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Design, Simulation and Comparative Study of Virtual Impactors for The Generation of Mono-disperse Aerosols

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Abstract

A mono-disperse aerosol based virtual space of moving air as virtual impactor is described. This paper describes the design, principle, numerical study and performance of a virtual impactor to generate mono-disperse aerosols. The generation system produces mono-disperse aerosols of a known uniform size with an geometrical standard deviation from 1 to 1.25. Modification of different virtual impactors and their numerical study has been performed and simulation results have been observed from the designed impactor's velocity distribution, pressure distribution, particle tracking and erosion contours. Observation of wall losses of different virtual impactors has been significantly demonstrated. This mono-disperse aerosol generation system can be utilized for technological & research applications such as instrumental calibration, filter testing, dispersal of pesticides and medical treatment of respiratory illnesses etc.

Keywords: virtual, impactor, simulation, ansys, aerosol.

1. Introduction

Nanometer particle size range has been focused newly by the present development in aerosol instrumentation system [1]. Sub-micrometer particles of small sizes are the most important in aerosol research now-a-days [2]. Air pollution monitoring instruments have the usage in mobile sources such as automobile exhausts, stationary sources such as stacks of industrial plants measurement of outdoor ambient particulate level and testing, evaluation and calibration of these instruments under subjugated laboratory conditions for indoor air quality assessment is ensured and presence of a required velocity flow field is required [3]. For a controlled flow field in terms of velocity vectors and turbulence levels and a pre-selected narrow band particle size distribution, laboratory test aerosols conditions are required. Non-availability of suitable aerosol technology creates difficulties in the implementation of aerosol generation system. Several equipment and techniques have been utilized into operation for producing mono-disperse test aerosol, among which virtual impactor based mono-disperse aerosol generation system is one of the best which has vast applicable fields. Dispersity is one of the physical behavior of aerosols. Mono-disperse aerosols contain particles of uniform size which are producible in the laboratory. Poly-disperse colloidal systems type aerosols contains a range of particle sizes [4].

2. Virtual Impactor as mono-disperse aerosol generator

A virtual impactor is a device used to separate particles by size into two airstreams. It is similar to a conventional impactor, but the impaction surface is replaced with a virtual space of stagnant or slow moving air. Large particles are captured in a collection probe rather than impacted onto a surface. The fig.1. shows a schematic diagram of a virtual impactor. The aerosol passes through an accelerating nozzle and is directed toward a collection probe. At this point a major portion of the flow is diverted at a definite angle away from the collection probe. This is where the particle-size separation takes place. Large particles with higher inertia follow the flow streamlines and are carried away vertically with the major flow. Small particles with lower inertia deviate from the flow lines and continue moving axially in their forward path down the collection probe with the minor flow. The separation efficiency curve is determined by the ratio of the major and minor flows and the physical dimensions of the nozzle and collection probe [5]. The inertial impactors has the problem of the interaction of the particles with the impaction surface, resulting in particle fragmentation, bounce, overload, and re-entrainment. The development of practical virtual impactors, however, was prompted by the need for large scale sampling of atmospheric aerosols [6].

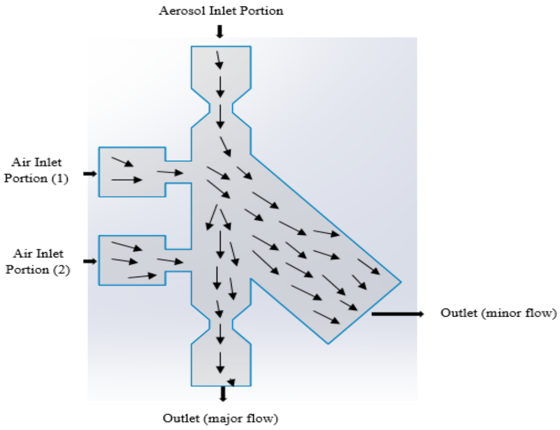


Fig. 1. Cross sectional view of a virtual impactor

3. Virtual Impactors for the comparative study

A. Virtual impactor consisting of two air inlets and two minor flow channels perpendicular to the major flow channel has been shown in fig.3. B. Virtual impactor consisting of two air inlets and minor flow channel is 45^0 inclined with the major flow channel has been shown in fig.4. C. Virtual impactor consisting of one air inlets and one minor flow channel where minor flow channel is inclined at 45º to the major flow channel has been shown in fig.5.

4. Parameters to be compared

A. Velocity distribution B. Pressure distribution C. Particle tracking D. Erosion contour

5. Ansys workbench

Workbench is a software platform which helps in our analysis (finite element analysis) activities. Finite element analysis is actually a numerical technique used to do stress analysis, heat transfer, fluid flow and other types of engineering problems [7]. Ansys workbench is the finite element analysis tool which is used in conjunction with CAD systems. The systems which can be analyzed in ansys workbench are electrical, dynamics, fluid flow, magneto-static, structural, thermal, thermal-electric etc.

6. Design and simulation

The virtual impactors that have been studied numerically consist of inlet and outlet portions. Poly-disperse aerosol produced from ethanol and olive oil solution has been used to be passed through the aerosol inlet portion of the impactors. For the comparative study, considerations of the design and simulation are density, viscosity and concentration of the liquid solution, acceleration nozzle size and shape, mesh sizing of structures and droplet diameter range.

7. Ansys workbench parameters:

For the numerical study of different virtual impactors in Ansys, solidworks software has been used for drawing and identifying the basic 2D geometry of the virtual impactors. Three simulations of virtual impactors of different designs have been prepared and compared with one another for the desired results.

Table.1 Basic simulation parameters

Name of the properties	values
Viscous Model	K-epsilon (2 equations)
K-epsilon Model	Realizable
Near wall treatment	Enhanced
Total Flow Rate	0.426 kg/sec
No of iterations	200
No of particles tracked	184

Table.2 Mesh parameters

Name of the properties	Values
Mesh Method	Triangle

Smoothing	High
Size Function	Adaptive
Relevance Center	Fine
Element Size	0.001 m
Transition	Slow
Smoothing	High

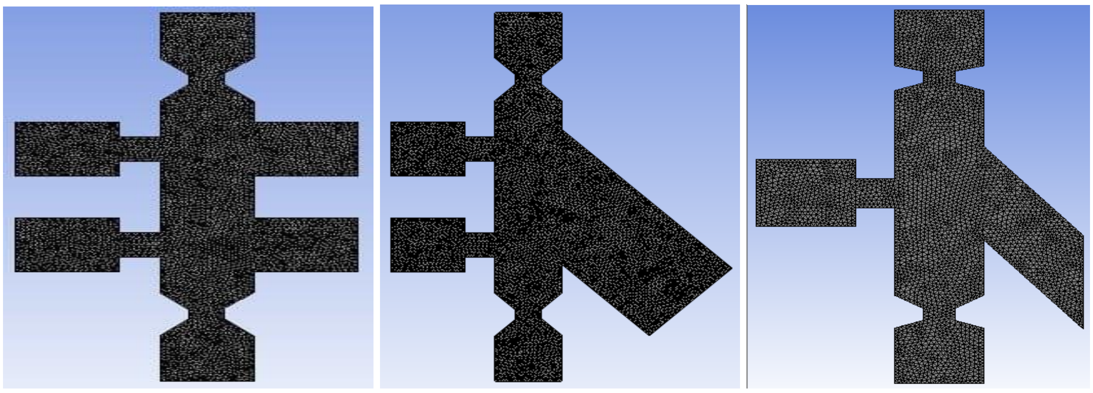

Virtual impactor-1 Virtual impactor-2 Virtual impactor-3

Fig. 2. Mesh structures of three virtual impactors

8. Simulation of virtual impactors of different designs

Table.3 Boundary Conditions

Name of the properties	Values
Velocity of Air	0.02 m/s
Velocity of Inlet Aerosol	0.5 m/s
Droplet Diameter (Maximum)	180 µm
Droplet Diameter (Minimum)	0.2 µm
Droplet Diameter (Mean)	50 µm
Convergence	0.0001

Virtual Impactor-1:
It consists of two air inlets and two minor flow channels perpendicular to the major flow channel.

Table.4 Mesh of virtual impactor 1

Name of the properties	Values
Element Size	10^{-3} m
Nodes	4839
Elements	8990

Virtual Impactor-2:
It consists of two air inlets and minor flow channel is 45^0 inclined with the major flow channel.

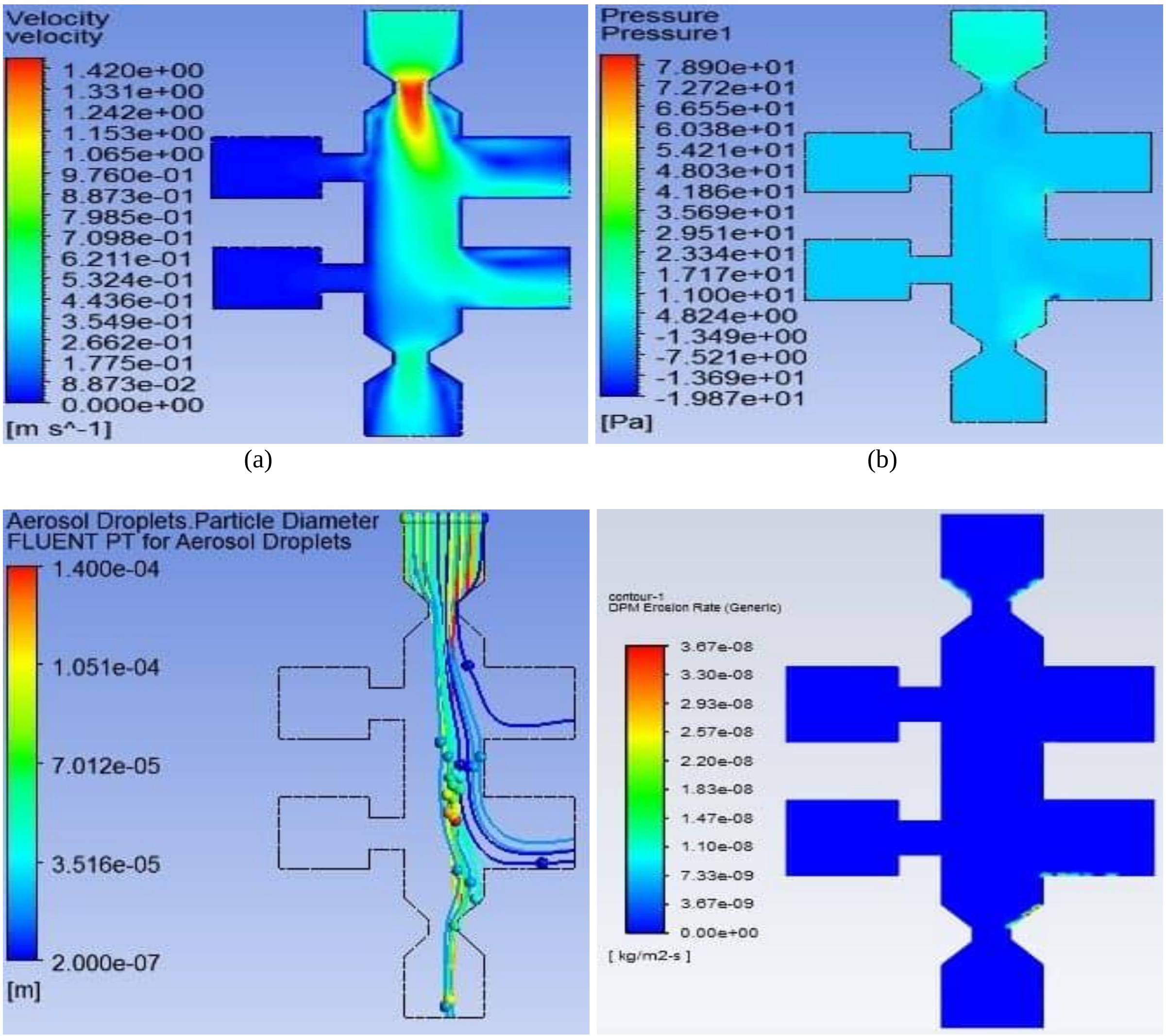
Table.5 Mesh of virtual impactor 2

Name of the properties	Values
Element size	10^{-3} m
Nodes	5656
Elements	10625

Virtual Impactor-3:
It consists of one air inlets and one minor flow channel where minor flow channel is inclined at 45° to the major flow channel.

Table.6 Mesh of virtual impactor 3

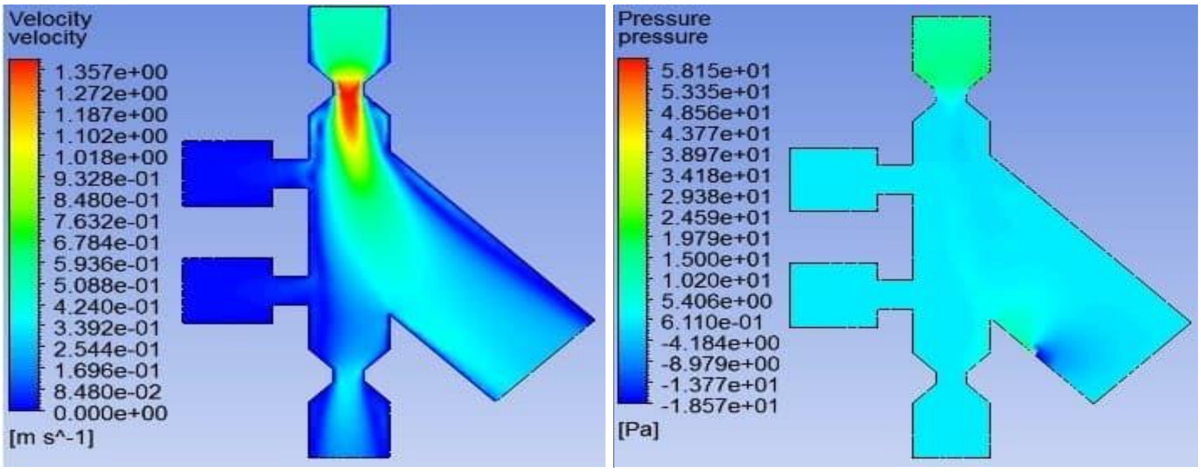
Name of the properties	Values
Element size	10^{-3} m
Nodes	3812
Elements	7077



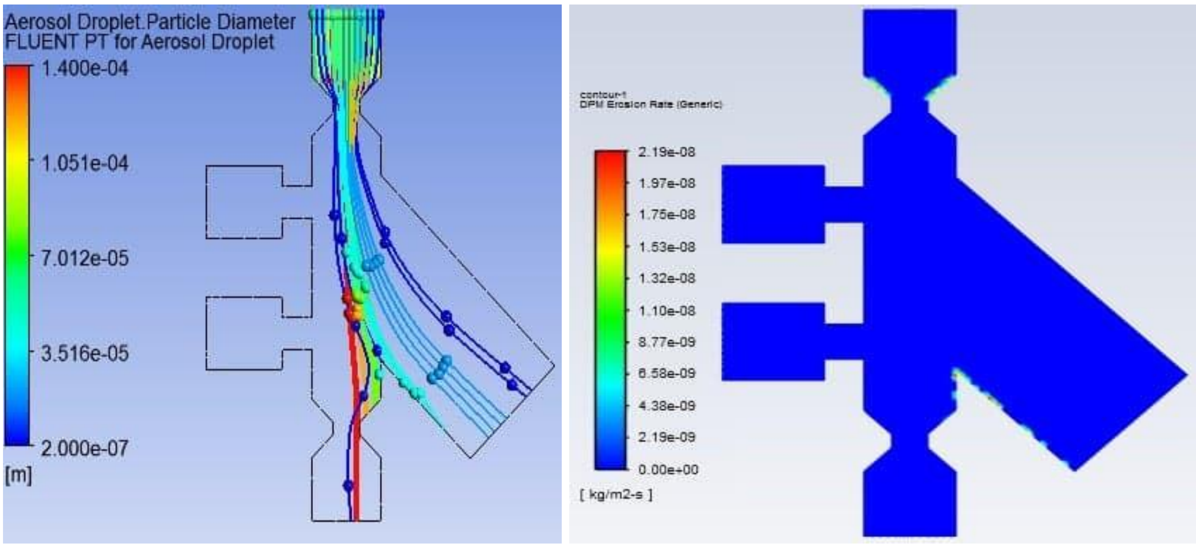
(a) (b)

(c) (d)

Fig. 3. (a) Velocity distribution, (b) pressure distribution, (c) particle tracking and (d) erosion contour, of virtual impactor 1

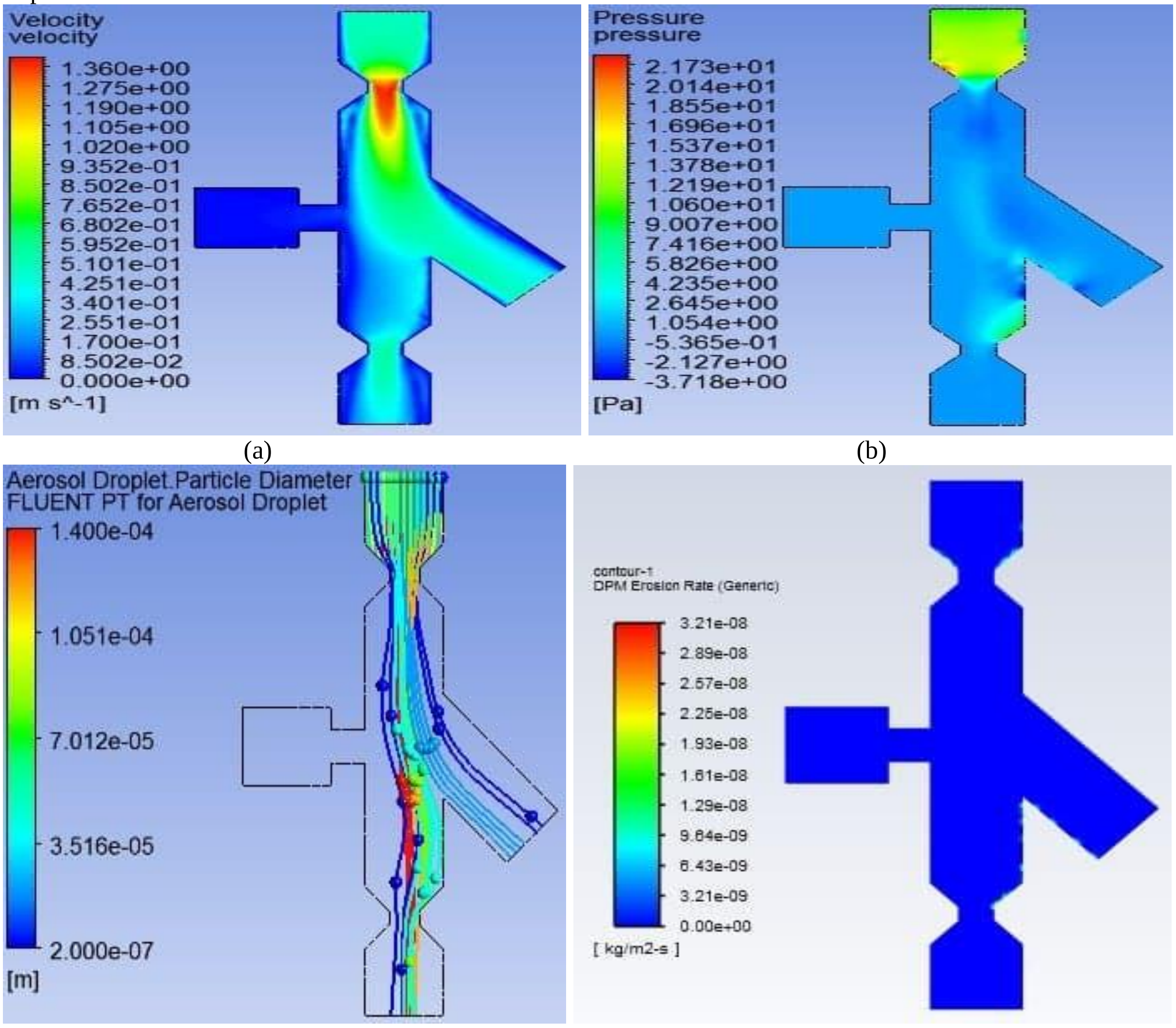


(a) (b)



(c) (d)

Fig. 4. (a) Velocity distribution, (b) pressure distribution, (c) particle tracking and (d) erosion contour of virtual impactor 2.



(a) (b)

(c) (d)

Fig. 5. (a) Velocity distribution, (b) pressure distribution, (c) particle tracking and (d) erosion contour of virtual impactor 3.

9. Results and discussion

The observation of particle tracking and escaping is demonstrated in table.7.

Table.7 Results

Virtual Impactor	Number of particles tracked	Number of particles escaped	Number of particles trapped
01	184	63	121
02	184	56	127
03	184	77	107

After doing the numerical study of three virtual impactors, we have come to the point that, the velocity and pressure distribution of virtual impactor 3 are more uniform throughout the entire cross section from the acceleration nozzle to the minor flow channel and wall losses at minor flow channel are lower than the other impactors. At the nozzle section, the velocity is increased and becomes higher and pressure becomes lower. Gradually, the velocity becomes lower and pressure becomes higher when moving from the nozzle towards the minor flow channel.

Erosion rate in the above figures of three virtual impactors is not significant. But, Erosion rates show the regions where the aerosol droplets are trapped which is an important factor for the selection of the virtual impactor.

The first minor outlet of virtual impactor 1 gives mono disperse aerosols of smaller diameter range and some of them are trapped in this outlet. The second minor outlet also does the same but the diameters here are larger than previous one. In case of virtual impactor 2, the minor outlet provides mono-disperse aerosols among which some larger diameter droplets tends to come out due to air impaction and these are trapped in the wall. By choosing appropriate air flow through air inlets, the design of impactor 2 can be effective.

Among the three impactors, the virtual impactor 3 has better particle separation characteristics. Mono disperse aerosol is obtained from minor outlet. Hence, impactor 3 is more acceptable to use due to less amount of particles being trapped in minor outlet as desired.

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10. Conclusion

From the comparative study of the impactors, we have identified that in case of virtual impactor 3, the velocity and pressure are distributed with suitable flow field of aerosol from acceleration nozzle throughout the cross section and less amount of particles are trapped with high amount of particles being escaped with less wall losses than the others at the minor flow channel. Hence, we have come to the point that virtual impactor 3 is more acceptable and suitable for mono-disperse aerosol generation of vast applicable fields out of the three virtual impactors that have been compared.

11. References

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