Optimization of low frequency sono chemical reactor based on computational modeling

Kandasamy Thangavadivel [1,4], Mallavarapu Megharaj [1,4], Roger St.C. Smart[2], Peter Lesniewski[3] , Ravi Naidu[1,4].
[1]Centre for Environmental Risk Assessment and Remediation, University of South Australia, Mawson Lakes Campus, Mawson Lakes, SA 5095, Australia;
[2]Applied Centre for Structural and Synchrotron Studies, University of South Australia, Mawson Lakes Campus, Mawson Lakes, SA5095;
[3]Applied Physics, School of EIE, University of South Australia, Mawson Lakes Campus, Mawson Lakes, SA5095;
[4]Cooperative Research Centre for Contamination Assessment and Remediation of the Environment, Salisbury South, PO Box 486, SA5095.

Introduction:

Generally, the existing low frequency ultrasonic power transfer efficiency to the medium which is being treated is below 30%. By optimizing the geometry of the reactor, the acoustic power transfer efficiency can be enhanced. This optimization will help to better distribution of the energy within the reactor thereby less localized heating, enhance the overall reaction rate throughout the reactor and minimize energy loss and optimum volume of the reactor being used. These will lead to better economical operation of the process.

Aims:

- Understand the factors governing the acoustic pressure distribution within the reactor
- Optimize the reactor size, shape and transducer position for better acoustic pressure distribution

Methods :

- Commercially available finite element software was used to model the reactor system.
- The acoustic wave propagation equation and associated boundary conditions are the main equations in this modelling and simulation work.
- Drawing -> define sub domain & boundary condition -> mesh the geometry -> solve the equation.
- These modelling was carried out under an ideal condition such as no cavitation never occur within the medium , no energy loss due to heat generation.
- Acoustic wave equations

$$\nabla(-\frac{1}{\rho}\nabla p)-\frac{\omega^2}{\rho\ c^2}p=0$$

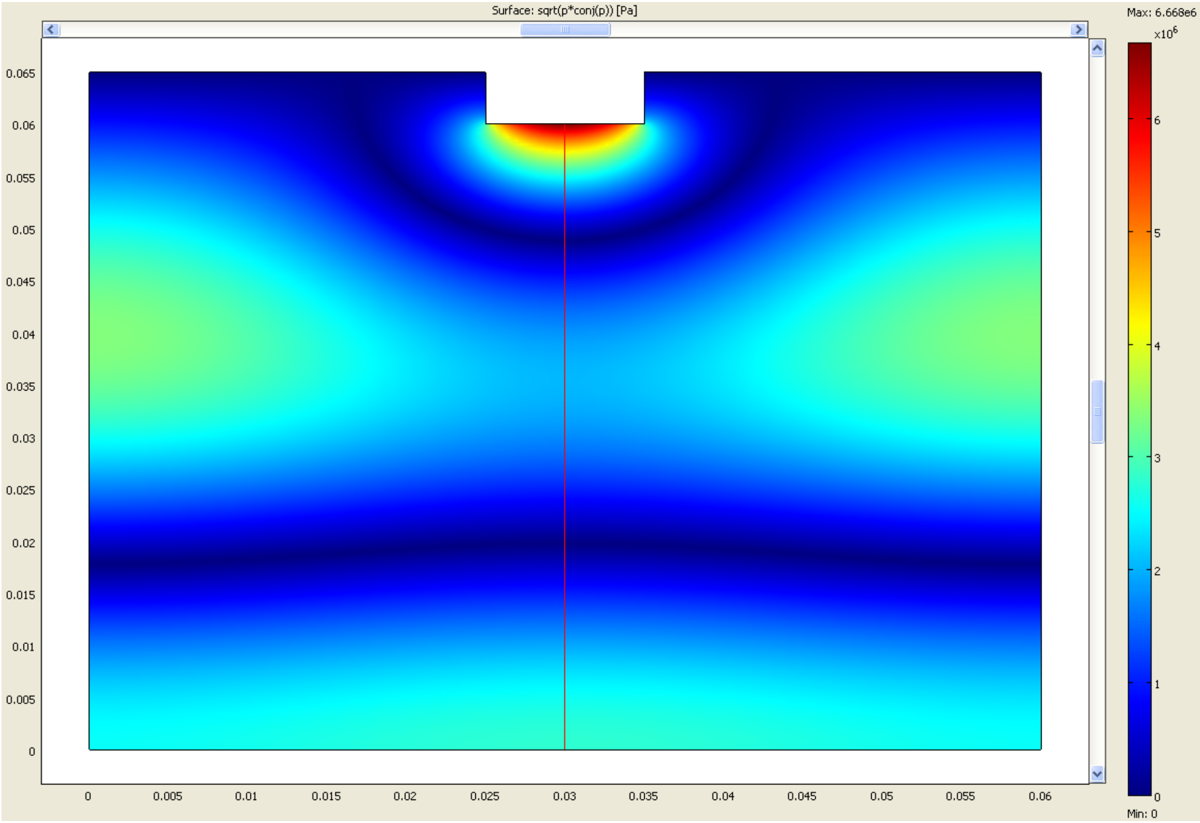
where p - acoustic pressure in Pascal
c - sound velocity in the fluid medium in m/s
P - fluid density in kg/m3
ω – angular velocity in radiant

- All the modelling were carried out at 20 kHz, fluid density is 1000 kg/m^3, sound velocity within the medium is 1500 m/s, wave length of the wave is 75 mm, transducer deflection is 72 µm, trasducer's vibrating elements diameter is 10 mm and normal acceleration is used to represent the transducer.

Results :

a) Rectangular reactor with Sound Hard wall boundary

W=60 mm, h=65 mm


Surface: sqrt(p*conj(p)) [Pa]
Max: 6.668e6
$\times 10^6$
0.065
0.06
0.055
0.05
0.045
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
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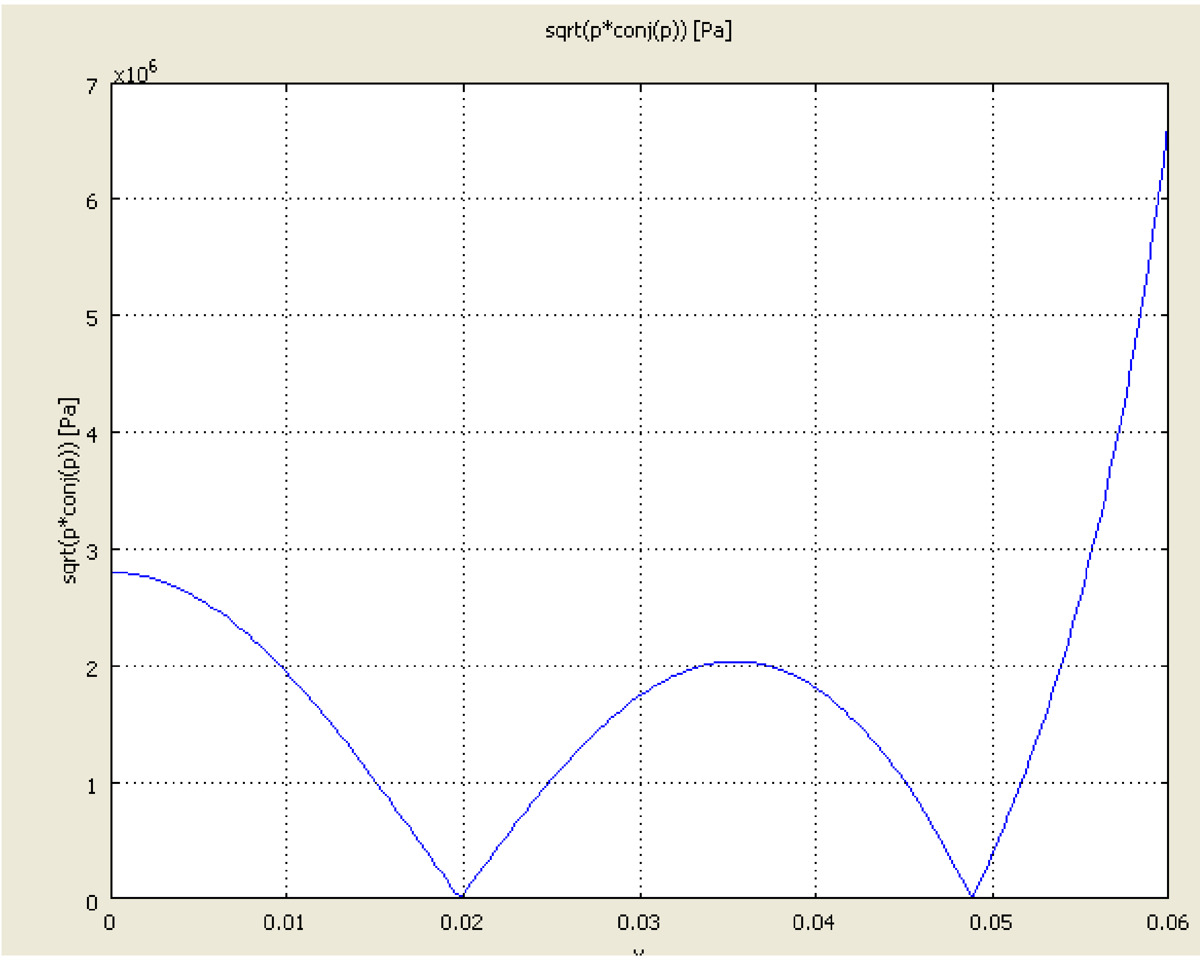
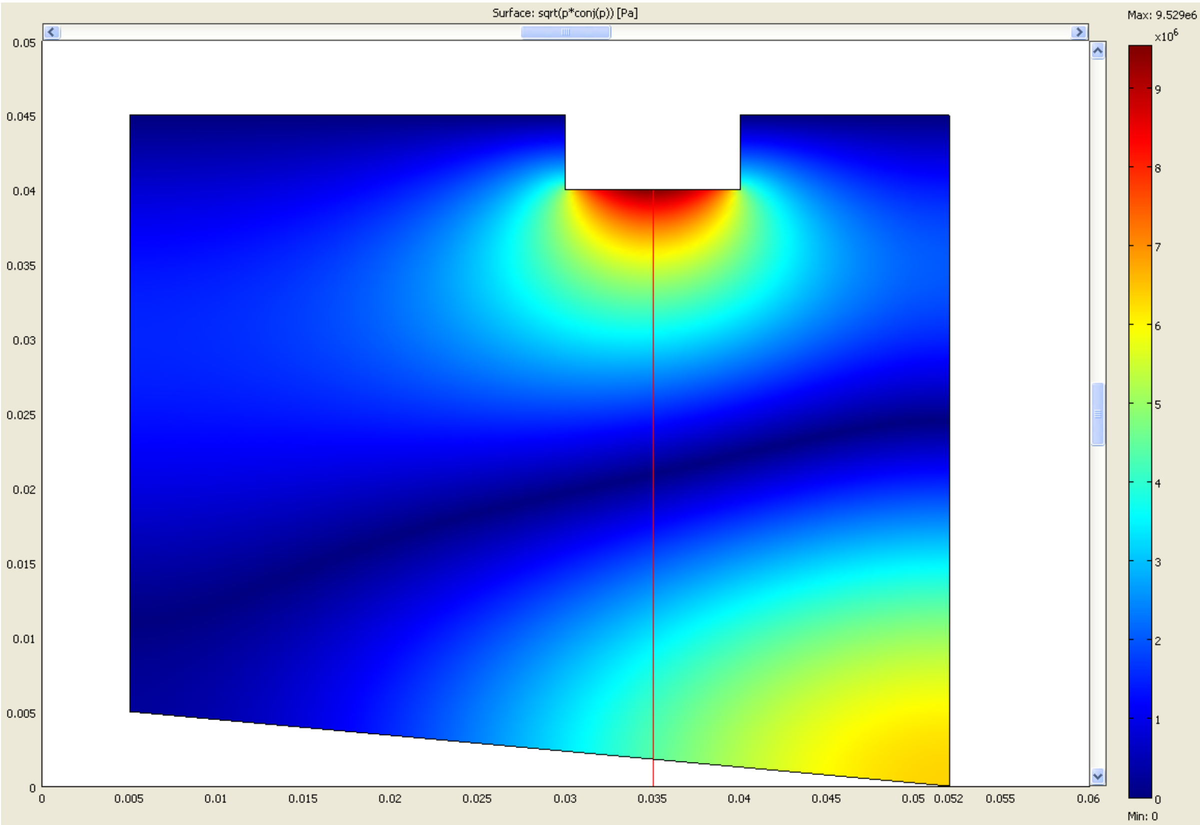
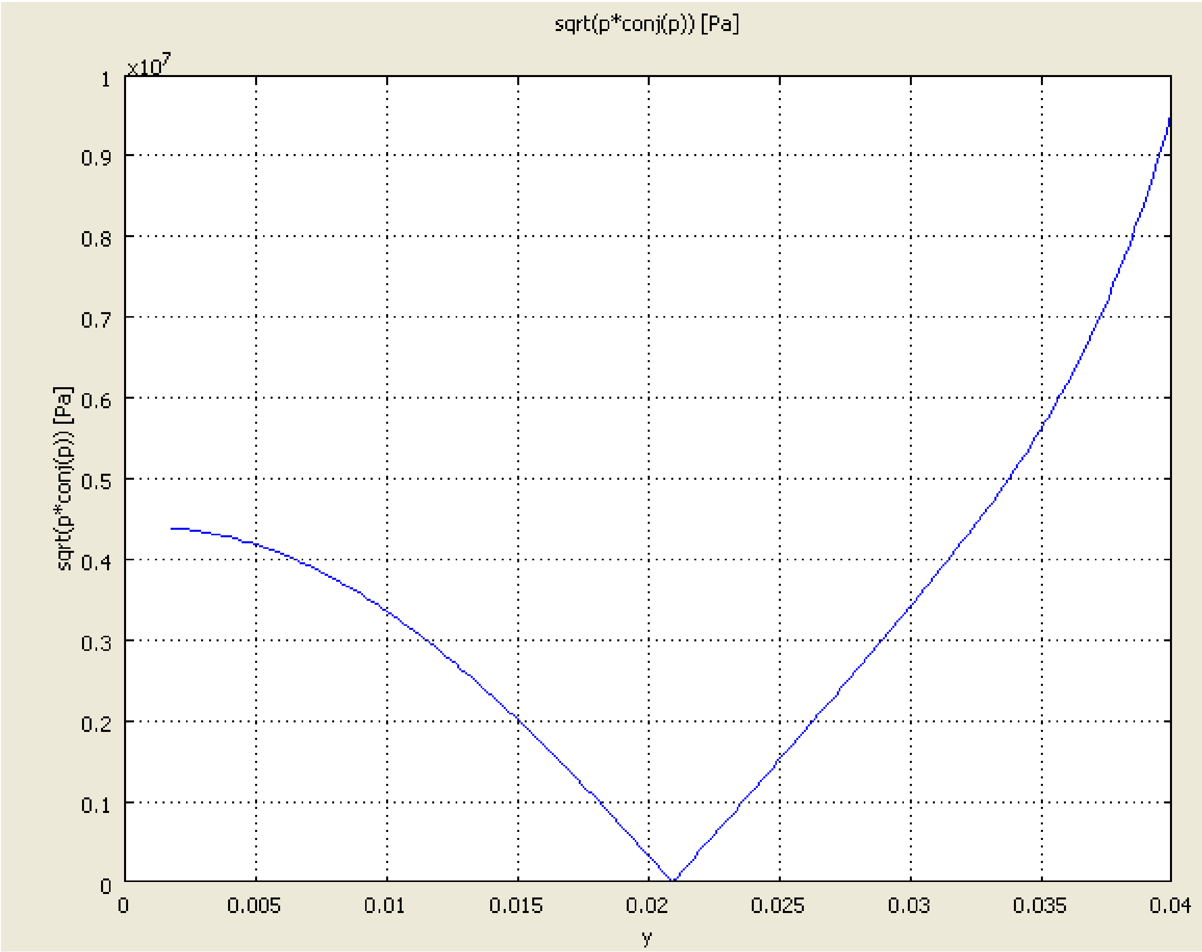
0 0.005 0.01 0.015 0.02 0.025 0.03 0.035 0.04 0.045 0.05 0.055 0.06
6 5 4 3 2 1 0
Min: 0

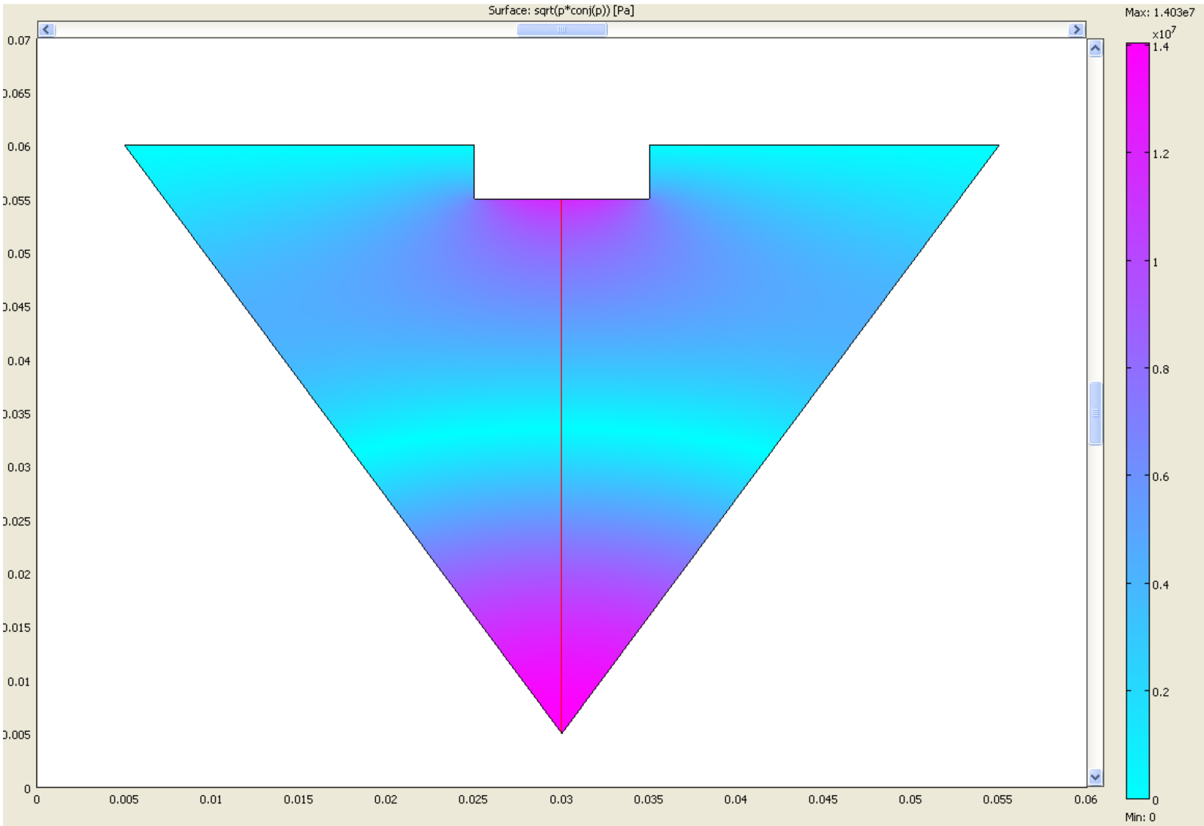

sqrt(p*conj(p)) [Pa]
$\times 10^6$
sqrt(p*conj(p)) [Pa]
7 6 5 4 3 2 1 0
0 0.01 0.02 0.03 0.04 0.05 0.06

b) Sloped bottom reactor with sound hard wall boundary; h =65 mm, w =45 mm





c) Conical reactor with sound hard wall boundary; h=55 mm, w=50 mm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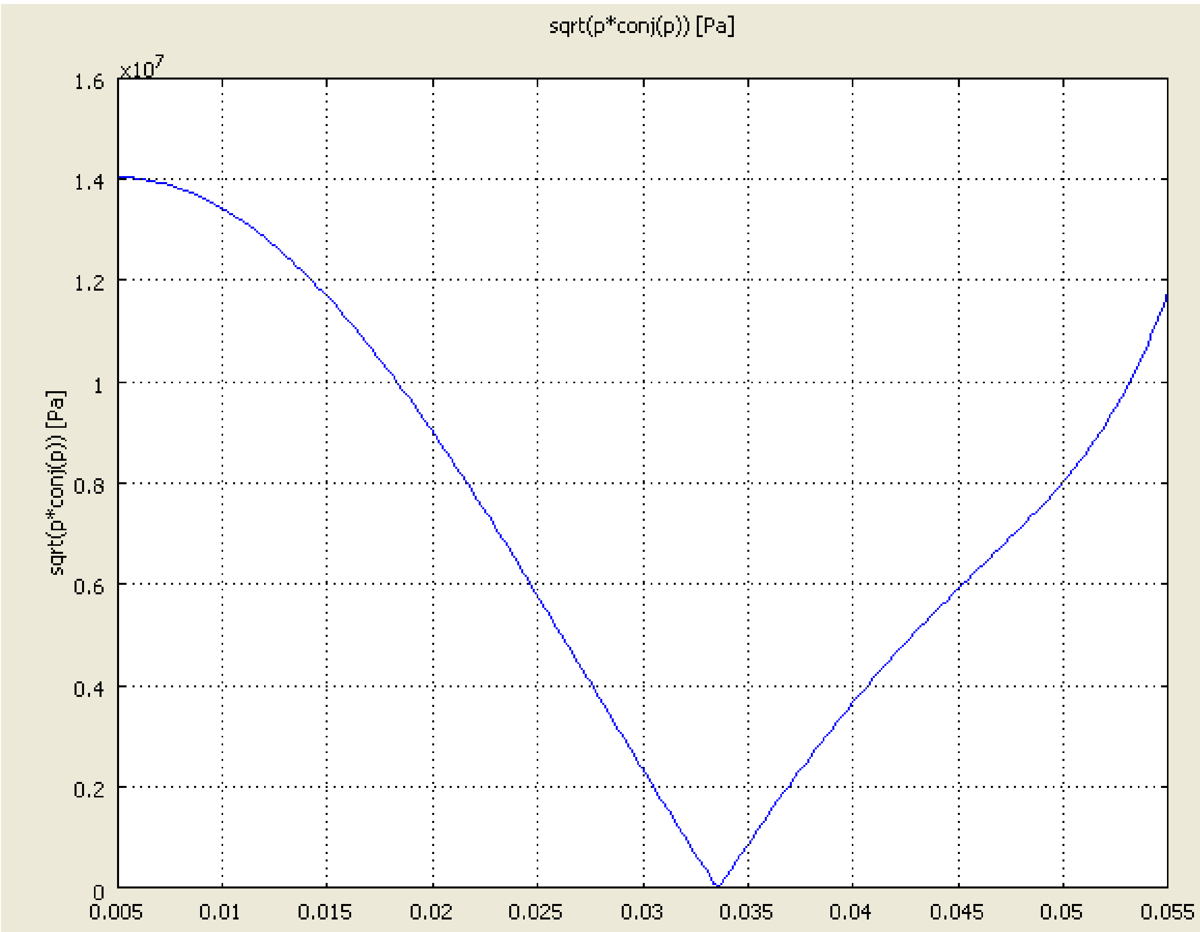
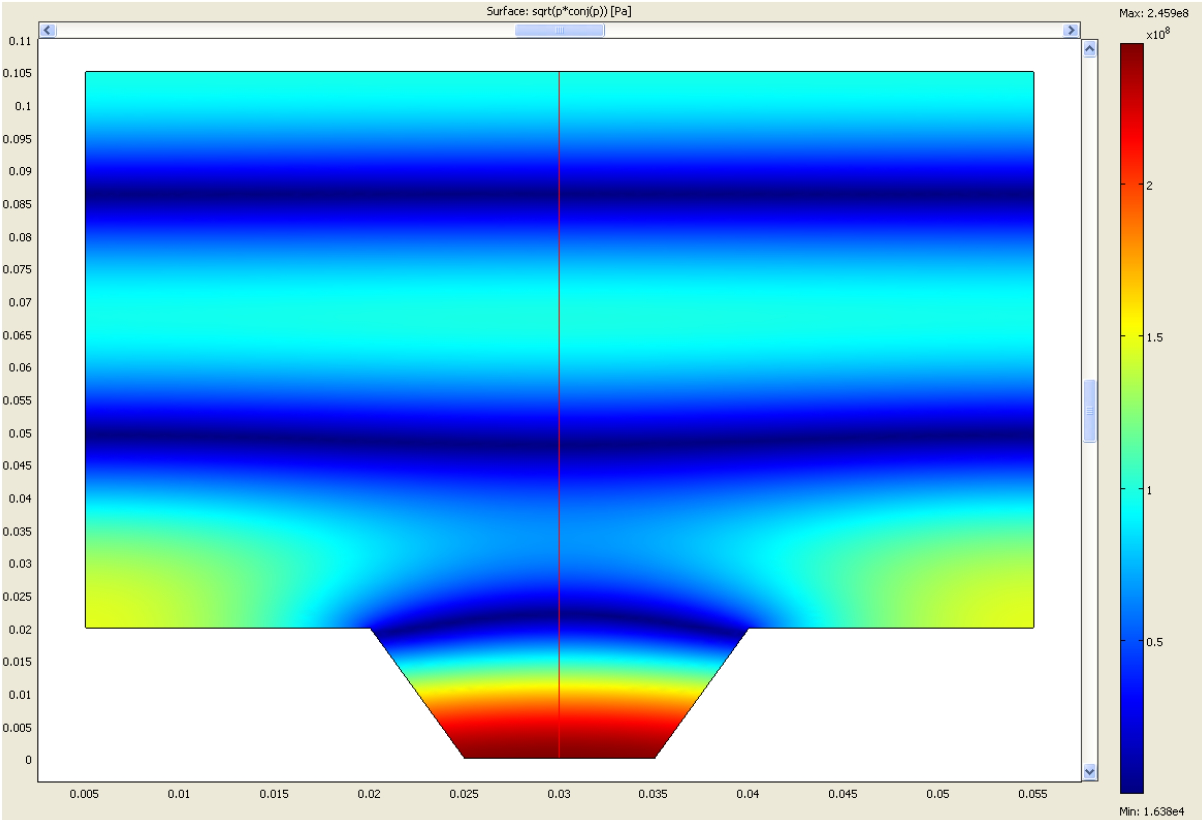
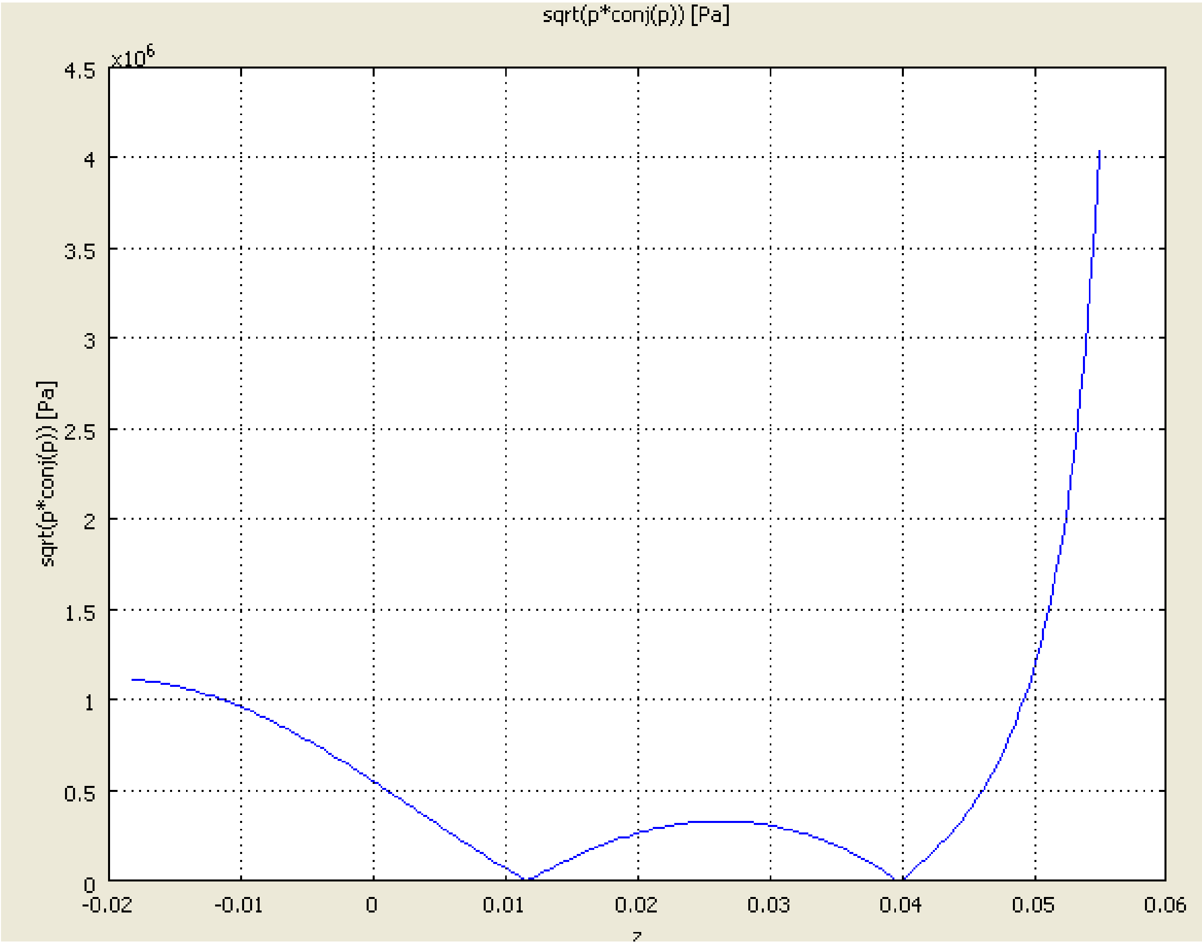
Min: 0

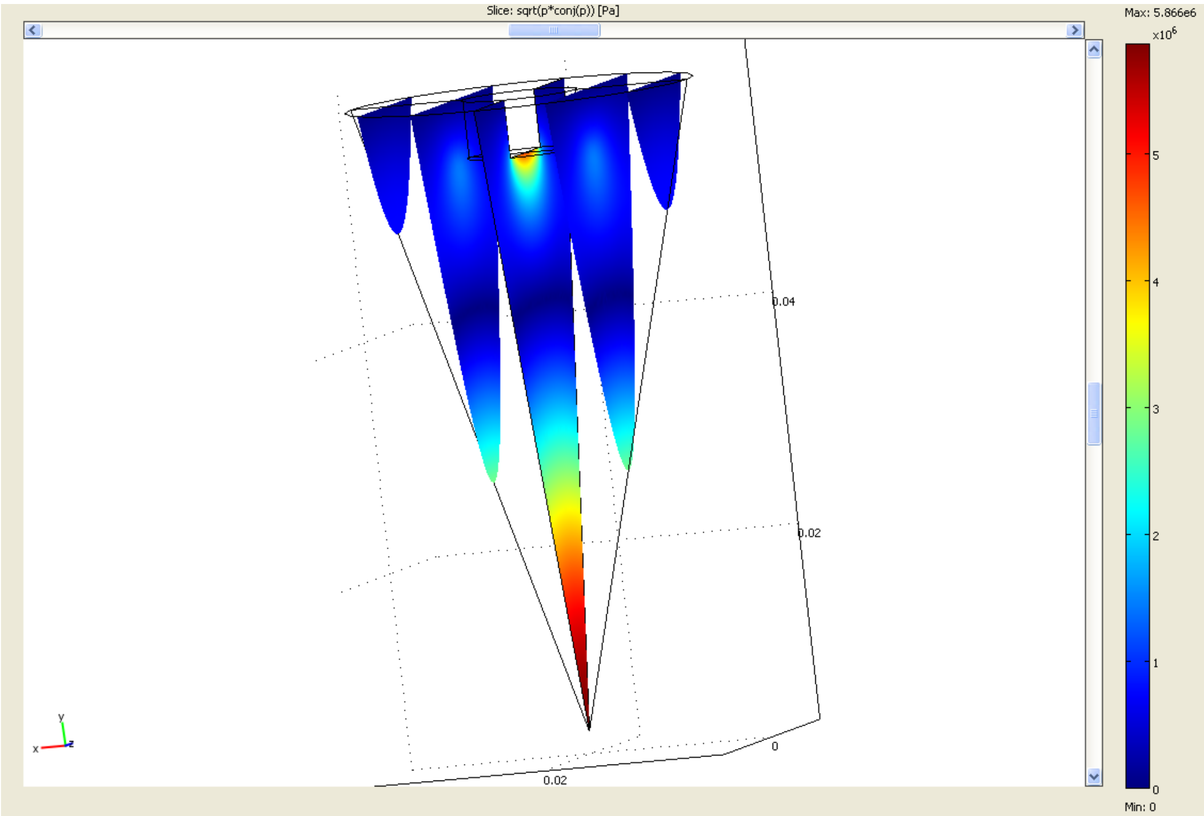

sqrt(p*conj(p)) [Pa]

d) Rectangular tank with bottom coupler with sound hard wall boundary
w= 50 mm, h = 85 mm, coupler length 20 mm



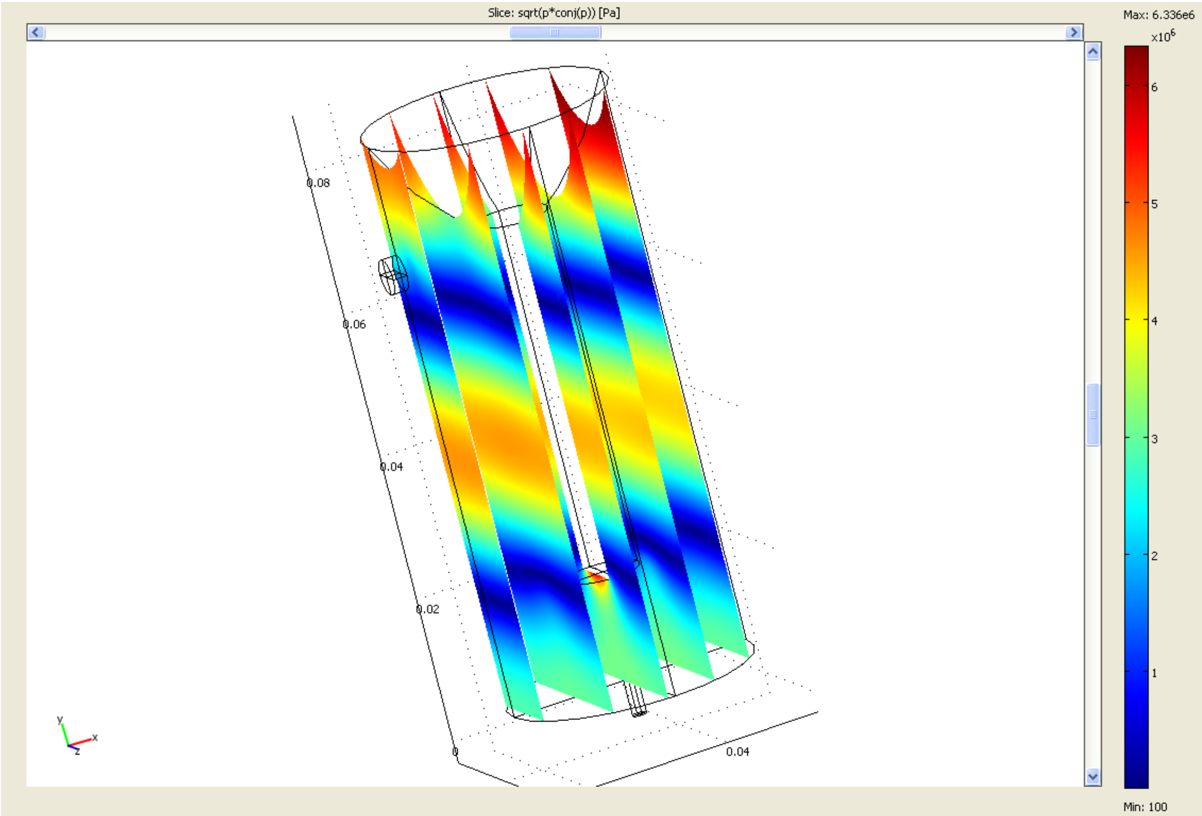


e) 3D conical reactor with sound hard wall boundary; Diameter 30 mm, h = 55 mm



f) Flow cell with sound hard boundary;

diameter is 34 mm, h = 80 mm
Inlet pressure is 100 Pa & Outlet pressure is 70 Pa



Discussion:

- For all the cases including the free boundary case, the acoustic pressure is the highest at the vicinity (a few mm only) of the transducer vibrating surface.
- Rectangular reactor with sono rod on the bottom may have some operational difficulties such as leaking from the transducer, the top of the reactor sealing always needed to prevent splashing etc. because of this, flow cell is the better choice for a more uniform acoustic pressure distribution.
- The number of transducers or transducer location or else the wall thickness of the reactor do not influence significantly the acoustic pressure distribution under ideal condition.

Conclusion:

- Regardless of the reactor geometry, the acoustic pressure is distributed with the main maximum near the transducer surface.
- The flow cell has the better acoustic pressure distribution compared to any other reactor shape.

Acknowledgement :

- CRC CARE
- Rio Tinto