Technical University of Denmark

Numerical Simulation of a Tapered Bed AMR

Dallolio, Stefano; Lei, Tian; Engelbrecht, Kurt; Bahl, Christian

Publication date:
2015

Document Version
Peer reviewed version

Citation (APA):
Dall'Olio, S., Lei, T., Engelbrecht, K., & Bahl, C. R. H. (2015). Numerical Simulation of a Tapered Bed AMR. Poster session presented at Delft Days on Magneto Calorics, Delft, Netherlands.

DTU Energy Conversion
Department of Energy Conversion and Storage

Numerical Simulation of an Tapered Bed AMR

Stefano Dall'Olio, Tian Lei, Kurt Engelbrecht, Christian R. H. Bahl

Department of Energy Conversion and Storage, Technical University of Denmark – Frederiksborgvej 399, DK-4000 Roskilde – Denmark

■ The objective of this poster is to show how the tapering angle of a regenerator influences the AMR performance, displaying results based on simulations.

Introduction

■ To optimize cooling power and COP of an AMR, we analysed numerically the effect of having a tapered regenerator.

■ Rowe and Barclay [1], deriving an expression describing the ideal magnetocaloric effect (MCE) as a function of temperature for the case of zero entropy generation, concluded that a possible solution is to have a linear variation of the adiabatic temperature change throughout the bed.

■ We satisfied this condition by increasing the amount of magnetocaloric material (MCM) along the bed, by means of tapering the AMR regenerator.

Model of Active Magnetic Regenerator

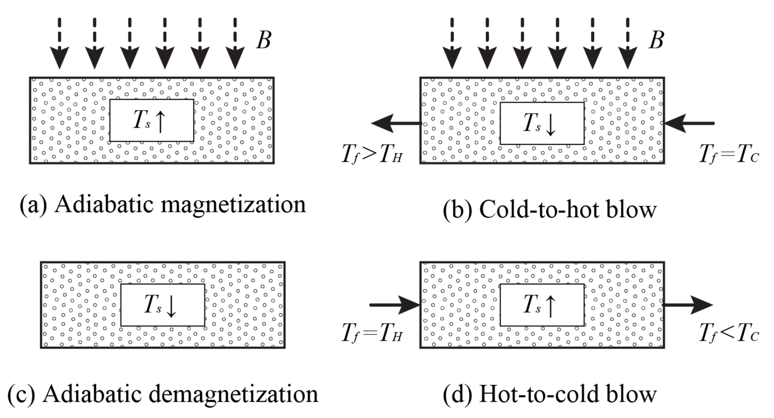

Figure 1: Active magnetic regeneration cycle

Considering the irreversibility of magnetic hysteresis, the governing equations for modelling the AMR are [2-3]:

$$\frac{\partial}{\partial x}\left(k_{disp}\frac{\partial T_f}{\partial x}\right)A_c - \dot{m}_f c_f \frac{\partial T_f}{\partial x} - \frac{Nuk_f}{d_h}a_s A_c (T_f - T_r) + \left|\frac{\partial P}{\partial x}\frac{\dot{m}_f}{\rho_f}\right| = \rho_f A_c \varepsilon c_f \frac{\partial T_f}{\partial t}$$

$$\frac{\partial}{\partial x}\left(k_{stat}\frac{\partial T_r}{\partial x}\right)A_c + \frac{Nuk_f}{d_h}a_s A_c(T_f-T_r) - A_c(1-\varepsilon)\rho_r T_r\left(\frac{\partial s_r}{\partial H}\right)_T\frac{\partial H}{\partial t} = A_c(1-\varepsilon)\rho_r c_H\frac{\partial T_r}{\partial t}$$

The geometric advantage: Tapering increases the specific cooling power (per unit volume)

- Using a tapered regenerator allows for better utilization of the volume (more MCM volume)
- By fixing several geometrical parameters, it is possible to quantify the advantages given by the tapering due to the better utilization of the magnetized volume:

Fixing:
- the number of regenerators, N
- the distance **a** between the beds
- the internal radius of the regenerators, $R_i = N \cdot (W + a)$
- the total MCM volume N x L x W x H of the parallel walls regenerators

There is an increase of the MCM volume of $\boldsymbol{N \cdot L^2 \cdot \tan\alpha}$, using tapered regenerators with a tapering angle of α

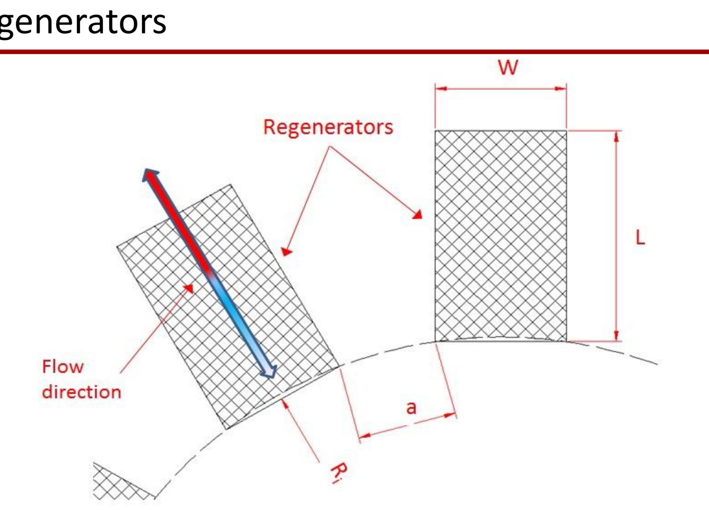

Fig. 2 . Radial distribution of parallel walls regenerators.

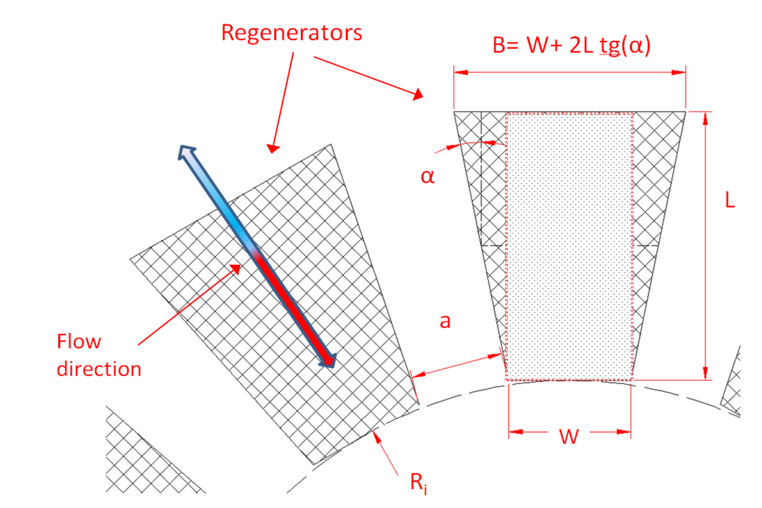

Fig. 3. Radial distribution of tapered regenerators.

Parameters of the simulations

Regenerator geometry
- Cross sectional area: 900 mm²
- Length= 50 mm
- Height= 15 mm
- Tapering angle α: -45 to 45 degrees

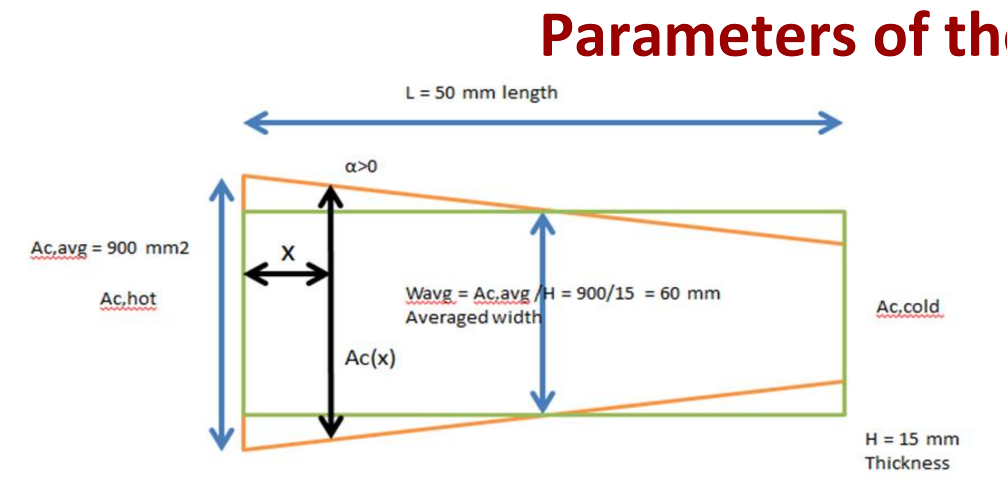

Fig. 4. Cross section of the tapered regenerator – main geometrical parameters.

MCM
- Gadolinium
- T_c = 292 K
- Mass = 200 g
- Spheres diameter = 0.3 mm
- Porosity = 0.36

Simulation general settings
- 1 Hz
- B= 1.4 T
- T_{amb}=295 K
- T_H=300 K
- ΔT_{span}= 20 K
- Demagnetization – off
- Working fluid: water

Results of the 1-D simulations

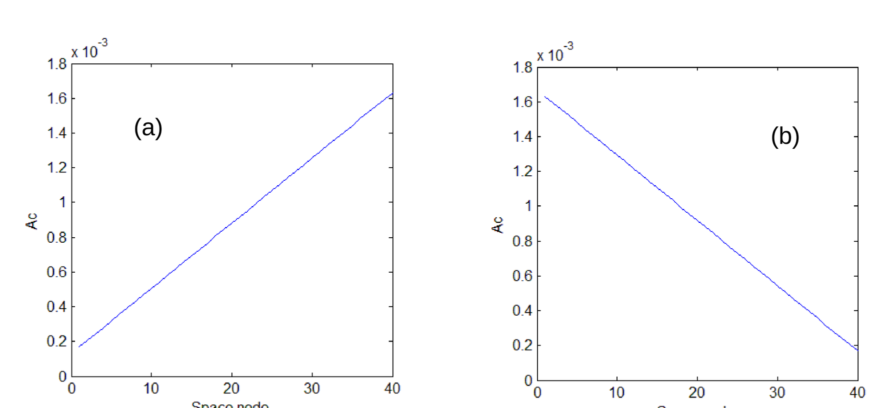

Fig. 5. Area progress along the regenerator for (a) α= - 45˚, and (b) α= 45˚.

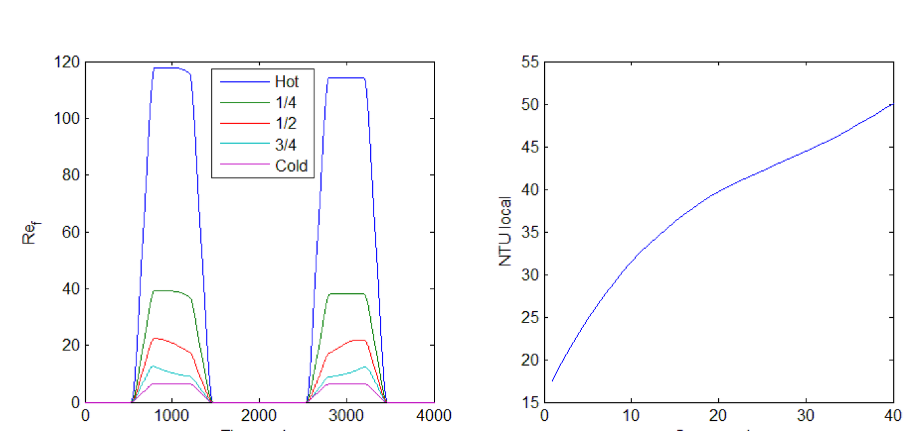

Fig. 6. Reynolds number and local NTU values along the regenerator , α= - 45˚.

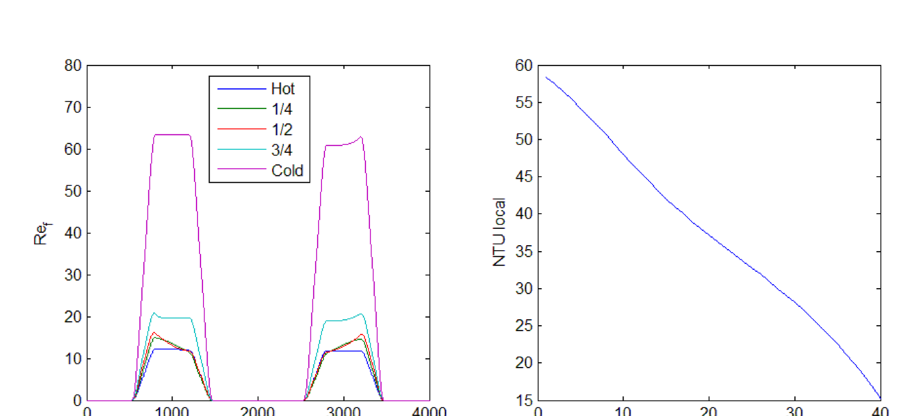

Fig. 7. Reynolds number and local NTU values along the regenerator , α= 45˚.

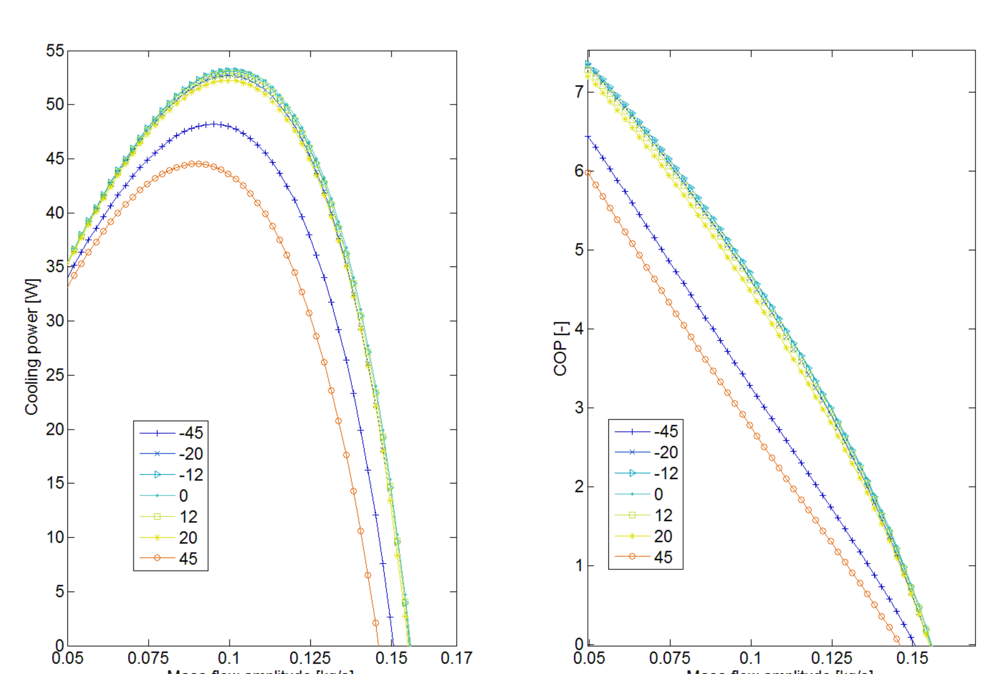

Fig. 8. Cooling power and COP as function of angle α , f= 1 Hz.

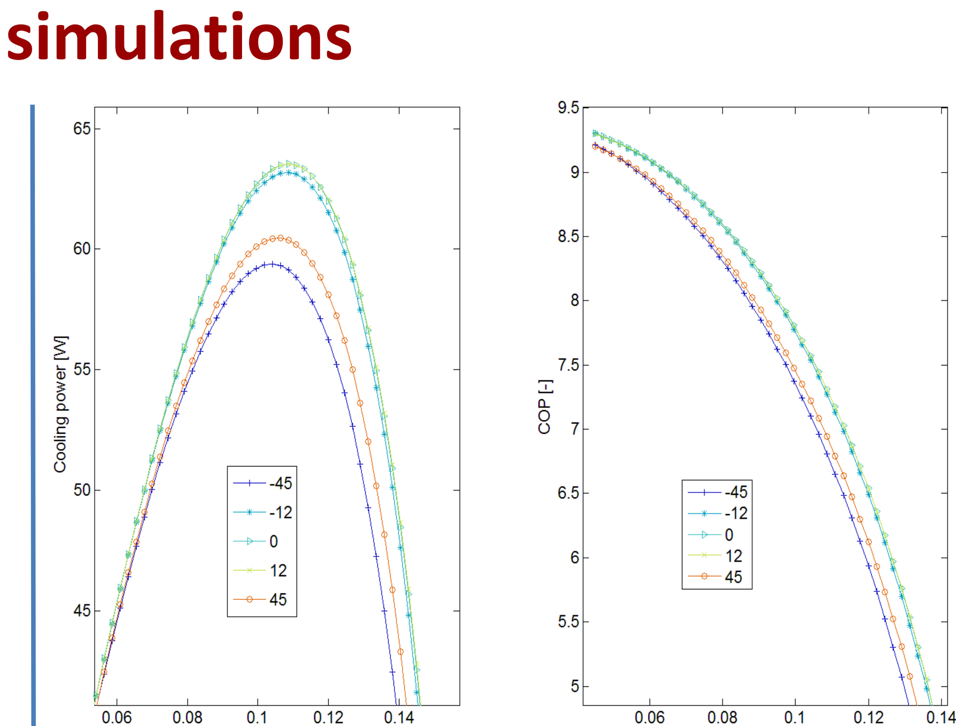

Fig. 9. Cooling power and COP as function of angle α , f= 1Hz. Conduction and viscosity set to 0.

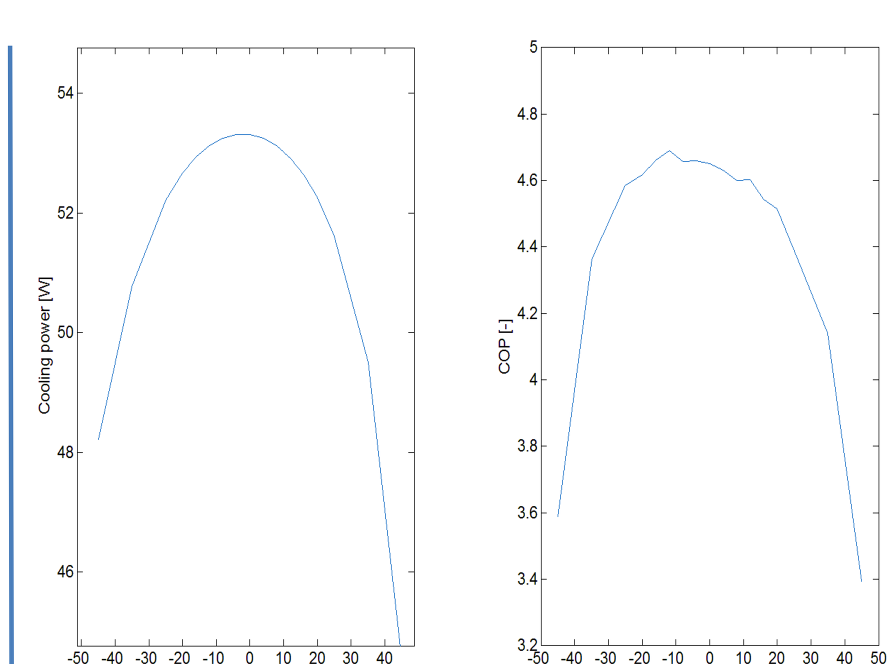

Fig. 10. Maximum Cooling power and COP as function of angle α , f= 1 Hz.

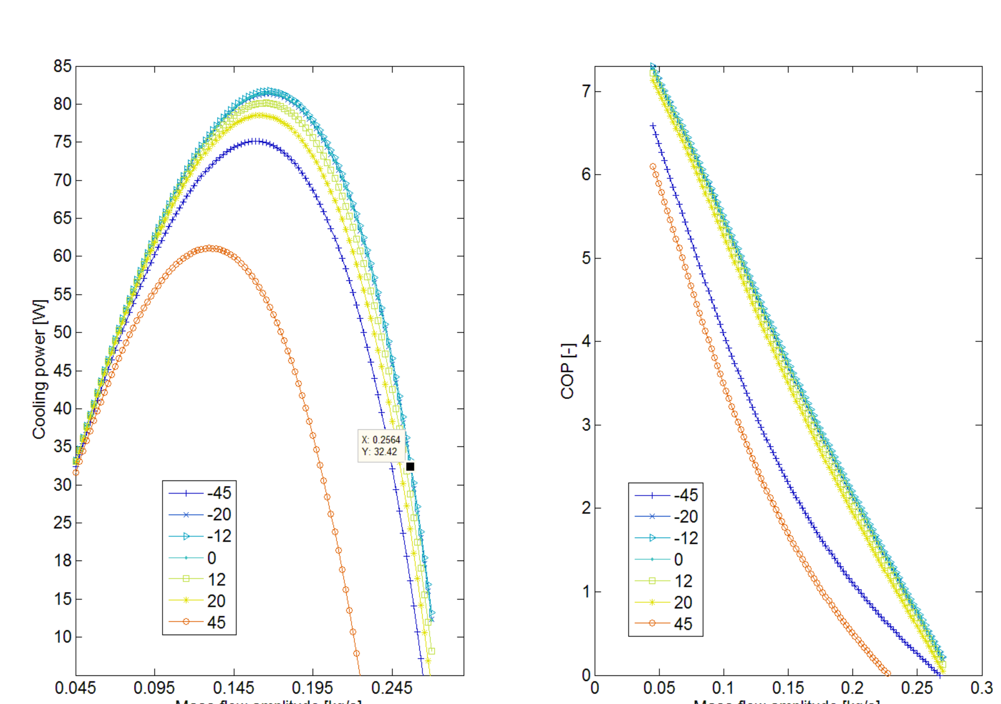

Fig. 11. Cooling power and COP function of angle α , f= 2 Hz.

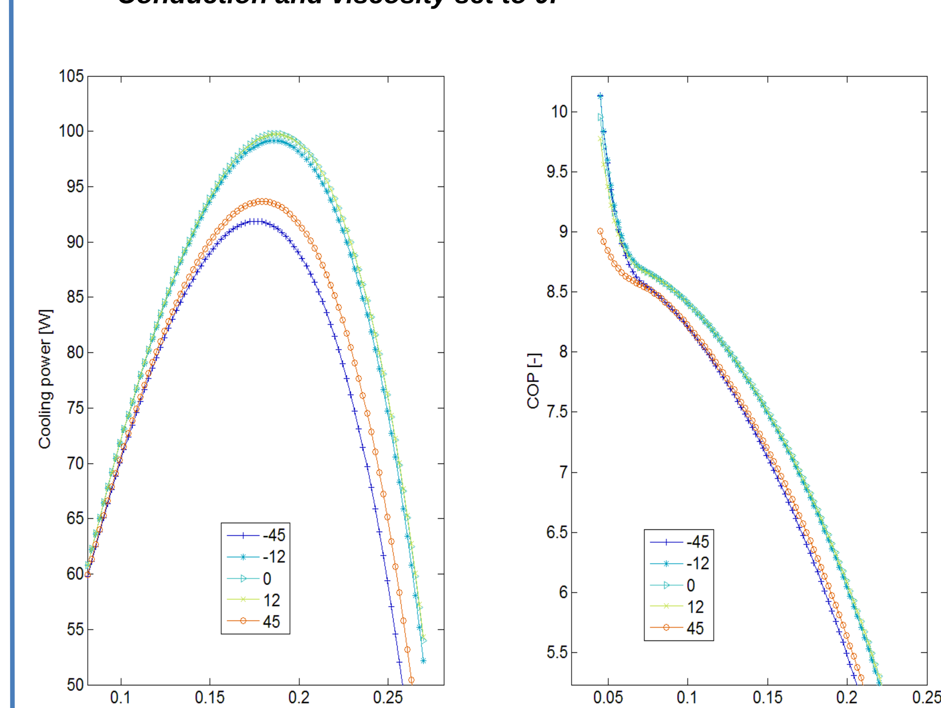

Fig. 12. Cooling power and COP as function of angle α , f= 2Hz. Conduction and viscosity set to 0.

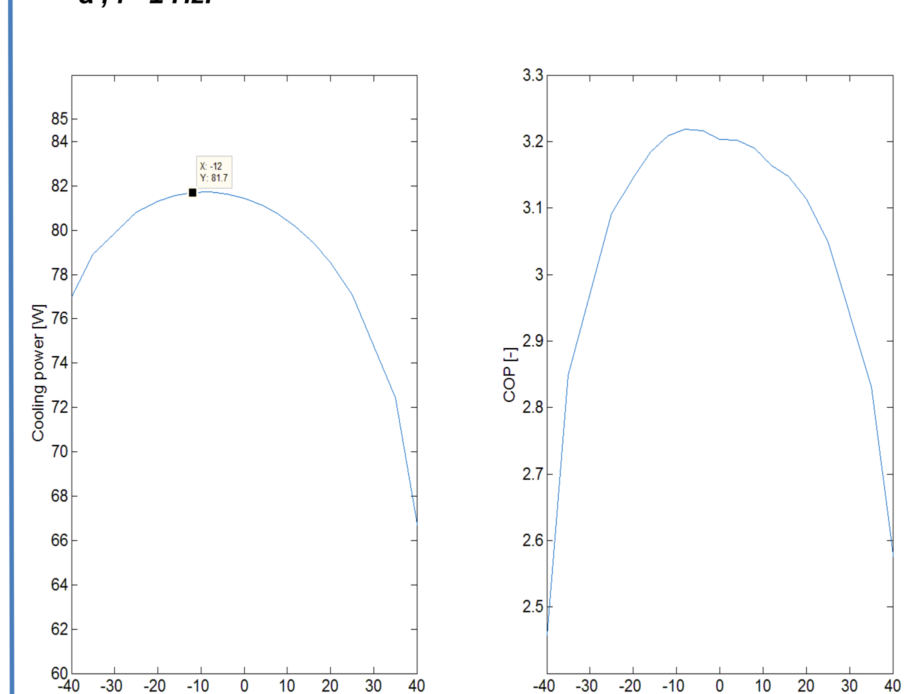

Fig. 13. Maximum Cooling power and COP as function of angle α , f= 2 Hz.

Conclusions and Outlook

- Considering the results of the simulations, tapering in the right direction does not have any evident disadvantages for the performance of the AMR.
- A negative tapering angle of around -12 degrees gives a slight improvement of the performance of the AMR.
- The improvement of the performance increases with frequency.
- The viscosity of the heat transfer fluid plays an important role in the behaviour of the AMR, and this can be seen by the values of the Reynolds number and of the local NTU along the regenerator.
- In a radial distribution of regenerators, tapering gives a significant space optimization advantage compared to the parallel wall configuration.
- Tapering a regenerator is analogous to increasing the volume of MCM in the same magnetized volume.
- Performance of the AMR begins to decrease significantly for a large value of the tapering angles, i.e. 35 degrees.
- A more complete analysis of the tapering effect will be performed in order to study in more detail the effect of the working fluid, the geometry of the regenerator, the MCM and of the frequency on the performance of an AMR.

Acknowledgements

■ This work was financed by the ENOVHEAT project which is funded by the Danish Council for Strategic Research (contract no 12-132673) within the Programme Commission on Sustainable Energy and Environment.

References

1. A. M. Rowe et al. J. Appl. Phys. 1672(2003)1536016.
2. T. Lei et al. J. Appl. Phys. 118(2015) 014903.
3. K. Engelbrecht, Ph.D. Thesis, 2008.

* Corresponding author e-mail: stefdal@dtu.dk