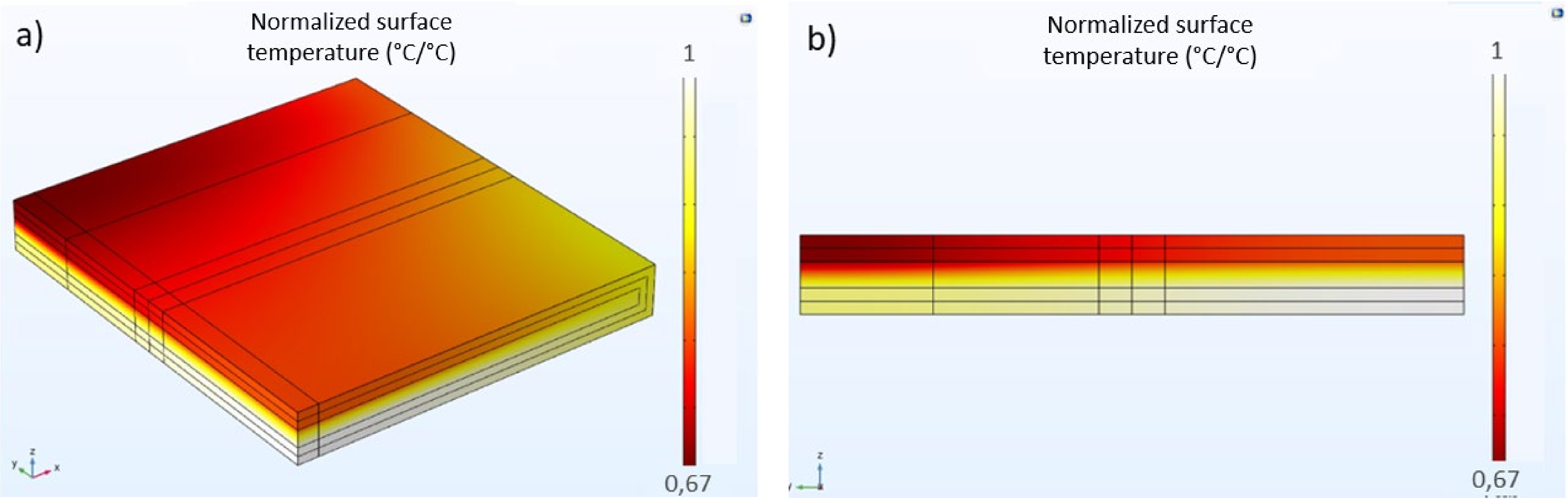


Figure 10. Temperature contours on the external surface of the vapor chamber: a) Isometric view and b) Cross-sectional view in the center of the chamber.

FINAL RESULTS FROM MODEL vs EXPERIMENTAL MEASSUREMENTS

Percentage of error between the different temperatures of the model and the experimental results

Temperature	Model	Laboratory	%error
Tj (°C/°C)	1.00	1.00	0.34
Tvc (°C/°C)	0.98	1.00	2.17
Thx (°C/°C)	0.96	1.00	3.70

Percentage of error between the thermal resistance deltas of the model and the experimental results

Temperature	Model	Laboratory	%error
Δ j-vc (°C/°C)	1.09	1.00	9.24
Δ vc-hx (°C/°C)	0.15	1.00	84.54
Δ hx-a (°C/°C)	1.06	1.00	6.01

FINAL RESULTS FROM MODEL

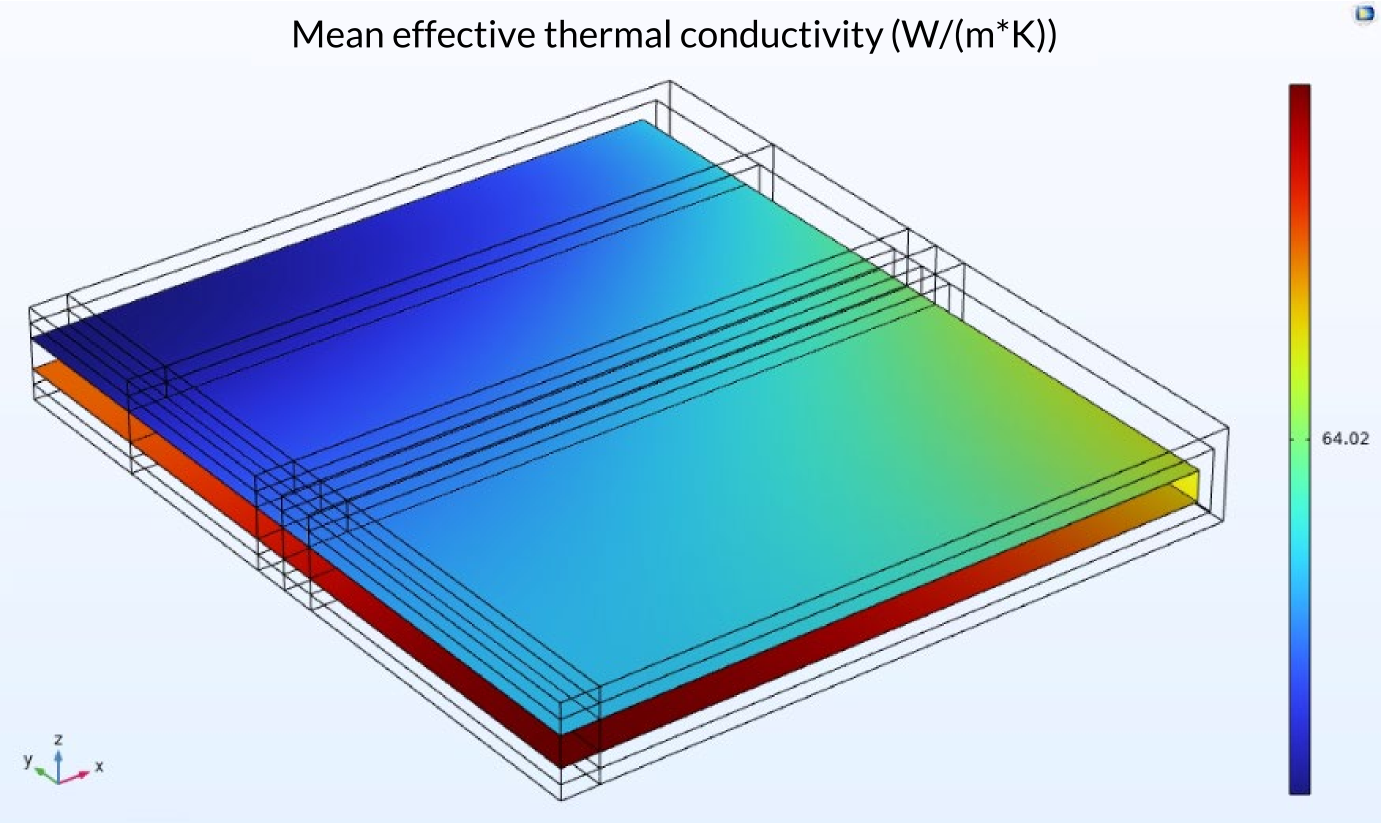


Figura 11. Average effective thermal conductivity at the vapor cavity-porous material interface.

CONCLUSIONS

- The model accurately simulates heat transfer from the heat source to the liquid condensation area in the heat exchanger. It demonstrates impressive fidelity to experimental data, exhibiting less than 1% error in reporting critical temperature values in the source region.

- The model can provide temperature values at the top surface of the chamber and in the heat exchanger, with errors of 2% and 4% respectively.

- The model's applicability is contingent on maintaining fixed geometry and specific normalized input parameters. Due to its scale, caution is advised in extrapolating results for real-world applications with higher power inputs.

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