

Parametric study and CFD Analysis of Air Filter

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Abstract

The objective of work is to analyze the fluid flow through the air filter with porous medium of four cylinder spark ignition engine by performing experimental and computational fluid dynamics analysis(CFD) for reducing pressure drop in air filters. CFD analysis will be performed using Ansys Fluent V14.5 using 2-D incompressible Reynolds Averaged Navier Stokes equations. A standard round air filter (Mahle KFA0247496) is used for performing experimental analysis with all laboratory equipment's for calculating pressure drop(using differential pressure gauge) and studying velocity profile(using Dantec anemometer) and boundary conditions for 2-Dimensional simulation air filter element are set with some approximations based on experimental values. Thus in order to improve air filtration efficiency parametric optimization of air filters is done by varying parameters like width of filter element, eccentricity of air flow in filter, and thickness of filter element using ANSYS Workbench after model validation with experimental results. Moreover a comparison is being made between triangular and rectangular air filter element to find out their effects in pressure drop. Thus an optimized value of parameters is be found which further reduces pressure drop in air filter to improve air filtration efficiency and engine performance of a vehicle.

Keywords- CFD Analysis, parametric optimization, ANSYS Workbench, air filtration efficiency

1. Introduction

Air cleaner is an important element of the automobile intake system. The clean air required by the engine is supplied by the air cleaner (Air Filter). The intake system of an engine has three main functions. Its first function is to provide a method of filtering the air to ensure that the engine receives clean air free of debris. Other characteristics that are of importance to the engineers designing the intake system are its flow and acoustic performance. The intake system flow efficiency of has a direct impact on the power the engine is able to deliver. The acoustic performance is important because government regulations dictate the maximum air mass flow level that vehicles can make during a pass-by test. The speed of air generated by the intake system can be a significant contributor to this pass-by filter and separated flow. The shape of air filter casing is critical in distributing the flow evenly over the filter element and to reduce the pressure loss due to flow separation. And flow recirculation. In this Paper initially experimentation is carried out to validate the boundary conditions of the model which is later designed in ANSYS for simulation. Parametric study on width, eccentricity of air flow and thickness of air filter is carried over the model to derive various concluding results.



Fig.1 Ring type filter element Sketch

2. Literature Review

2.1 Analytical Study Papers

Hocking M [1] found that there are many technologies, i.e. pleated filters and electrostatic precipitators, are available for removing the air particles. Pleated filters, such as High -Efficiency Particulate Air (HEPA) filters, are widely used in buildings and airplanes.

Clausen G. [2] studied Electrostatic precipitators (ESPs) collect the particles by use of an electric field. ESPs have a low pressure drop but also a low collection efficiency for submicron particles.

Dziubak. T [3] studied the properties of filtering media used as porous membranes in air cleaners of modern motor vehicles have been analyzed. A relation that defines the air filter life has been presented and a dust absorption coefficient k_m of a filtering medium has been defined.

Feng Z. Y [4] derived an analytical method by using Darcy's law for predicting pressure drop through a pleated filter, and the results matched the experimental data well.

Kevin Norman [5] studied the effect of intake air filter condition on vehicle fuel economy. A study was carried experimentally to define air filtration efficiency and find its effects on economy of vehicle.

2.2 Numerical Study Papers

Pavan Kumar Goud [6] studied the effects of air filters performance were studied and the analysis is carried out with different simulation results in the form of numerical simulation of flow particles captured by air filters.

Nicholas West [7] studied a particle filter, in combination with noisy observations of mass-flow made in the isolator, is used to estimate the state of the engine and make predictions about future behavior. This filter is used in a closed-loop control to prevent the engine from stalling.

Dipak C. Talele [8] proposed the volumetric efficiency, majority car manufacturers place air grill at the front of a vehicle. In this Paper, the causes and effect of air induction pressure variation on performance of compression Ignition engine is studied. It is observed that due to increased inlet air pressure results in better mechanical efficiency, volumetric efficiency, scavenging and reduced exhaust temperature at the engine exhaust thereby reduced oxides of Nitrogen.

CM Mak [9] studied pollutant dilution in a natural ventilated dental clinic. Despite the position of the pollutant source and facilities such as bulkheads, escape time was significantly reduced when the ventilation flow rate was increased under the single narrow and dispersive paths. However, for the narrow path, these factors played a more dominant role in the escape time than the ventilation flow rate.

S. Hosseinzadeh [10] studied pressure drop against 0%, 26%, 52%, 66% and 74% of air filter hole's masking for different mass flow rates has been studied by computational fluid dynamics. The effect of masking on altitude and performance at different revolutions per minute of the engine is investigated an experimental and computational fluid dynamics study was carried out to predict altitude against different proportions of air filter hole's masking at 1000 rpm.

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B.O Anderson [15] studied on Numerical and experimental study of pulse-jet cleaning in fabric filters. In the work presented, pulse-jet cleaning of low-pressure fabric filters (2 bar) is studied using a full three-dimensional (3D) CFD model. Experimental results obtained in a pilot-scale test filter with 28 bags, in length of 10 m and in general full-scale dimensions of the cleaning system are used to verify the reliability of the present CFD model.

2.3 CFD Analysis Study Papers

Feng Z, Long Z and Chen Q [16] In this paper, CFD was used to observe the performance of pleated filters under different turbulent schemes such as standard k-e model, low Reynolds number ke models, the v2f model, Large Eddy Simulation (LES) models, and Detached Eddy Simulation (DES) models.

Balasankar P et al. [17] In this paper, the air cleaner is analysed to understand the flow through the filter using Acusolve CFD codes and post processing is done in Hyperview. Moreover, air cleaner geometry is optimized to reduce the flow recirculation to achieve lesser pressure drop. Guiding vanes are introduced into the air cleaner to guide the flow over the filter element for better filter area utilization.

Yerrum R et al. [18] In this paper, focus is given on optimizing the geometry of an intake system in automobile industry to reduce the pressure drop and enhance the filter utilization area. Based on existing model CFD results, geometrical changes like baffle placement in inlet plenum of the filter, inclusion of bell mouth in outlet plenum and dirty pipe, optimization of mesh size, removal of contraction in clean pipe of intake system etc. are carried out, to improve the flow characteristics.

Kesslar M. P et al [19] In this paper, CFD analysis was carried out on a 3d model of an air filter to understand the pressure drop for an Air Intake System. Fully isothermal incompressible viscous flow simulations with turbulence modeling for steady state conditions have been performed for two geometries. Seven operation conditions have been studied, representing different points of engine operation.

Valvade A P et al [20] In this paper, a 3d model of an air filter is made and emphasis is given to optimize the air filter location with respect to housing. Based on the CFD results, geometrical changes like introduction of eccentricity is done so as to improve the flow characteristics.

Phulpagar A S [21] In this paper, 3D viscous CFD analysis was carried out for an existing model to understand the flow behavior through the intake system, air filter geometry and filter media using ANSYS Software. Flow behavior through the intake system, air filter geometry and filter media were studied. A CFD result shows 9-10% of variation in results, CFD Analysis shows that maximum flow is going through from one side of the filter.

Kaushik G S [22] studied Ceramic air-filters can replace the existing air-filters with even better pressure drop. The thicknesses of these filters are in the range of 5 mm to 10 mm which will result in huge savings compared to the existing very large filters in terms of space required. A stack of these hollow air filters can also be effectively used for superior dirt protection. However using these filters with thickness more than 20mm will have higher pressure drop and hence it is not recommended to go beyond this thickness. As the filters are made out of ceramics the life span of the filter will be very high. Damage of the filter due to either the harder and sharp particles or due to cleaning process is avoided. **Mullins B J et al [23]** This work examined the pressure drop and efficiency of a knitted filter geometry at 3 different packing densities. The CFD results were compared to classical single fiber efficiency theory for conventional fibrous filters. The CFD results showed increased capture efficiency and pressure drop compared to fibrous filter theory.

Rosa Siqueria et al [24] presented the three-dimensional CFD analysis of flow inside an automotive air filter conducted by SMARTtechFluidos for SOGEFI Filtration do Brasil Ltda., in order to determine the pressure drop over AIS (Air Intake System). Two geometries have been analyzed in seven operation conditions, each. The flow was considered steady-state, incompressible, turbulent and isothermal. The region occupied by the filter element was treated as a porous medium and the porosity coefficients were extracted from experimental results. The contribution given by each component to the total pressure drop was determined.

2.4 Summary from Literature and present study

In present study use of Electrostatic precipitators is not considered because they are expensive as compared to pleated filters and are not commonly used in vehicles. Thus Present work deals with use of Pleated filter. Analytical study is done using Darcy law for pressure drop prediction. Present study deals with 2-dimensional flow which would be interpolated using Ansys Fluent and time averaged Navier Stokes equation where parameters of filter element will be varied. Many of the literature study focused mainly on filter utilization area and also lack experimental validation but our study will consider every parameter along with

experimental validation. After literature survey it was concluded that round air filter should be used, so in present study we will consider round air filter over rectangular air filter because round filter offers more surface area for air to get cleaned up. Moreover it is easy to replace round filters as compared to flat or rectangular filters.

3. Experimental set up

Figure 3.1 shows our experimental test rig for measuring the velocity distributions and turbulence characteristics downstream from a pleated filter. Compressed air was first stored in a constant-pressure tank for supplying clean air to the system. A valve was used to control the air flow rate, which was measured by a flow meter. The air was divided into four parts through a gas distributor. The four parts entered the experimental channel from the four sides which created a uniform flow field in the upstream section of the channel.

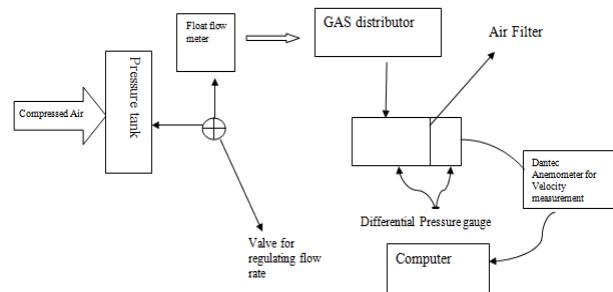


Fig. 3.1 Layout of experimental set up

The pressure drop across the filter was recorded using a differential pressure gauge. The flow velocities behind the filter were measured using a Dantec constant temperature anemometer, and the data were recorded with a computer.

3.1 Experimental Observation Table

Sr. No	Inlet Temperature (K)	Outlet Temperature (K)	Inlet Pressure (N/m ²)	Pressure drop (N/m ²)	Inlet velocity (m/s)	Outlet Velocity (m/s)
1	28	28	1	26	0.5	0.48
2	28	28	1	40	0.8	0.79
3	28	28	1	60	1.2	1.1
4	28	28	1	75	1.5	1.4

4. CFD analysis of Air Filter

4.1 Preparation of CAD model in Ansys Design Modular

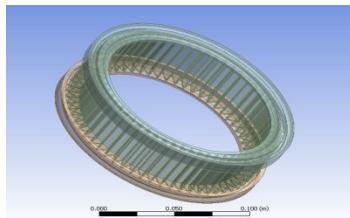


Fig 4.1 CAD Design Model

4.2 Boundary conditions named before importing the model in ANSYS Fluent

In below schematic the boundary conditions are shown on a 2 D filament of a Round type Air filter used for study.

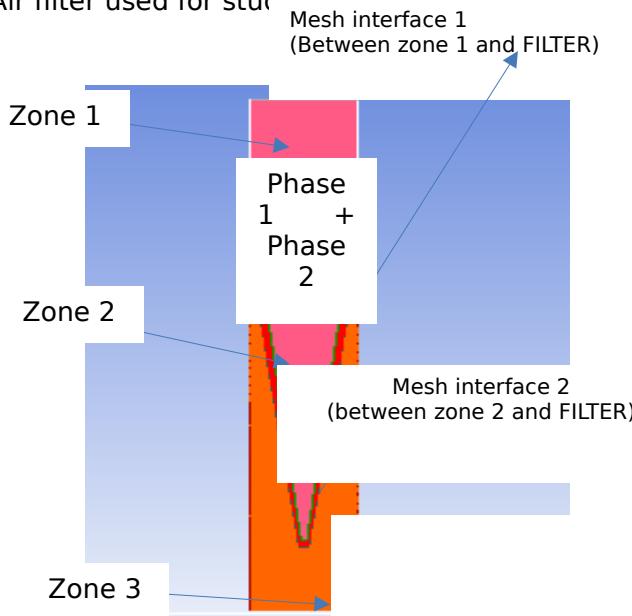


Fig.4.2 Wall boundary conditions

Due to the iteration performed in simulation we use convergence as the monitor for achieving the final solution

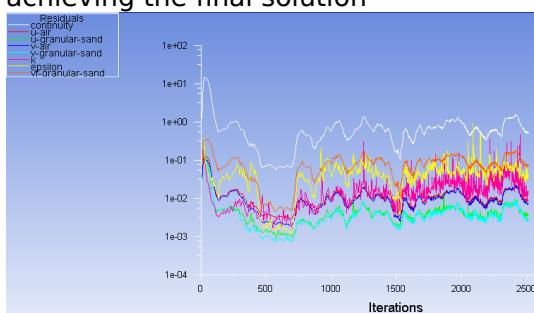


Fig 4.3 Convergence of Solution

The criterion of convergence of the numerical solution is based on the absolute normalized residuals of the equations that were summed for all cells in the computational domain. Convergence was considered as being achieved when these residuals became less than 10-2, which was the case for most of the

dependent variables. Iterative convergence was also checked when values of velocity, continuity, phases became almost constant. Furthermore, checks for the achievement of a final solution were made on the basis of the conservation of mass flow rate and momentum. Thus it can be noted that it took 2500 iterations for the solution to reach the convergence.

4.3 Model validation with experimental data

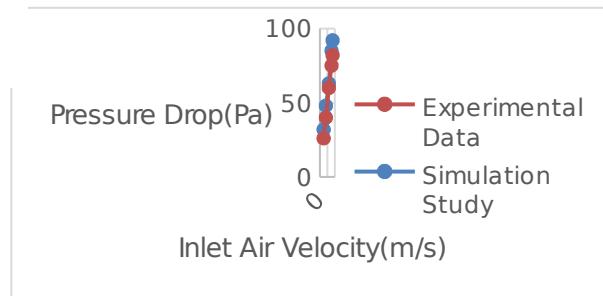


Fig 4.3.1 Validation of Experimental and Simulation Results

order to know mechanism of flow the simulation result matched with experimental study before going for parametric study. For verification of the computational algorithm, simulations are conducted to compare computational results with experimental data.

5 Results and discussion

5.1 Parametric Study

Table 5.1-Variation of Filter width

Filter Width(m)	VF of Sand at Outlet	Air Velocity at outlet(m/s)	Total Pressure Drop(Pa)
6	0.007382757	0.96117479	60.02950395
8	0.005184183	0.96724272	53.07515597
10	0.003992866	0.99022466	62.16073836
12	0.003409201	0.97623527	72.23818643
14	0.003330417	0.96700281	84.79048491

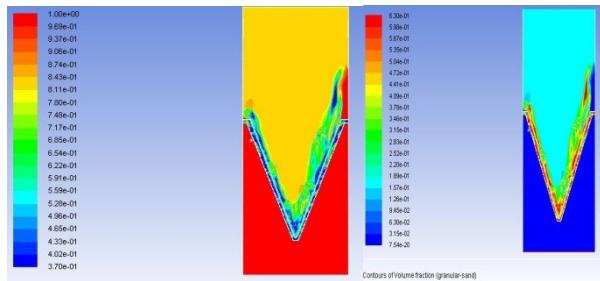


Fig 5.1.1 Volume fraction for varying width air filter

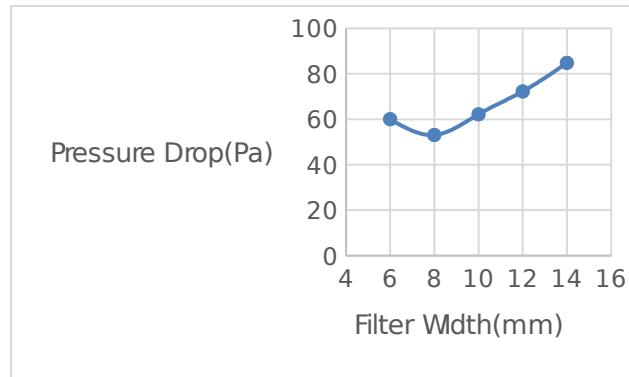


Fig 5.1.2 Filter width versus Pressure drop at outlet

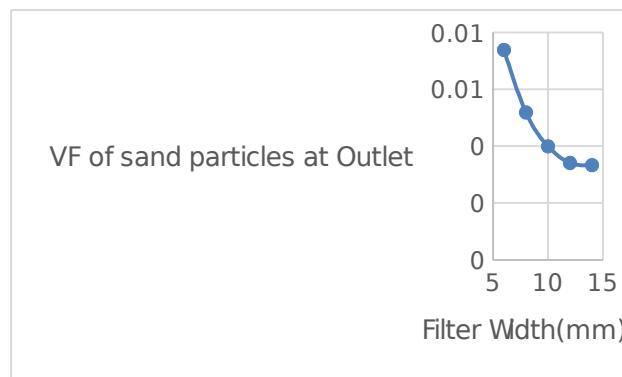


Fig 5.1.3 Filter width versus Sand Volume fraction at outlet

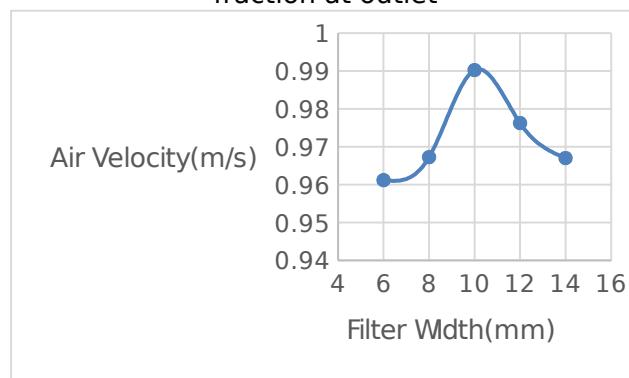


Fig.5.1.4 Filter width variation with air outlet velocity

From the above figure it can be seen that width of air filter is varied, it can be observed

that with increased width very few amount of granular particles can pass through air filter but at the same time it can be observed from Table below that Pressure drop decreases with increasing filter width till 8mm only, if width of filter increases from 8mm pressure drop begins to increase. So after some time filter will begin to accumulate more dust and finally its efficiency will decrease. Thus we cannot go beyond 8mm with filter width. Also Volume fraction of sand particles will decrease as the filter width increases but as mentioned it will increase pressure drop. Although there is almost negligible change in air velocity entering and leaving the air filter on varying filter width but we can observe that velocity increases to maximum (0.99m/sec) at filter width of 10mm and the again begin to decrease.

Table 5.2 Variation of Filter thickness

Filter Thickness (mm)	VF of Sand at Outlet	Air Velocity at outlet (m/s)	Total Pressure Drop (Pa)
0.5	0.007382757	0.96117479	60.02950395
1	0.007032911	0.96485919	56.31197562
2	0.007912108	0.95583117	62.50674663
3	0.008665819	0.96973526	60.59707984
4	0.006929135	0.95842445	67.40484144
5	0.007011171	0.96507561	84.99936974

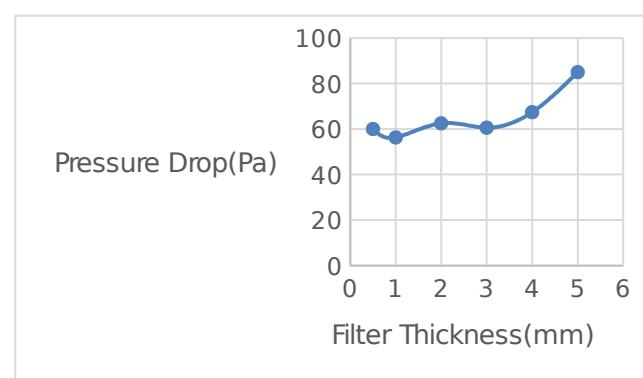


Fig.5.2.1 Filter thickness versus Pressure Drop

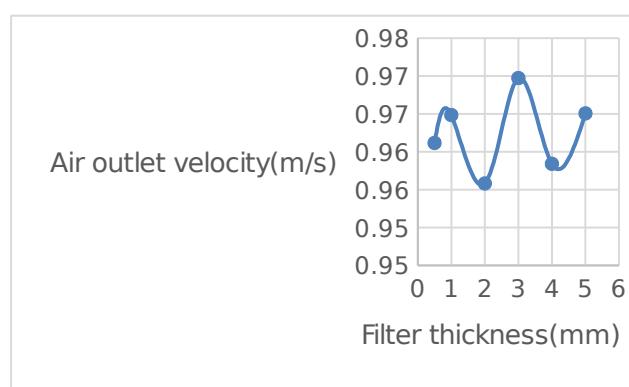


Fig.5.2.2 Filter thickness variation with air outlet velocity

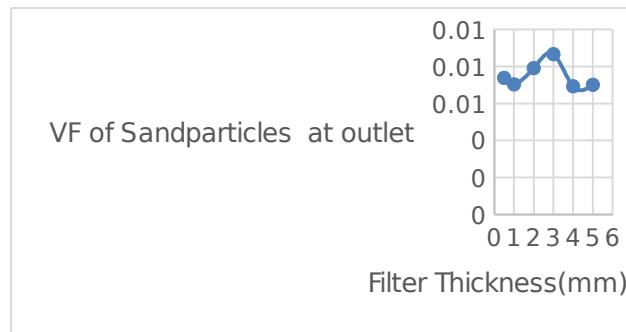


Fig.5.2.3 Filter thickness versus sand volume fraction at outlet

From the above figure it can be seen that thickness of air filter is varied, it can be observed that with increased thickness very few amount of granular particles can pass through air filter but at the same time it can be observed from Table below that Pressure drop decreases with increasing filter thickness till 1mm only, if thickness of filter increases from 1mm pressure drop begins to increase. So after some time filter will begin to accumulate more dust and finally its efficiency will decrease. Thus we cannot go beyond 1mm with filter thickness. It can be seen from above figure that there is little in velocity with varying filter thickness, velocity begins to change sinusoidal. Also it can be seen from above figure that at filter thickness of 3mm, VF of sand particles increases at 3mm but again starts to decrease and is minimum at 1mm. So the above plot is in accordance with pressure drop variation plot

5.3 Changing air flow direction for air filter

The direction of air entering inside air filter is being varied by restricting air flow or air entering the air filter.

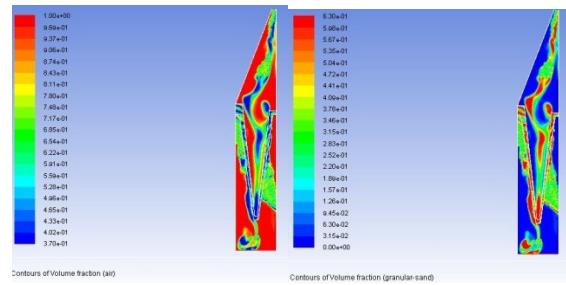


Fig.5.3.1 Contours of sand and filter VF on restricting Air Flow at angle 45 to air filter

When air flow was restricted to 45° it was observed that granular particles start to pass through filter (VF of granular sand increases). Moreover the pressure at the outlet region was found to be negative. On restricting air flow to 55° angle the results were more absurd. Thus it can be observed that air should flow only perpendicular to air filter element in order to maintain laminar flow inside filter and maintain pressure drop.

6. Conclusions

- 1) An experimental and numerical study of air filter is carried out. 2- Dimensional CFD analysis of air filter element considering all continuity and momentum equations was carried. The granular sand flow was restricted by air filter leading to pressure drop.
- 2) The flow around the air filter used in commercial vehicle was determined both experimentally and numerically using a finite volume based computational fluid dynamics (CFD). Parametric study was carried out for a systematic theoretical investigation of the effects of filter element geometric parameters on pressure drop and volume fraction at filter outlet of granular particles was involved. Overall we can conclude that pressure drop varies non-linearly with filter width and filter thickness. Moreover a comparison has been made between rectangular and triangular air filter along with restricting air flow study. Thus an optimized value for filter element geometry is found considering all the observations and theories.
- 3) The results obtained from simulation study from ANSYS Fluent were observed to be in good accordance with the literature; maximum difference was observed to be 10%.

- 4) From comparative study between rectangular and triangular filter it was found that triangular filter was more efficient than rectangular filter with less pressure drop and providing more space for air to pass.
- 5) From parametric study it can be concluded that in order to reduce pressure drop and also amount of granular particles passing through filter air filter width should be around 8mm and air filter thickness should be around 1mm.
- 6) By restricting the air flow, it was observed that filter begins to behave absurdly due to high turbulence inside filter. Thus it was concluded that air flow should be perpendicular to filter

7. References

[1] Hocking M. (2000), "Passenger aircraft cabin air quality: trends, effects, societal costs, proposals", *Chemosphere*; 41:603-15.

[2] Clausen G., (2004), "Ventilation filters and indoor air quality: a review of research from the International Centre for Indoor Environment and Energy", *Indoor Air*; 14(7):202-207.

[3] Dziubak TA, (2014), Szwedkowicz SE, "Experimental research on nonwoven filter fabric for intake air filtration in the IC engine of an off-road vehicle", *ArchiwumMotoryzacji*; 63(4).

[4] Feng ZY.,(2007), "An experimental study of the relationship between resistance and structure of a high efficiency particulate air filter [M.S. thesis]", *China: Tsinghua University* .

[5] Norman Kevin, Shean Huff, and Brian West, (2009) "Effect of intake air filter condition on vehicle fuel economy", *ORNL/021*.

[6] Subrenat A, Bellette J and Cloirec PL, (2003), "3-D numerical simulations of flows in a cylindrical pleated filter packed with activated carbon cloth", *ChemEngSci*; 58(22):4965-73.

[7] QarabRaza Butt, AamerIqbalBhatti, Mohammed Rafiq Mufti, Mudassar Abbas Rizvi, IrfanAwan, (2013), "Modeling and online parameter estimation of intake manifold in gasoline engines using sliding mode observer", *Simulation Modelling practice and theory*; 32:138-154.

[8] Ramasamy, D. "Zamri. M, S. Mahendran, S. Vijayan, (2010), "Design Optimization of Air Intake System (AIS) of 1.6 L Engine by Adding Guide Vane", *Proceedings of the International Multi-conference of Engineers and comport scientists*, Vol. 51.

[9] Chopade, M. R., A. P. Valavade, and S. H. Barhatte. (2012), "Performance Enhancement of Air Filter by Design Optimization", *International journal of Advanced Engineering Technology*, E-ISSN 0976-3945, Volume 3, Issue 1, January – March, Page 68-70.

[10] Hosseinzadeh, Sepideh, MofidGorji-Bandpy, GhasemJavadi Rad, and MojtabaKeshavarz, (2012), "Experimental and Numerical Study of Impact of Air Filter Holes Masking on Altitude at Heavy-Duty Diesel Engine", *Modern Mechanical Engineering* 2, no. 04: 157.

[11] Goud, B Pavan Kumar, and D. R. S Chakradhara, (2014), "Experimental and Numerical Study on Performance of Air Filters for Diesel Engine", *IJESIT*, Volume 3, Issue 6.

[12] West, Nicholas, et al. (2011), "Student Paper Competition: A Numerical Study of Filtering and Control for Scramjet Engine Flow" (2011).

[13] Dipak C Talele, Dheeraj S Deshmukh and Prashant P Boranare, (2015), "A Review on Effect of Air Induction Pressure Variation on Compression Ignition Engine Performance", *IJSBT*.Vol.4, No. 1, Pg-2277-7261.

[14] Mak, C. M., W. Zhang, and H. M. Wong. (2012), "Numerical Study of Pollutant Dilution in a Natural Ventilated Dental Clinic: Ventilation Path Types Used for Exhausting Pollutant" *Biomedical Engineering and Biotechnology (ICBEB), International Conference on. IEEE*.

[15] Andersen, B.O., Nielsen, N.F. and Walther, J.H., (2016). Numerical and experimental study of pulse-jet cleaning in fabric filters. *Powder Technology*,291, pp.284-298.

[16] Feng, Zhuangbo, Zhengwei Long, and Qingyan Chen, (2014), "Assessment of various CFD models for predicting airflow and pressure drop through pleated filter system", *Building and Environment* 75: 132-141.

[17] Balasankar P and Gokhale A,(2012), "Optimization of Automobile Air Cleaner for Effective filter Area utilization using Acusolve CFD".

[18] Yerram, Ravinder, et al.(2006), "Optimization of Intake System and Filter of an Automobile using C FD analysis," *Quality Engineering & Software Technologies (QUEST)*, Bangalore.

[19] Siqueira, C.D.L.R., Kessler, M.P., Moreira, F., Costa, A.D.S., Tamburi, L.E. and Malagutti, R., (2006). Three-dimensional Numerical Analysis of Flow inside an Automotive Air Filter (No. 2006-01-2629).SAE Technical Paper.

[20] Chopade, M.R., Valavade, A.P. and Barhatte, S.H., PERFORMANCE ENHANCEMENT OF AIR FILTER BY DESIGN OPTIMIZATION.

[21] Phupagar AS and Gohel NS,(2015), "CFD Analysis of Air Intake System", *IRD INDIA, ISSN: 2319-3182*, Volume 4, Issue 2.

[22] Koushik, GandikotaSai, and R. Panneer, (2015), "Design and Simulation of a Hollow Cylindrical Ceramic Air filter using Finite Volume Technique", *Indian Journal of Science and Technology 8.23.*

[23]Mullins, Benjamin James, A. J. C. Kinga, and Roger David Braddock,(2011), "Modelling the Influence of Filter Structure on Efficiency and Pressure Drop in Knitted Filters", *19th International Congress on Modelling and Simulation, Perth, Australia. Vol. 7.*

[24]Siqueira, Cesareo de La Rosa, et al. (2006), "Three-dimensional Numerical Analysis of Flow inside an Automotive Air Filter", *No. 2006-01-2629.SAE Technical Paper.*