Photoacoustics Modeling using Amplitude Mode Expansion Method in a Multi-scale T-cell Resonator

S. El-Busaidy[1,2], B. Baumann[1], M. Wolff[1], L. Duggen[2]
1. Department of Mechanical and Production Engineering, Hamburg University of Applied Sciences, Hamburg, Germany
2. Mads Clausen Institute, University of Southern Denmark, Sønderborg, Denmark

INTRODUCTION

The viscothermal (VT) method is considered the most accurate method for simulating the photoacoustic (PA) signal in small resonators [1]. However, it is computationally very demanding and slow. We present the amplitude mode expansion method (AME) as a faster and computationally less demanding simulation alternative [2]. The method is used to simulate the PA signal in a T-cell resonator over a wide frequency range and the simulation results are compared and analyzed against the results from the viscothermal method.

COMPUTATIONAL METHODS

AME model	VT model
➢ The Acoustic pressure is calculated as a superposition of the acoustical eigenmodes of the resonator. $p(\boldsymbol{r},\omega) = \sum_j A_j(\omega) p_j(\boldsymbol{r})$ ➢ The modes $p_j(\boldsymbol{r})$ are calculated using the Pressure Acoustics, Frequency Domain COMSOL Multiphysics® module. ➢ Losses are introduced by loss factors l_j in the amplitude $A_j(\omega) = \mathrm{i}\frac{\mathcal{A}_j \omega}{\omega^2 - \omega_j^2 + \mathrm{i}\omega\omega_j l_j}$ ➢ Simulation time is 7 minutes.	➢ Based on solving the linearized Navier-Stokes equation, the continuity equation for the mass and the energy balance equation. ➢ Executed using the Thermoviscous Acoustics, Frequency Domain COMSOL Multiphysics®. ➢ The walls of the resonator are set as sound hard (no-slip and isothermal boundary conditions). ➢ Simulation time is 1 week.

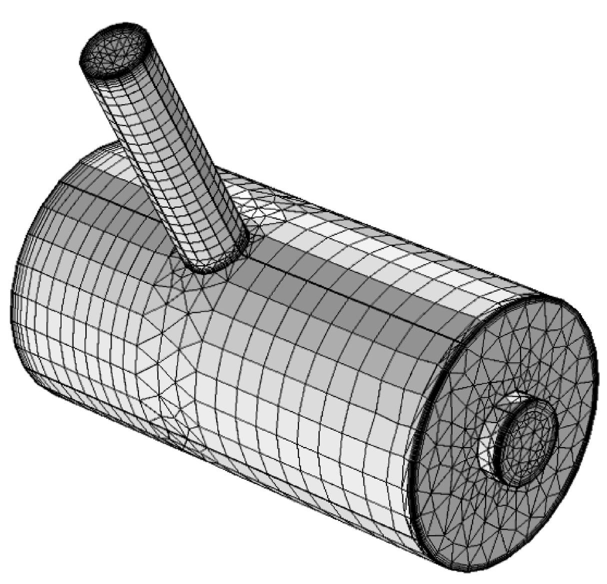


Figure 1. Meshing of the resonator. The mesh consists of a swept mesh and a triangular mesh where a swept mesh could not be applied.

RESULTS

- ➢ AME model reproduced all the resonance frequencies from VT model model with a deviation of less than 1.8%.
- ➢ The relative height of a resonance amplitude depends on the location of the main mode within the resonator. If a mode is mainly located where the surface area to volume ratio is large, the AME model underestimates the losses and has larger amplitudes than the VT model. If the mode is mainly located where the surface area to volume ratio is small, the AME model slightly overestimates the losses and has smaller amplitudes. than the VT model.

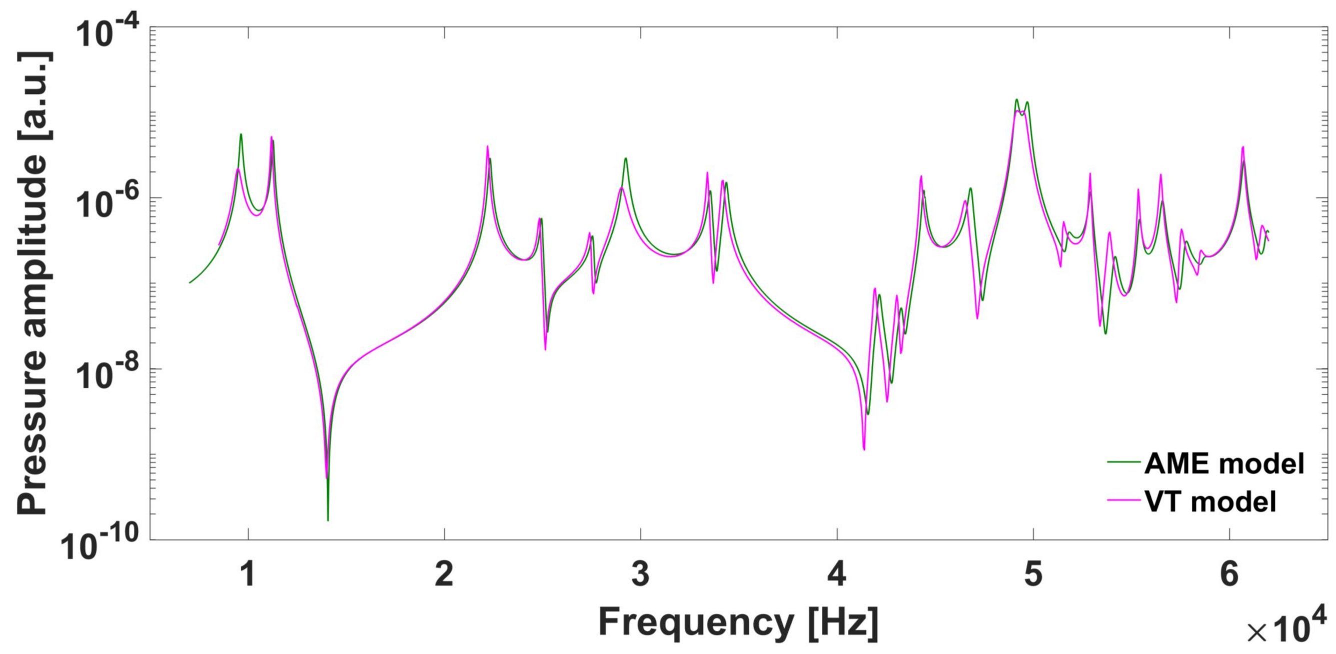


Figure 2. Frequency response curves of AME and VT model

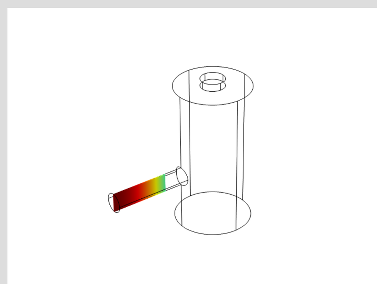
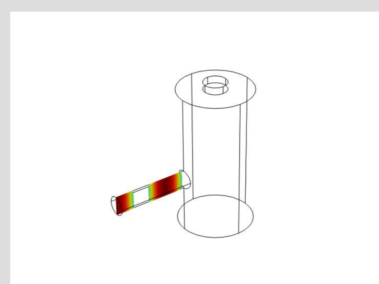
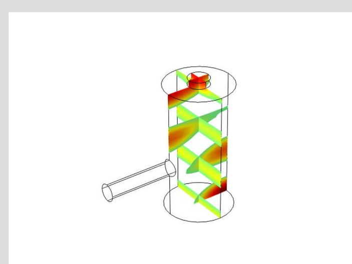
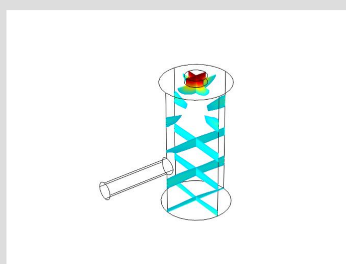
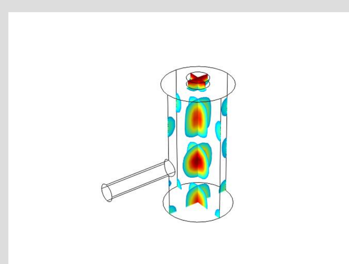
$\text{Amplitude}_{\text{AME}} > \text{Amplitude}_{\text{VT}}$	 9500 Hz	 29050 Hz	
$\text{Amplitude}_{\text{AME}} < \text{Amplitude}_{\text{VT}}$	 33400 Hz	 44300 Hz	 60700 Hz

Table 1. Randomly selected resonances showing the dependence of the relative height of a resonance's amplitude on the main location of their strong antinodes.

CONCLUSIONS

The AME method provides a much faster simulation alternative to the VT model. This is particularly useful in the design and optimization of photoacoustic resonators where numerical methods are preferred over experimental measurements due to their speed and low cost.

REFERENCES

1. A. Glière, J. Rouxel, M. Brun, B. Parvitte, V. Zèninari, S. Nicoletti. Challenges in the design and fabrication of a lab-on-chip photoacoustic gas sensor. *Sensors, volume 14, pages 957-974* (2014).
2. B. Baumann, M. Wolff, B. Kost, H. Groninga. Finite element calculation of photoacoustic signals. *Applied Optics, volume 46, pages 1120-1125* (2007).