Brunel University London

Department of Mechanical and Aerospace Engineering

Research Seminar

Sound waves in fluidized bed using CFD–DEM simulations

H Khawaja
Associate Professor
Department of Engineering and Safety
UiT The Arctic University of Norway

12th April 2018,
TBC
Howell Building,
Room 313

Abstract

The seminar is about modelling sound waves in a fluidized bed using CFD–DEM numerical simulations. The presented case includes the application of appropriate initial and boundary conditions to reproduce bed phenomena and the effect of varying the bed height. The results of the simulations matched those from the literature. The pressure and particle velocity profiles obtained feature oscillatory behaviour to which functions (based on a damped standing wave) were fitted, enabling an explicit dependence on time and space variables to be established. These fitted functions were substituted into the linearised governing equations for the two-phase flow. These solutions enabled a new relationship to be derived for the speed of sound and damping in the system. The conclusion drawn is that the damping in the system is governed by the effective bulk viscosity of the solid phase, which arises from the particle viscosity.

Speaker's brief CV

Hassan A Khawaja is an Associate Professor at the UiT-The Arctic University of Norway, Norway. He studied his PhD in Computational Fluid Dynamics – Discrete Element Modelling (CFD-DEM) Simulations of Two-Phase Flow in Fluidised Beds at the University of Cambridge. He has been awarded distinguished prizes such as the Multiphysics Student Prize and the W F Reddaway Prize. He was the post-doc researcher on 'Multiphysics Investigation of CFRP Structures Subjected to Shock Wave', sponsored by the Norwegian Research Council (NFR) under the PETROMAKS programme. He holds the posts of Vice President (Scandinavia) of the International Society of Multiphysics, Communication Director of the Association of Aerospace Universities (AAU). He is the Coordinator of the annual Multiphysics Conference and the Editorial Manager for the International Journal of Multiphysics.

Contact information

Stakkevollvegen 333, 9019, Tromsø, Norway, +47 91266409, hassan.a.khawaja@uit.no

RESEARCH SEMINAR

H KHAWAJA

ASSOCIATE PROFESSOR
DEPARTMENT OF ENGINEERING & SAFETY
FACULTY OF ENGINEERING & TECHNOLOGY
UiT - THE ARCTIC UNIVERSITY OF NORWAY

UNIVERSITY OF TROMSØ

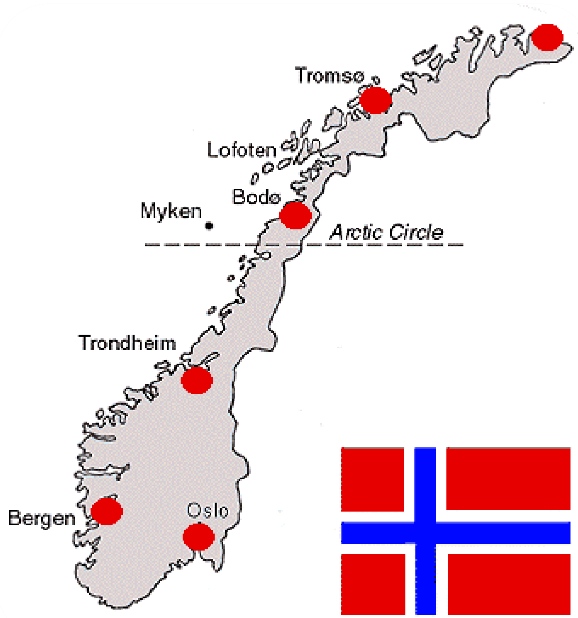
UiT / THE ARCTIC UNIVERSITY OF NORWAY

Brunel University London

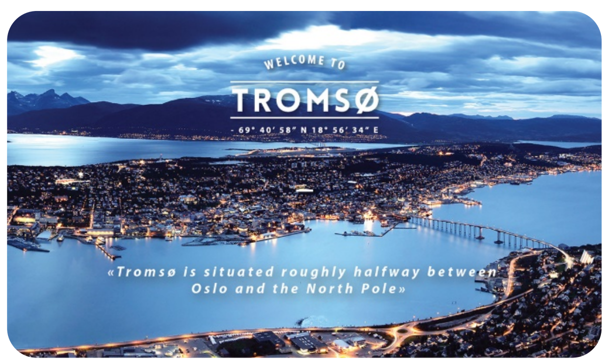
BRUNEL UNIVERSITY, LONDON, UNITED KINGDOM, 12 APRIL 18

PRESENTATION OVERVIEW

- ABOUT US
  - UiT The Arctic University of Norway, Tromsø, Norway
  - Presenter's Biography & Research Interests
- INTRODUCTION
  - Fluidized Bed
  - CFD-DEM Simulations
  - Governing Equations
  - Demonstration
- WAVES
  - Sound Waves in Fluidized Bed
  - Sound Waves in Fluidized Bed (CFD-DEM)
- SUMMARY & CONCLUSION



Established in 1968
Staff ~3500
Students ~12000
Faculties 9
Departments 40



Presenter's Biography & Research Interests

INSTITUTIONAL RESPONSIBILITY

2014 - Associate Professor & Research Group Leader,
Department of Engineering and Safety, UiT The Arctic University of Norway

ORGANIZATIONAL POSITIONS

2018 - Elected Academician, Euro-Mediterranean Academy of Arts and Sciences (EMAAS)
2018 - Director, Technical Listening Division, Global Listening Centre (GLC)
2017 - Chief Technical Officer and Founding Member, Windtech AS, Norway
2016 - Communication Director, Association of Aerospace Universities (AAU)
2014 - Vice President, The International Society of Multiphysics
2010 - Conference Coordinator, The International Conference of Multiphysics

EDITORIAL POSITIONS & AUTHORED BOOKS

2018 - Editor, Natural and Engineering Sciences, Vestnik of MSTU (ISSN 1560-9278)
2018 - M Motamedi, H Khawaja, Finite Element Analysis (ISBN 978-1-138-32073-4)
2015 - H Khawaja, J Kapaya, M Motamedi, Shock Tube (ISBN 978-3-847-33876-5)
2014 - Editorial Manager, The International Journal of Multiphysics (ISSN 1750-9548)
2010 - Conference Coordinator, MULTIPHYSICS Abstract Booklet (ISSN 2409-7527)

RESEARCH INTERESTS

Process & Gas Engineering, Shock-tube & High-Pressure Systems, Computational Fluid Dynamics & Discrete Element Modelling, Structures, Materials, & Multiphysics Simulations, Thermography & Infrared Imaging

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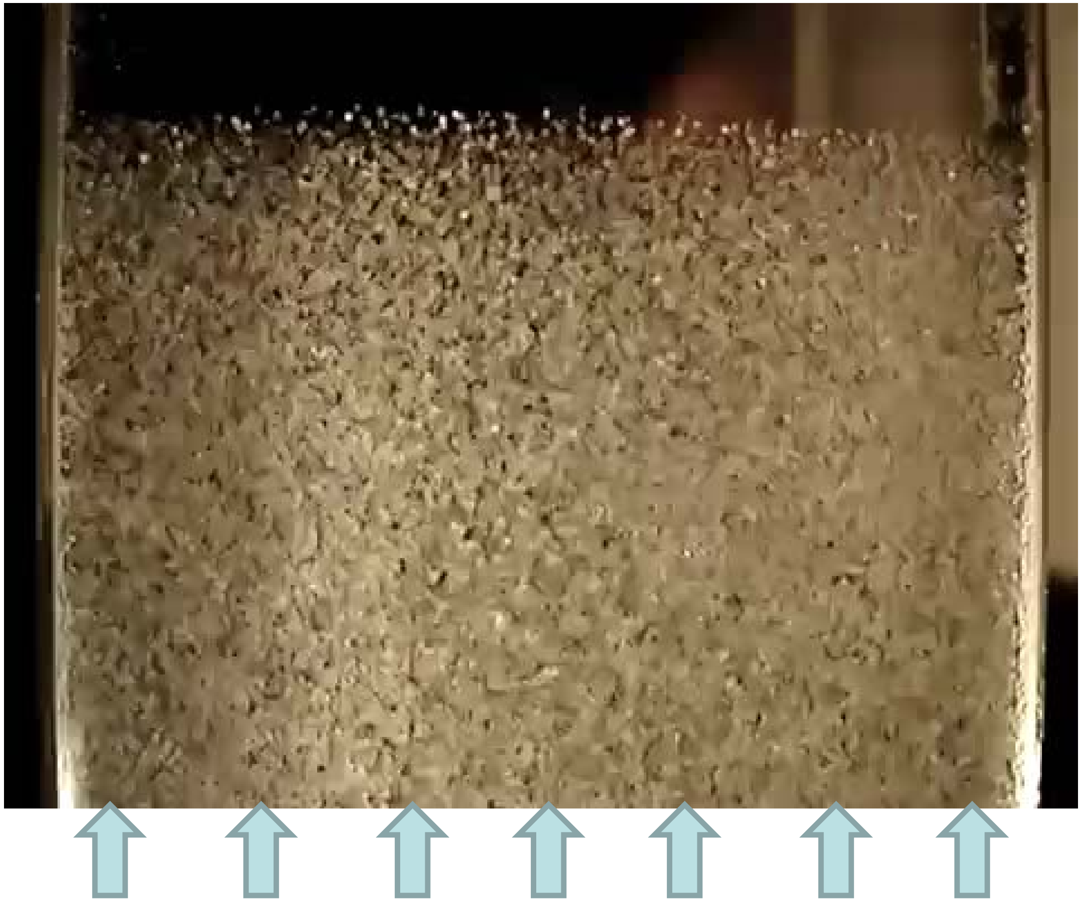
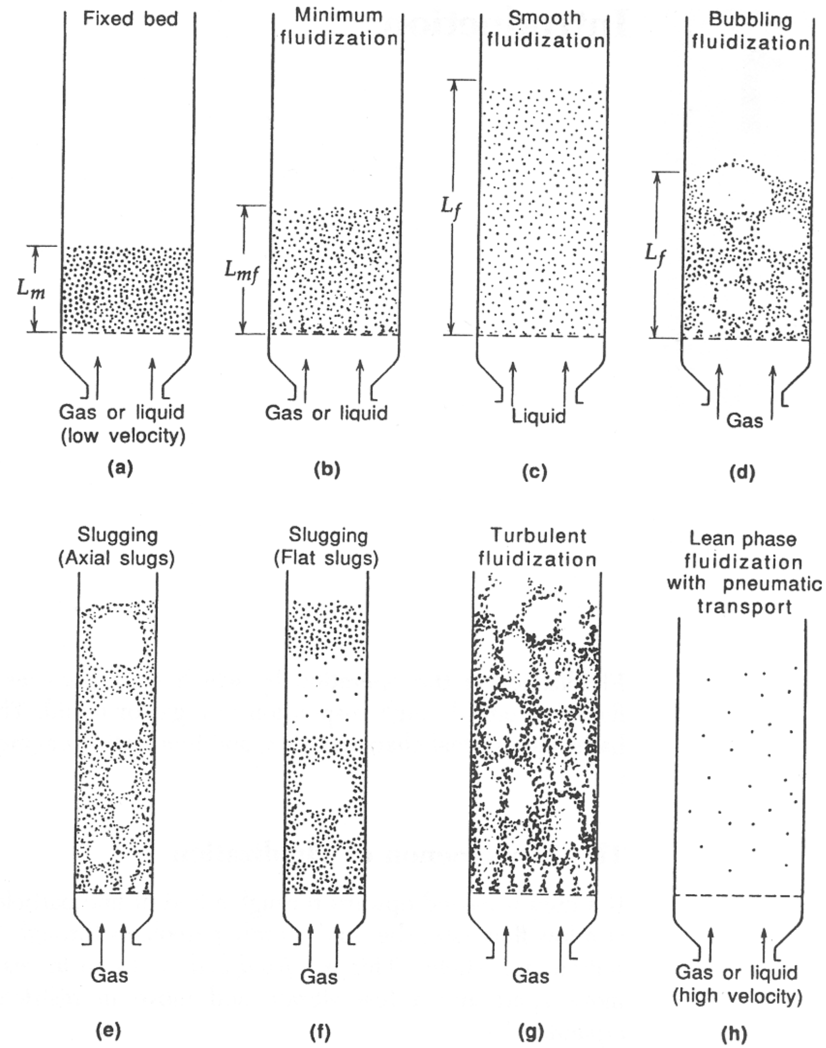


Fluid Inlet

FLUIDIZED BED



*Uniform thermal distribution!
*Control chemical process!

CFD-DEM is the Eulerian-Lagrangian method of solution for two phase systems.

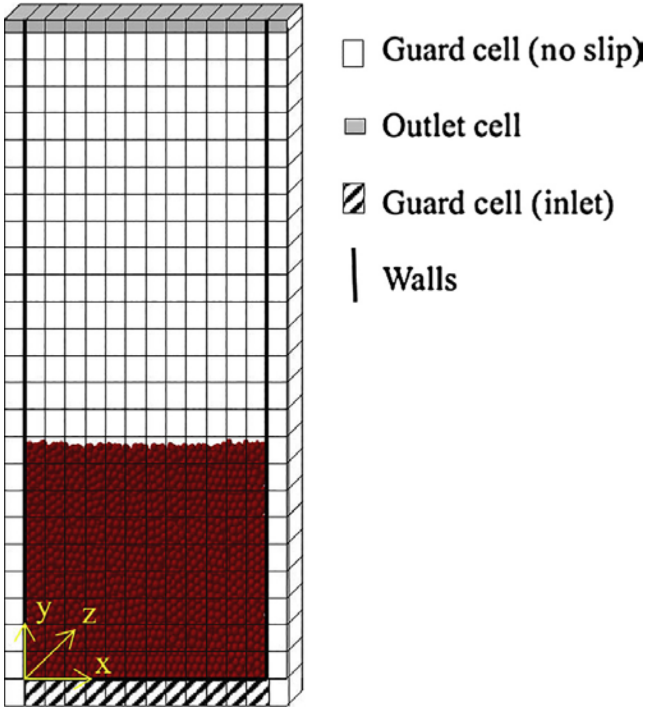
Computational Fluid Dynamics (CFD) Model comprised of:

- *Volume Averaged Navier-Stokes Equations*
- *Volume Averaged Continuity Equation*
- *Volume Averaged Energy Equation*

Discrete Element Model (DEM) comprised of:

- *Newton's Laws of mechanics*
- *Contact mechanics*

CFD and DEM are coupled by Drag Law



CFD Model is solved in staggered grid using Eulerian method:

•*Volume Averaged Navier-Stokes Equation*

$$\frac{\partial(\rho\epsilon u_i)}{\partial t}+\frac{\partial(\rho\epsilon u_i u_k)}{\partial x_k}=\frac{\partial}{\partial x_k}\epsilon p+\frac{\partial}{\partial x_k}\epsilon\tau_{\mathrm{f}}-\vec{F}_i+\rho\epsilon g_i$$

•*Volume Averaged Continuity Equation*

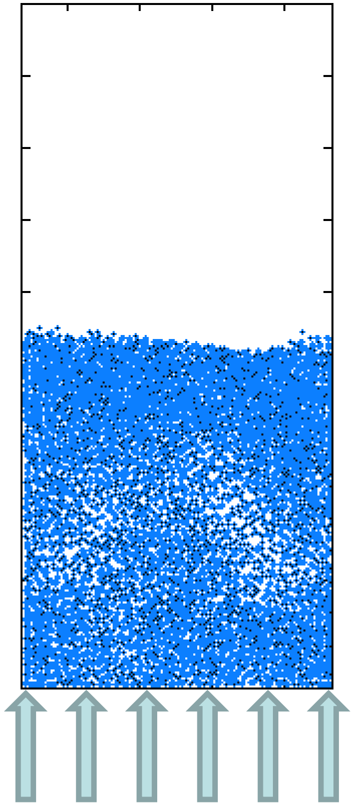
$$\frac{\partial(\rho\epsilon)}{\partial t}+\frac{\partial(\rho\epsilon u_k)}{\partial x_k}=0$$

DEM is solved for each particles using Lagrangian method:

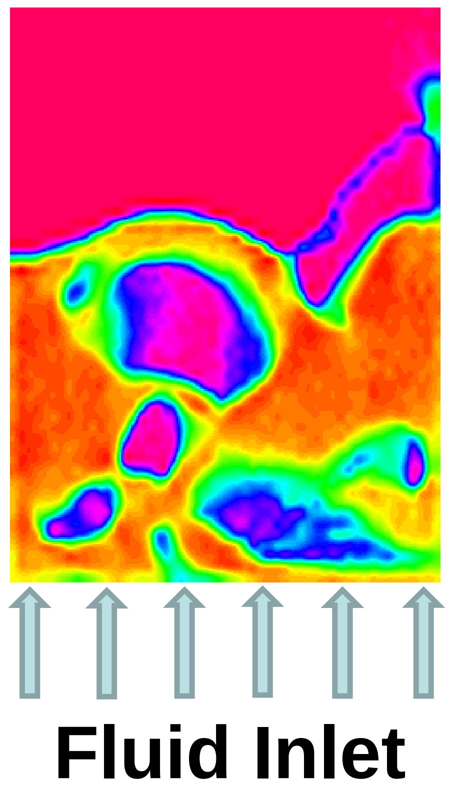
• *Newton's Second Law of Mechanics*

$$m_{\mathrm{p}}\vec{a}_{\mathrm{p}}=\vec{f}_i+\sum_{\mathrm{contacts}}\vec{f}_{\mathrm{contacts}}+\ m_{\mathrm{p}}\vec{g}$$

CFD and DEM are coupled using a Drag Equation.

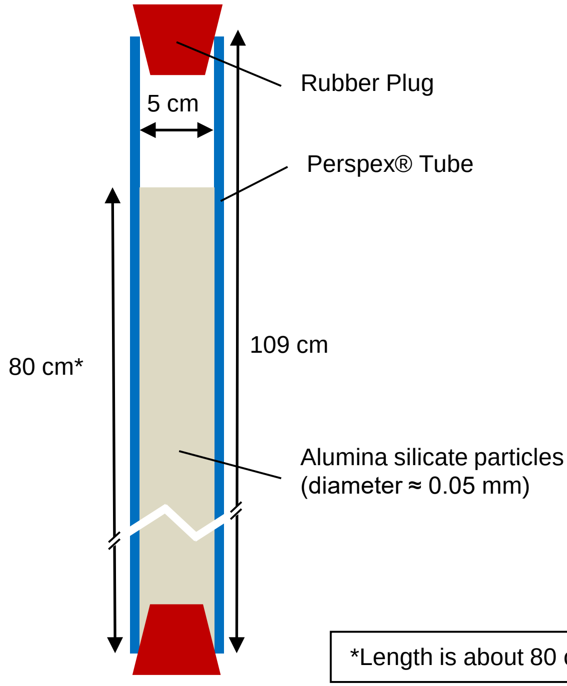


Fluid Inlet

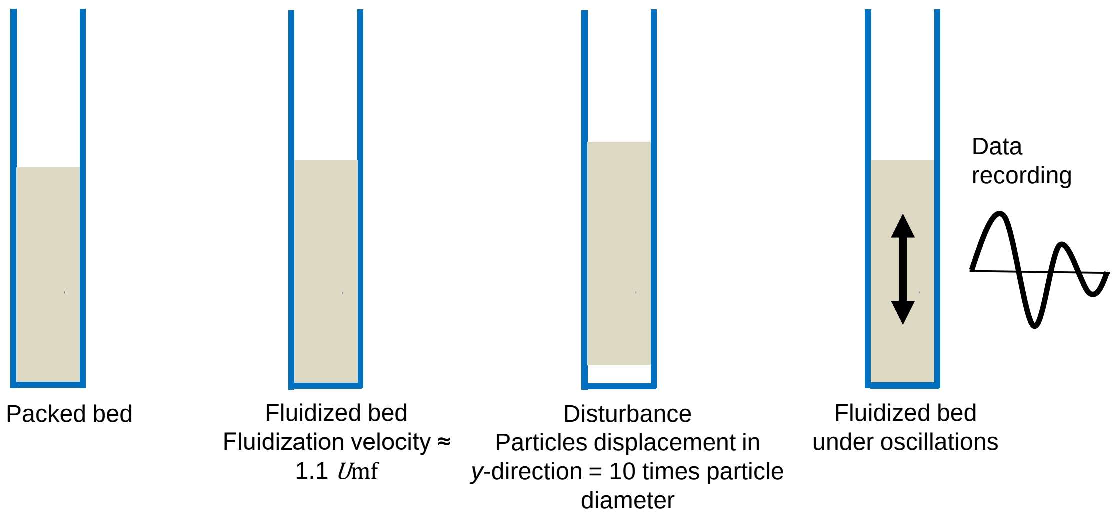

Fluid Inlet

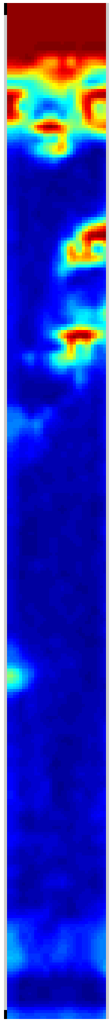
SOUND WAVES IN FLUIDIZED BED

Figure is not to scale

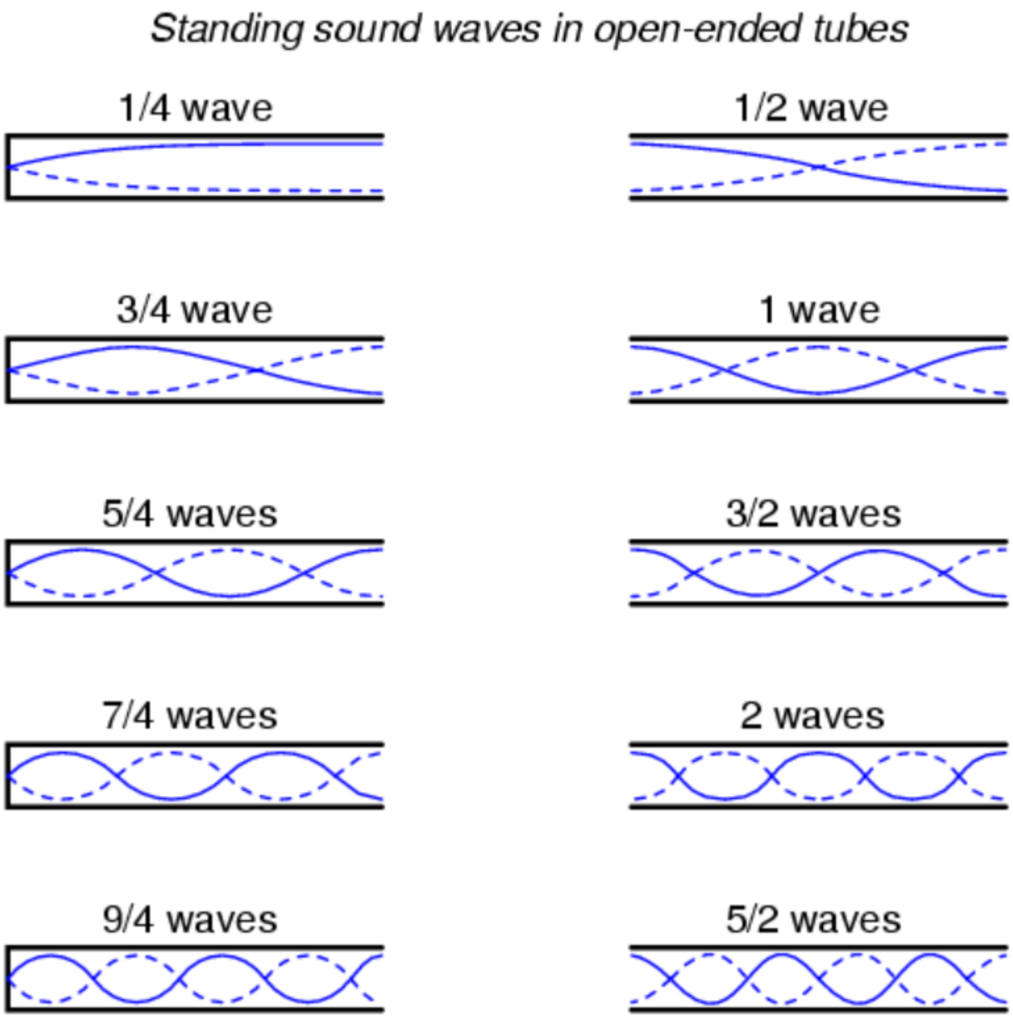


*Length is about 80 cm after fluidization


Packed bed
Fluidized bed
Fluidization velocity ≈ 1.1 Umf
Disturbance
Particles displacement in y-direction = 10 times particle diameter
Fluidized bed under oscillations
Data recording

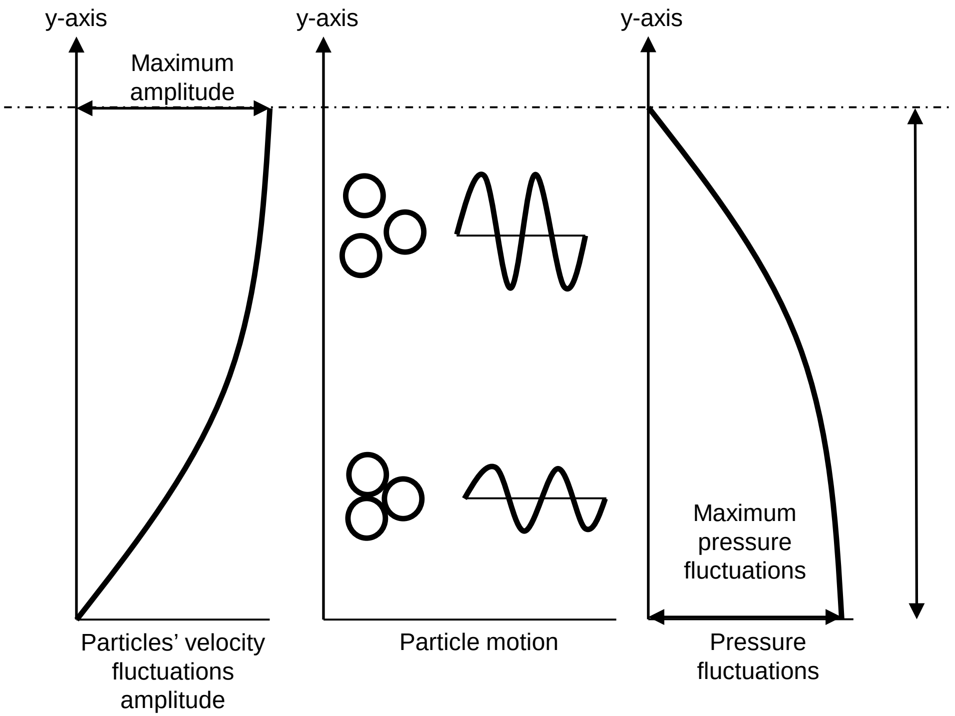


SOUND WAVES IN FLUIDIZED BED (CFD-DEM)



Sound Waves in Fluidized Bed (CFD-DEM)

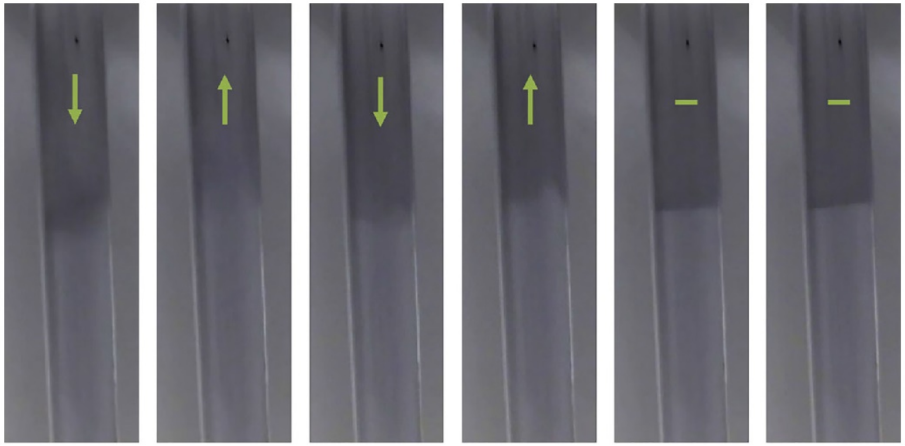
$$p'(y,t) = P_o e^{-\frac{t}{\tau}} \cos(cy) \cos(\omega t + \phi_p)$$



$$u'_p(y,t) = U_{p_o} e^{-\frac{t}{\tau}} \sin(cy) \cos(\omega t + \phi_u)$$

Substituted into Governing Equations

SOUND WAVES IN FLUIDIZED BED (CFD-DEM)



$t = 0.0$ s $t = 0.033$ s $t = 0.266$ s $t = 0.300$ s $t = 0.566$ s $t = 0.600$ s

$$u_s = f\lambda = 4\,X\,\frac{Tube\ Height}{Time\ Period}$$

$$u_s = \sqrt{\frac{\rho_g R T_g}{\epsilon\big(\rho_s(1-\epsilon) + \rho_g \epsilon\big)}}$$

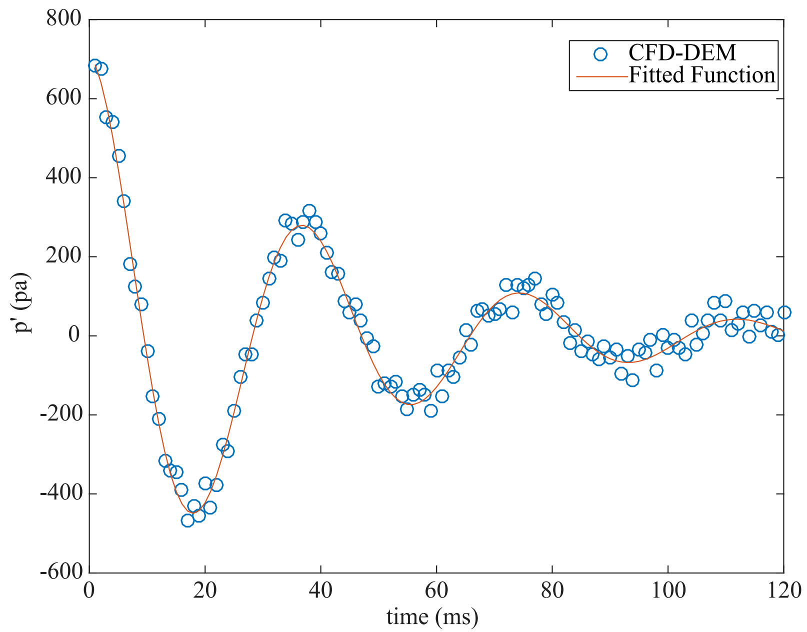
$$\tau = \frac{2g}{\omega^2 U_{mf}}$$

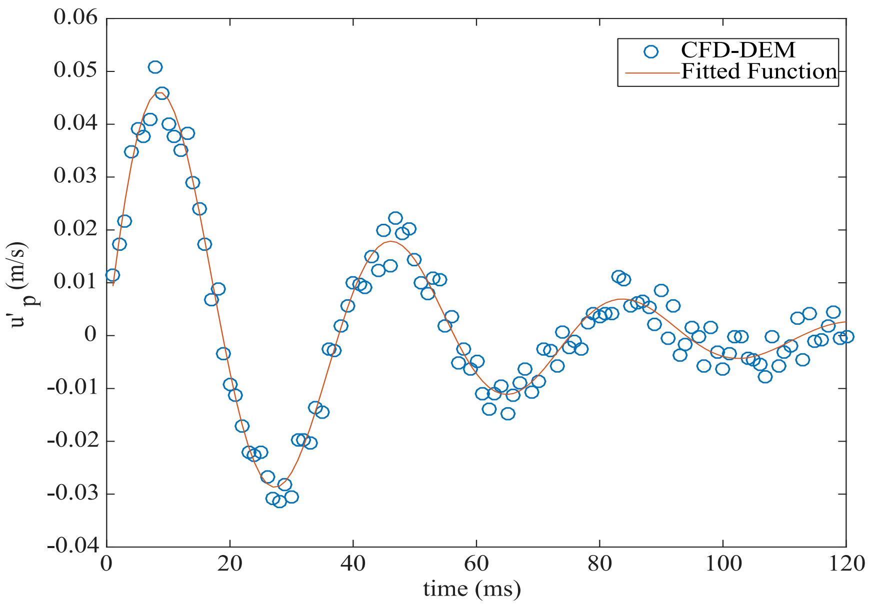
$$u_s \cong 11.2 \text{ m/s}$$

Roy et al. (1990)*

SOUND WAVES IN FLUIDIZED BED (CFD-DEM)

$$u_s = \frac{P_o}{(1-\epsilon)\rho_p U_{po}}$$





$$\tau = \frac{\rho_p}{\mu_p c^2}$$

Khawaja et al. (2018)*

SUMMARY, CONCLUSION & FUTURE WORK

- **Summary:**
  - ☞ CFD-DEM is the Eulerian-Lagrangian method of solution for two phase systems (such as fluidized bed).
  - ☞ CFD-DEM simulations can modelled sound waves provided correct boundary conditions are applies.

- **Conclusion:**
  - ☞ CFD-DEM models sound waves within reasonable accuracy.
  - ☞ CFD-DEM results allowed to derive analytical correlation for damping in sound waves in fluidized beds.

- **Future Work:**
  - ☞ CFD-DEM model can be employed to study particle viscosity.

References:

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Thank You

Contact

Hassan Khawaja

hassan.a.khawaja@uit.no