Natural Convection Effects On The Solidification In Cylinders At Different Filling Percentages

Adel Alshayji, **Raed Bourisli**

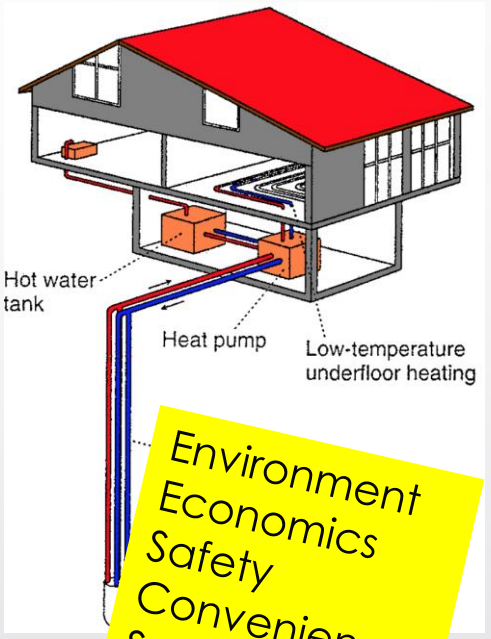
Mechanical Engineering Department
Kuwait University

COMSOL CONFERENCE 2017 ROTTERDAM

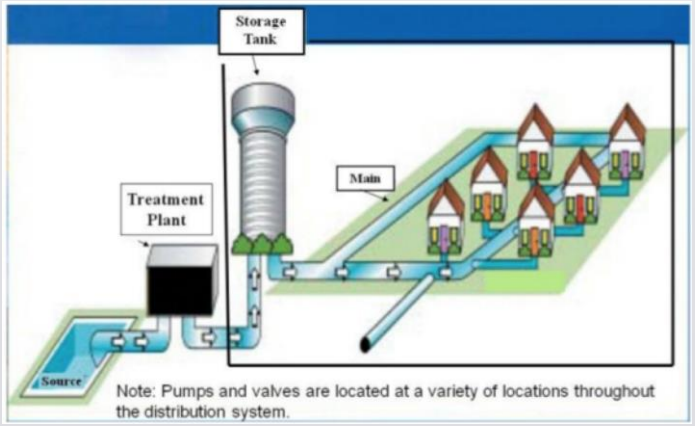
Motivation

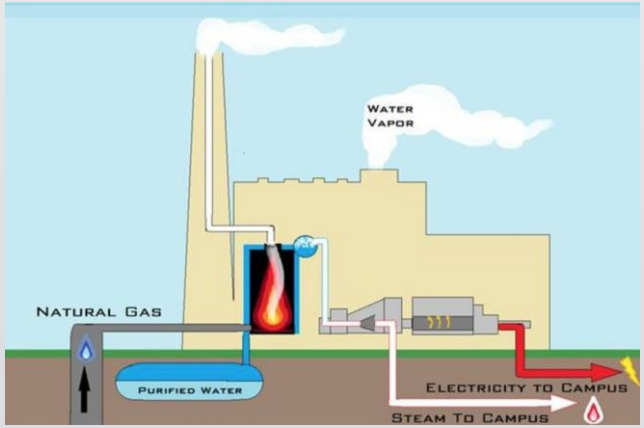
Fluid transport in buried pipelines:

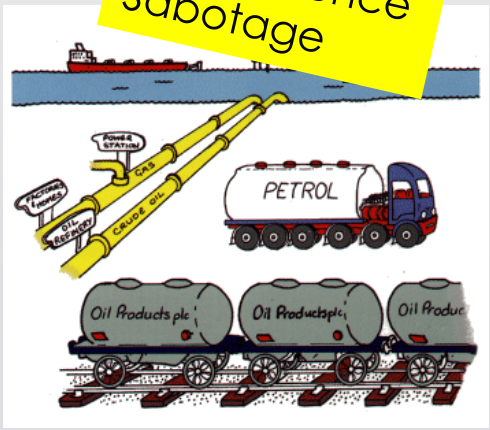
- Oil and natural gas pipelines
- Water and sewage distribution network
- Refinery products pipelines
- Power plant steam lines
- Heat exchangers in soil (thermal energy storage)



Environment
Economics
Safety
Convenience
Sabotage

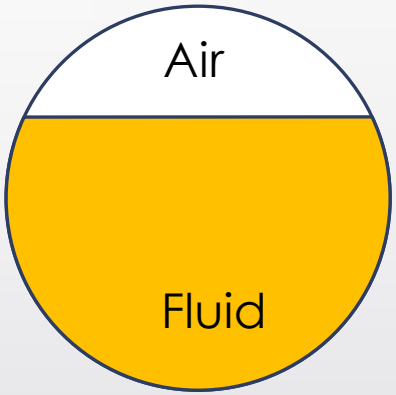






Problem Definition and Governing Equations

- Two-dimensional cylinder of diameter *D*
- Different filling levels, from 20% to100% (fully liquid).
- Rayleigh numbers of 10^7 to 5 x 10^8



Mass

$$\nabla \cdot \mathbf{u} = 0$$

Momentum

$$\rho\left(\frac{\partial \mathbf{u}}{\partial t} + \mathbf{u} \cdot \nabla \mathbf{u}\right) = -\nabla p + \mu \nabla \cdot (\nabla \mathbf{u} + (\nabla \mathbf{u})^T) + \rho \mathbf{g}$$

Energy

$$\rho c_p\left(\frac{\partial T}{\partial t} + \mathbf{u} \cdot \nabla T\right) = \frac{\partial p}{\partial t} + \mathbf{u} \cdot \nabla p + k\nabla^2 T$$

$$Ra_D = \frac{g\beta\Delta T D^3}{\nu\alpha}$$

$$\Delta T = T_{initial} - T_{cold}$$

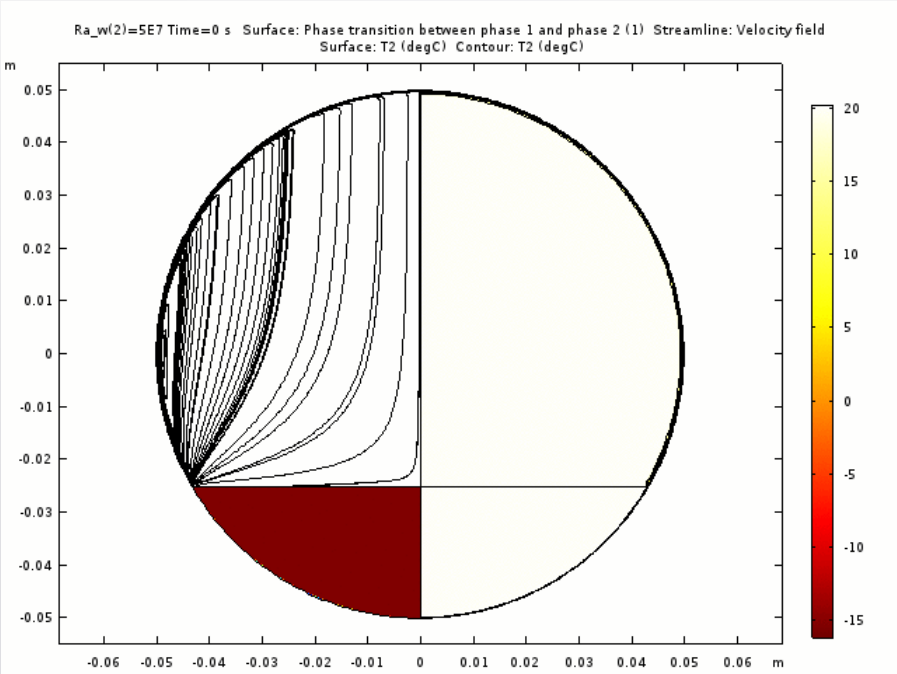
Numerical Model and Assumptions

- Finite element method by way of COMSOL Mutiphysics.
  - *single-phase laminar flow (spf)* module, and,
  - *heat transfer in fluids (htf)* module.
- Natural convection effect is captured by including the effect of *gravity* in the laminar flow physics.
- A *phase-change* node is added under the heat transfer physics (to the water domain.)
  - The solidification effect is captured by defining two materials, a liquid and a solid, with the viscosity of the solid phase be 10^{22} times that of the fluid.
- All other properties are assumed to be constant.

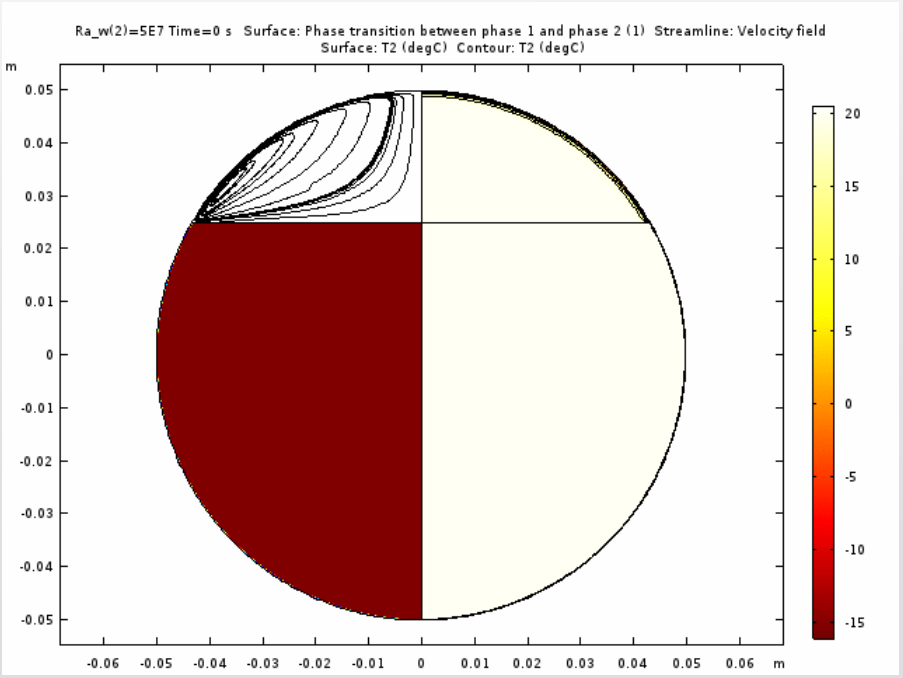
Results: flow and phase field

* A mesh with 50,000 dof's (extremely fine) in the end was used, which gave a change of less than 1% in time and heat flux.

25%-filling; Ra = 5 x 10^7

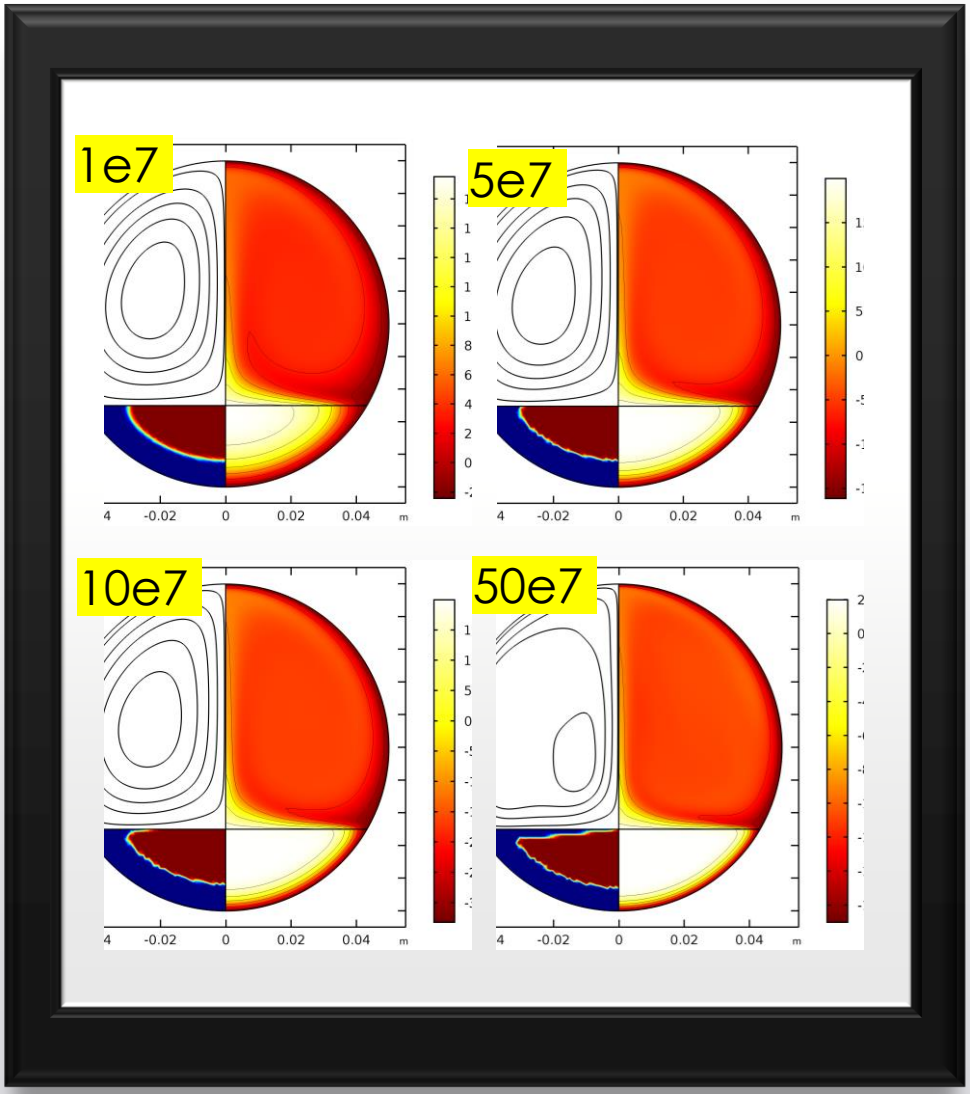


75%-filling; Ra = 5 x 10^7



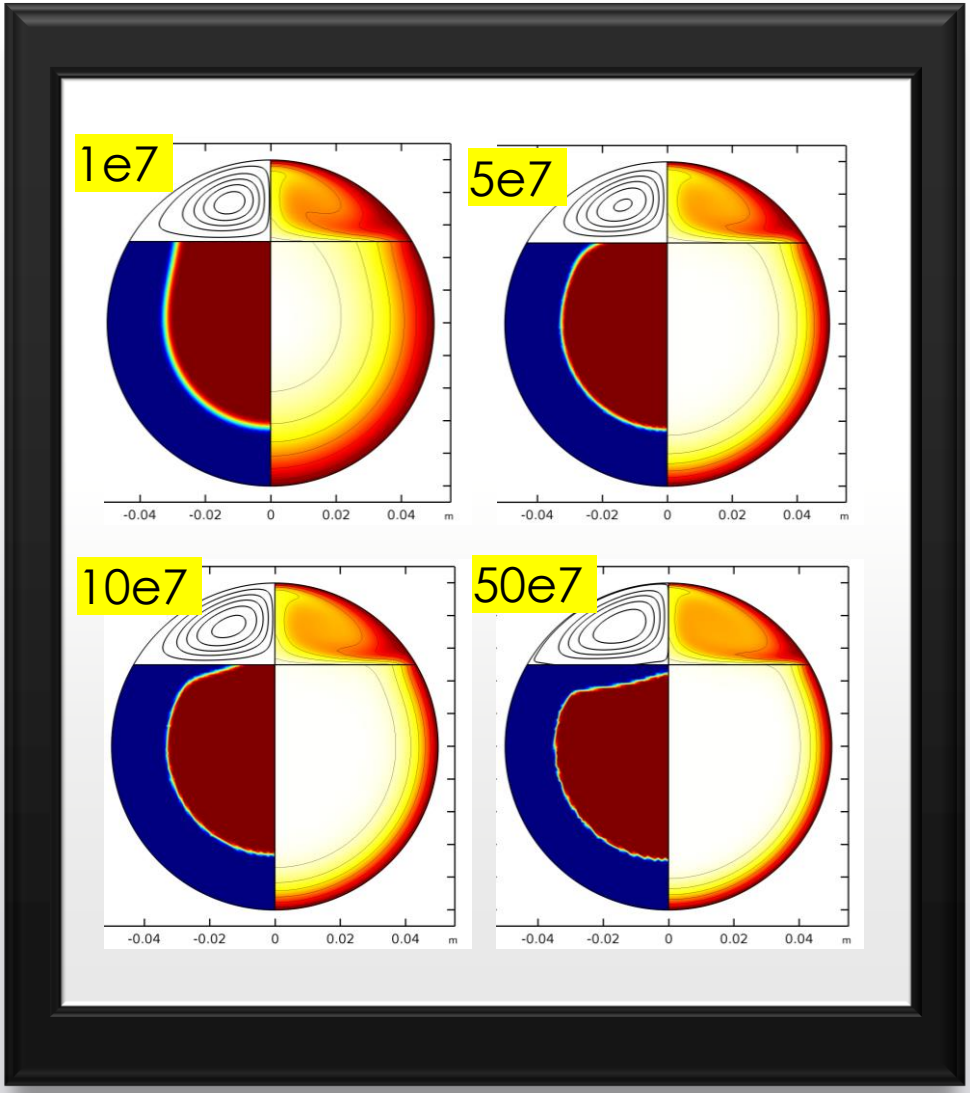
Results: flow and phase field

- 25%-filling cases.
- At 50% solidification



Results: flow and phase field

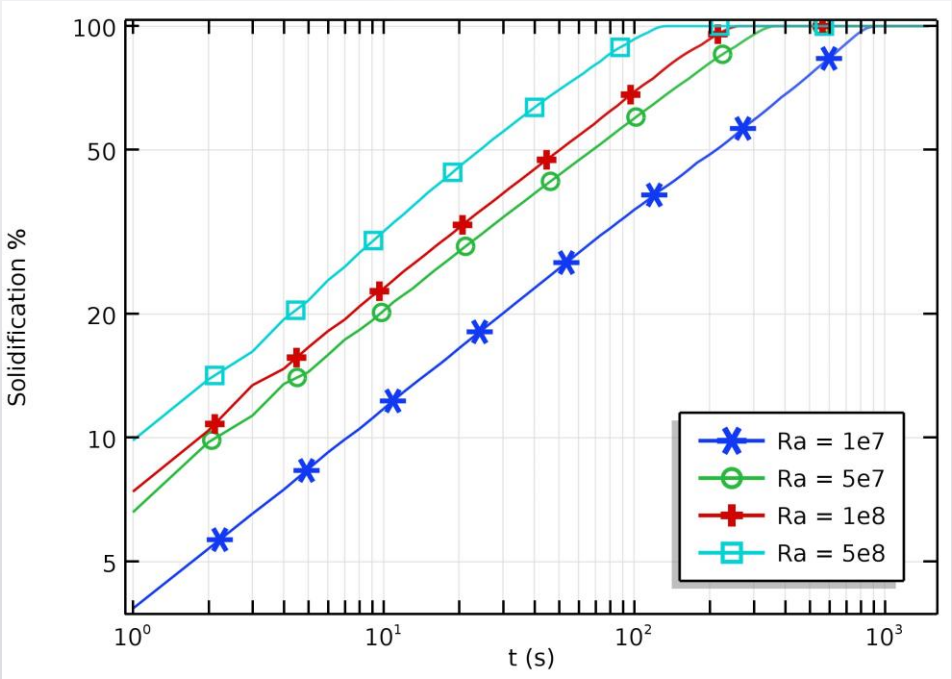
- 75%-filling cases.
- At 50% solidification



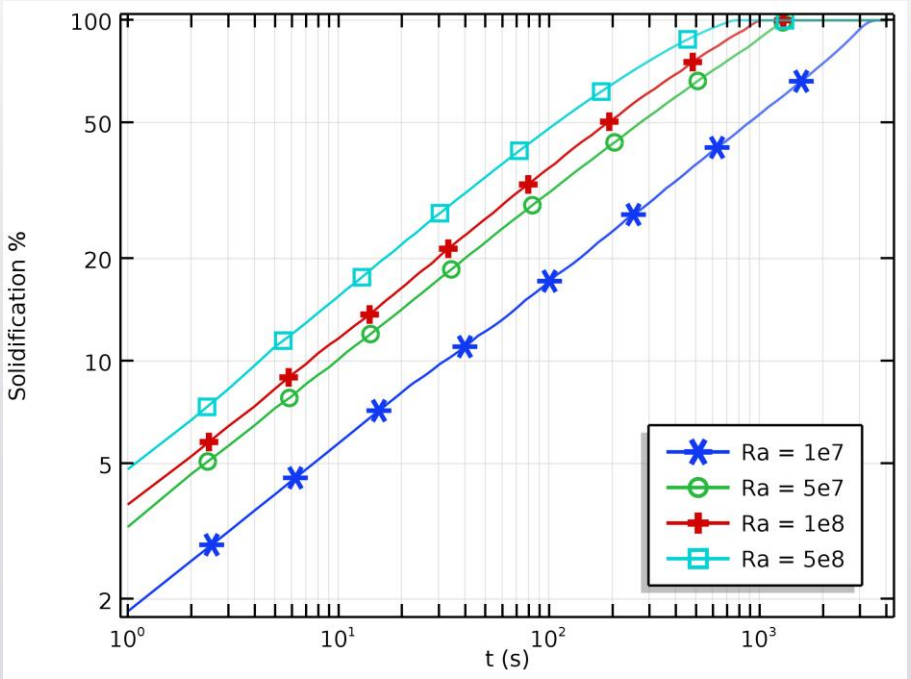
Results: Effect of Rayleigh number

Solidification percentage vs. time ($Ra=5x10^7$)

25%-filling

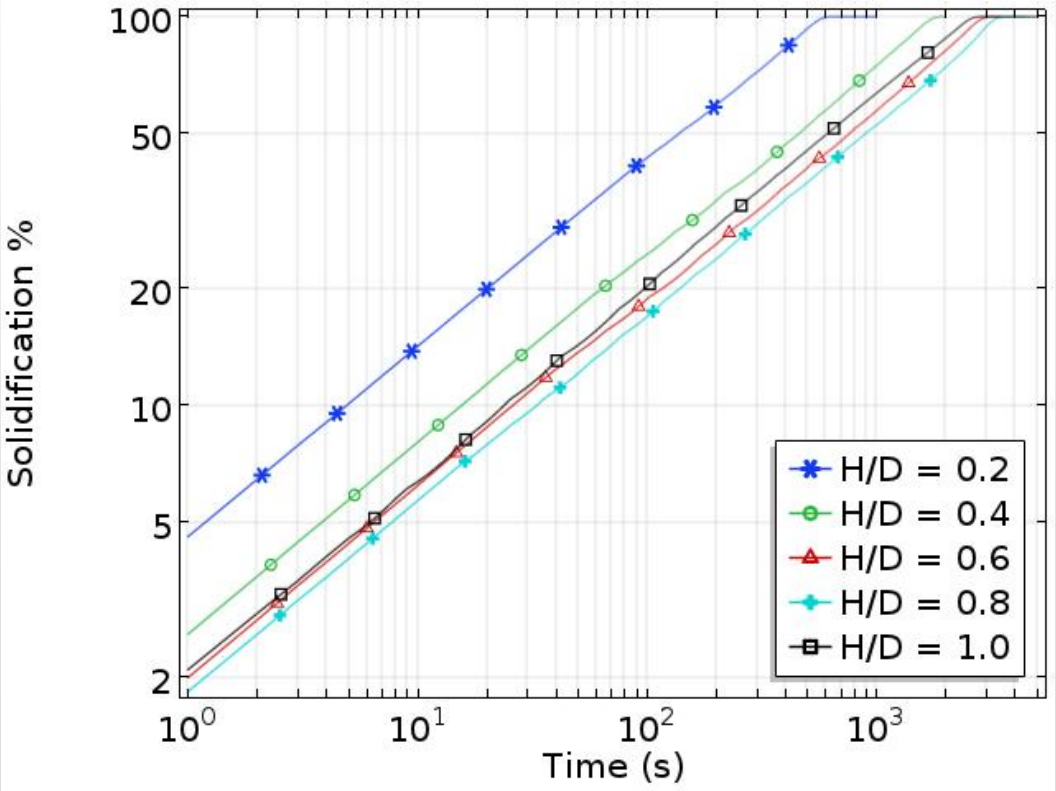


75%-filling



Results: Effect of filling percentage

Solidification percentage vs. time ($Ra=10^7$)



Conclusions

- The time to full solidification depends greatly (and nonlinearly) on the filling percentage and that this dependence is nonlinear.
- The effect of Rayleigh number on accelerating the solidification is clear: due to advection of warm fluid from the core to the peripheries.
- Inclusion of the free surface motion will result in more accurate results for the heat transfer.

On-going work…

- Ongoing work investigates and modifies more quantities and parameters of the problem.
- Investigate 3D cases where *turbulent* flow exhibits interesting asymmetries in the low filling percentage cases tried.
- Ultimate goal is to devise a non-dimensional group, or dependence on groups, that accounts for the filling percentage.

Thanks for listening!