Lagrangian RANS simulation of aerosol deposition in 90° bend turbulent flow

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Abstract:

The numerical study of 90 ° bend flow laden with monodisperse particles can be an effective tool for the prediction of pharmaceutical aerosol deposition in the extra thoracic airway. The continuous phase is calculated using RANS approach. The particulate phase is simulated by using a Lagrangian approach where hundred of thousands of monodisperse particles are released and tracked in the computational domain. This work is carried out using an in-house code namely Code_Saturne which Electricite de France (EDF) is the owner. According to the Stokes number of particles which is defined from operating conditions and the releasing locations at the entrance of the bend, the particles will either deposit on the wall or exit the bend. The results of this simulation (RANS) employing the stochastic model show an agreement with the experimental values obtained by Pui [1987] and the numerical data of LES Breuer [1987] except for small Stokes number St.

1. Introduction

One of the most interesting problems in fluid dynamics is the prediction of particle laden turbulent flows. It is characterised by interaction between two different kinds of matter. The difference between the matters can be their thermodynamic state, called the phase (gas, liquid or solid) or their chemical composition. Such flows occur in wide ranging industrial application. Examples include spray combustion, turbo machinery operating in polluted environment, filtration, nuclear reactor cooling, pollution control, and particle transport through pipes and ducts. In such processes, the fluid flow is turbulent, and turbulence plays a very important role in transport of mass, momentum and energy between the solid and fluid phases. In spite of such varied application these flows are poorly understood. A better understanding of these flows is required to develop devices that can counter the current threats and can help in achieving a cleaner and safer environment. In order to enhance our current knowledge level in particle laden flow, efforts are needed in modelling of fundamental processes like particle dispersion , mixing, concentration and phase changes.

2. Numerical method

Numerical predictions are compared to the experimental observations of Pui et al. In this experimental work, the deposition efficiency of particle in tube bends of circular cross section was measured for flow Reynolds number of 10.000 (based on the bend diameter and mean flow velocity)

•**Continuous Phase** : In finite bends of circular cross-section, the turbulent flow dynamics is complex. Indeed, it is characterised by the existence of recirculation regions and curved streamlines. If the flow in the bend is meant to represent the flow in the human airways such the throat, the Reynolds number is on the order of a few thousands. So transitional flow that is neither fully laminar nor fully turbulent may occur. For curvature ratio (R_0 > 5), the flow field in bends of circular cross section depends only on the Dean number [Mcfarland, 1997].

***Particulate phase :** For Lagrangian particle tracking used in conjunction with RANS calculation of the carrier phase, the use of the stochastic approach to predict the fluid velocity seen by the inertial particle along their trajectories is based on the mean fluid velocity and the turbulent kinetic energy (Reynolds stress tensor) and its dissipation rate.

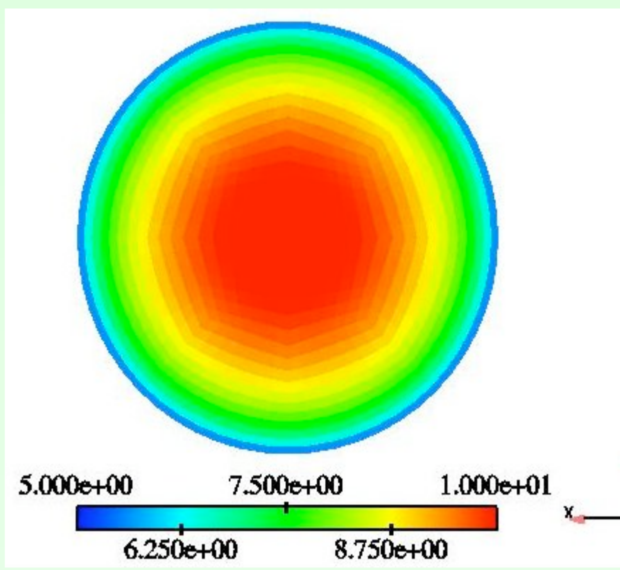

Fig1 : velocity field of the mean flow

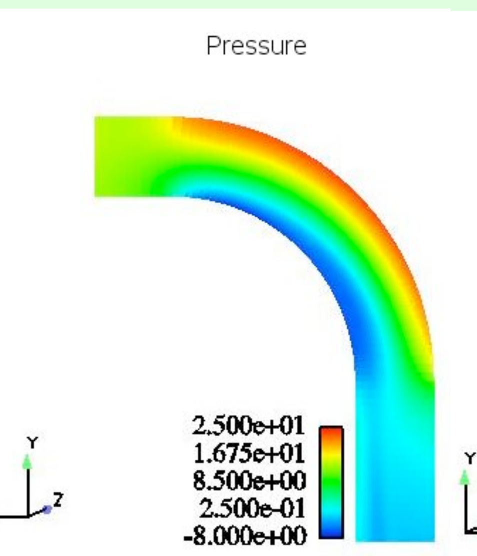

Fig2 : pressure field of the mean flow

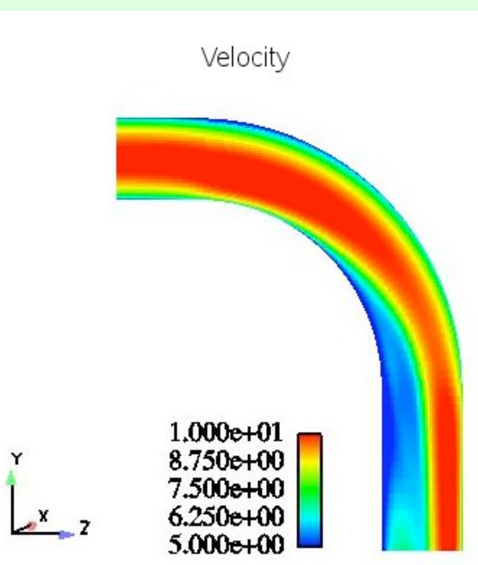

Fig3 : velocity magnitude of the mean flow

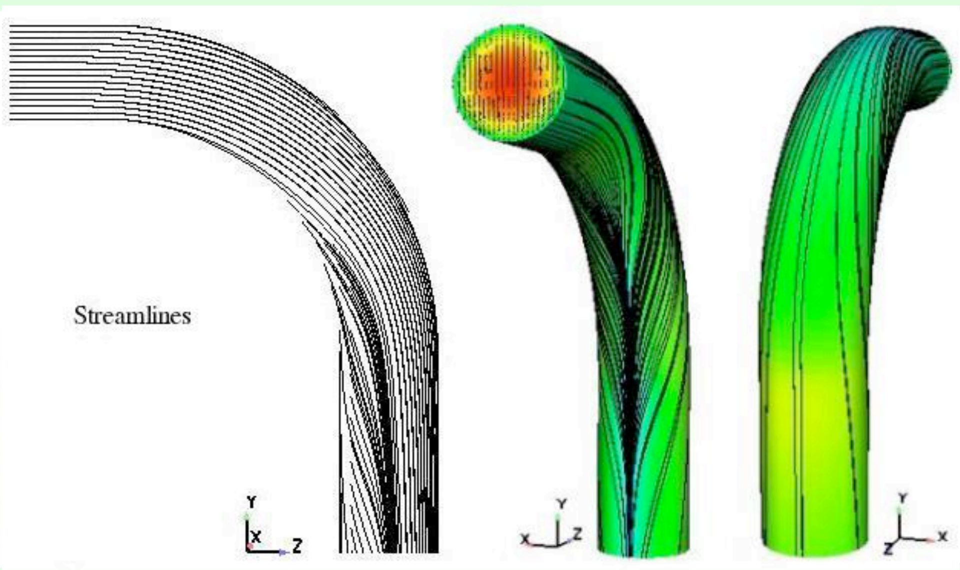

Fig4 : streamlines of the mean flow (a) midplane of the bend (b) near the wall

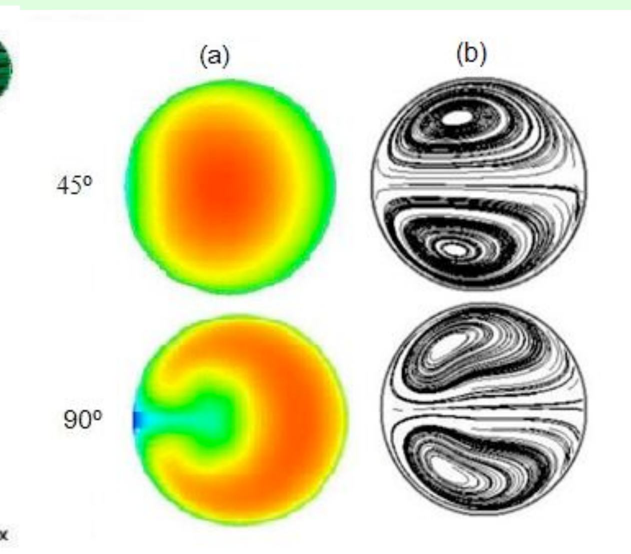

Fig5 : (a) mean axial velocity (b) streamlines of the secondary motion in different sections of the bend (45° , 90°)

3. Results and discussion

Continuous phase : The continuous phase was simulated using RANS for the precursor calculation (periodic straight pipe) and monophase calculation (90°bend). Figures (1) show the field of the velocity of straight pipe. Results show also that the flow is fully developed and we can inject the data obtained from the calculation such as the mean velocity, Reynolds stresses, and dissipation at the inlet of the bend (monophase calculation). About the monophase calculation figures (2), (3) show the pressure and velocity field respectively, and figure (4) streamlines at midplane (x=0) and near the wall. Figure (5) show the mean axial velocities and the streamlines of the secondary flow in which appear in the sections 45° and 90°.

Dispersed phase : For the particles tracked by using only the average flow produces by RANS; the results show that a prediction of the deposition efficiency for small Stokes number is better, on the other hand for the other categories we can notice an under prediction of the deposition followed by an over prediction, which is far from the real results. For the deposition of particles tracked using the Lagrangian model and which have a small Stokes number, the use of the complete formulation shows an improvement in comparison with the standard formulation which seems to produce more turbulence than it would have and this is justified by a over estimation of the deposition efficiency on almost all the range of Stokes number considered. In spite of this, results remain over estimation and do not express really the behaviour of the small particles which do not have a large inertia which enables them to penetrate the viscous sublayer and deposit on the walls. The intermediate category shows a better prediction for the standard formulation even if it over estimates the deposition of the particles, but for the complete formulation, deposition efficiency is underestimated. Finally for the third category which represents particles with large Stokes number, the deposition is identical to the LES results for both, standard and complete formulations.

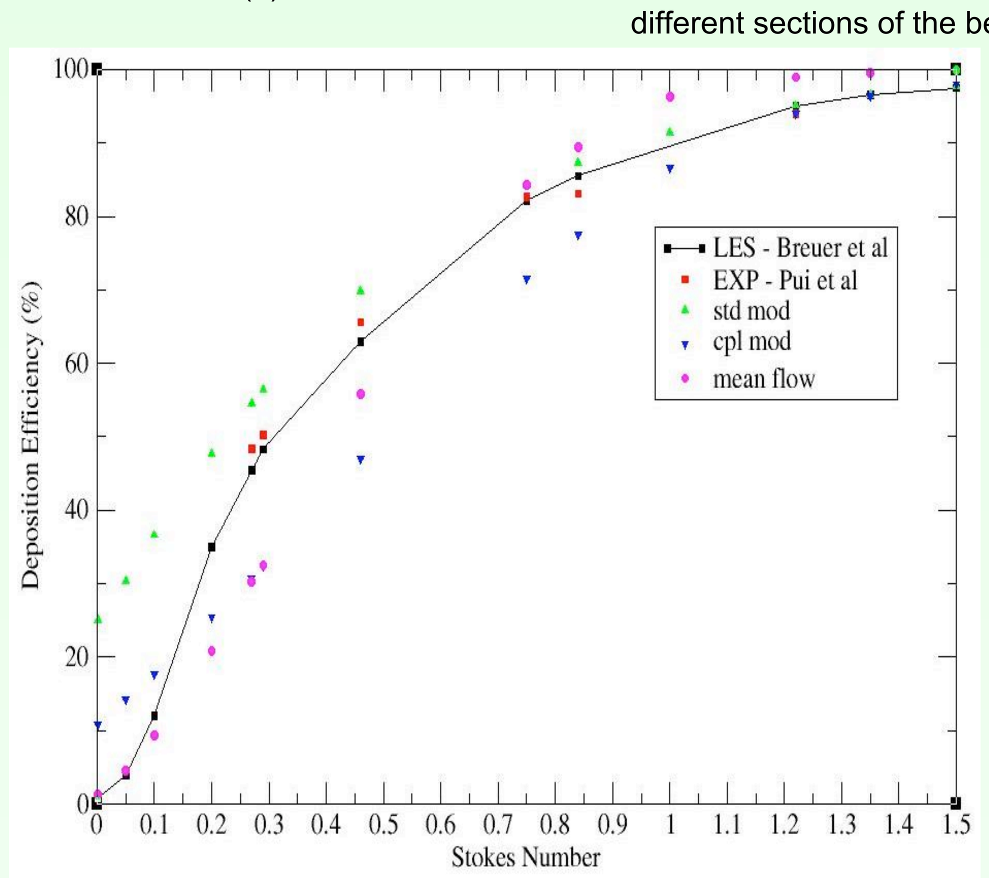

Fig6 : deposition efficiency versus Stokes number

4. Conclusions

For the case studied, we can notice that:

- The prediction of the deposition efficiency by using only the mean flow does not give good results accepts for small particles.
- The use of the Lagrangian model generate an over estimation level of turbulence which explain high deposition efficiency for small particles.
- The results obtained are in agreement with theoretical work and experimental observations on the deposition of large particles.
- The heavy particles with a larger diameter (large Stokes number) deposit on walls with higher efficiency than the small particles (small Stokes number), due to their strong inertia.

Finally, we can conclude from the comparisons of the results obtained to the LES simulation and the experimental observations, that the Lagrangian-RANS approach does not predict with effectiveness the deposition of particles for small Stokes number, but gives satisfactory results for the other categories.

5. Acknowledgements

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6. References

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