The Application of Computational Fluid Dynamics (CFD) for modelling flow and Visualization in a cement mill and Experimental Residence Time Distribution (RTD) Validation using Radiotracer Technology

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Background 1

- The grinding process is the most energy-consuming operation in cement production
- 40 % of the total energy used for the production of a ton of cement goes into clinker finish grinding
- Adopting effective strategies to optimize operating parameters of the mill such as retention time is of critical importance if a more efficient cement grinding operation is to be achieved.
- Computational fluid dynamics (CFD) is known for its capabilities in simulating and visualizing the motion of material inside process equipment
- It deals with the numerical solutions of the governing equations of fluid flows and enables a fairly accurate calculation of the flow field in process equipment.

Background 2

- The Ghana Cement (GHACEM) Plant in Tema is one of Ghana's largest manufacturing establishments for production of cement with a total capacity of 2.4 million tons per annum.
- GHACEM produces cement using three basic raw materials - 90% clinker, 5% limestone and 5% of gypsum
- Clinker fed to the mill is crushed and milled by attrition between steel balls which are accelerated via rotation into collision with the clinker
- GHACEM employs a closed circuit system

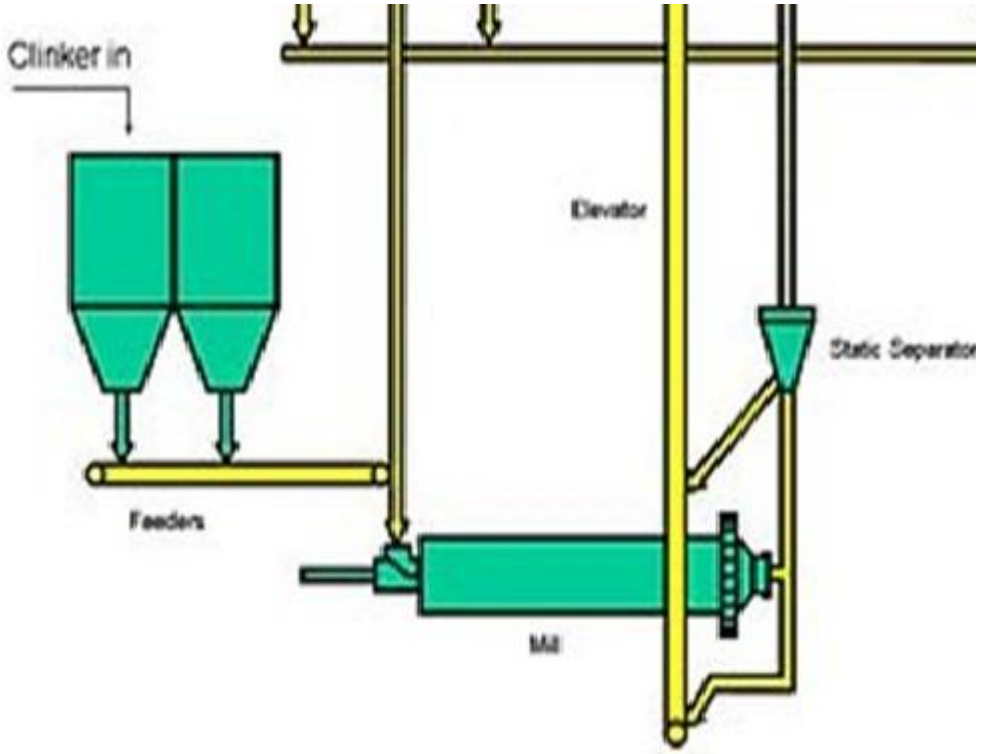


Fig 1. Diagram of closed-circuit Milling system

Objective

- To simulate the flow in the mill using computational fluid dynamics(CFD) for flow visualisation
- Attempt to validate the CFD model of the mill flow using radiotracer Residence Time Distribution(RTD) data.

Experimental Set-Up 1

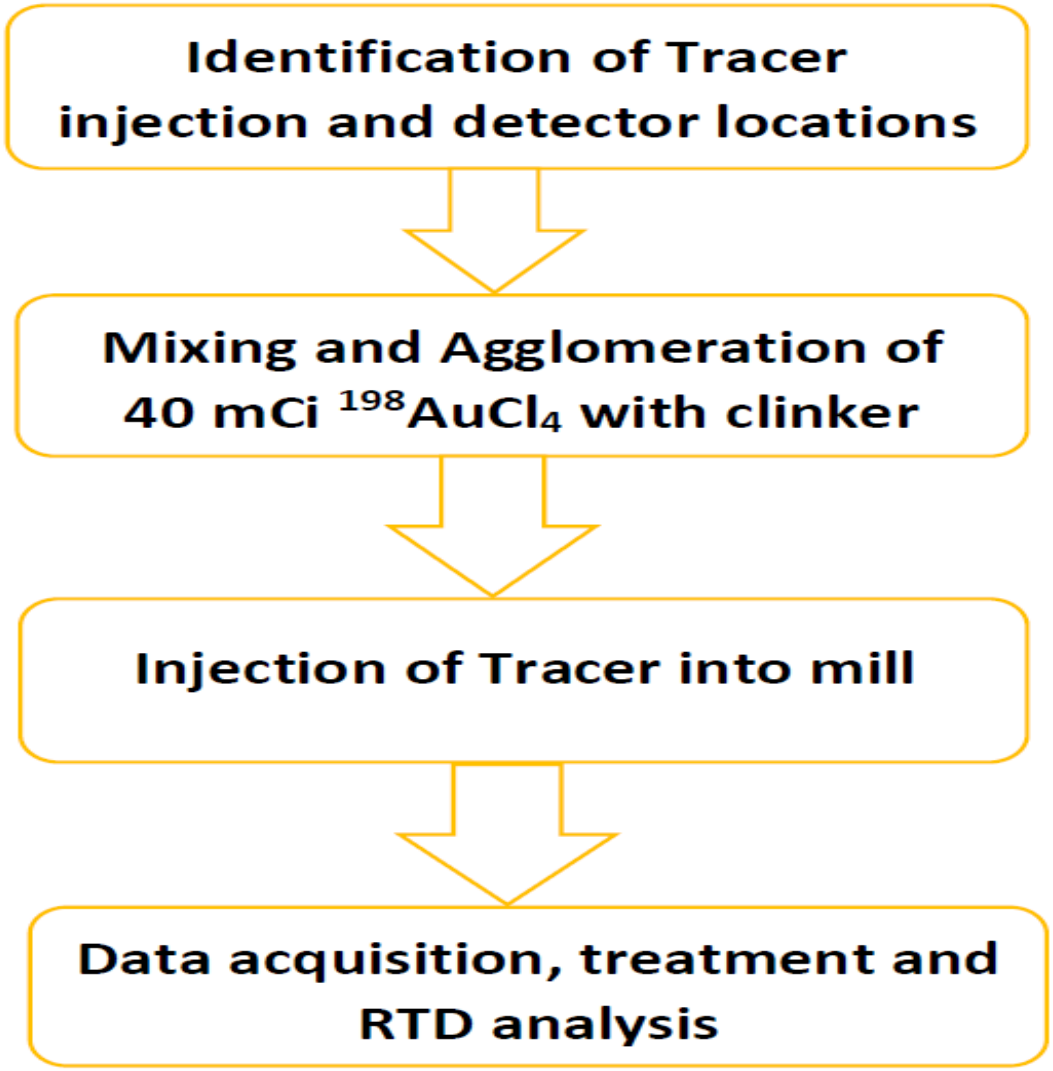


Fig 2. Flow diagram of tracer RTD investigation

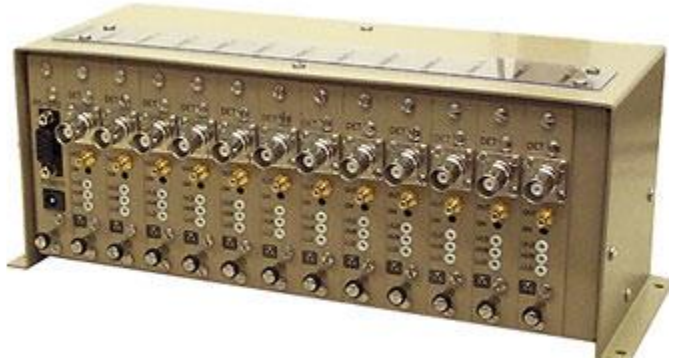
Fig 3. GHACEM Mill

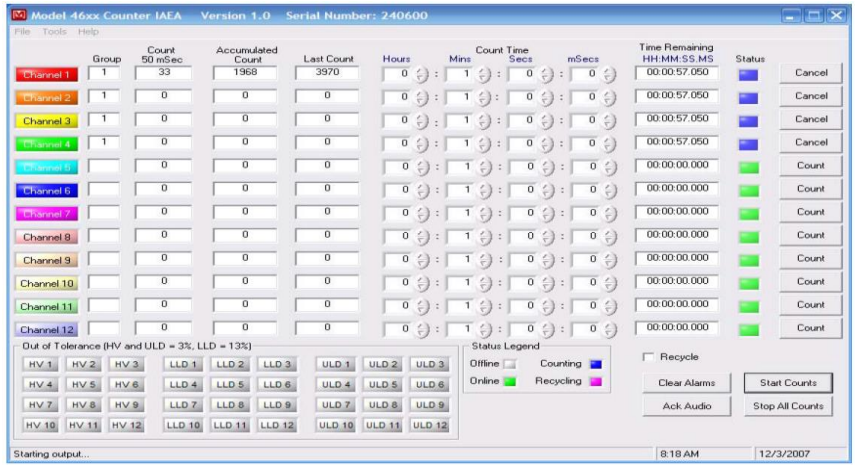
Table 1. Mill Parameters

Parameter	Value
Diameter	3.6 m
Length	11.4 m
Grinding Capacity	65 ton/h
Mill Speed	16 rpm

Experimental Set-Up 2

Fig 4a: Detector at mill inlet b. Mill c. Mill outlet detector





4d. Ludlum multichannel analyser e. Ludlum software interface

Numerical Simulation Set-Up 2

- A CFD-DPM (Computational Fluid Dynamics – Discrete Phase Model) coupling model was used.

- The clinker-steel and air mixture was modelled as a two-phase eulerian model.

- Due to the rotation of the mill (high rotational Reynolds number), the k-ε RNG turbulent model was used

- The equations of conservation of mass, momentum and energy were solved in a rotating frame of reference

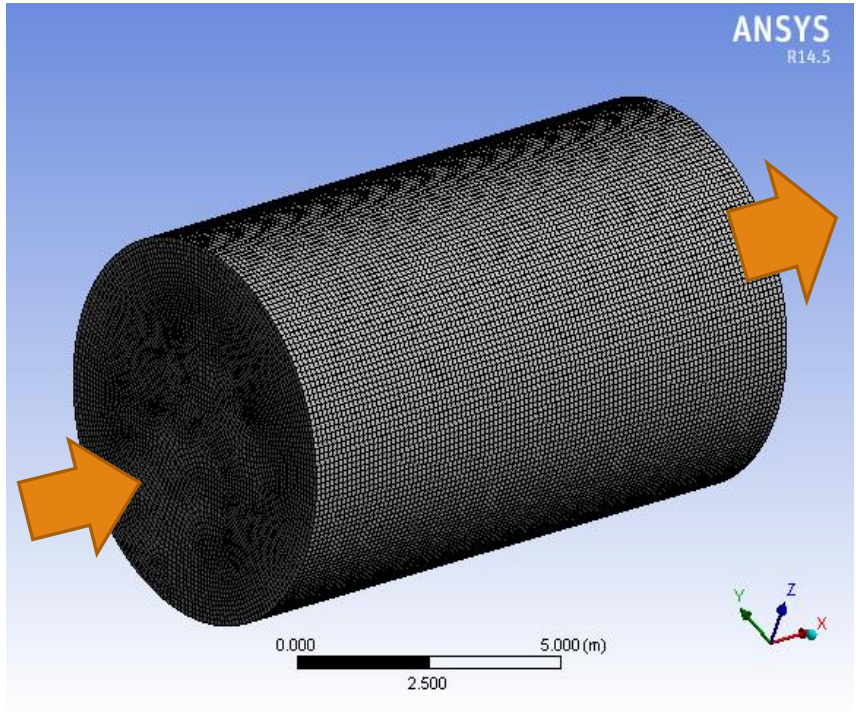


Fig 5. Simplified meshed mill

Numerical Simulation Set-Up 1

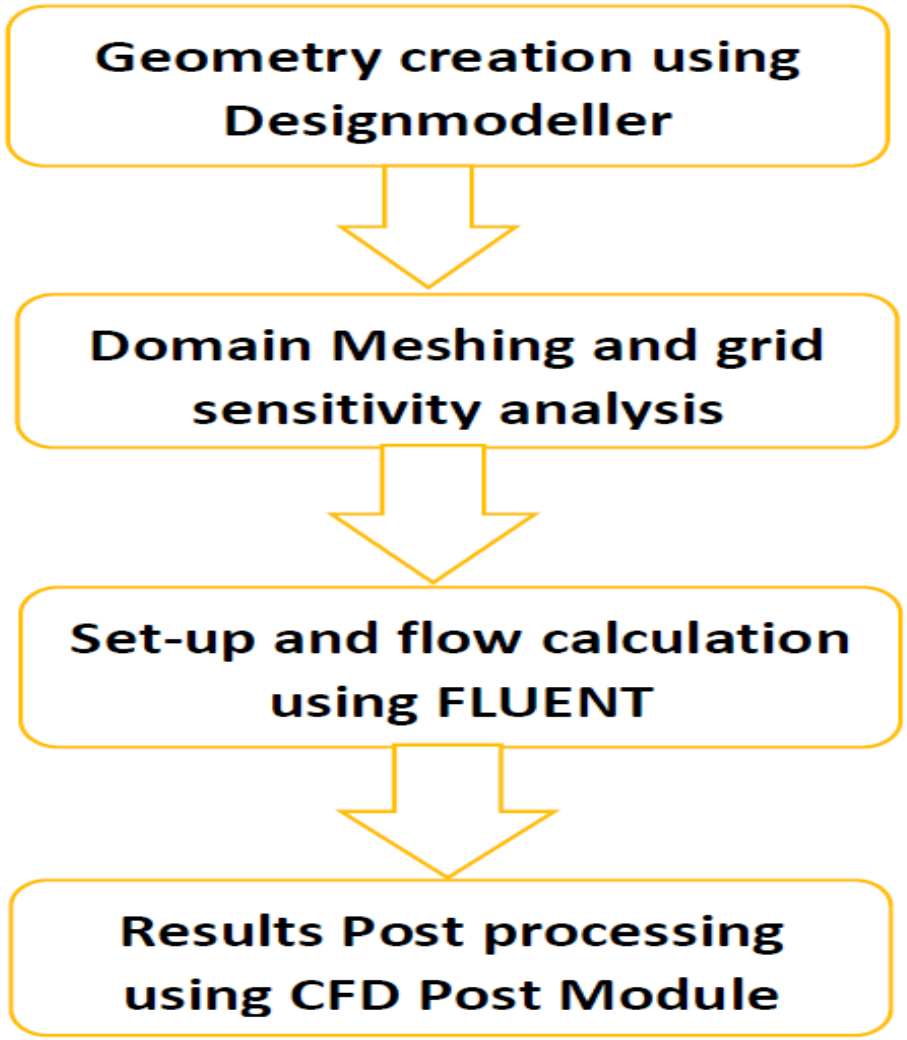


Fig 6. Flow chart of numerical simulation set-up

Table 2. Simulation Solution Conditions and Methods

Solution Conditions and Methods	Description
Pressure-Velocity Coupling	SIMPLE
Spatial Discretization of Gradient	Green Gauss cell based
Pressure	Standard
Momentum,	First order upwind, QUICK
Turbulent Kinetic Energy, Turbulence Model	First order upwind QUICK k-ε RNG
Turbulent Dissipation Rate	First order upwind, QUICK
Solution Initialization	Standard, from inlet
Average simulation time	60 hrs
Number of Iterations	10000
DPM	
Number of particles injected	10000
Number tracked	7560

Results and Discussion 1

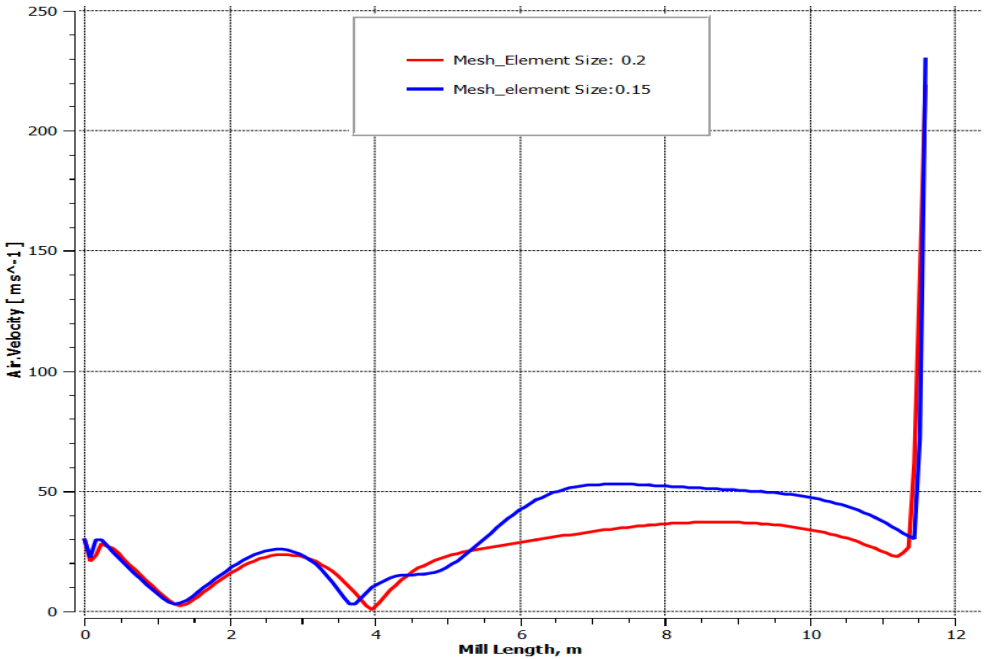
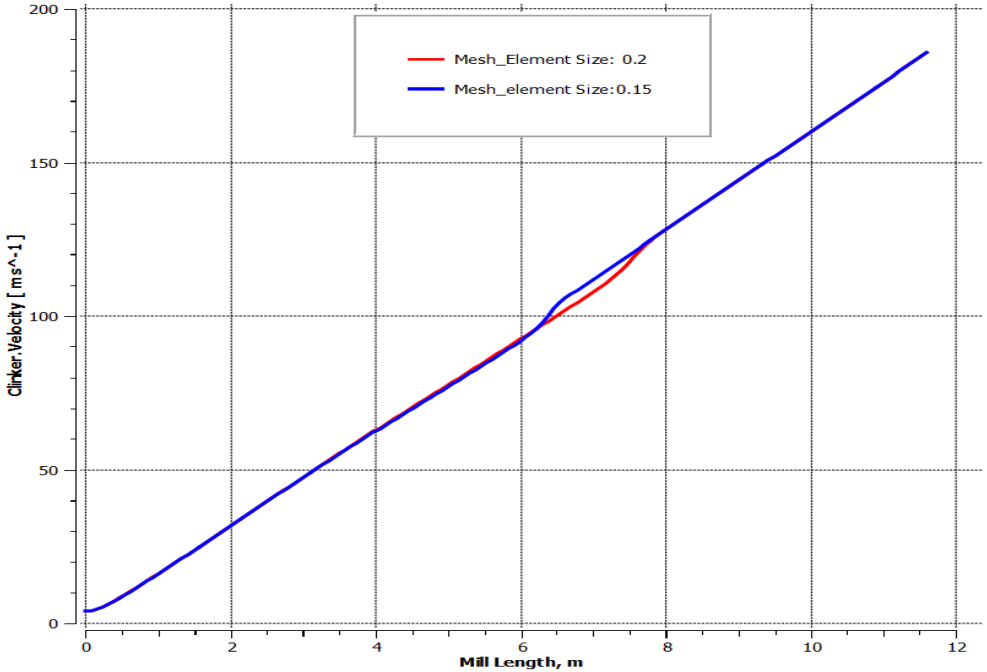


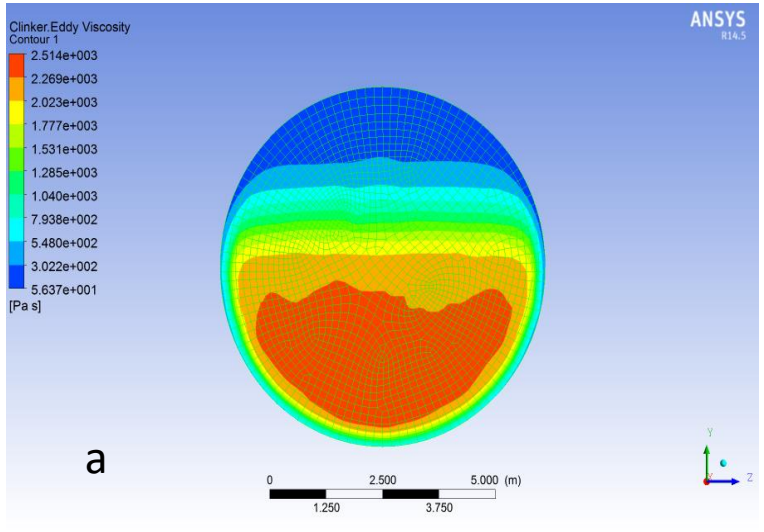
Fig 7 a. Air velocity

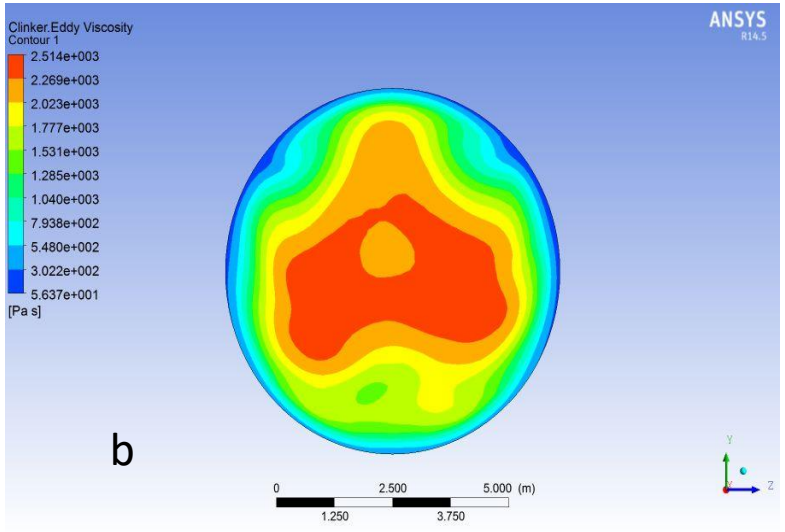


b. Clinker velocity

- ✓The coincidence of the velocity profiles of cell sizes 0.2 (114202 elements) and 0.15 (404100 elements) along selected sections
- ✓Variation of air streamwise velocity
- ✓Clinker velocity increases sharply from the inlet and reaches its maximum near the outlet

Results and Discussion 2





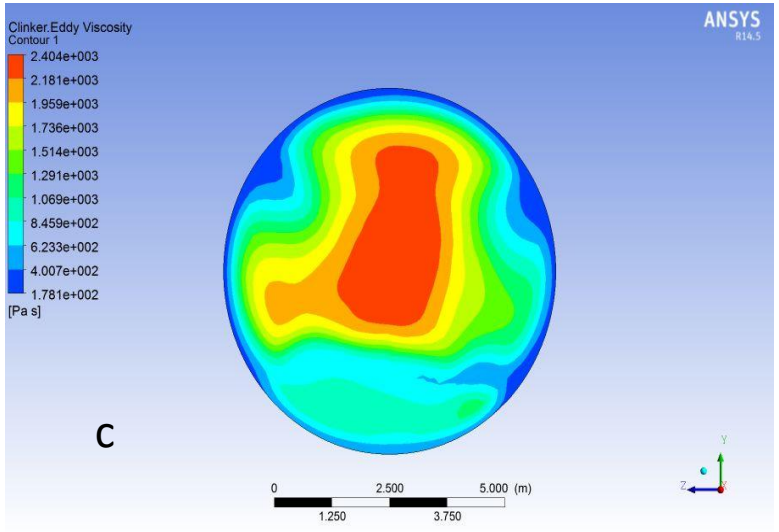
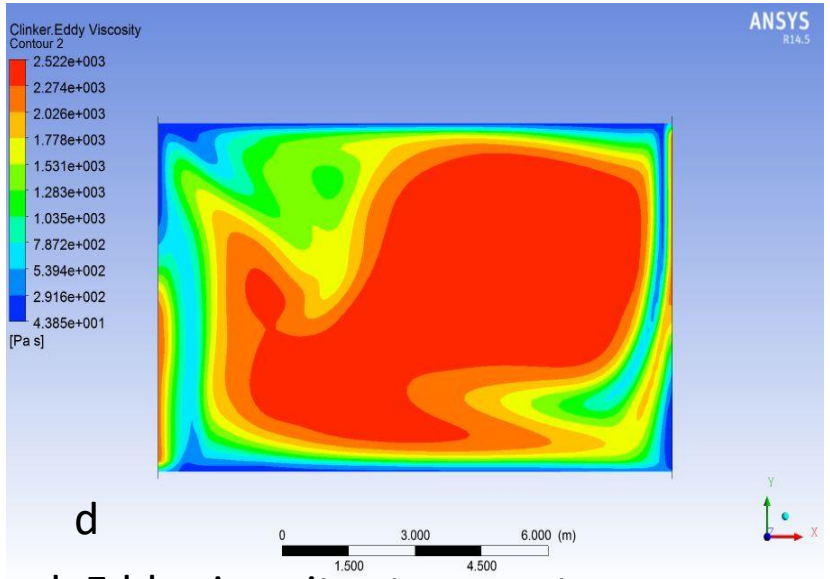


Fig 8. Eddy viscosity : a. near mill inlet b. At mid-section c. Near mill discharge



d. Eddy viscosity at symmetry

- ✓Contours of turbulent eddy viscosity represent the extent of mixing
- ✓Mixing was not uniform throughout the mill as indicated by varying magnitudes of eddy viscosity in the mill.
- ✓Mixing better at mid-section

Results and Discussions 6

- ✓ Detectors D6 close to D5. It 'saw' the tracer just as it approached the injection point.
- ✓ This resulted in two parasitic peaks
- ✓ Experimental MRT of the mill was found to be 16 min

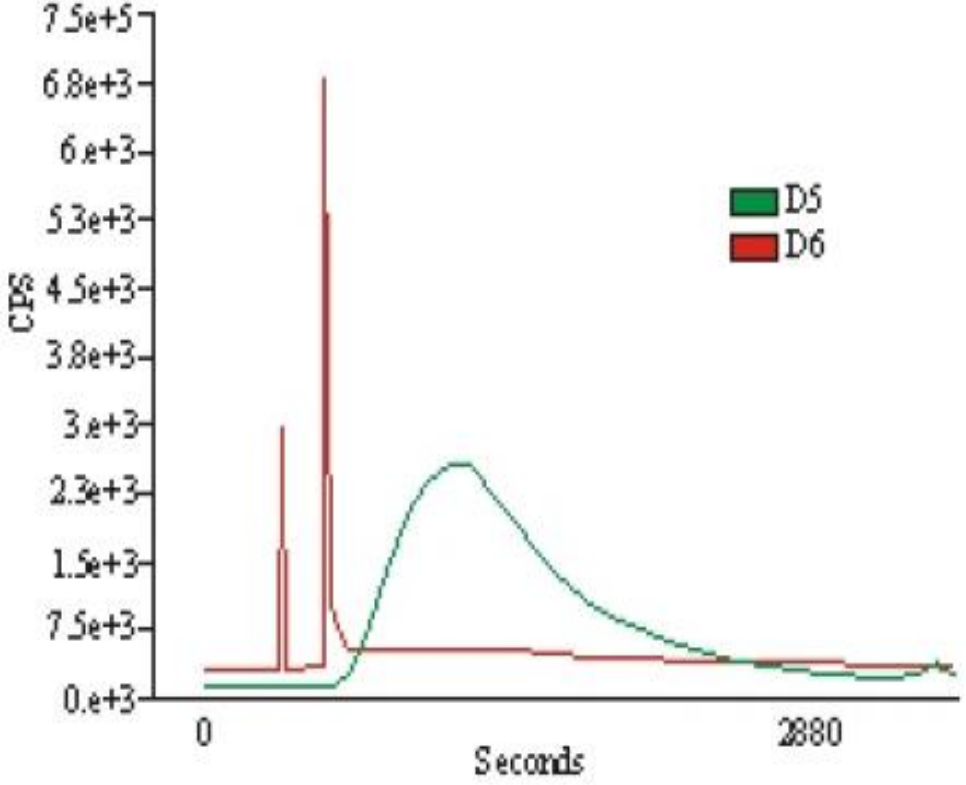


Fig 9. Experimental response curves of detectors around the mill

Results and Discussions 6

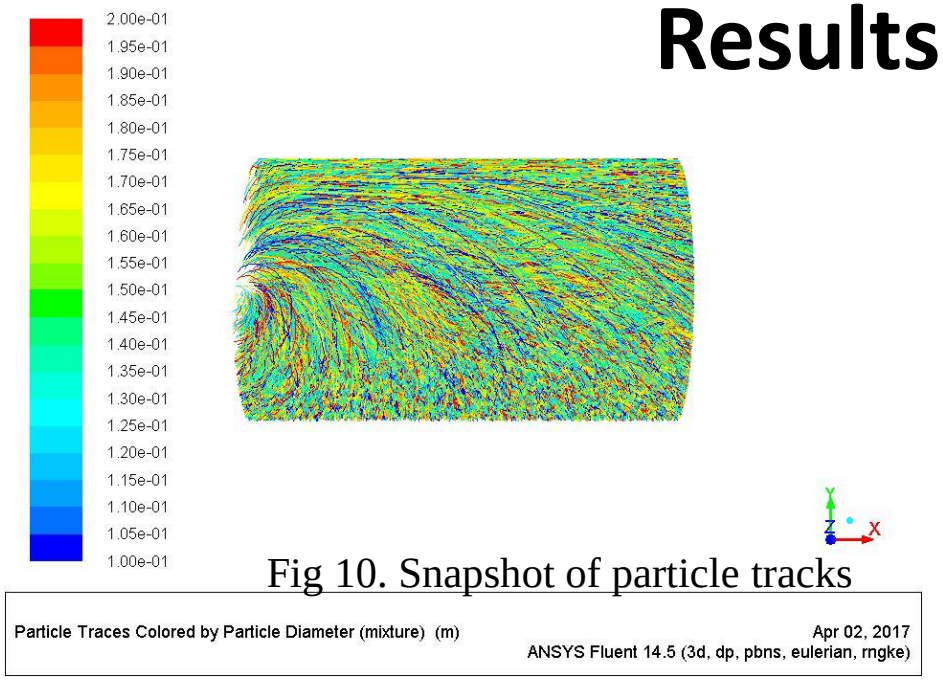


Fig 10. Snapshot of particle tracks

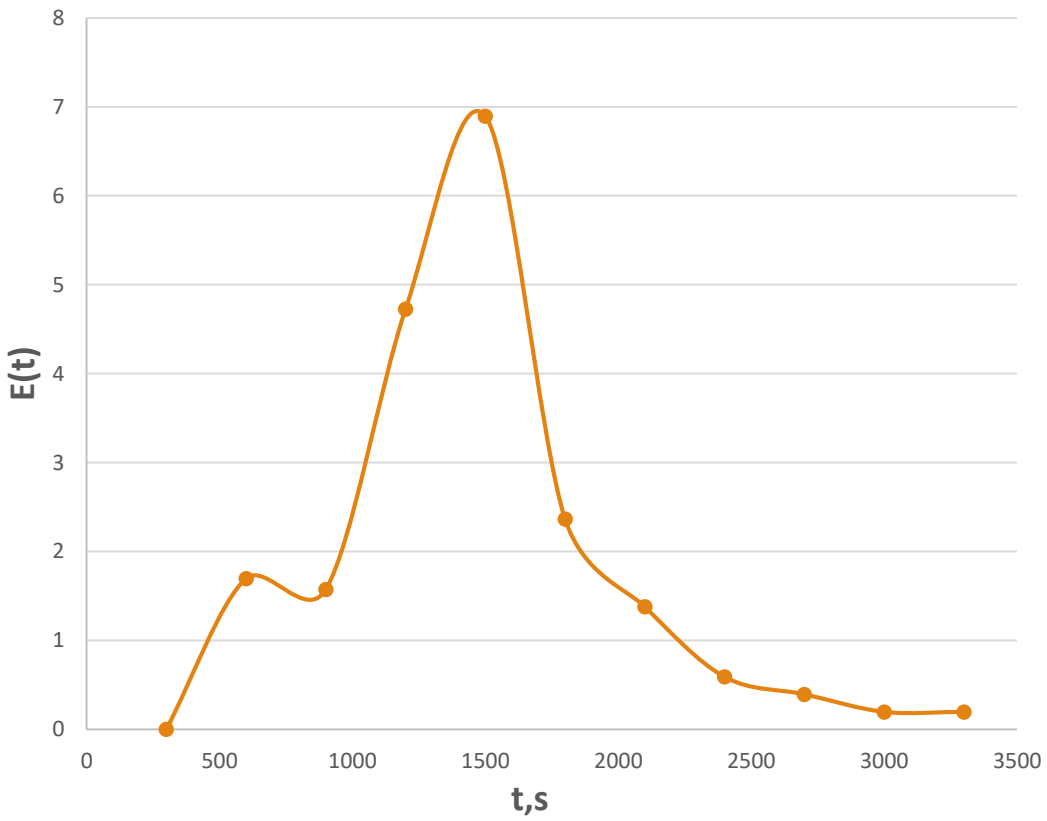


Fig 11. CFD RTD Curve

- CFD MRT was 25 min, shorter than design MRT, implying shorter contact/milling time
- This suggests the presence of dead zones or channeling within the mill as indicated by the disparity in the MRTs

Conclusion

- A coupled CFD-DPM model has been successfully employed to simulate the flow in a cement mill
- Eddy viscosity contours revealed that mixing is better in the mid-section of the mill than the outlet and inlet.
- The MRT predicted by the model compared better with the experimental MRT than the design MRT
- The approach used in this study gives a pictorial images of mixing in the mill and is useful for visualization.

References

- Benzer, H., Ergun, L., Lynch, A., Oner, M., Gunlu, A., Celik, I., and Aydogan, N.2001. Modeling Cement grinding circuits. Minerals Engineering, 14(11), 1469-1482.

- Fogler, H.S., 1997, Elements of Chemical Engineering Reaction. 2nd Edn, Prentice-Hall of India PrivateLtd., New Delhi, pp: 708-723, 759-765.

- H. Benzer, L. Ergun, M. Oner and A.J. Lynch, 2003.Case Studies of Models of Tube Mill and Air Separator Grinding Circuits, Proceedings: XXII International Mineral Processing Congress, Chief Editors: L. Lorenzen and D.J. Bradshaw, pp 1524-1533.

- GHACEM plant report, (2009).

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