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RESEARCH ARTICLE OPEN ACCESS

Review on Automotive Air Filter Performances

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ABSTRACT
Air filter system plays a major role in getting good quality air in automobile engines. It improves the combustion efficiency and also reduces air pollution. The work of an air filter is to filter the dirt particles from the intake air and supply cleaner air to the automobile engines. Optimum utilization of filter can significantly reduce the cost of filter replacements frequently and keep the filter in use for longer time. Computational Fluid Dynamics (CFD) is considered to be the most cost effective solution for flow analysis of intake system along with filter media as experimental set up takes time and very expensive. This current paper discusses about the air filter performances criteria for their optimum usage in automobile engines.
Keywords – Air Filter, Air intake system, CFD, Fluid mechanics, Pressure drop, Uniformity Index.

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I. INTRODUCTION

In the beginning of the life of the automobile, oil was cheap and seemed endless. Also no one ever thought about today's major concern like greenhouse gases or global warming. In recent years though, more and more people become aware about these problems and simultaneously the oil prices has increased a lot in past decades too. Considering all these things and continuous up gradation in government policies for reducing pollution in automotive sector leads the consumers to demand for more fuel efficient cars or motor cycle. And this puts the automotive industry under more efforts to improve on majorly 2 areas i.e. packaging & better fuel efficient engines.

Packaging involves optimum usage of space in automobile. But this is not always compatible with the desired performance. To sustain high performance from engines, clean air flow plays a vital role, which is necessary for combustion in engine. This is provided by **Air filter** system. The air supplied to combustion chamber thru air induction system contains various substances of atmosphere. This may damage the engine parts such as piston or cylinder. The role of air filter is to filter out the air containing foreign substances and to reduce the air flow rate in the air filter, so that the noise generated by intake system can be reduced. The air induction system consists of following:

1) An air intake duct, where dirty air enters
2) Case pre filter, where dirt gets accumulated
3) Air filter, where dirty air gets filtered
4) Case post filter, which accumulates the filtered air
5) Resonator, it helps in making engine paradoxically quieter and powerful
6) Air outlet duct, which supplies clean air to engine

The air introduced into the air induction system is sucked into the case through the filter and then transferred to the engine. It is important that the air passes thru the filter should be uniformly distributed. Optimum usage of filter element can reduce the cost of filter replacement frequently and therefore keep the filter in usage for longer time. The Air induction system geometry plays a huge role in understanding the quality of air flow. When the diffuser sucked air in, the shape of the diffuser and the flow around it affects the engine's performance. This is due to the large amount of air gathering characteristics.

Reduction in the fuel consumption results in reducing the pressure losses in the air induction system. The desired air induction system should have high airflows while keeping the minimum pressure losses.

To optimize air induction system, thorough understanding of flows and pressure drop through the system is essential. To predict the flow as well as experiments performed in flow rigs are predicted with the help of many tools. One of the significant tools to predict the same is CFD (computational flow dynamics) analysis. CFD is considered to be the most effective solution for flow analysis of complete air induction system. Here we are focusing on the review of air filter performances criteria for its optimum usage in the motorcycle application.

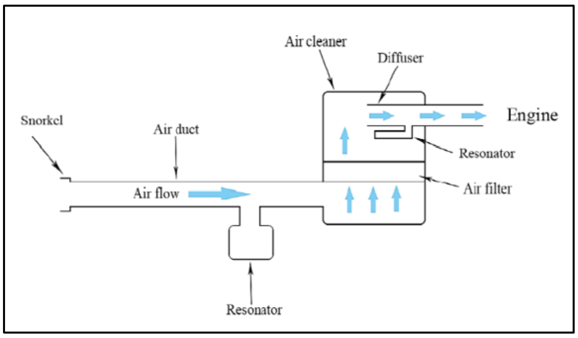

Fig. 1 Simple structural diagram of an intake system

II. TYPES OF AIR FILTER

Air filters are mainly classified on the basis of following 2 categories:

GEOMETRY BASED CLASSIFICATION:

i) Rectangular
ii) Circular
iii) Polygon

MATERIAL BASED CLASSIFICATION:

i) Foam air filters

These filters were used in the very beginning. Foam is a very dense material and hence can be used quite efficiently as an air filter and it does filter out air quite efficiently. Even today in many bikes like dirt bikes which have to handle a lot of dirt, foam air filters are used. The main reason being they are efficient and most importantly are washable and reusable. They do not cost a lot, but they are quite expensive compared to paper filters, but they are reusable by washing and hence are quite value for money in the long run. Some of them even come in an oiled variant so that they can work even better since the oil helps capturing more minute particles in it being sticky.

ii) Paper air filters

These are the cheapest, widely used and most easily available filters. Many of the modern single cylinder engines uses this type of filter because it's cheap to get, easy for maintenance and can be disposed off after a certain amount of run depending upon how dirty it has become. Maintenance is very easy because all one needs to do is blow a little pressurized air on it to clear the dust caught in it. These types of filters are not really efficient in very dirty conditions which could cause issues. Hence they are mostly used on commuter's bikes/scooters; which are meant to be used on the highways and regular roads and not for any of the off-roading bikes because the huge dirt particles would easily clog up the system and could rupture the paper element.

iii) Cotton air filters

These are the best performers and the most expensive in the list. Cotton air filters are actually made of cotton fabric which is strong, breathing material and fine enough to filter the air really well. They are used mainly in the performance bikes because it allows for the best air filtration and that too at a very rapid rate which allows for better performance of the machines. Maintenance of these filters is easy.

Fig. 2 Types of Air filters

III. DESCRIPTION AND MAIN FUNCTION OF AIS

The AIS has following basic functions:

a) To arrest maximum proportion of dust from entering the engine
b) To offer minimum restriction to the intake air flow to the engine
c) To have large dust holding capacity to increase the element cleaning interval
d) Dampen the intake noise by designing the filter to act as a reflection sound absorber

To generate the power to crankshaft; the combustion chamber of engine needs air as well as fuel. The air is guided by AIS to the combustion chamber. Depends upon the type of vehicle; the location of AIS is defined. The amount of air needed in the combustion chamber depends on many factors but mainly it depends on the speed and acceleration of the engine. When the vehicle accelerates from low to high rpm; the fuel consumption is high. And therefore the amount of air (or oxygen) needed inside the combustion chamber is also high. The amount of air is mainly controlled by ECU in the engines.

The second purpose of AIS is cleaning of the incoming air from particles like sand, leaves etc. This is done by using air filter inside the filter box. The standard requirement of air filter filtration is approx. 99.8% of the incoming air. Air filter also helps in reducing the noise from the engine. A concept image of AIS is shown below for understanding point of view where air velocity is denoted by U_∞. In actual application, the design and layout may differ.[1]

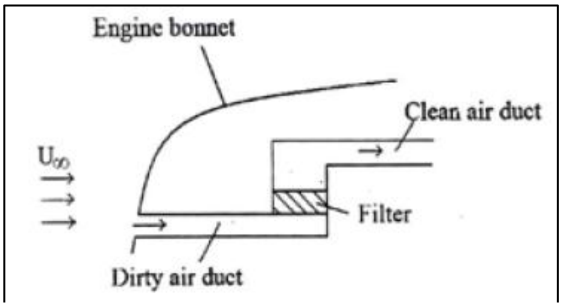

Fig. 3 Concept image of AIS [1]

IV. LITERATURE REVIEW

K.L.Srinivasulu [2] describes the design and analysis of air filter by using CFD analysis tool. Here to improve the flow characteristics within the AIS; it was decided to use rectangular type filter and there will be a change on baffle placement inside the inlet plenum of the filter. The result of the analysis shows clearly the large pressure drop was presented with large recirculation zone. But to reduce the large pressure drop in the existed design of filters, the baffle plates are proposed in different positions in order to improve the percentage of reduction in pressure drop up to 14%.

Hoseop Song [3] in his paper describes the optimized diffuser shape to provide the efficient engine. In order to confirm the flow characteristics, flow noise and pressure drop of the air cleaner, a normal air cleaner without shape change was investigated through finite element analysis. The air introduced through the inlet rotates along the wall of the upper box through the filter and shows the shape sucked through the diffuser. Analysis was performed by assuming the flow inside the air cleaner as an incompressible perfect turbulent flow and by using the stabilized and the most frequently employed k-ε realizable model for reproduction of a turbulent flow.

M. R. Chopade [4] also explains in his research paper about the performance enhancement of air filter by optimization of the AIS design. The author studies the reduction of pressure drop across the filter by making the housing eccentric to the casing. Here casing is a cylindrical element used to protect the filter and the housing and provides the annular space for the movement of the air.

Chang Ming Tsang [5] in his thesis investigated the factors influencing the pressure drop and flow pattern across pleated air filters by doing a numerical study. In this with the help of FLUENT and numerical analysis, it is examined the effects of air velocity, geometry, shape and shape of filter pleat on the filter pressure drop.

Below in fig. 4; the pressure drop is compared with the pleat shape and pleat count.

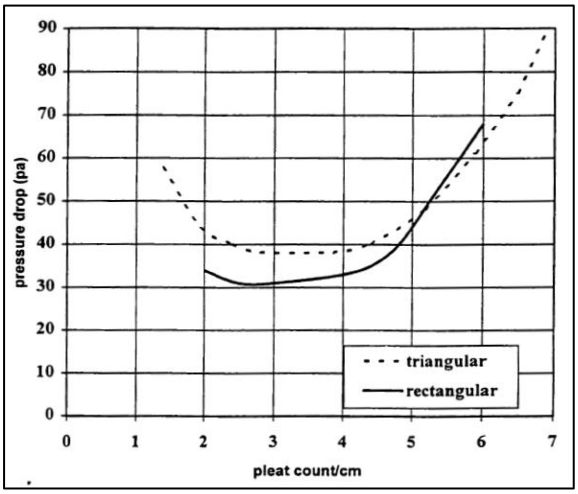

Fig.4 Pleat shape effect on pressure drop, pleat height 1.3 cm, inlet velocity 1m/s [5]

M. A. Abd Halim [6] in his paper discusses explicitly the flow characteristics of air flowing inside the air box of a 4-stroke motorcycle and its effects on pressure drop. The direction of the flow is from the atmospheric to the outlet clean pipe connected to the throttle body. A numerical investigation of the flow in the standard air cleaner was conducted using the ANSYS Fluent κ-ω SST turbulence model. The CFD simulation results were validated using a commercial flow bench. The characteristic flow features upon volume in Cubic Feet per Minutes (CFM) changes and the total pressure of air entering the throttle body are the parameters of interest.

The fig.5 shown below is the outcome of the paper. It shows the pressure drop increases as the volumetric air flow rate CFM increases. The pressure drop difference is very small at low CFM.

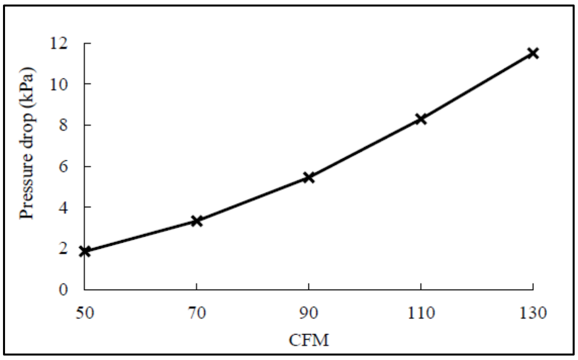

Fig. 5 Pressure drop Vs CFM [6]

R. Manikantan [7] also explain the flow characteristics of the air filter by modeling and analyzing the model thru CFD tool and same has been verified with the experimental set up. The simulation condition is tested over the benchmarked product. And on the basis of constant conditions the simulation results in the deficit on the current design. The intake passage then re-arranged to provide upward tangential motion, which enhanced the removal of largest dust and soot particles effectively by inertial action of the air alone.

The graph shown below (Fig. 6) depicts the pressure drop results comparison between simulation vs experimental data. It shows up to 8 m/s exit velocity the results are reasonable comparable.

However at 10 m/s and 12 m/s; the difference in result may be attributed to the lower resistance offered by permeability factor used in the calculations. It is clear as the velocity increases the pressure also increases.

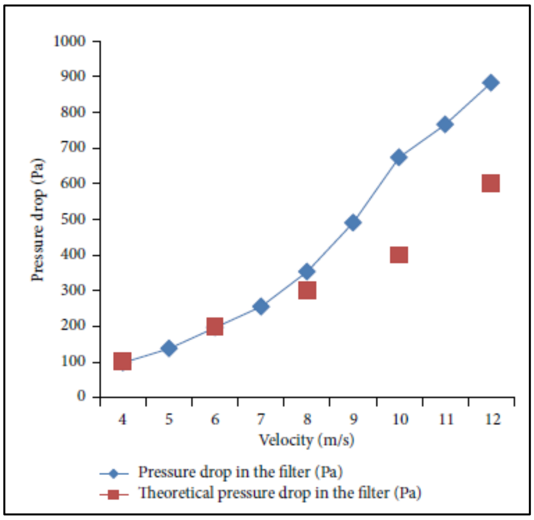

Fig.6 Pressure drop Vs Velocity [7]

Yang An-jie [8] studies about the effects of different air filters on the performance of a single cylinder diesel engine. In this article two types of filters were tested and results compared accordingly. Type A is the traditional one air filter. Type B is the newly designed oil bath type composite air filter. Then the test carried on both the cases including one case, where no filter has been used. The focus is mainly to analyze the maximum engine power, Fuel consumption rates, Exhaust emissions, Smoke emissions, Torque etc. under different test conditions. The test results shows that the newly designed oil bath composite air filters significantly improve the power and economy. And also lowers the emission smoke level. The maximum power increased by 5.5% in type B air filter.

G. Nagarajan [9] presents a numerical study of air filters used for off highway vehicles. The tool used for the analysis is FLUENT. Mainly 2 filters are used in off highway vehicle i.e. primary and secondary air filters. The pressure drop observed in the filters is well agreed thru the experiments too. Primary filters are cyclonic type filters while the secondary filters are consist of filter medium for fine dust similar to a single cylinder engine air filters. The primary filter geometry is modeled in detail; whereas for secondary air filter, it is modeled as porous filter medium. The results mainly in term of pressure drop w.r.t. flow velocity are shown below (Fig. 7). The same results are comparable with the experimental values.

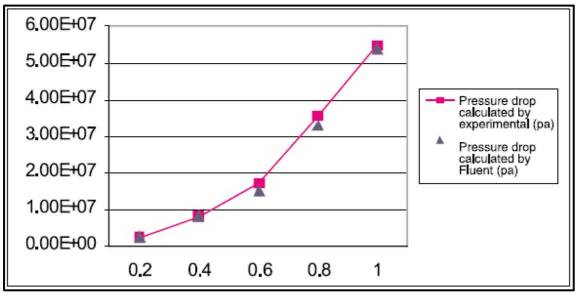

Fig.7 Pressure drop values for different flow velocities [10]

George A Brown [10] in his paper compared the simulated and measured pressure drops for heavy duty air filters. K-ε turbulence model has been used to solve the governing equations of air flow in the passages. Also this paper states the reduction in the development cost of the filter by using the CFD tool for analysis rather than experimental set up every time. In first phase of the program, it is important to develop a filter medium model which can take the input data of fiber, proposed medium processing etc. and predict the medium characteristics. In the second phase, it is required to develop a pleated structure model which can take input data in the medium together with geometry data on the structure to predict the cartridge characteristics. The detailed structure of both filters used in this program is also mentioned. With the geometrical details of both the filters mentioned in the paper; the static as well as stagnation pressure drop comparison (Simulation Vs Experimental) data is provided below.

The filter model used to predict the pressure drop employs a turbulent flow model everywhere except for the cartridge. For cartridge the Darcian material model has been used. The boundary conditions are defined in [10]. By execution of the same; the results predicted.

Xinpeng Wang[11] discussed about the relationship between filter efficiency and pressure drop with the porosity, fiber diameter and thickness of filter. And it found in the study that filter efficiency has an exponential relationship with the porosity, fibre diameter and thickness of filter. However pressure drop has a linear relationship with filter thickness but exponential relationship with filter porosity and fiber diameter.

Lizheng Ma [12] performed a simulation based flow optimization of Diesel particulate filter (DPF) system. Mainly in this study the geometry & swirl component of the inlet flow is optimized to improve flow uniformity of filter and to decrease overall pressure drop. In the study, the diameter of the filter, inlet and outlet pipes are standard. Therefore the geometry of the cone (it joins the inlet and outlet pipes to the cylindrical filters) can be optimized to increase the use of the filter.

In this paper, the filter is assumed to behave as an isotropic material and therefore the Darcy's law easily conveniently utilized. Flow distribution and pressure drop across the system are the main parameters other than the filter that affect the performance of DPF system. As discussed, the size of the filter and diameter of inlet and outlet pipes are fixed. Therefore, only the geometry of the cone diffuser and nozzle can be optimized to increase the use of the filter.

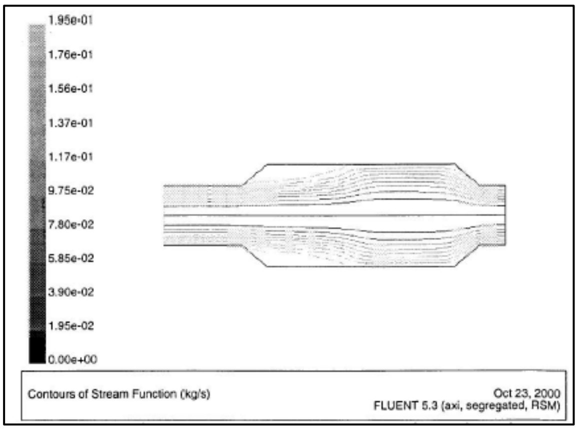

Fig.8 Contours of the stream function in the original DPF system [13]

In Fig. 8; it clearly shows that due to sharp corners, the flow separates and creates vortices. This recirculation zone reduces the effective working area. The air flows at higher velocity in the center and lower velocity near the walls through the filter. This non- uniform of flow reduces the filter's utilization area. Due to this the pressure drop is reduced very rapidly along the axis due to the filter.

However the DPF system with USF (Unipolar sigmoid function) shape improves the flow uniformity in this system. In this system, to modify the sharp corners into smooth corners results in better uniform flow. The streamlines follow the shape and no recirculation zone is generated.

R. D Sabnis [13] understands and studied regarding the problem in performance repeatability measurements in the panel filter universal test housing specified by the SAE J726 air cleaner test code. During trails; it has been noticed that the flow inside the housing was very turbulent, recirculating and separated from the walls. The filter received non uniform flow velocities. The center of filter received higher velocities than the sides. Calculations predicted that for larger particles the filtration efficiencies for uniform flow distribution are better than non uniform flow distribution. For small particles the filtration efficiency decreases for the uniform flow distribution.

The objective is to calculate the filtration efficiency with different sizes of particles being filtered by clean filters subject to uniform as well as non uniform measured flow distribution. The three important mechanisms of filtration are also explained as below:

- **Diffusive filtration:** In this process the particles settle down on the fibers due to Brownian motion; known as diffusive filtration. Applicable for particles below 0.2 microns.
- **Interception filtration:** In this a particle following the streamline of fluid flow gets

attached to the fiber and separated from the flow. The mass is ignored, if interception filtration considered alone.

- **Inertial Impaction:** If a particle with inertia deviates from the flow streamline due to its inertia and intercepts a fiber; then it is termed as inertial impaction. If assumed it alone, then the particle mass is assumed to be concentrated at a point. However the particle size is ignored.

AL Sarkhi [14] also describes the filter housing design optimization with improved performance and filtration efficiency. In this the filter housing geometry has been designed optimally to provide a user specified velocity distribution through the filter. Controlled flow filed across the filter can improve the filter efficiency. A computational optimization method is used to minimize the pressure drop variation along the filter by modifying the geometry of upper wall of the housing. For viscous laminar flow, the CFD calculations performed in the upstream and downstream of the filter by two dimensional Navier Stoke's equations. The upper wall profile has been numerically changed results in the repetition of CFD computations and the re evaluation of pressure drop until an optimum configuration is achieved. The optimization results produced a pressure drop, which is very close to the specified uniform distribution.

With the defined filter housing configuration and the boundary conditions the CFD calculations as well as experimental tests done. The pressure drop across the filter is a function of flow rates at all the ports along the filter.

Xiaogang Zhang [15] studied the numerical optimization of the flow uniformity inside the DPF. To achieve the desired performance and life of filter system, the uniform flow inside the filter system is critical. This study mainly focused on the effects of spiral rib inside inlet tube, inlet and outlet cones, length and angle of inlet cone. By adding single spiral in the inlet tube in front of diffuser (inlet cone) shows no improvement in uniformity flow. The results get even worse by adding single deeper rib. On the contrary, the pressure drop increases rapidly. The flow uniformity index could be improved by increasing number of ribs and this leads to higher pressure drop than that of without spiral rib but much lower in comparison to single rib geometry. The inlet cone has more effect on uniformity index in comparison to outlet cone on the basis of results.

Hongliang Wang [16] also explained about the numerical based analysis to study about the flow characteristics of the filter system due to the front intake pipe. The original model has been analyzed numerically and then on the basis of the results a new proposed model analyzed for better results. And it was found that the flow characteristics have been improved significantly.

The pressure drop in improved profile is lower as compared to the initial model. The pressure drop before improvement was 1880 Pa; which comes to 444 Pa after the improvement in intake pipe. Also the pressure distribution is more uniform. Based on the numerical analysis; the pressure drop significantly reduced, the intake resistance is also reduced and the internal flow movement is more in line with the flow characteristics of the gas.

There is also a strong back flow at the entrance corner of the model, and local negative pressure still exists. This will produce a further resistance loss. To improve the intake resistance and the flow characteristics, there is still further optimization required in the inlet pipe.

Han Bo Ronald Gan [17] describes about the improvement of AIS for the proton iris vehicle. A turbulent flow is caused due to the geometry of the air box and air filter. This turbulent flow results in the pressure drop within the air box; which would lead to a decrease in the performance of the engine. The simulation is done in simulation software with complete AIS while the pressure drop within this flow was observed and analyzed. And these simulation results are compared with the experimental data and the simulation results were found within the acceptable limits. To solve the pressure drop problem inside the air box, the hypothesis was made that the geometry of the AIS is the root cause of pressure drop and it occurs where the flow begins to transform from laminar to turbulent. Three design improvements have been made to the existing AIS design and were simulated. The simulation results show an improvement of about four percent for the 1st design, three percent for the 2nd design and two percent for the 3rd design improvement.

V. CONCLUSION

From the review of literature, different findings are concluded as mentioned below.

- Air filter is the integral part of AIS that helps in the filtration of air for better combustion of fuel in the combustion chamber of automobile engines.
- Air intake through the Bell mouth of inlet pipe results in low acoustic and pressure drop.
- Parameters affects the air filter performance are as:
  - ✓ Shape of the air filter & filter pleat
  - ✓ Position/geometry of the air filter or AIS
  - ✓ Material of the filter element
  - ✓ Air velocity

- ✓ Cross section and area of inlet pipe for air flow

- ➢ The pressure drop increases as the volumetric air flow rate CFM increases
- ➢ Higher velocity air into the filter results in aerosol particles penetration into the filter element. This results in the drop of filtration efficiency and therefore higher pressure drop across the filter.
- ➢ Higher flow velocity at exit results in higher pressure drop however at lower flow velocity the pressure drop is also reduced.
- ➢ Due to larger particles penetration into the filter, the filtration efficiencies for uniform flow distribution are better than non uniform flow distribution. For small particles the filtration efficiency decreases for the uniform flow distribution.
- ➢ Pressure drop has a linear with the filter thickness but exponential relationship with filter porosity and fiber diameter.
- ➢ The flow uniformity index could be improved by increasing number of ribs in the inlet tube and this leads to higher pressure drop than that of without spiral rib but much lower in comparison to single rib geometry.

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