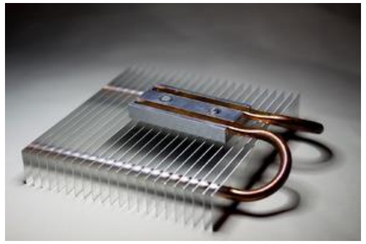
Thermacore (GB)

State of the art of heat transfer of Heat Pipes and Thermosyphons employing nanofluids as working fluid

M.H. Buschmann, A. Huminic, S. Mancin, R.R. Riehl

ILK Dresden, Germany; Univ. of Brașov, Romania; Univ. of Padua, Italy; INPE Brasil



Heat pipe system Situs Technicals GmbH (DE)

Unfortunately non of these devices is operated with nanofluids.

Laptop with heat pipe system
English Wikipedia

Heat sink (Al) wit heat pipes (Cu)
English Wikipedia

Heat pipe heat exchanger for heat recovery
Cooler India [P] Ltd. (India)

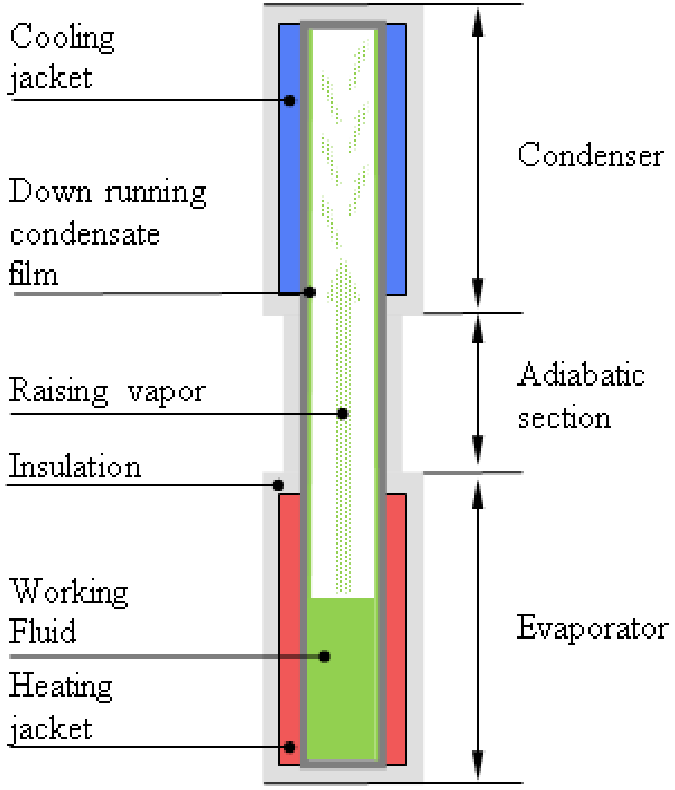
Heat pipe assembly
wakefield vette (USA)

1st European Symposium on Nanofluids (ESNf2017)
8-10 October 2017, Lisbon, Portugal

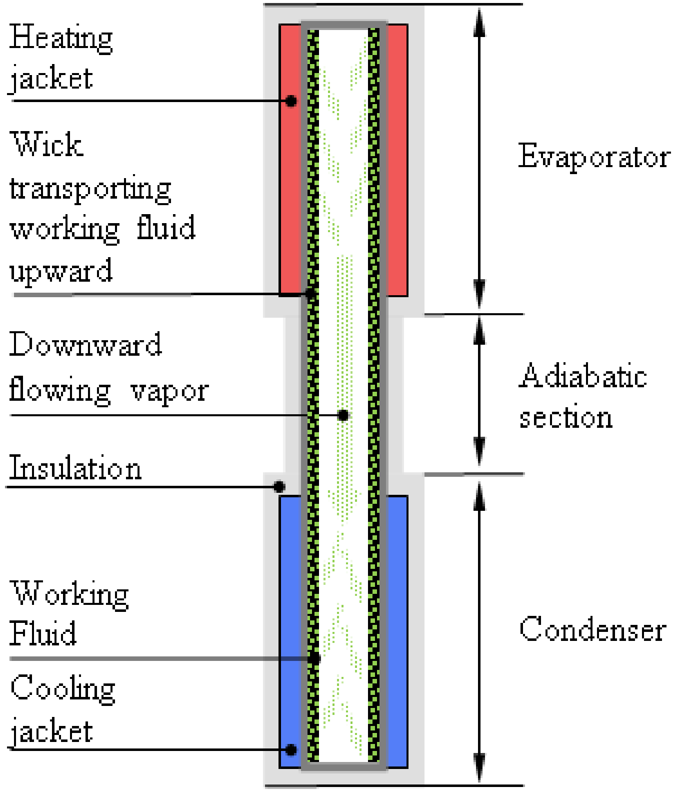
Outline

- Working principles
- Where could and how nanofluids act?
- Experiments from ILK / TU Freiberg (Germany)
- University of Padua (Italy)
- University of Brașov (Romania)
- GamaTech Thermal Solutions (Brasil)
- Conclusiones

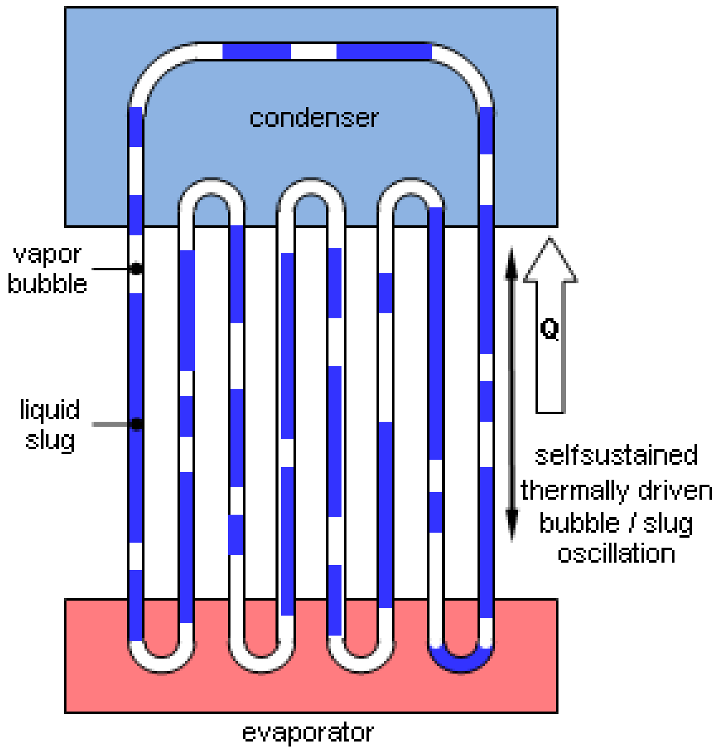
Working principles



thermosyphon



heat pipe

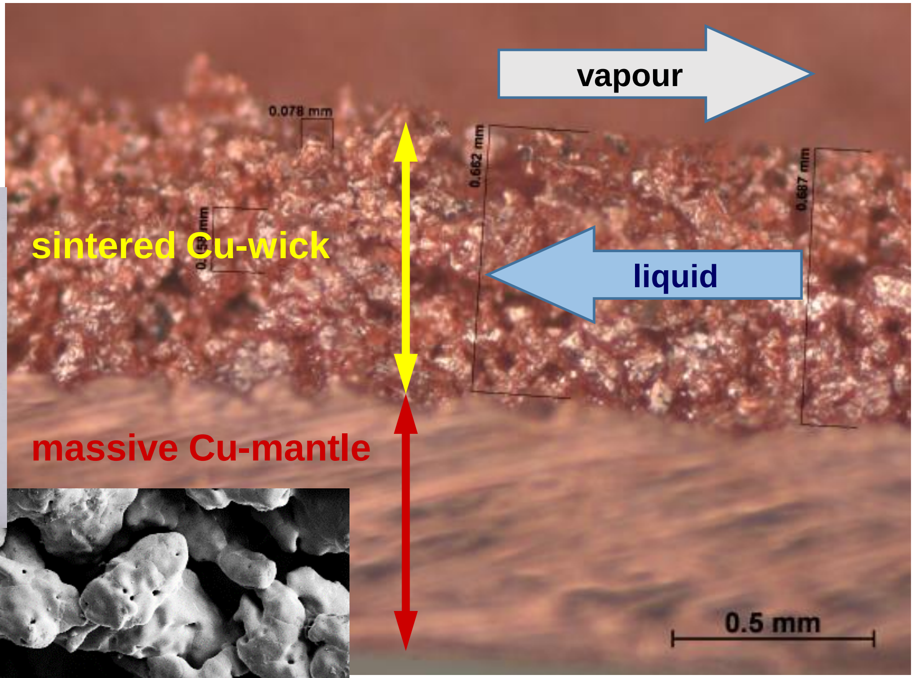


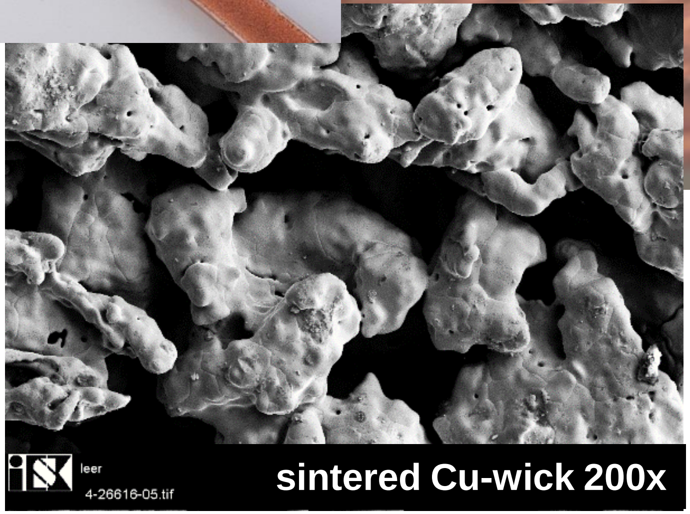
oscillating heat pipe

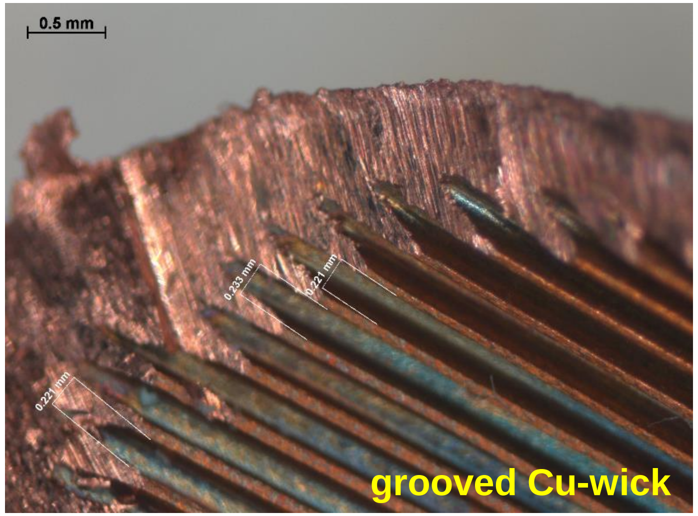
A. Zucker, Bachelor Thesis 2016.

Wick of heat pipe

Cu heat pipe
length 400 mm
inner diameter 8 mm
transmissible heat 120 W





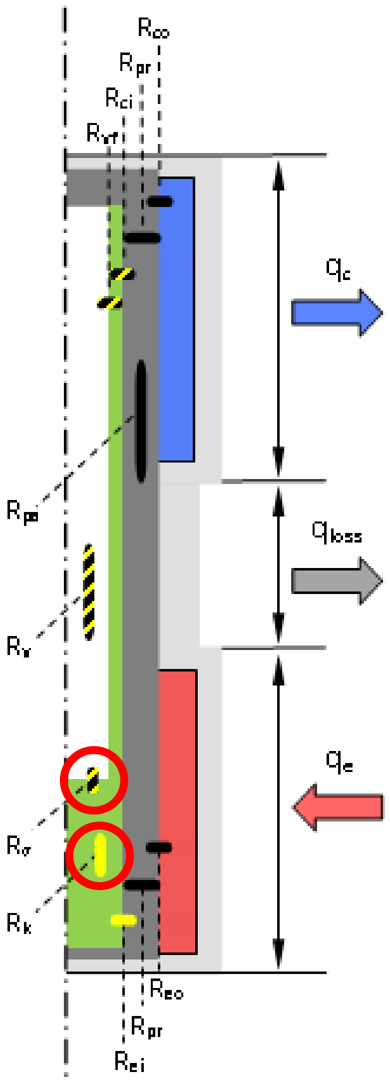


M.H. Buschmann, Heat Pipes and Thermosyphons Operated with Nanofluids (Sec. 14)
in Heat Transfer Enhancement with Nanofluids
EDITORS: V. Bianco, O. Manca, S. Nardini, K. Vafai CRC Press 2015.

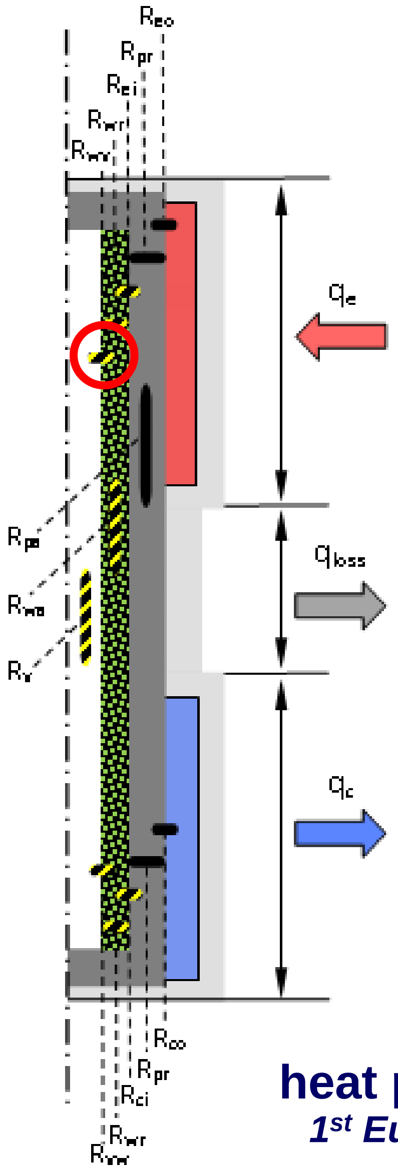
Where could nanofluids act?

Are nanoparticles transported by vapour?

What about thermal conductivity?



thermosyphon



heat pipe

highly likely

possible
but must be proven

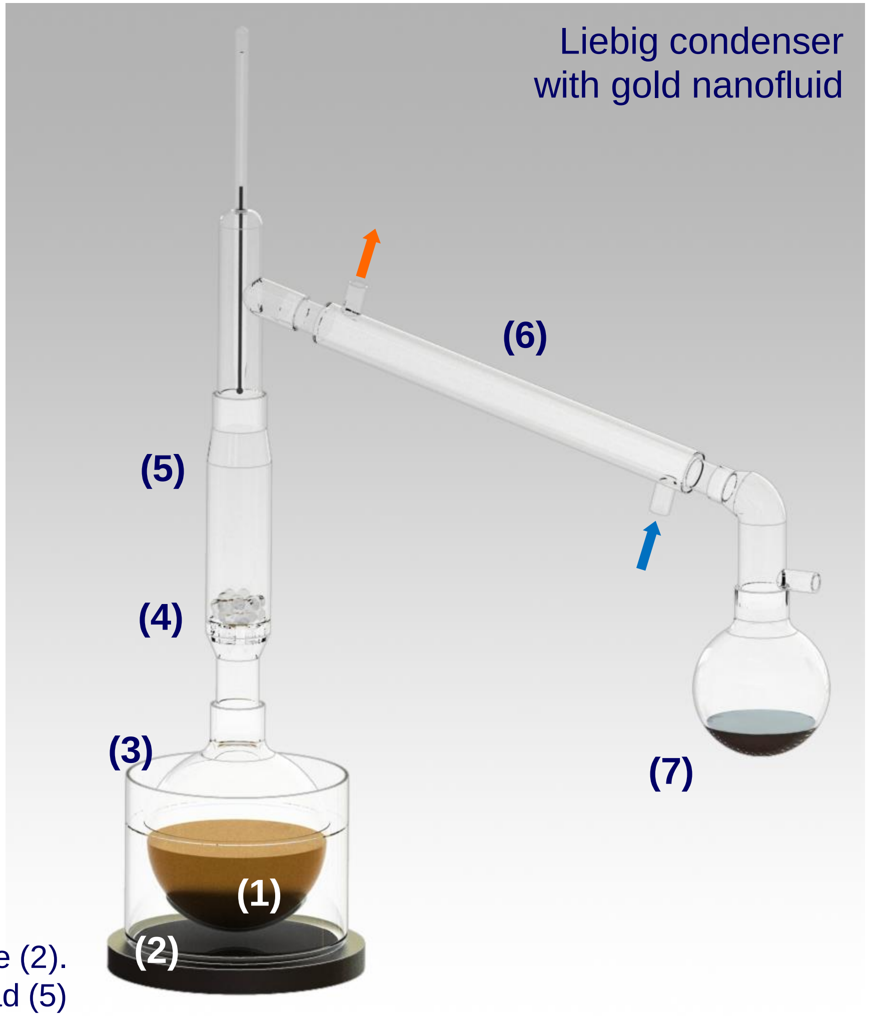
impossible

T. Grab, U. Groß, U. Franzke, M.H. Buschmann, Operation performance of thermosyphons employing titania and gold nanofluid, Int. J. Thermal Sciences 86 (2014) 352-364.

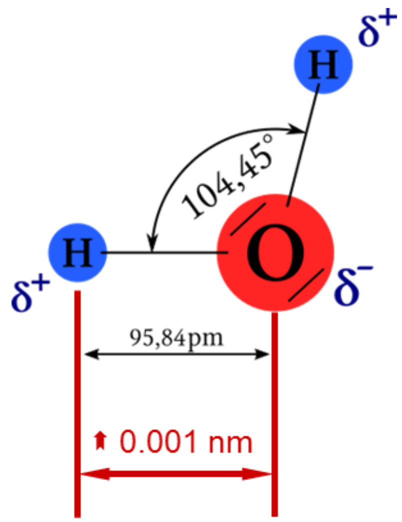
Are nanoparticles transported by vapour?

Au NF original	Au NF distillate
10^{-4} wt. %. / 16 nm	$60.0 \pm 6.0 \times 10^{-9}$ wt. %.
10^{-4} wt. %. / 66 nm	$37.0 \pm 3.7 \times 10^{-9}$ wt. %.

The obtained gold concentrations are roughly one to two-thirds per mil of the original concentrations of the Au-nanofluids.



Nanofluid (1) is heated by an electric heat source (2). Vapour runs through still pot (3) and still head (5) to reach finally the condenser (6). A bed of glass spheres (4) avoids the uncontrolled transport of liquid through bumping. Distillate is collected in the distillate flask (7).



https://de.wikipedia.org/wiki/Wasser

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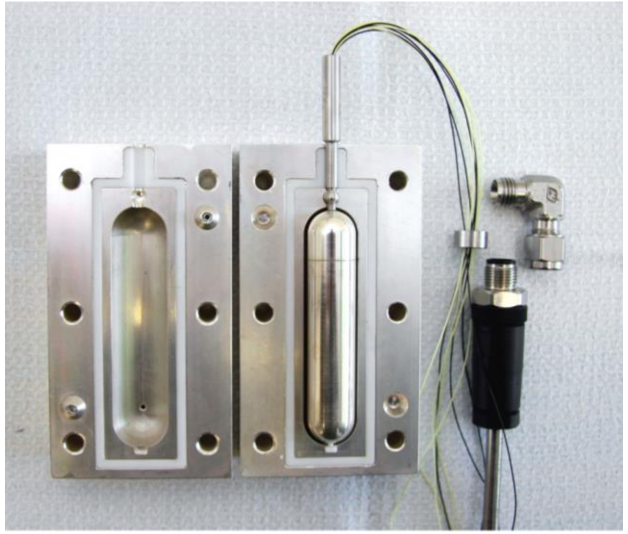
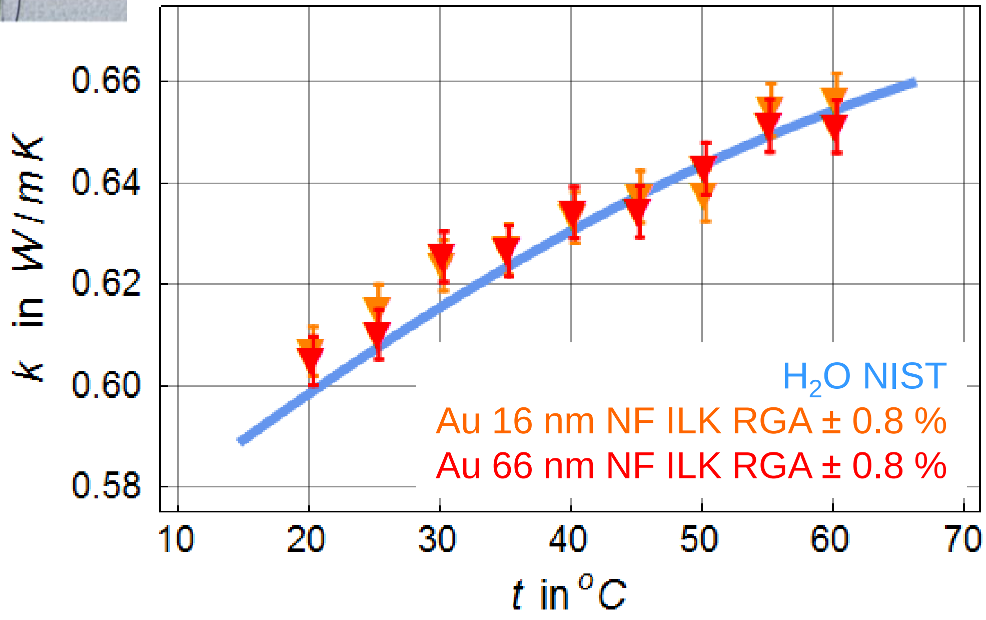
What about thermal conductivity?



1594A/1595A Super-Thermometer

Note: Other thermophysical parameters may have changed more dramatically. Viscosity e.g. may have altered from Newtonian to non-Newtonian.



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How could nanofluids act?

BOILING HEAT TRANSFER

thermophysical properties of working fluid

- liquid / vapour density (low)
- evaporation enthalpy (low)
- specific heat capacity (low)
- liquid / vapour viscosity (medium)
- liquid / vapour thermal conductivity (medium)
- surface tension (high)

characteristic of heater surface

- macroscopic structure (medium)
- microscopic structure (high)
- surface chemistry (high)

- contact angle (high)
- number of active nucleation sites (high)
- wettability (high)
- wickabillity (medium)

near surface hydrodynamics

- bubble departure diameter (high)
- bubble departure frequency (high)
- dry / hot spot dynamics (medium)

bubble release behaviour

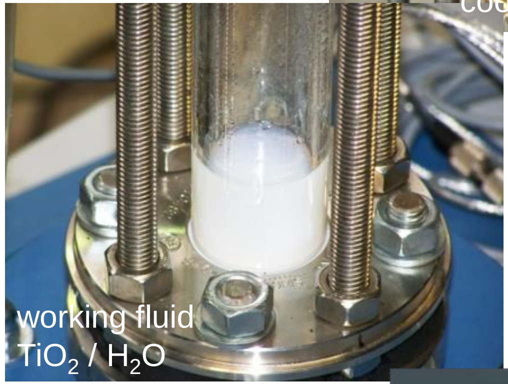
critical heat flux

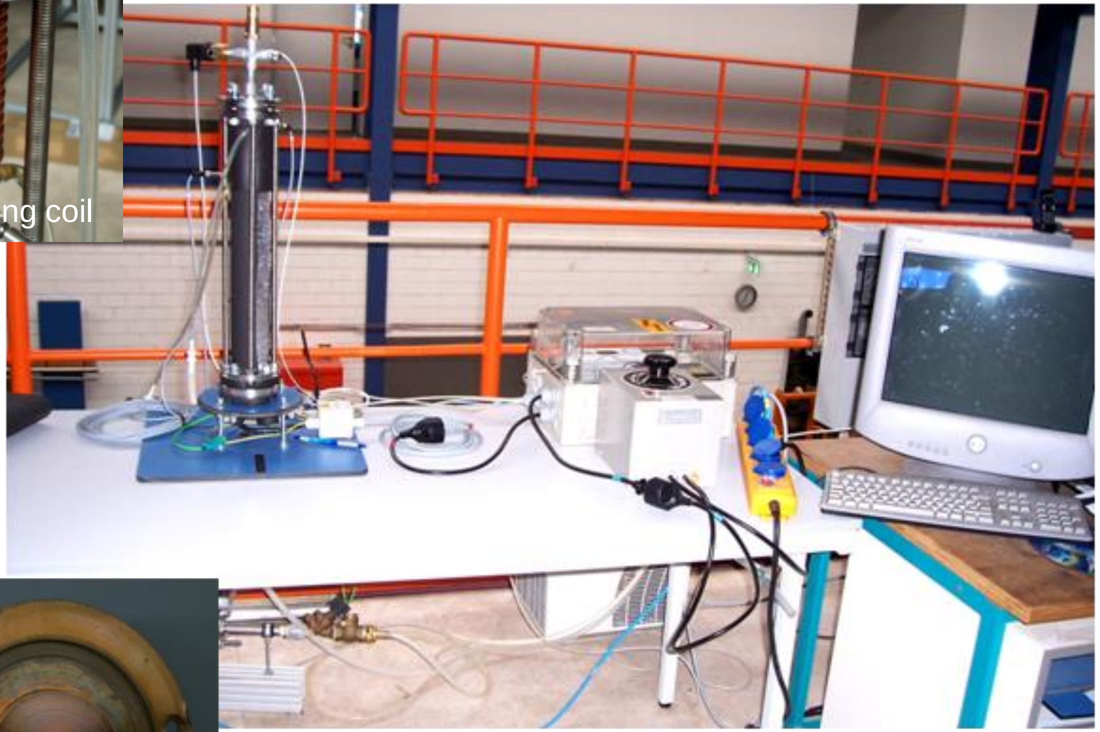
importance

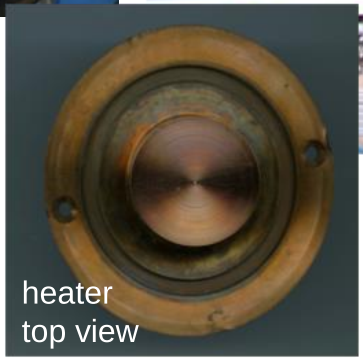
- low
- medium
- high

M.H. Buschmann & U. Franzke, Improvement of thermosyphon performance by employing nanofluid
Int. J. Refrigeration 40 (2014) 416-428.

Experiment I – ILK
Test rig







magical thermal
hat

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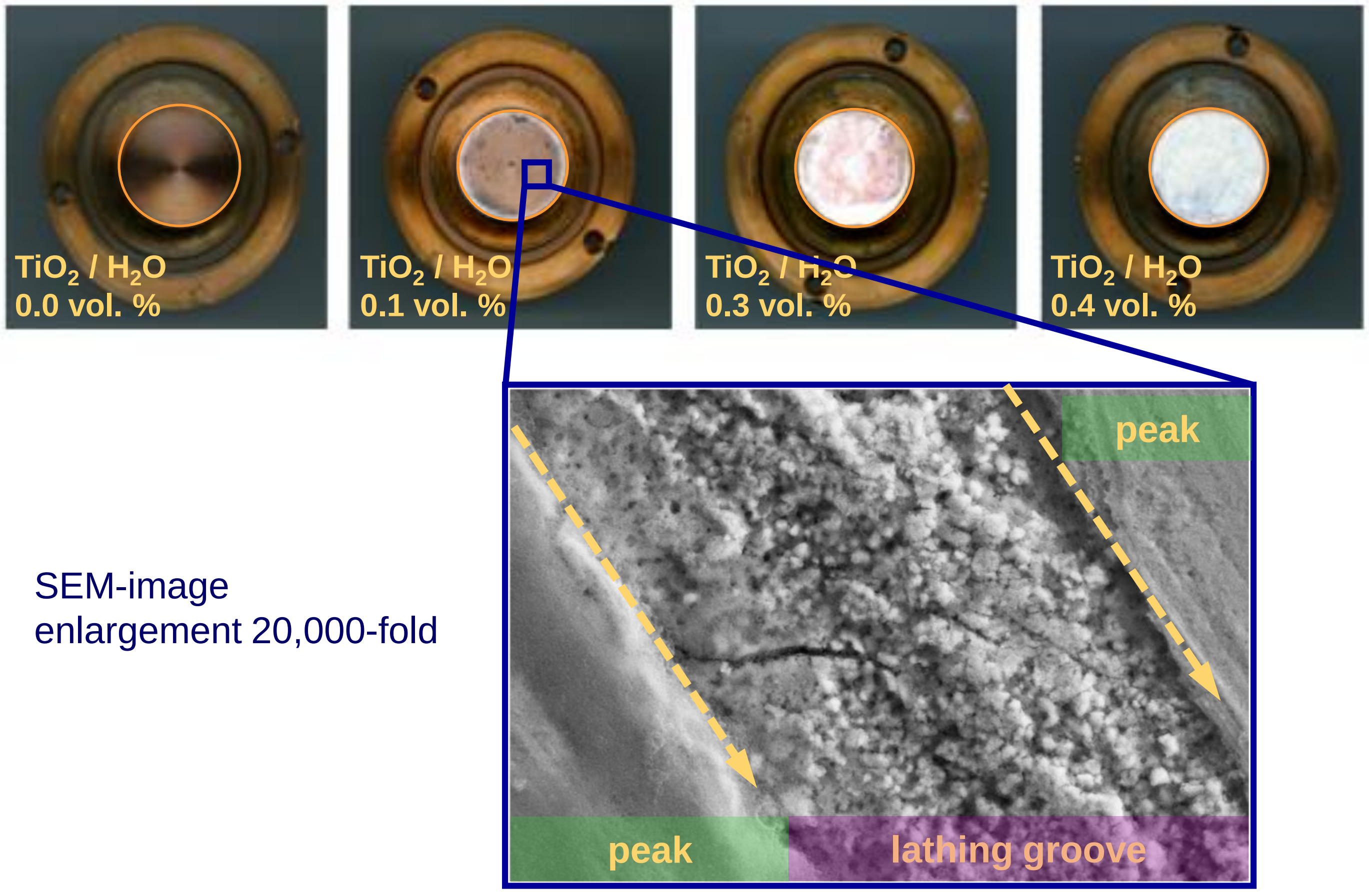
M.H. Buschmann & U. Franzke, Improvement of thermosyphon performance by employing nanofluid
Int. J. Refrigeration 40 (2014) 416-428.

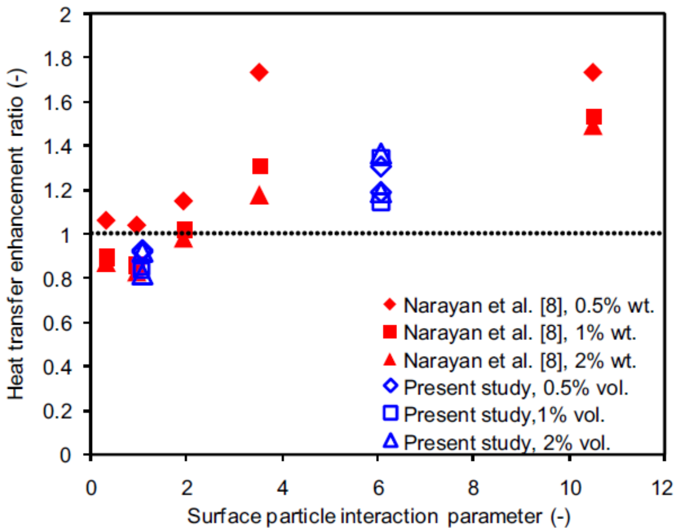
Experiment I – ILK Evaporator

Evaporator surface
fresh

after operation with TiO_2 / H_2O-nanofluid



SEM-image
enlargement 20,000-fold

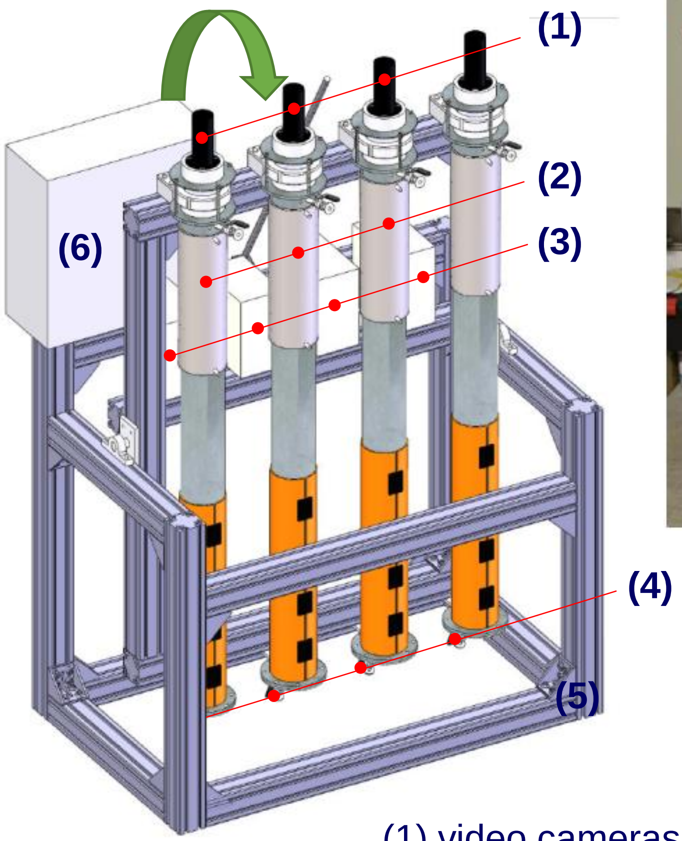


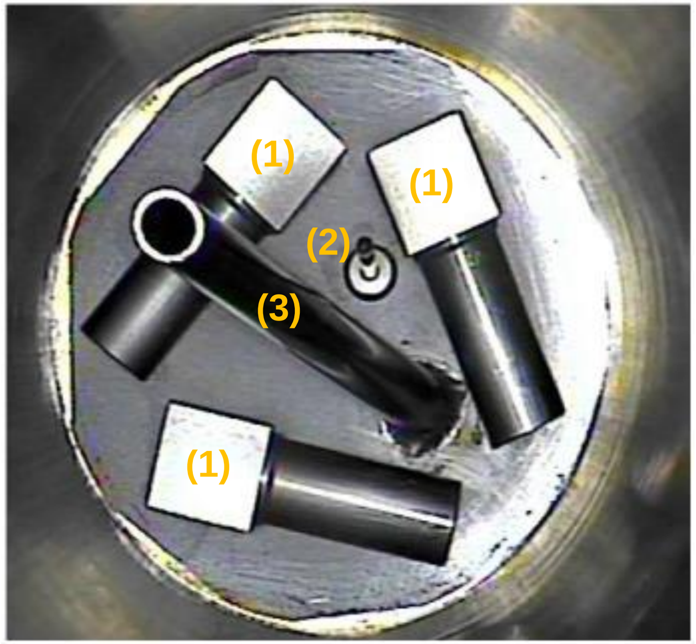
The surface particle interaction parameter which is the ratio of average surface roughness to average particle diameter is a prime factor that controls boiling performance (Harish et al., THESCIE 2011)

T. Grab, U. Groß, U. Franzke, M.H. Buschmann, Operation performance of thermosyphons employing titania and gold nanofluid, Int. J. Thermal Sciences 86 (2014) 352-364.

Experiment II – ILK / TU Freiberg

Test rig



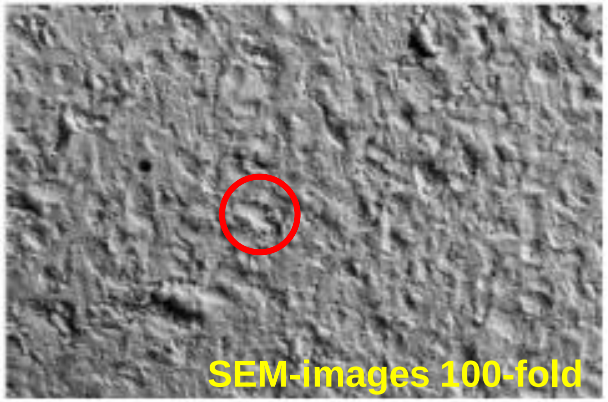


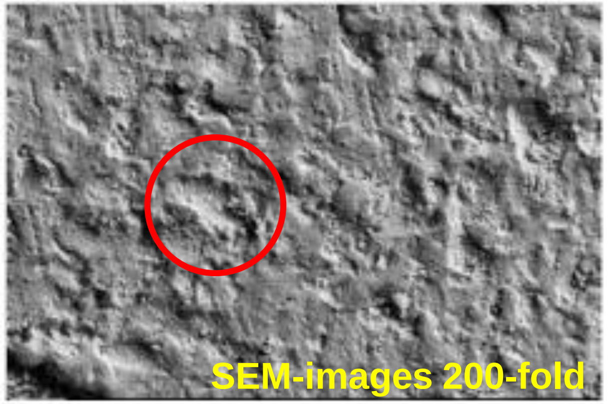
(1) video cameras, (2) cooling jackets,
(3) light sources for illumination of thermosyphon interior,
(4) filling nozzles, (5) aluminium frame, and (6) switch case.

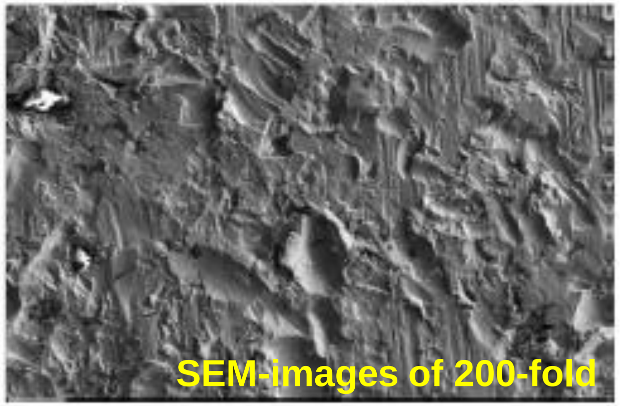
(1) heater cartridges,
(2) resistance thermometer,
and (3) filling nozzle.

T. Grab, U. Groß, U. Franzke, M.H. Buschmann, Operation performance of thermosyphons employing titania and gold nanofluid, Int. J. Thermal Sciences 86 (2014) 352-364.

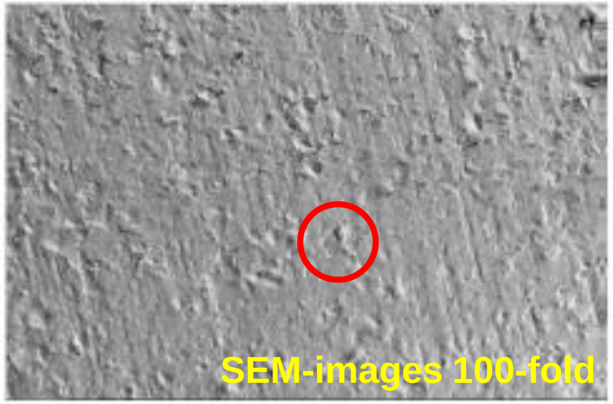
Experiment II – ILK / TU Freiberg Evaporator

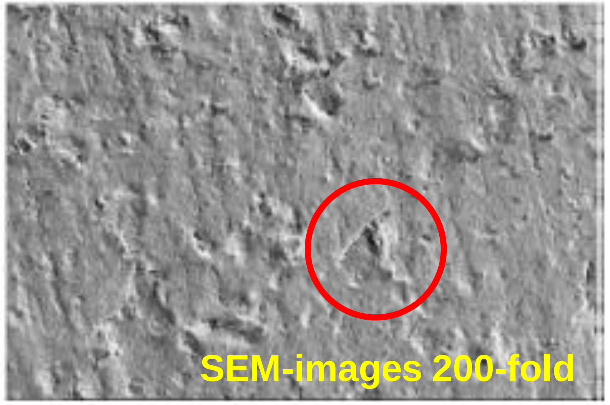






original sand blasted surface





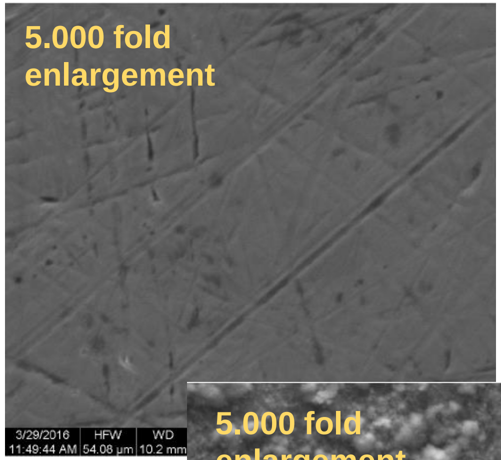
Once again a layer of nanoparticles covers the evaporator surface. So surface is changed with respect to:

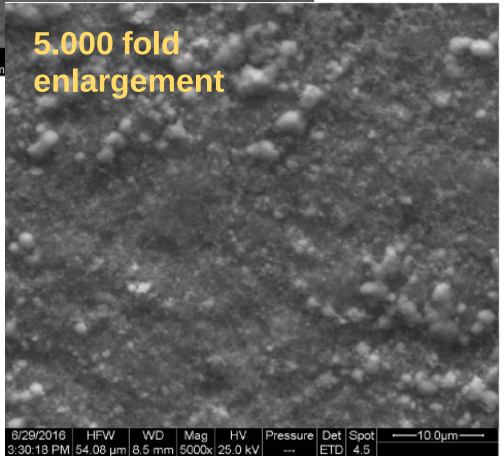
- roughness
- surface material
- surface energy

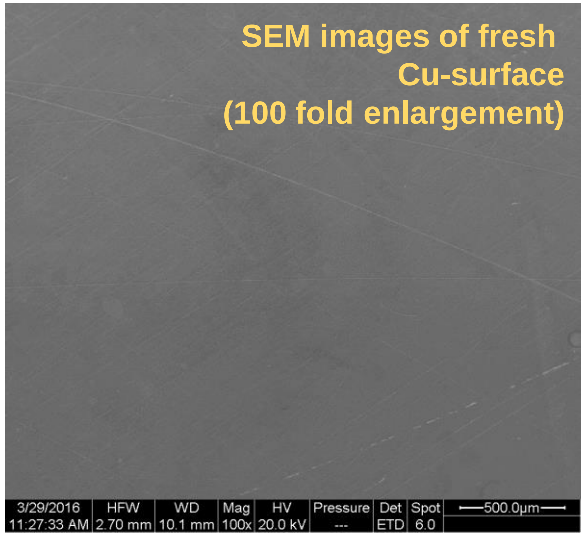
All of that affects boiling and therewith thermal performance.

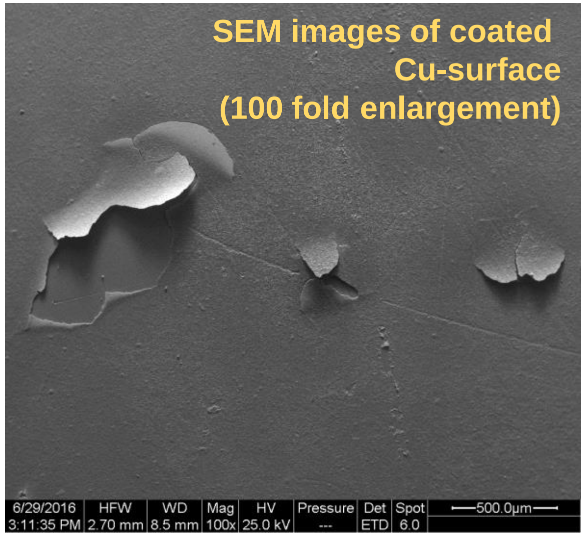
L. Doretti, G.A. Longo, S. Mancin, G Righetti, J.A. Weibel, Nanoparticle Deposition During Cu-Water Nanofluid Pool Boiling, University of Padua, 2017.

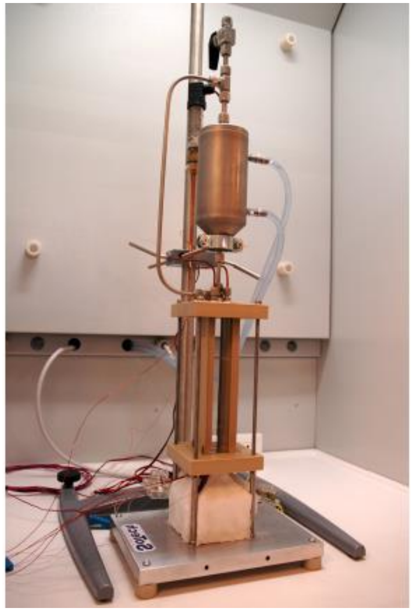
Nanofluid pool boiling University of Padua

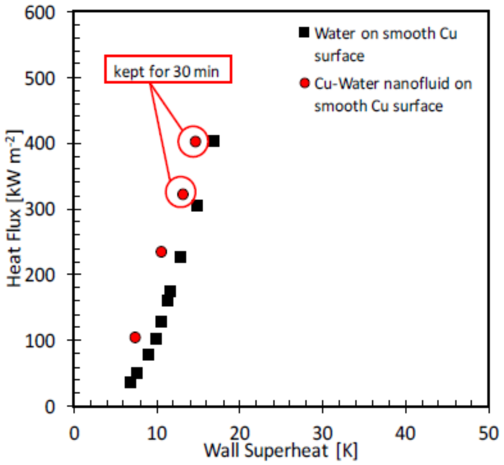


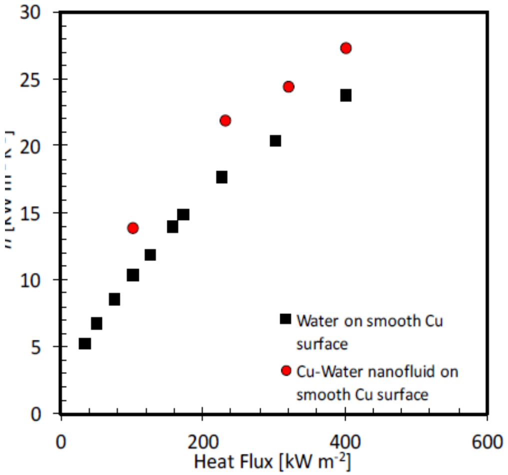












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L. M. Wilde, Druckmessung in einem Thermosyphon mit unterschiedlichen Arbeitsfluiden, Bachelorarbeit, ILK Dresden / TU Bergakademie Freiberg, 2017.

Experiment III – ILK
What about the basefluid?

fresh gold nanofluid
66 nm / 100 ml/L / PVP

DI-water
after use

gold nanofluid
after use

G. Huminic, A. Huminic, C. Fleaca, F. Dumitrache, Heat transfer characteristics of a two-phase closed thermosyphon using nanofluids based on SiC nanoparticles
Int. J. Heat and Technology 34 (2016) S200-S204.

Experimental set-up I
University of Brașov

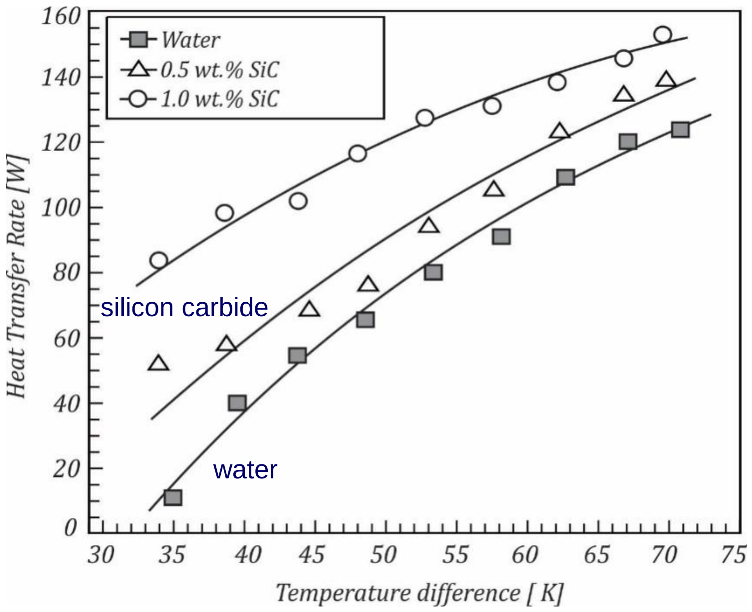
Dimensions of the TPCT, [mm]

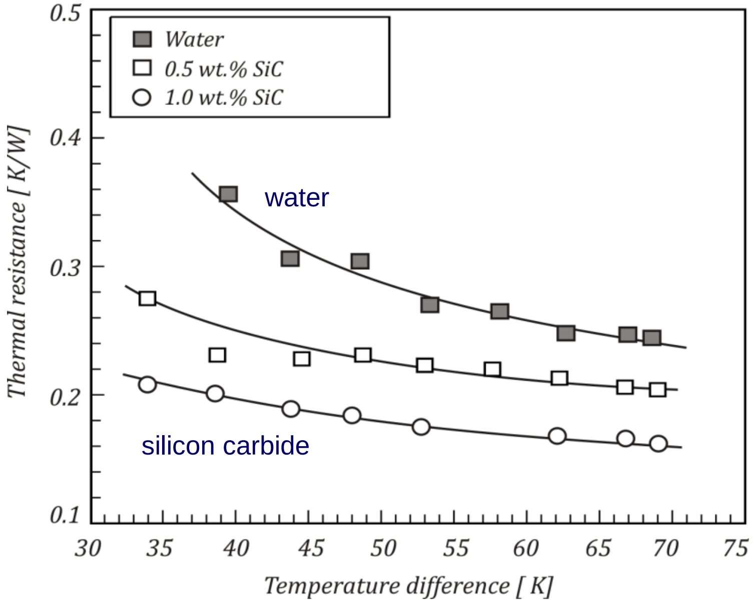
length	305
outer diameter	10
wall thickness	1
evaporator	121
adiabatic section	54
condenser	130
material	copper

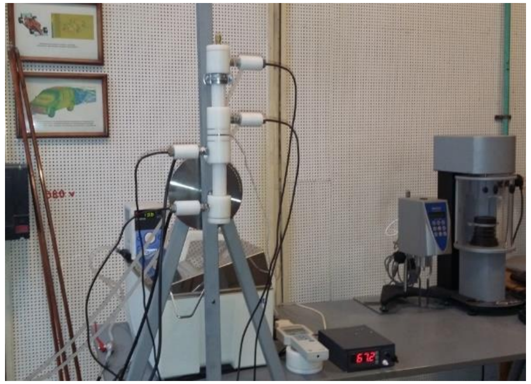
Working fluid silicon carbide SiC

G. Huminic, A. Huminic, C. Fleaca, F. Dumitrache, Heat transfer characteristics of a two-phase closed thermosyphon using nanofluids based on SiC nanoparticles
Int. J. Heat and Technology 34 (2016) S200-S204.

Results set-up I
University of Brașov







- Heat transfer rate increases up to 24.4 % at a mass concentration of 1.0 wt. % compared with that of the TPCT using water
- Thermal resistance decreases up to 32.8 % for the TPCT with SiC/water nanofluid at a mass concentration of 1.0 wt. % and up to 16.6 % for 0.5 wt. % compared with that of the TPCT using water.

Working fluid silicon carbide SiC

G. Huminic, A. Huminic, Heat transfer characteristics of a two-phase closed thermosyphons using nanofluids
Experimental Thermal and Fluid Science 35 (2011) 550-5571.

Experimental set-up II
University of Brașov

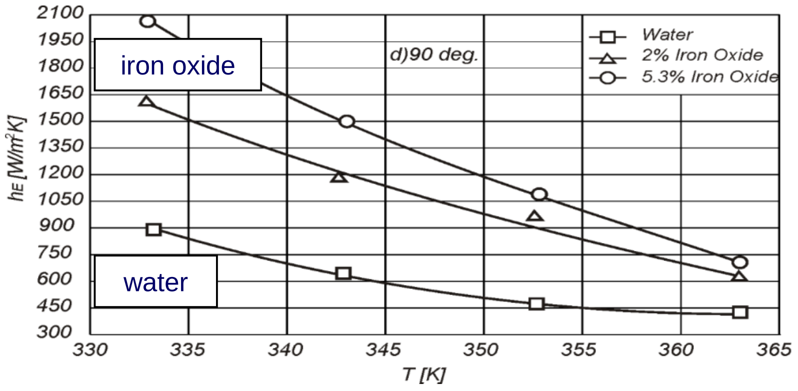
Working fluid iron oxide Fe_2O_3

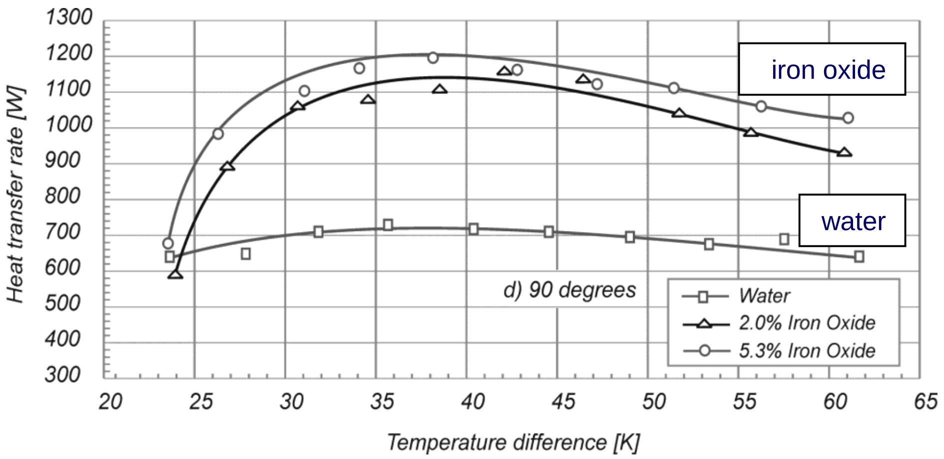
Dimensions of the TPCT, [mm]

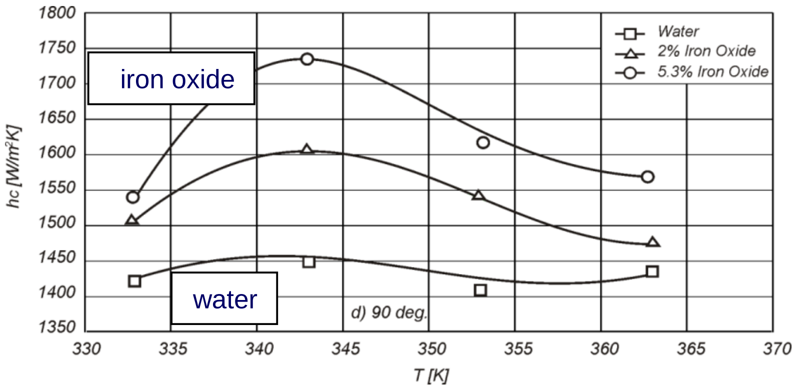
length	2000
outer diameter	15
wall thickness	0.70
evaporator	850
adiabatic section	300
condenser	850
material	copper

Results set-up II
University of Brașov

G. Huminic, A. Huminic, Heat transfer characteristics of a two-phase closed thermosyphons using nanofluids
Experimental Thermal and Fluid Science 35 (2011) 550-5571.





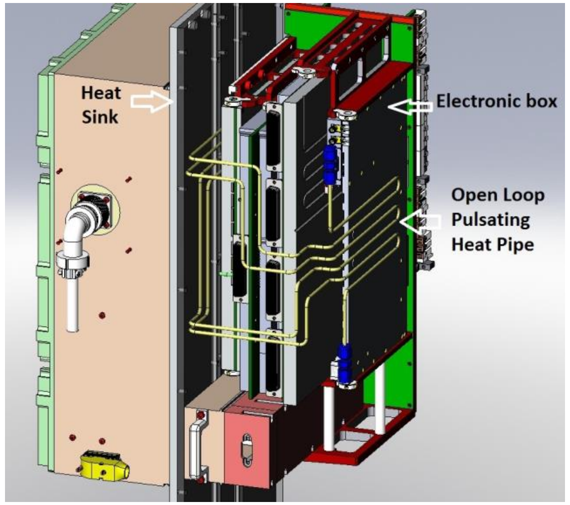


- Heat transfer rate increases up to 42 % at a volume concentration of 5.3 vol. % compared with that of the TPCT employing water.
- The heat transfer rate increases, in the case of the TPCT with iron oxide nanoparticles, as the inclination angle increases.

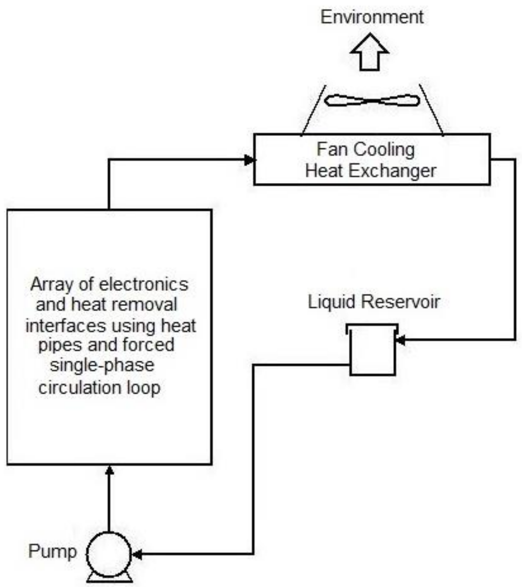
Nanofluids applied to the thermal management of PCBs in surveillance systems (OHP)

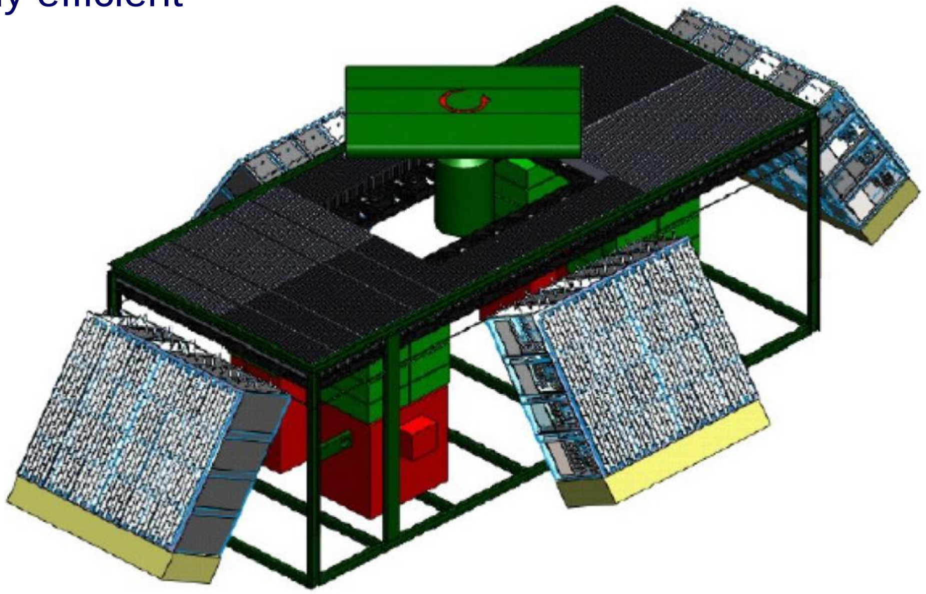
R.R. Riehl, Utilisation of passive thermal control technologies in cooling electronics: A brief review, Heat Pipe Science and Technology: An International Journal 7 (2016) 161-183.

- High demand for heat dissipation
- Reduced space for installation of conventional system (air cooling)
- Must be reliable and highly efficient



Array of heat sinks and heat pipes.



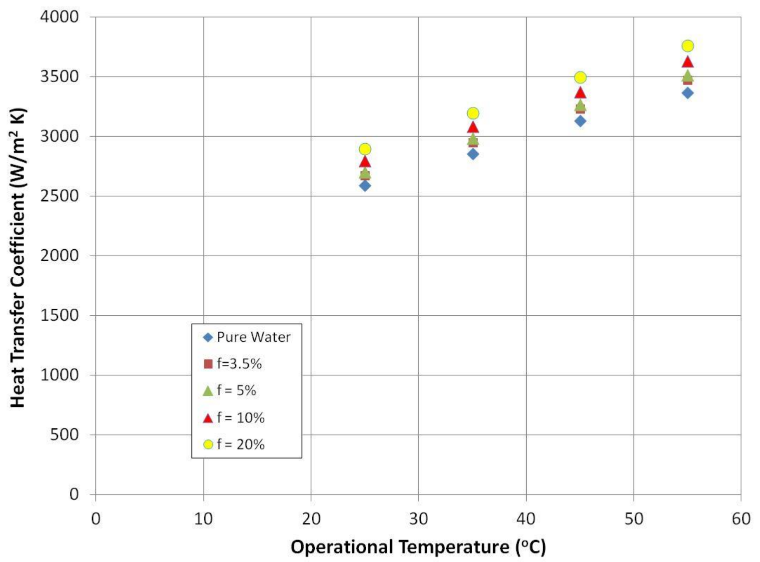


surveillance System – 65 kW of rejected heat

Liquid cooling system using Water-CuO nanofluid

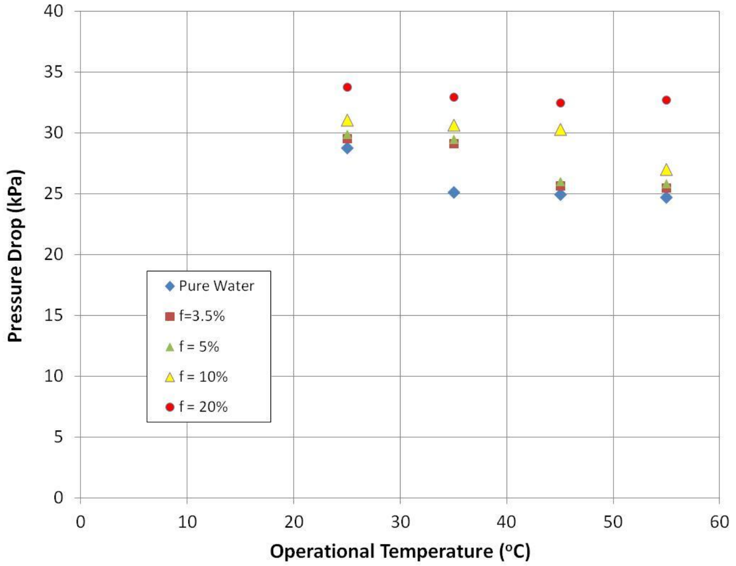
Nanofluids applied to the thermal management of PCBs in surveillance systems

R.R. Riehl, Utilisation of passive thermal control technologies in cooling electronics: A brief review, Heat Pipe Science and Technology: An International Journal 7 (2016) 161-183.



$$\eta_3 = \frac{h_{nf}}{h_{ref}}\left(\frac{\Delta p_{ref}}{\Delta p_{nf}}\right)^{1/3}$$

$$\eta_3 = 1.02 \ldots 1.05$$



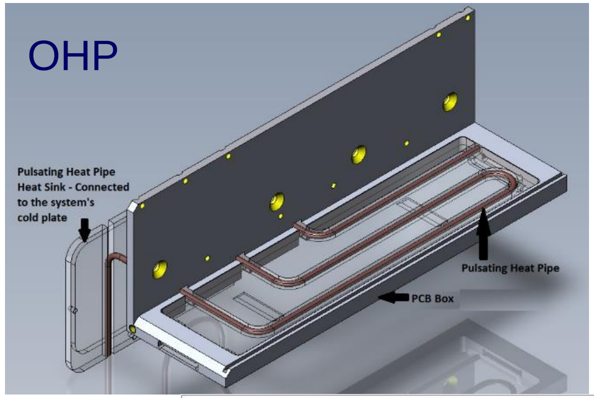
Overall system pressure drop, comparing pure water and different concentrations of CuO nanoparticles.

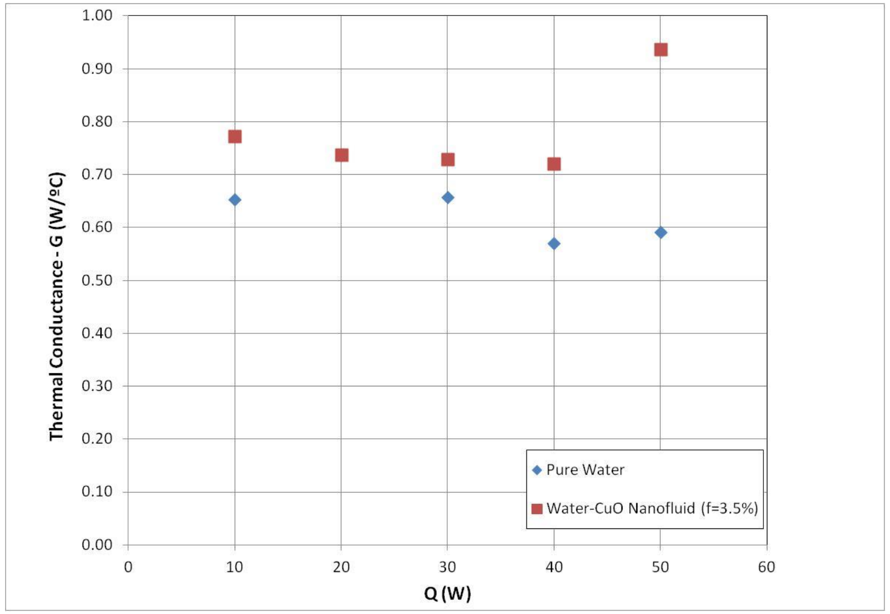
increase of 32 % on the pressure drop for f = 20 vol. %

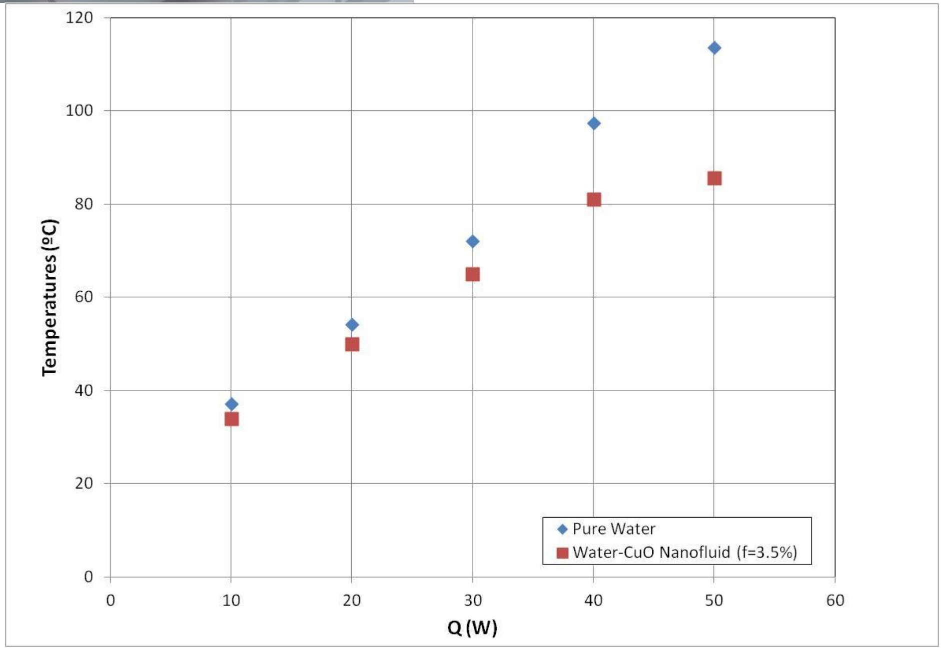
Heat transfer coefficient at condenser unit circulating the liquid pure water and different concentrations of CuO nanoparticles.

gain of 12 % on the heat transfer coefficient for f = 20 vol. %

Nanofluids applied to the thermal management of PCBs in surveillance systems (OHP)







The addition of CuO-nanoparticle to water improves the thermal performance of the pulsating heat pipe (PH).

However, considering the entire system (liquid cooling cycle and PHP), the overall gain is negligible due to the **increased on pumping** power and **high costs** related to the CuO nanoparticles.

A. Zucker, Bachelor Thesis 2016.

Experiment IV – ILK
What about heat pipes?

water

ZrO_2 acid

ZrO_2 alkaline

Au 30 – 50 nm

Au 10 nm

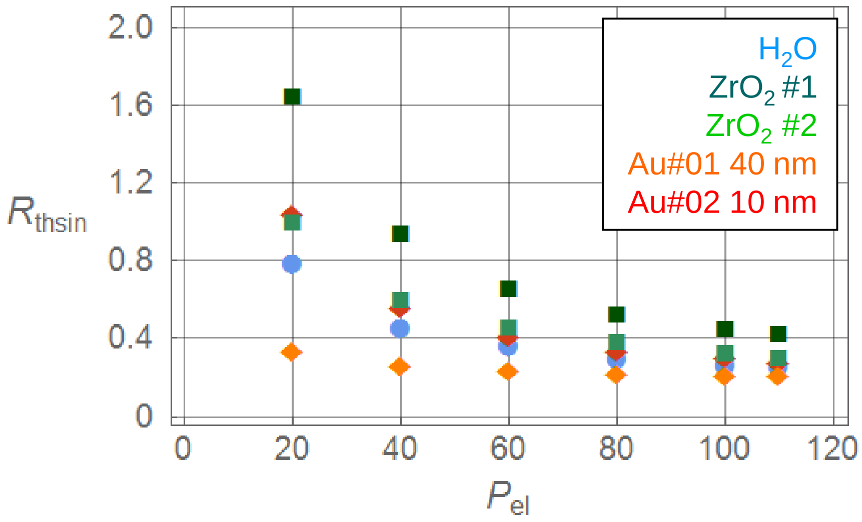
diamond 0.001 vol. %

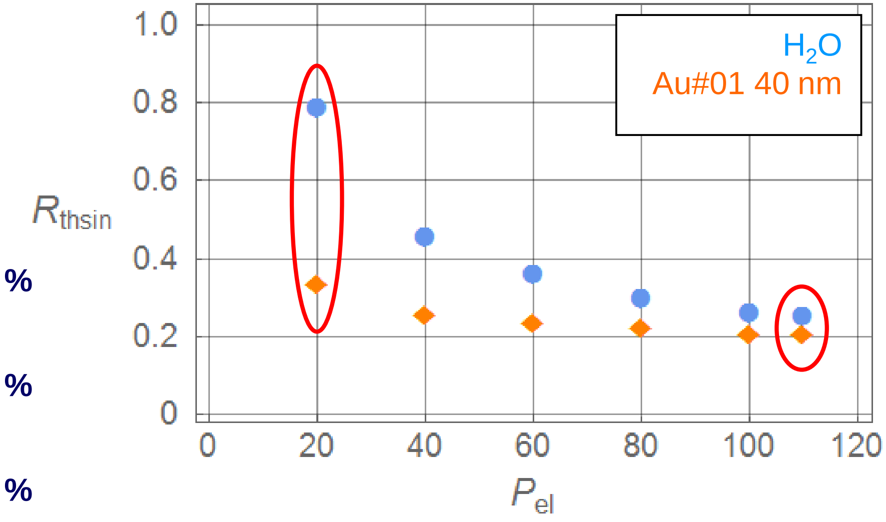
diamond 0.010 vol. %

diamond 0.100 vol. %

diamond 1.000 vol. %

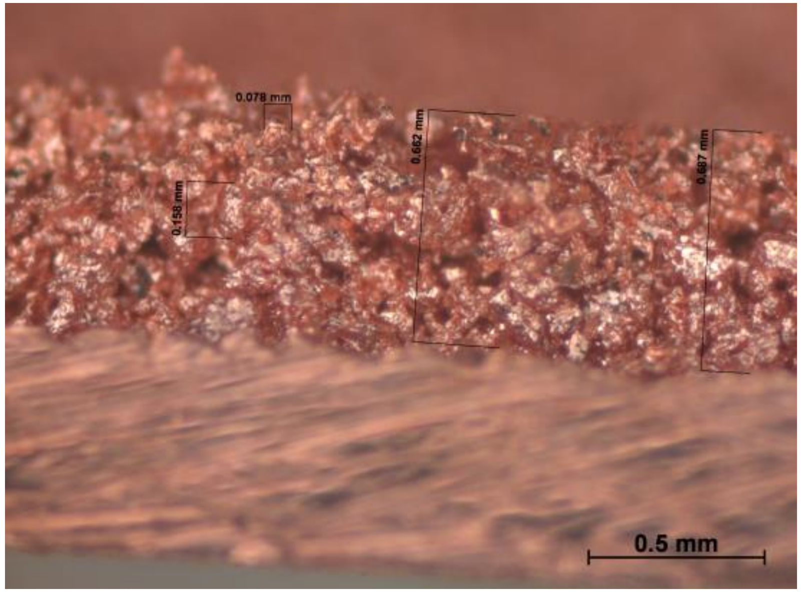
evaporator condenser



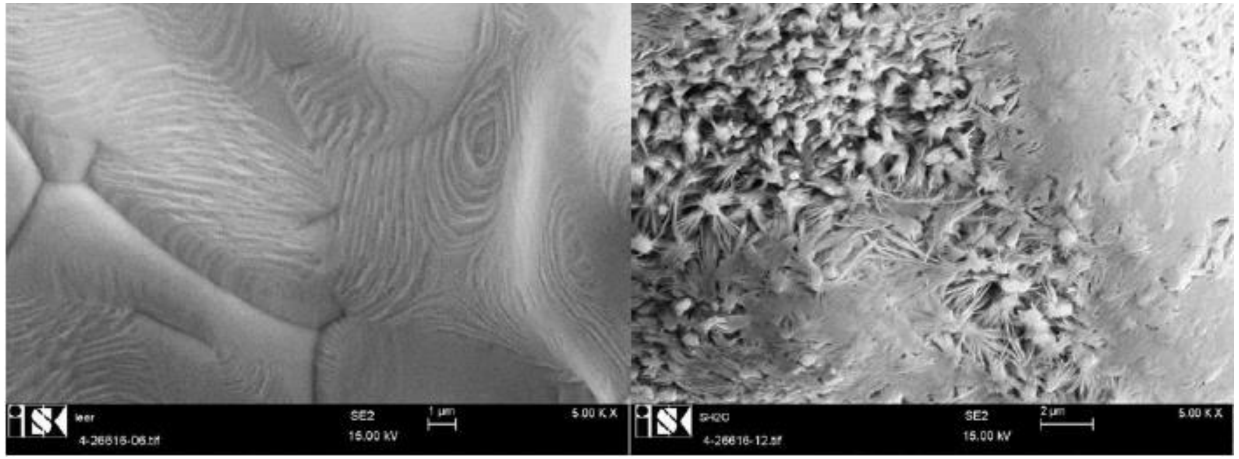


A. Zucker, Bachelor Thesis 2016.

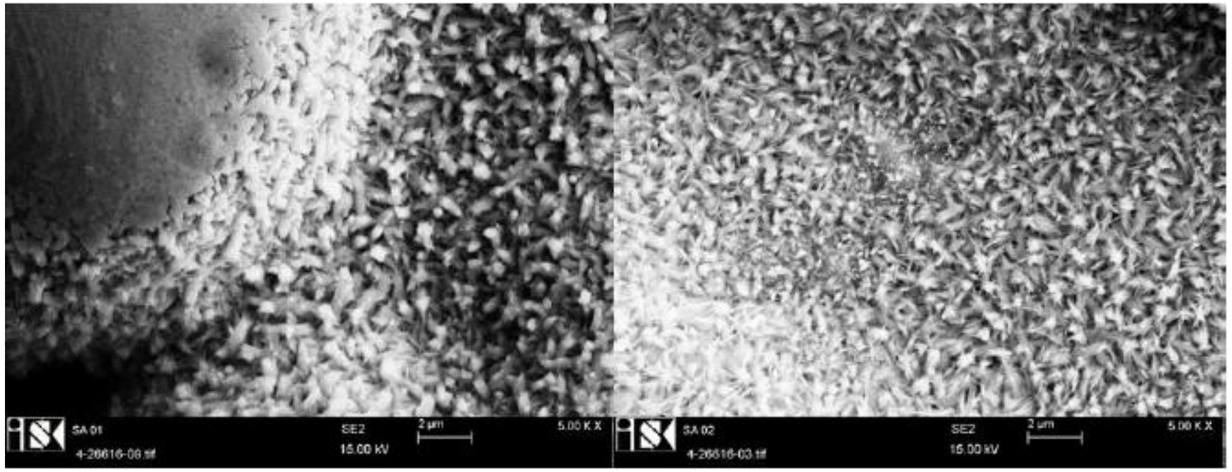
Experiment IV – ILK
What about heat pipes?



Nanofluids und water change surface in the nanometer scale.



SEM-image (5000 fold) unused (left) and after water (right)



SEM-image (5000 fold) Au-nanofluid 10 nm (left) and 30 – 50 nm (right)

Conclusions

There is some hope that it works physically.

However, there are major open issues to be solved

- Can we bring data of different devices together to obtain design rules?
- What is the best way to compare systems – thermal performance parameters?
- How can costs for pumping power lowered?
  We need to understand the mechanisms increasing viscosity.
- How can cost in general be lowered (nanoparticles, maintenance of system etc.)?
- What about long term stability?

Where we are with respect to H2020-proposals? My personal view.