# Resorcinol formaldehyde xerogels for loop heat pipe applications


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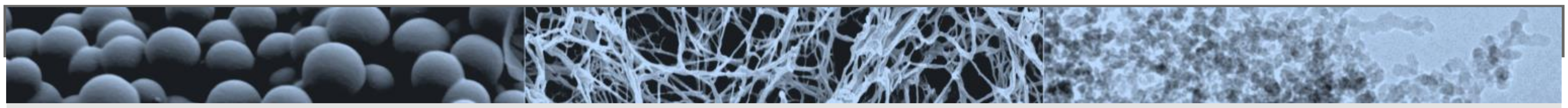
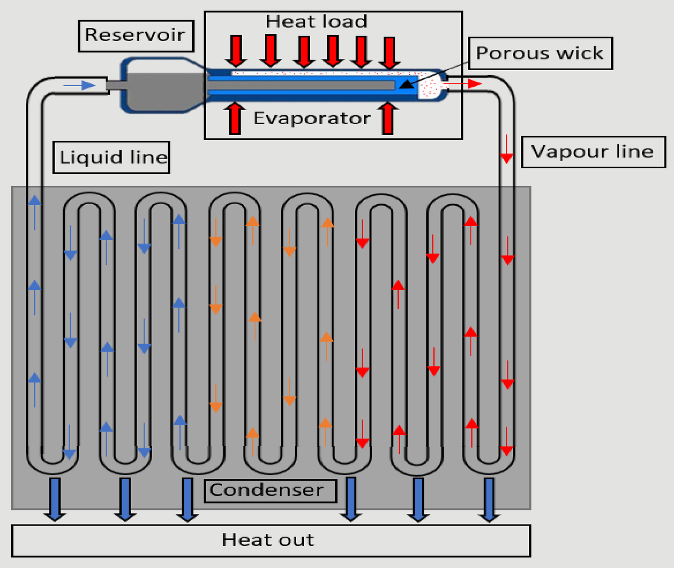


## Motivation

Heat pumps are being targeted in research and development because they represent energy-efficient means of transporting heat. Of particular interest are loop heat pipes (LHPs), passive systems based on continuous evaporation and condensation of a fluid in a closed-loop fashion. One key component in a LHP is the evaporator where the liquid enters at least one tube-shaped porous body (wick) and leaves it as gas through the porous network. Typical wick structures are composed of sintered metal (stainless steel, copper), however polymer-based examples are known to be similarly effective in LHPs. As wicks ideally possess high porosity and pores in the (sub-) micrometer range, aerogels might be efficient candidates for wick development. Preliminary studies indicated that organic resorcinol-formaldehyde (RF) xerogels appear to be the most suitable because pore size and density can be adjusted.



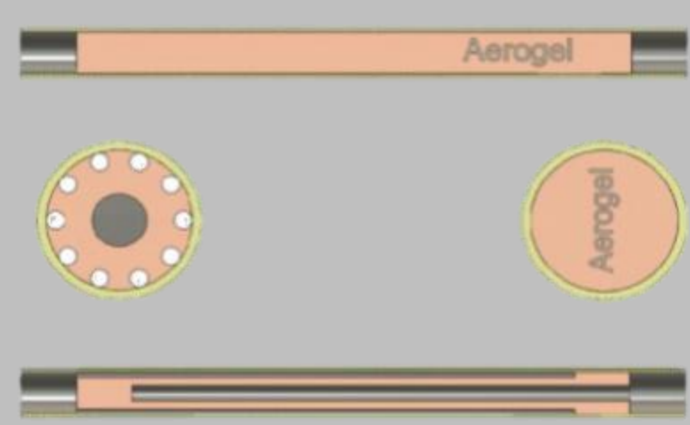

## Experimental & Machining

### Wick requirements

- Porosity: ≥ 70%
- Capillary pore size radius: 0.1 - 10 µm
- Thermal conductivity (rt): ≤ 0.8 W·m$^{-1}$K$^{-1}$
- Permeability: K > 10-13 m$^2$
- Radial shrinkage ≤ 0.2%
- Machinability in cylindrical shape and high precision: ± 5 µm

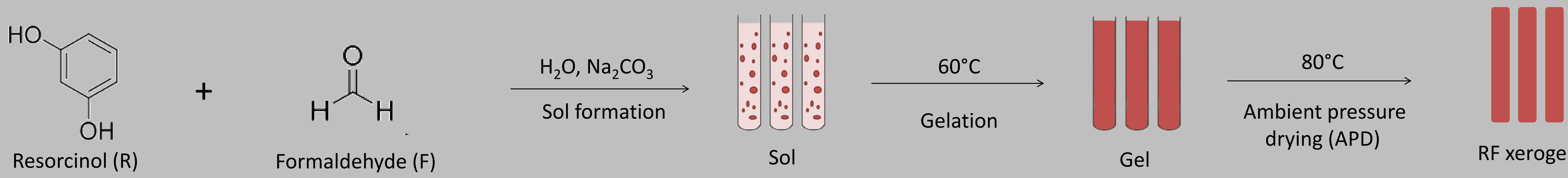
### Design of Wicks

- Unhoused wicks: 100 mm length and 9.0 mm diameter
- A central hole of 90 mm length and 3.0 mm diameter
- Longitudinal grooves (every 36°) of 90 mm length and 1.0 mm diameter
- Stainless steel metal tubing of 120 mm length with wall thickness of 0.5 mm




Schematic drawing of an aerogel wick

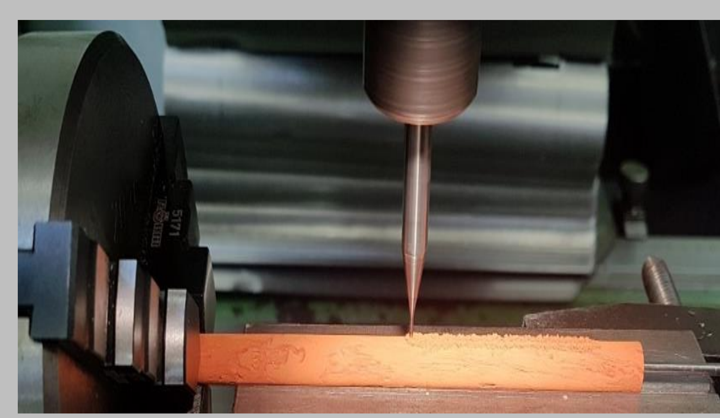
### Synthesis of RF xerogels in cylindrical shape




### Mechanical processing of RF xerogels in wick shape bodies

RF xerogel

Drilling, → Turning, Milling



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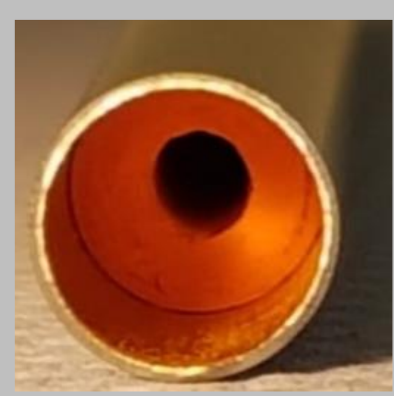
RF xerogel wick

Housing →



RF xerogel wick housed in stainless steel tube

Machining process
1. Frontface planning
2. Drilling hole d= 2 mm
3. Turn to d= 8 mm
4. Cutting to 120 mm
5. Milling grooves every 36°
6. Planning the backface
7. Drill the hole d= 3 mm

## Characterization

| Xerogel | R/W | R/F | R/C | pH | Envelope density [g·cm$^{-3}$] | Skeletal density [g·cm$^{-3}$] | Porosity [%] | Average capillary pore radius [µm] | Standard deviation of capillary pore radius [µm] |
|---|---|---|---|---|---|---|---|---|---|
| **A** | 0.06 | 0.7 | 1500 | 5.50 | -[1] | -[1] | -[1] | 0.82 | -[2] |
| **B** | 0.06 | 0.65 | 1500 | 5.52 | 0.48 | 1.44 | 66.3 | 2.00 | 0.06 |
| **C** | 0.06 | 0.6 | 1500 | 5.48 | 0.46 | 1.43 | 67.9 | 0.59 | 0.00 |
| **D** | 0.06 | 0.55 | 1500 | 5.43 | 0.43 | 1.43 | 69.8 | 1.13 | 0.08 |
| **E** | 0.06 | 0.5 | 1500 | 5.52 | 0.42 | 1.48 | 72.0 | 0.73 | -[2] |
| **F** | 0.06 | 0.7 | 1200 | 5.47 | 0.41 | 1.46 | 71.7 | 0.96 | 0.05 |
| **G** | 0.06 | 0.65 | 1200 | 5.51 | 0.55 | 1.44 | 61.8 | 1.03 | 0.04 |
| **H** | 0.06 | 0.6 | 1200 | 5.46 | 0.56 | 1.44 | 61.0 | 1.37 | 0.01 |
| **I** | 0.06 | 0.55 | 1200 | 5.42 | 0.48 | 1.41 | 66.1 | 1.70 | 0.02 |
| **J** | 0.06 | 0.5 | 1200 | 5.32 | 0.44 | 1.46 | 69.5 | 1.85 | 0.07 |
| **K** | 0.06 | 0.7 | 1000 | 5.48 | 0.52 | 1.45 | 64.3 | 2.06 | 0.22 |
| **L** | 0.06 | 0.65 | 1000 | 5.53 | 0.52 | 1.43 | 63.9 | 2.26 | 0.75 |
| **M** | 0.06 | 0.6 | 1000 | 5.44 | 0.47 | 1.45 | 67.6 | 1.92 | 0.05 |
| **N** | 0.06 | 0.55 | 1000 | 5.54 | 0.40 | 1.39 | 71.6 | 2.29 | 0.46 |
| **O** | 0.06 | 0.5 | 1000 | 5.44 | 0.41 | 1.48 | 72.4 | 2.23 | 0.01 |
| **P** | 0.055 | 0.74 | 1000 | 5.53 | 0.39 | 1.58 | 75.3 | -[1] | -[1] |
| **N + housing** | 0.06 | 0.55 | 1000 | 5.54 | 0.40 | 1.39 | 71.6 | 3.54 | -[2] |
| **P + housing** | 0.055 | 0.74 | 1000 | 5.53 | 0.39 | 1.58 | 75.3 | 4.38 | -[2] |

[1]not determined; [2]not applicable (single measurement)

| Xerogel | Solvent | Average shrinkage [%] | Deviation of shrinkage [%] |
|---|---|---|---|
| **C** | ethanol | 0.65 | 0.73 |
| | acetone | 3.10 | 0.35 |
| | water | 0.59 | 0.15 |
| | toluene | 0.49 | 0.27 |
| **D** | ethanol | 0.80 | 0.56 |
| | acetone | 2.69 | 0.01 |
| | water | -0.02 | 0.11 |
| | toluene | 0.33 | 0.16 |

- Acetone caused large shrinkage with audible cracking upon wetting
- Exposure to ethanol associated to significant shrinkage
- Water and toluene performed better (induced shrinkage significantly below 1%)

**Test in liquified ammonia ($NH_3$(l))**

- volume changes radially by >15%
- Housed sample P slightly stood out of tubing after submerging in ammonia
- Shrinkage after drying (heat gun: 50°C, 5 min) but remained housed

- More than 60 different synthetic recipes were investigated
- Porosity and pore size must remain within the specified limits while maintaining the mechanical processability of the xerogel
- Porosities were found to be acceptable within the range of 61-72%
- Capillary pore size is in the range of 0.6-2.3 µm
- Xerogel materials show thermal conductivities (rt) below 0.1 W·m$^{-1}$K$^{-1}$
- Permeability resulted in desired range (K > 10-13 m$^2$)
- Low radial shrinkage in water (sample D) below 0.2%

## Conclusion

- Based on the requirements for the wick, the properties of xerogels and their machinability, different recipes for wick production were considered
- Several gels were analyzed with respect to:
  i) capillary pore dimensions ii) porosity iii) wetting behavior
- Wick structures were successfully machined and enclosed in metal tubes
- Sample N and P showed most promising properties and appear to be suitable as wicks for water-, toluene-, and expectedly even ammonia-based LHPs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