JOANNEUM RESEARCH

COMSOL Conference Stuttgart 2011

Stored Fluid Cooling

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1. Motivation
2. Modelling Setup
3. Results
4. Conclusion

1. Motivation

HOW can 2 Watt of cooling power applied to a stored pre-cooled water surface @ 5 degC most efficiently avoid the fluid‘s heating to ambient temperature @ 22 degC?

By varying (designing)?

- Storage Geometry ?
- Location of cooling boundaries ?
- Cooling power flux function ?

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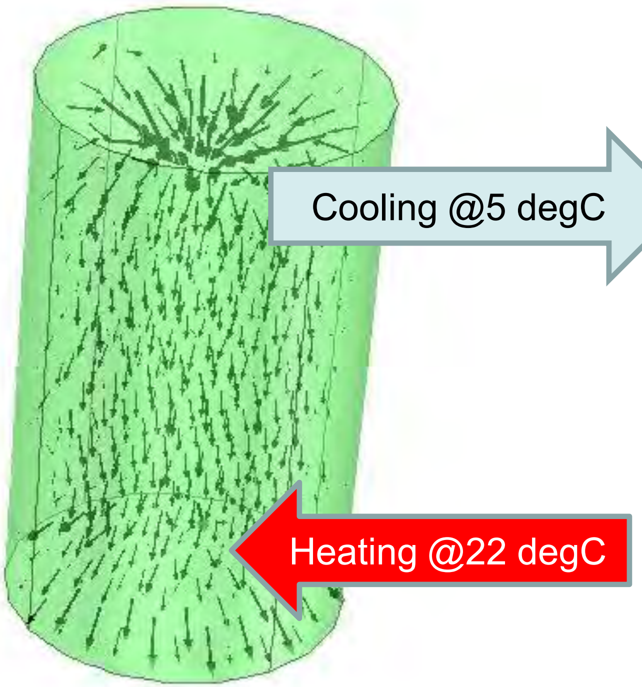
2. Modelling Setup Flow Model

- Start with cylinder geometry of stored water
- Full 3D geometry of fluid (0.33 liters)
  - No storage container geometry
- Laminar Flow Model
  - See flow character considerations
- Internal natural convection
  - Buoyancy force – local density variations
  - Newtonian fluid
- COMSOL 4.1 release
  - MUMPS Time-dependent direct solver
  - 30 sec stored time steps



2. Modelling Setup
Turbulent/ Laminar Flow?

Dimensionless Parameters

- External driving force:
  - Reynolds number

$$Re = \frac{Inertial\ forces}{Viscous\ forces} = \frac{\rho u L}{\mu}$$

- Internal driving force:
  - Grashof number

$$Gr = \frac{Buoyancy\ forces}{Viscous\ forces} = \frac{\rho^2 \beta g L^3 \Delta T}{\mu^2}$$

- Characteristic Length

$$L = 264mm$$

$$Gr(water, 5\deg C,\ \Delta T = 17\deg C) = 2.3*10^7 << 10^9\ transitional$$

→ LAMINAR FLOW MODEL

2. Modelling Setup
Re, Gr calculations

Reynolds and Grashof number for water@ 5 degC

- Characteristic length $L = \frac{4 * area\ section\ of\ duct}{wetted\ perimeter} = \frac{4 * d^2 \pi}{d \pi} = 0.264 m$
- Reynolds number
  - » Transitional fluid velocity $\mathrm{Re}(water, 5 \deg C) = 2300 ... 4000$
    $u = (15...26) mm\ s^{-1}$
- Grashof number
  - » $Gr(water, 5 \deg C, \Delta T = 17 \deg C) = 2.3 * 10^7$
  - » Transition from laminar → turbulent @ $Gr \approx 10^9$

LAMINAR FLOW MODEL

2. Modelling Setup
Flow Settings

- Non-Isothermal Laminar Flow:
  - Pressure $p = p_{fluid} + p_{Ref}\ (1atm)$
  - Fluid Boundary $no\ slip\ (wall\ \ friction)$
  - Initial Values $u(x,y,z)=0$

    $p_0 = g * nitf.rho * (h-z),\ h\ \mathrm{var}iable$

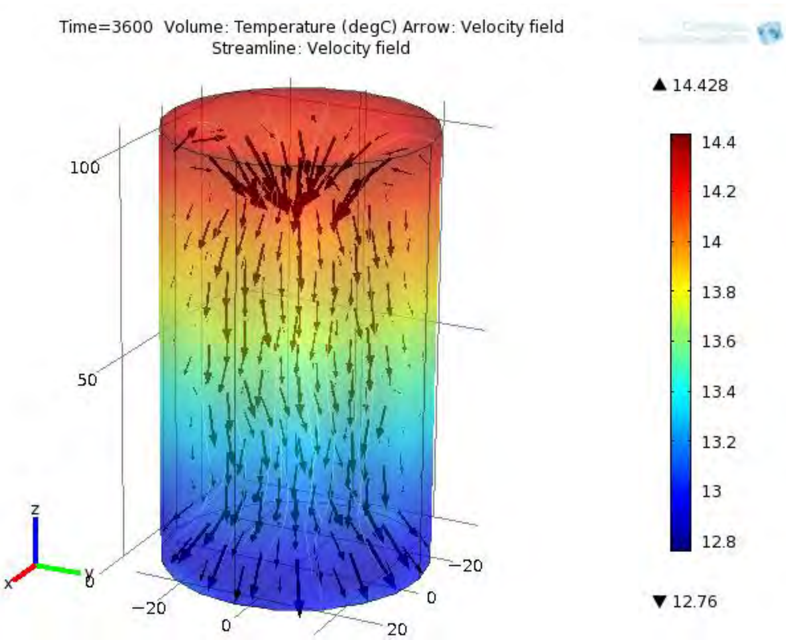
    $T_{init} = 5\deg C$
  - Volume Force $F_z = (\max op1(nitf.rho) - nitf.rho) * g$
  - Pressure Point Constraints $p = 0\ on\ top\ area$
  - Ambient $h = h_{air}(L, p_A, T_{ext})$

    $p_A = 1\ atm$

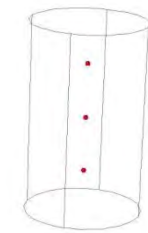
    $T_{ext} = 22\deg C$

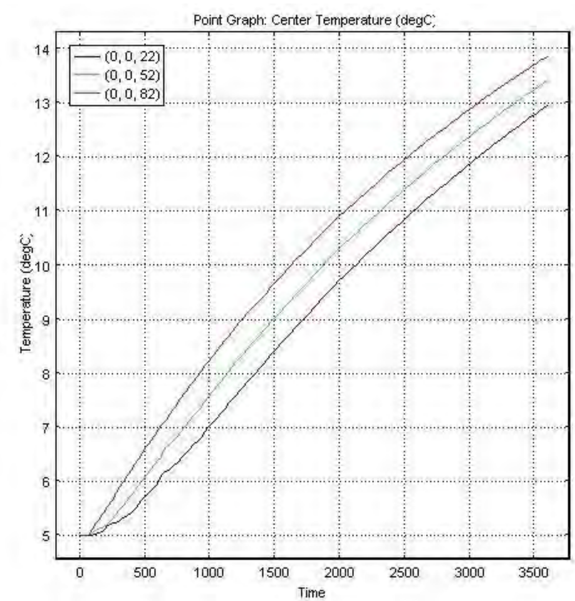
3. Results

No cooling



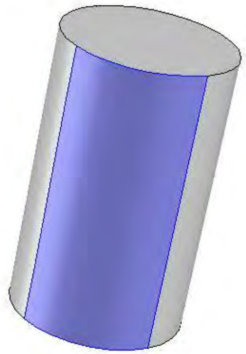
Center temperature

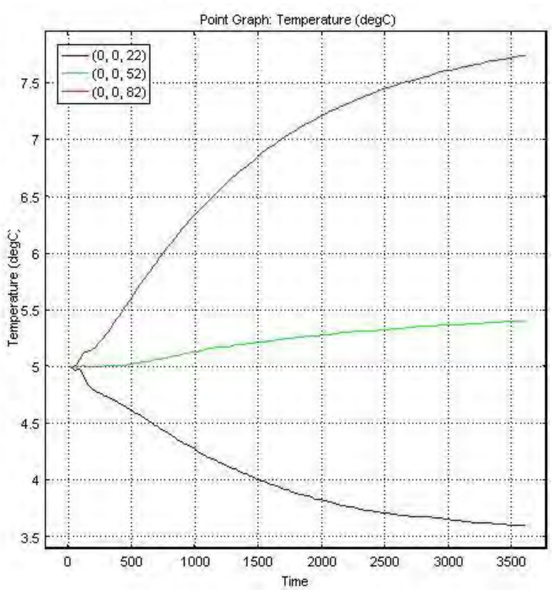




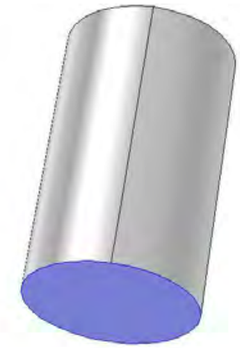
3. Results
Cylinder

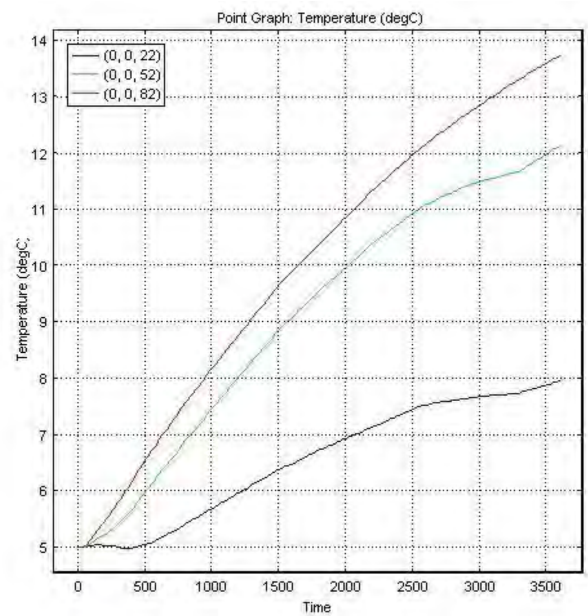
Sidewall cooling





Bottom Cooling

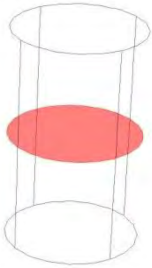


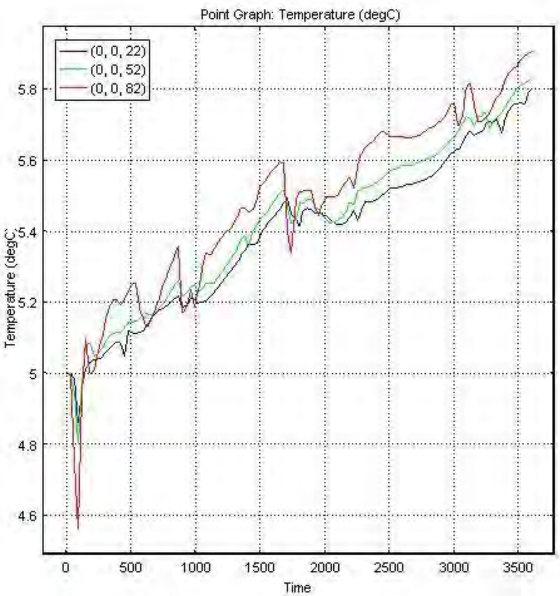


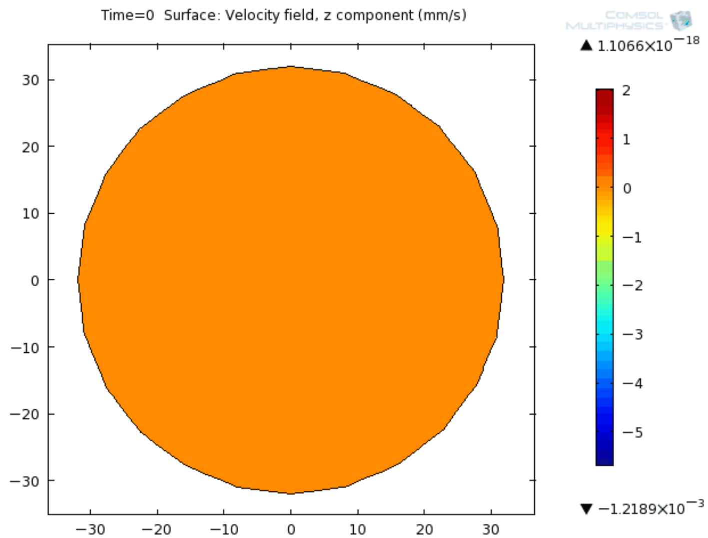
3. Results
Cylinder Top Cooling

Top cooling

Cut plane
z velocity field

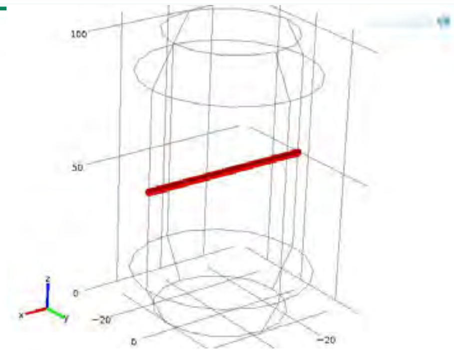




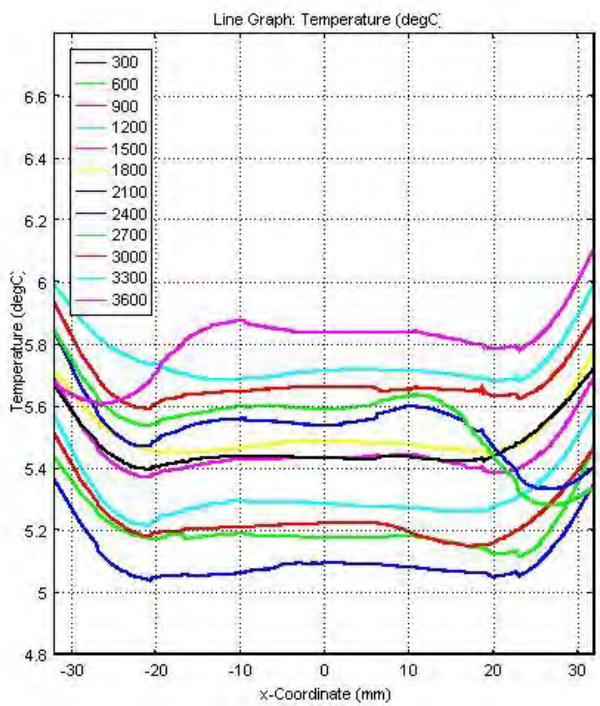


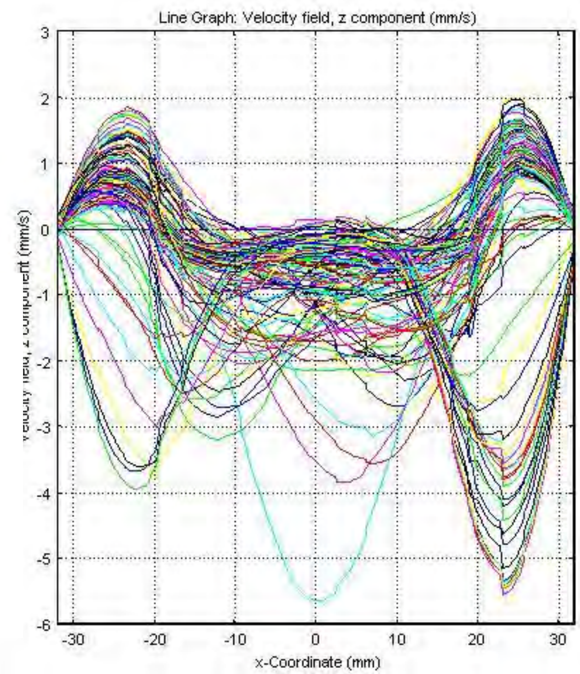
3. Results
Cylinder Top Cooling

Center x axis cutline
T profile
5 min – 1 hr



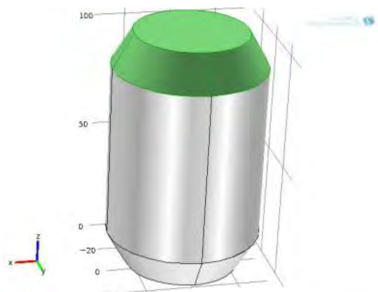
Center x axis cutline
Z velocity profile
30 sec solver steps

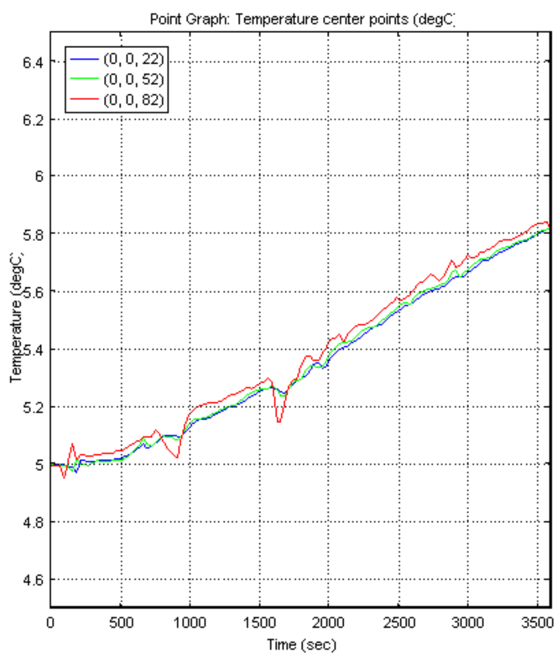




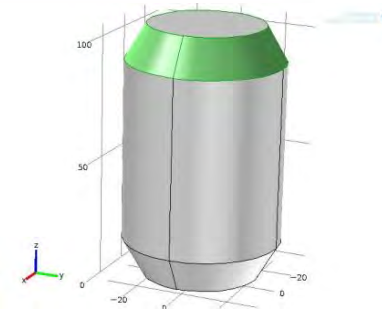
3. Results
Chamfered Cylinder

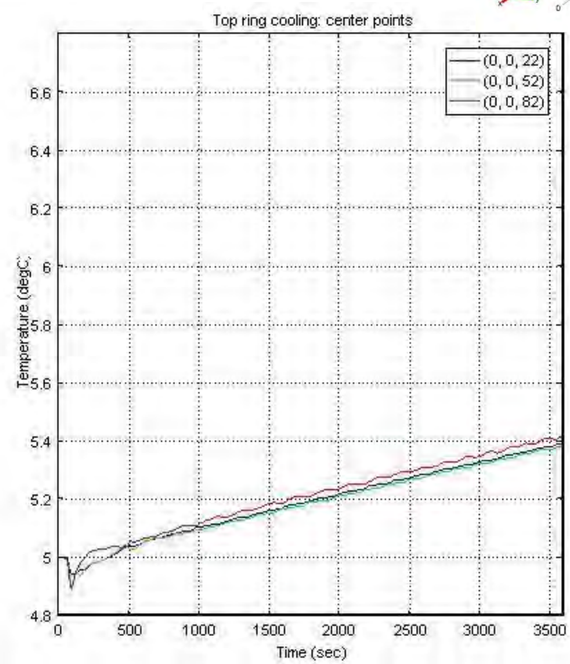
Top cooling





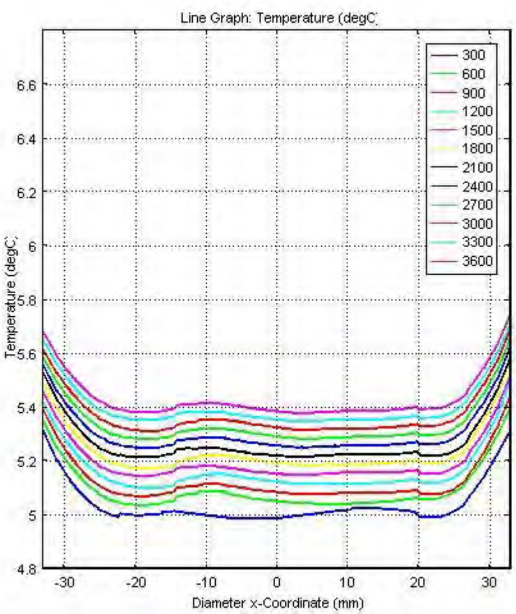
Top ring cooling

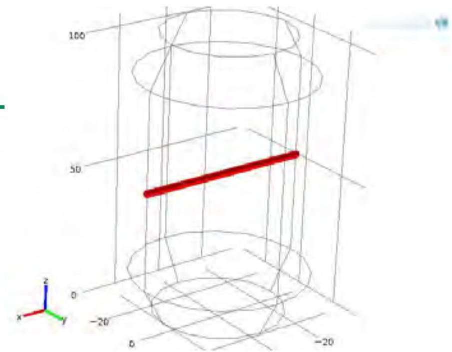




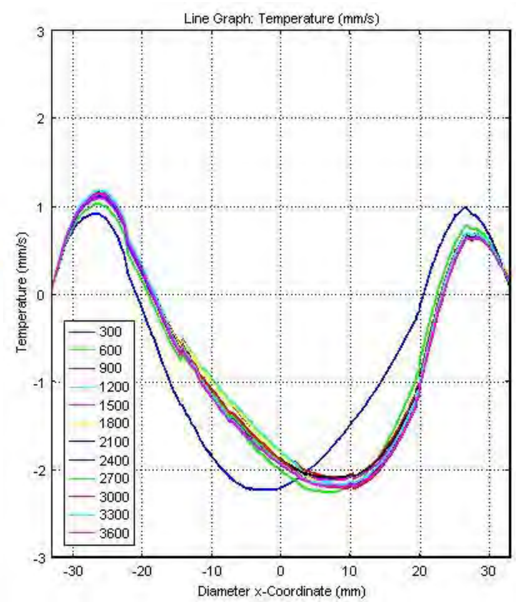
3. Results
Top ring cooling

Center cutline
Temperature profile
5 min





Center cutline
Z velocity profile
5 min steps



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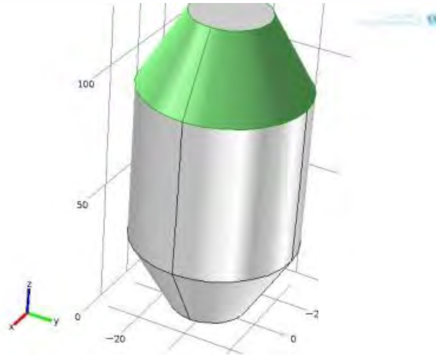
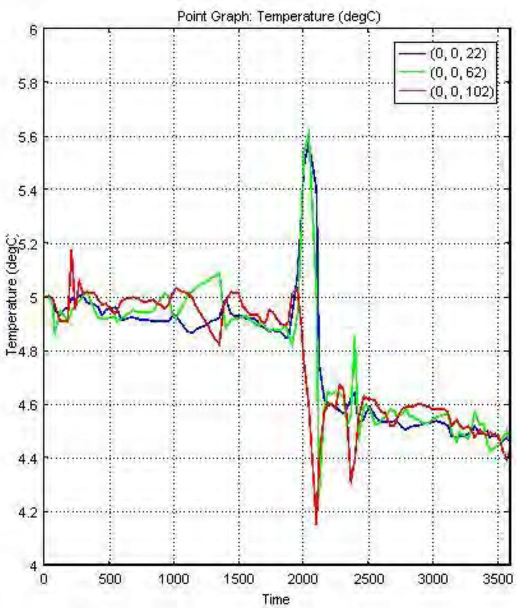
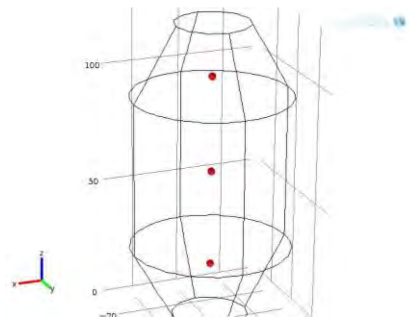
3. Results
Increased Chamfering

Coarse mesh

6k elements

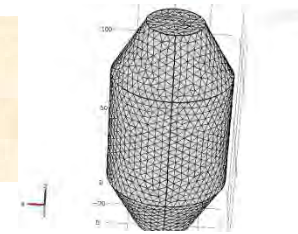


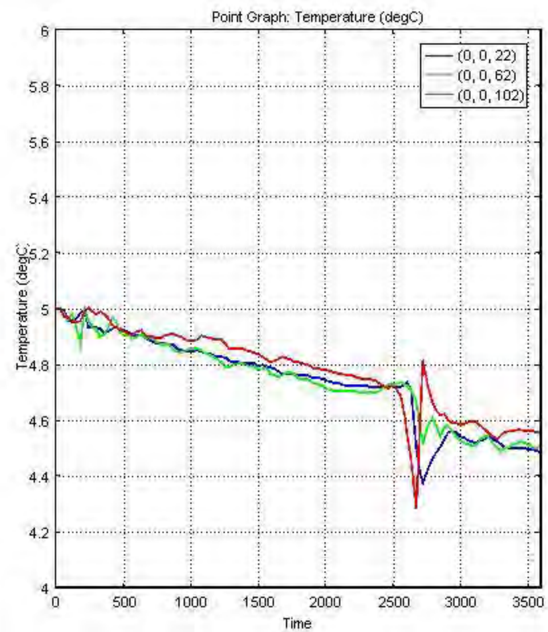




Refined mesh

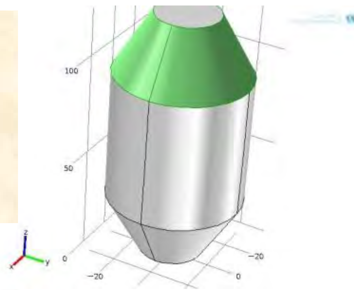
34k elements



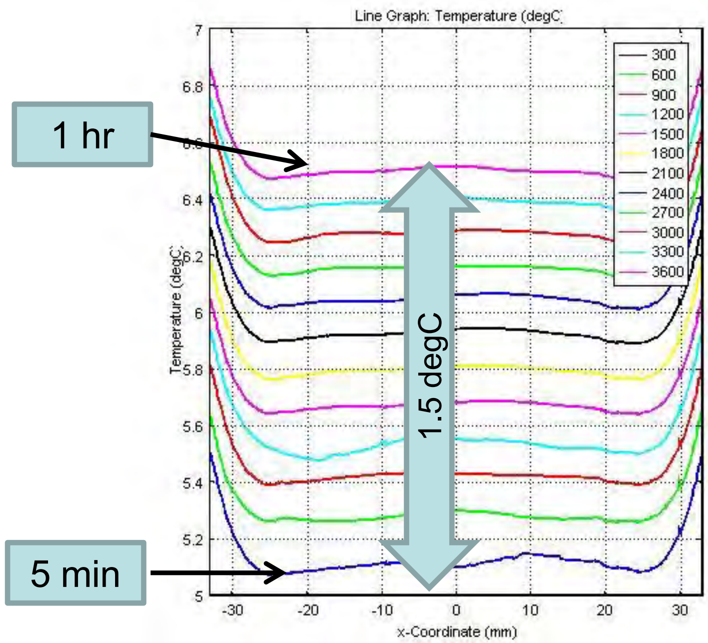


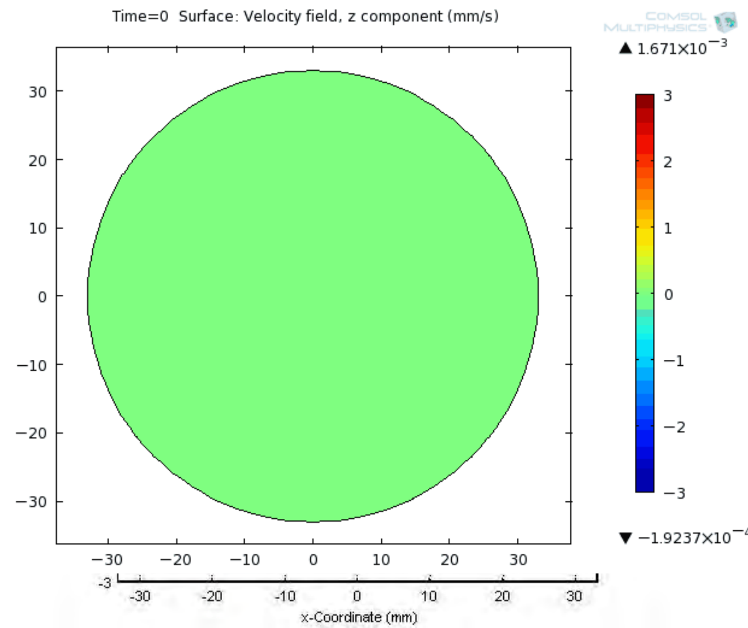
3. Results
1 Watt Cooling Power

Center cutline
Temperature profile
5 min – 1 hr



Center cutline
Z velocity profile
5 min steps





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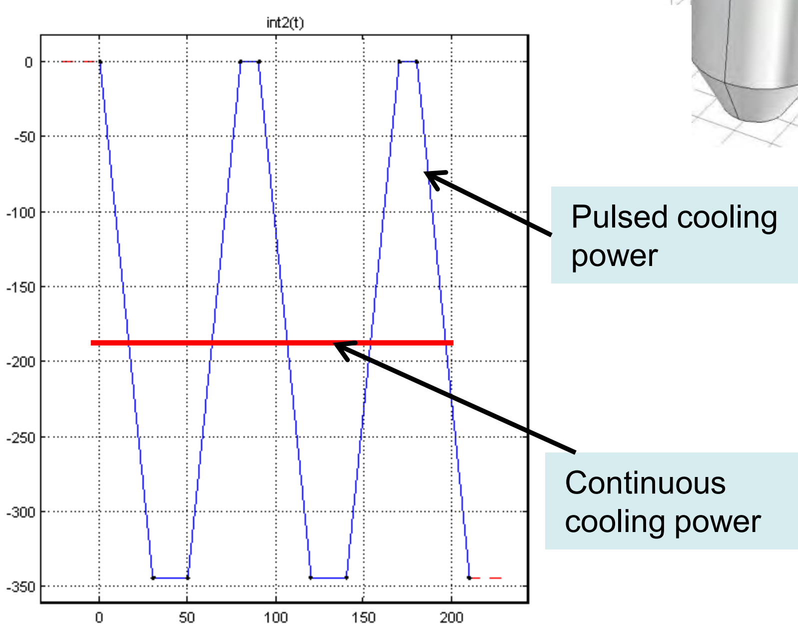
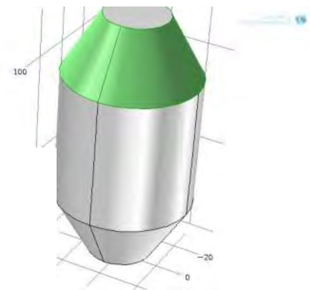
3. Results
Pulsed cooling

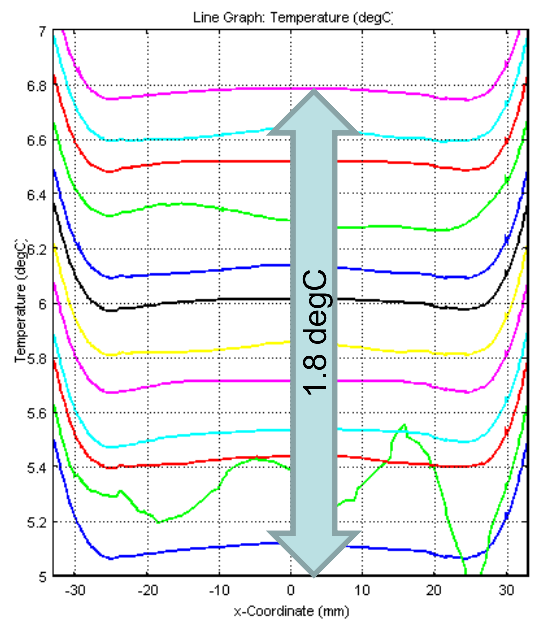
Integrated Pulsing power corresp. 1 Watt medium cooling power flow





X axis cutline

Temperature profile

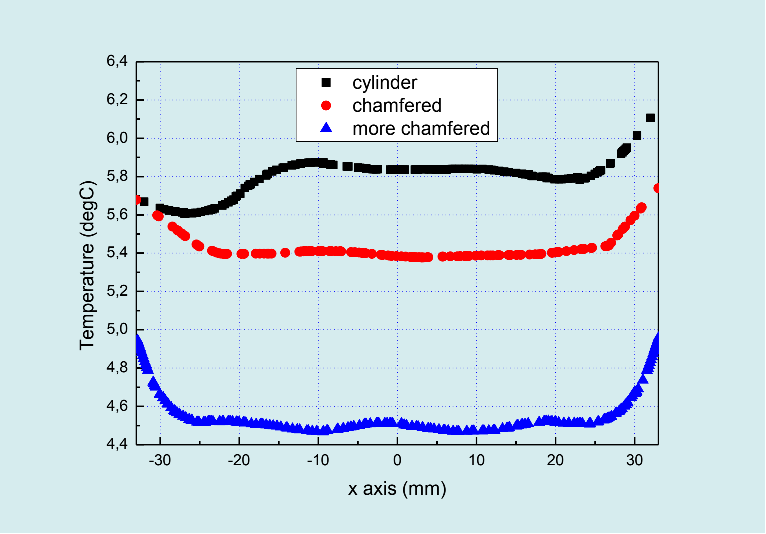


4. Summary

- **Cooling efficiency may be raised by geometry design of storage container**
- **Chamfering supports a stabilized internal buoyancy flow**
- **Pulsation (T=80 sec) will not effect a cooling efficiency rise**

X axis cutline

T profiles after 1 hour of cooling



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Thank you

… for your attention