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Optimization of Air Filter in an Automobile Diesel Engine by Using CFD Analysis

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Abstract: *Air filter system play major role in getting good quality air into automobile engine. It improves the combustion efficiency and also reduces air pollution. Our project focuses on optimizing the geometry of an Air filter in automobile industry to reduce the pressure drop and enhance the filter utilization area. 3D viscous CFD analysis was carried out for an existing model to understand the flow behavior through the air filter geometry and filter media. Results obtained from CFD analysis of the existing model showed good correlation with experimental data. Based on existing model CFD results, geometrical changes like baffle placement in inlet plenum of the filter, optimization of mesh size, removal of contraction in clean pipe of intake system etc are carried out, to improve the flow characteristics. The CFD analysis of the optimized model was again carried out and the results showed good improvement in flow behavior, better filter utilization with considerable reduction in pressure drop and significant reduction in re-circulation zones of the air filter geometry. By using 3D CFD analysis, optimal design of the air filter system for an automobile engine is achieved with considerable reduction in development time and cost.*

Keywords: *Air filter, Baffle plates, Solid works, CFD, ICEM, SIMPLE etc.*

I. Introduction Of Air Filter

The engine of a car needs air for the combustion process in the cylinders. It is required for the air to be as clean as possible in order for the engine to be as efficient as possible. Hence the air must in some way be "cleaned" before it enters the combustion chamber. The system that cleans the air and guides it into the cylinders is called an Air Intake System (AIS). The AIS may be divided into three main parts: an inlet and intake section in which the incoming "dirty" air is guided into, a filter box section where a filter is located that cleans the polluted air and hinders soot and other particles from entering the cylinders, and an inlet to the engine where the clean air is guided to the cylinders.

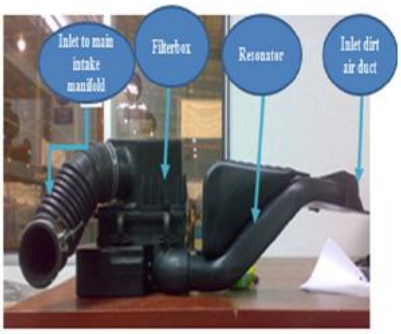


Fig.1.1 Basic air intake system

1.1 Description and Main Functions of an Air In Take System

1. Guide incoming air into the engine
2. Clean the air from dirt

The man purpose of the AIS is to guide the incoming air to the cylinder in which the air will take part in the combustion process. It is located in the front part of the engine room under the bonnet, directly behind the front grill where the company emblem is mounted. How much air that is needed for the combustion process is influenced by several variables but mainly one can say that speed and acceleration contributes the most to the need for air. If a car accelerates from low to high speed, the fuel consumption increases and hence the engine needs more oxygen (air). This unit is very sensitive to water and if exposed to water it might malfunction and thus give wrong air flow rates to the engine. The second purpose of the AIS is to clean the incoming air from particles such as sand, ' leaves, snow etc. This is done by using a filter in the filter box section in which the dirt will be trapped, and the standard requirement of a filter is to clean 99.8 % of the incoming air. A secondary function of the filter is to reduce noise from the engine. A graphical description of the system is viewed in the fig where U_ denotes the air velocity generated by the speed of the car. Note that this image is a general description of an intake system. In real life the intake system may come in different shapes and variations.

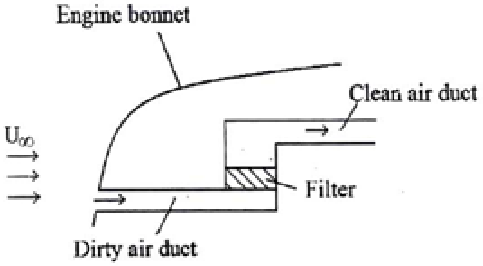


Fig.1.2. Concept image of an air intake system

The intake system that is used to develop the ingestion model is in production and installed in The Malaysian National car (Proton Waja) diesel engine and has been on the market for several years. It is located just behind the front grill under the bonnet of the car close to the engine compartment, as shown in Fig below. The system is divided into three sections and are numbered in the figure, which indexes denotes
1. Inlet and intake section
2. Filter box section
3. Inlet to main engine

A photograph of the engine compartment taken from below. The inlet and intake section is located in the bottom left in the figure from which the air is guided into the filter box section, indicated by the first arrow pointing to the right. The air is then led through the filter, located in the black box but is not visible, to the inlet to the main engine as shown with the arrow pointing to the left. Note that the most of the inlet part is covered under the grey plastic engine shell. A second intake, but not visible in the figure, is present in the AIS and is located at the other end of the filter box section to where dirty air enter. It is used as an alternative intake if the primary intake will be filled with too much snow or dirt and is unable to guide the air to the engine.

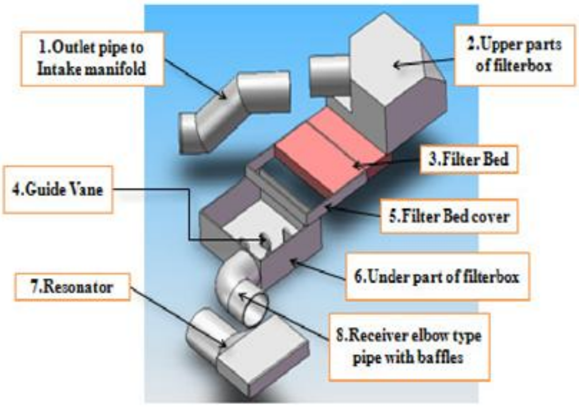


Fig.1.3. Filter box section

Fig .1.4.AIS located under the bonnet

II. Specification of the Problem

The objective of the present work is to design and analysis of air filter by using CFD analysis. The exciting model flow behavior is not in uniform in air filter media then pressure drop is increases. The new model of the air filter geometrical changes of the components like Baffle placement in inlet Plenum of the filter , optimization of mesh size, Removal of contraction in clean pipe of intake system etc.. are carried out . Then to improve the characteristics of the flow.

III. Introduction To Cfd

The physical aspects of any fluid flow are governed by three fundamental principles:
1) Mass is conserved; (2) Newton's second law (force = mass x acceleration); and 3) Energy is conserved. These fundamental physical principles can be expressed in terms of basic mathematical equations, which in their most general form are either integral equations or partial differential equations. Computational Fluid Dynamics (CFD) is the process of replacing the integrals or the partial derivatives in these equations with disc retied algebraic forms. Which in turn are solved to obtain numbers for the flow field values at discrete points in time and or space. The solution methods are mesh-based. Where the equations are discredited in either Finite-difference, finite-volume or finite-element form. The mesh itself must be defined by the user so that it represents the geometry of the flow domain of interest. Equations for velocity components, Pressure. Temperature and contaminant Concentration are solved at each of the small volumes (called cells or elements) defined by the mesh.

In the 70s, due to the limitation of the algorithms and the high cost of computers, CFD was used almost exclusively in aircraft and nuclear power industries. Also, the storage and speed capacities of digital computers were not sufficient to allow CFD to simulate any complicated three-dimensional geometry. Today, however, this story had changed substantially due to the developments in areas of numerical analysis and in faster and lower-cost computers. In today's CFD, three-dimensional flow field solutions are abundant; they may not be routine in the sense that a great deal of human and computer resources are still frequently needed to successfully carry out such three-dimensional solutions, but such solutions are becoming more and more prevalent within industry. Indeed. Modern CFD cuts across the disciplines where the flow of fluid is important, and is increasingly becoming a vital component in the design of industrial products and processes.

One such area is concerned with the design of cartridge air filters. Cartridge air filters are used in a variety of industry applications. Including automobile air inlet, home furnaces and air conditioners, etc. Cartridge air filters come in a variety of shapes; the two most popular configurations found in practice are tie rectangular panel filter and the cylindrical filter In general, cartridge air filters have several features which distinguish them from other types of air filters. They have two basic components: housing and a module. The housing holds the filter module and fluid being filtered. It may be permanently mounted onto a piece of equipment or disposable. In contrast to some other types of filters, the filter module is removable. The module consists of filter medium, seals, and related support materials. The filter medium is the hem of the cartridge filter since it performs the actual separation. Pleated filter medium is often used to increase the effective area of filtration, so reducing the filter medium face velocity and thus the pressure drop across the filter medium. Seals ensure that unfiltered fluid is not allowed to bypass the filter medium. Additional support material is often required to maintain the physical integrity of the medium. Through the years the design of cartridge air filters has usually been based on laboratory testing: prototypes are built, tested and modified until a 'best' design is obtained. Although laboratory testing is an invaluable tool of the designer, it suffers a. number of drawbacks. Building and testing prototypes is in most cases expensive, time consuming, and often the testing results do not tell the engineer why a design change is having the observed Effect on performance.

CFD techniques have the potential to allow the effect of a proposed design change to be evaluated relatively quickly. A computational investigation can be performed with remarkable speed and the cost of a computer run, in most applications. Lower than the cost of a corresponding experimental investigation. The output from CFD codes gives detailed and complete information. It can provide the values of all the relevant variables (such as velocity, pressure, temperature, concentration, turbulence intensity) throughout the domain of interest. A designer can study the implications of hundreds of different configurations in a short period of time and choose the optimum design.

IV. Specification Of Air Filter

4.1.1 Specifications of Air Filter:
(Rectangular air filter)

1.Dimensions:
Rectangular air filter - length - 201 mm
Rectangular air filter - Width -220 mm Rectangular air filter - Height – 44 mm

Cross sectional area of pipe - 0.03756 m^2.

2. Meterial: - Stain Less Steel

3. Baffle Plate

Length of curvature : 92 mm
Available of Height s : 38, 43, 48 ,53 in mm
Available of Angles : 50^0 60^0 70^0 75^0

3.1.2. Boundary Conditions:

1. Inlet conditions

Pressure = atmospheric pressure

2. Outlet conditions

Mass flow at 6000 r.p.m = 312 kg/hr

3. Air properties

Density = 1.12 kg/m^3
Viscosity = 1.94 $x10^5$ kg/m-s
Filter porosity = 0.85

V. Analysis Of Air Filter

5.1.1.Loads and boundary conditions

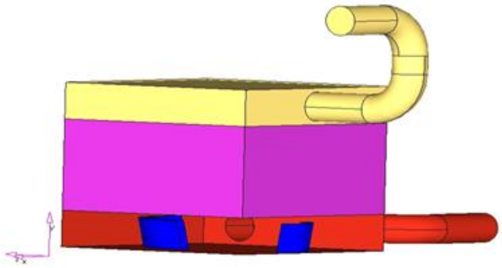


Fig 5.1.1 Loads and boundary conditions

5.1.2. Cfd Meshing

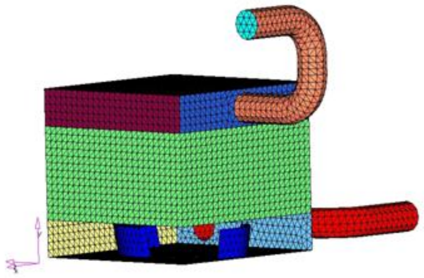


Fig.5.1.2. Surface mesh

5.2: Standard Model

5.2.1: Velocity Contour Plot

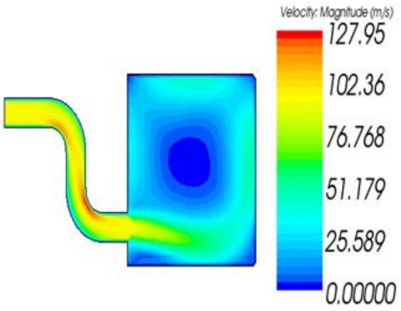


Fig. 5.2.1: Velocity Contour plot

5.2.2 Velocity Vector Plot

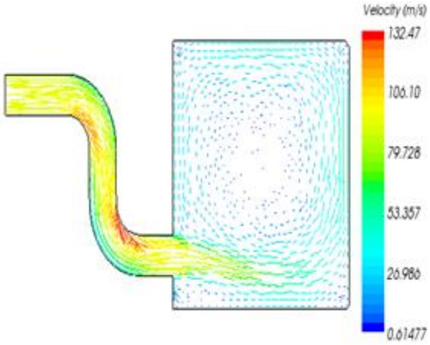


Fig.5.5.2: Velocity Vector plot

5.2.3: Stream Lines flow contours for full domain and inlet section

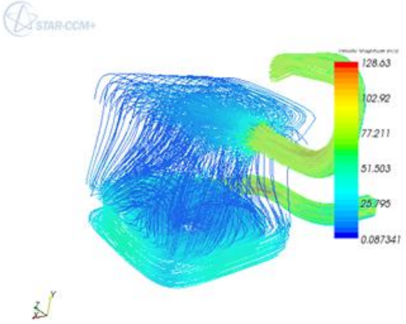


Fig 6.1.2 Meshing

Fig. 5.2.3.1: Stream Lines flow contours for full domain

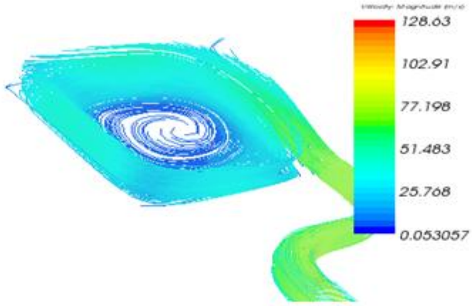


Fig. 5.2.3.2: Stream Lines flow contours for inlet section

5.2.4: Pressure Plot along the Porous:

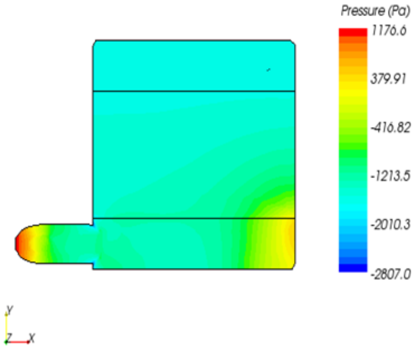


Fig. 5.2.4: Pressure Plot along porous

5.2.4.1: Residual plot

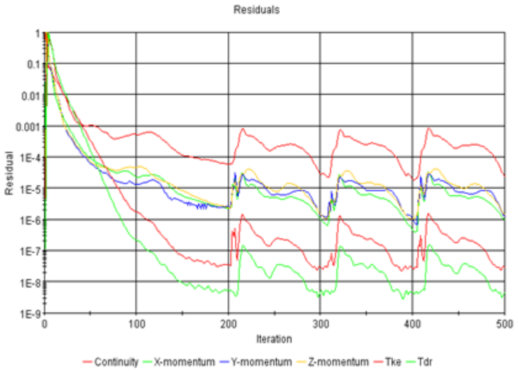


Fig. 5.2.4.1: Residual plot

5.3: Baffle Design-1

5.3.1 Velocity Contour Plot

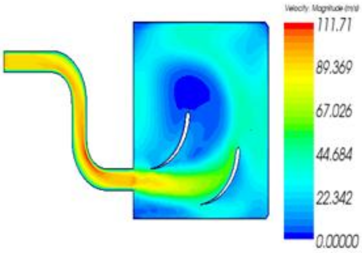


Fig.5.3.1 Velocity Contour Plot

5.3.2: Velocity Vector Plot

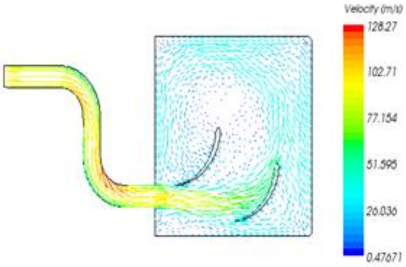


Fig.5.3.2: Velocity Vector Plot

5.3.3 Stream Lines flow contours for full domain and inlet

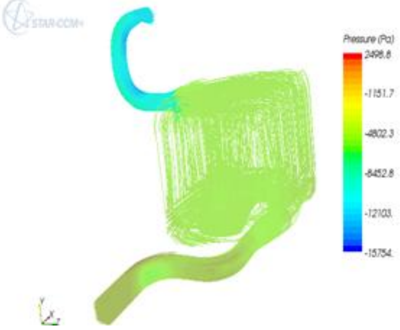


Fig. 5.3.3: Stream Lines flow contours for full domain

5.3.4: Stream Lines flow contours for inlet section

Fig. 5.3.4: Stream Lines flow contours for inlet section

5.3.5 Pressure plot along the porous:

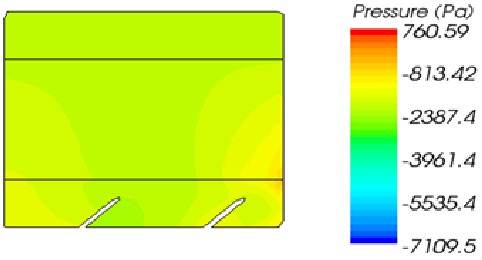


Fig. 5.3.5: Pressure plot along the porous

5.3.6: Residual plot

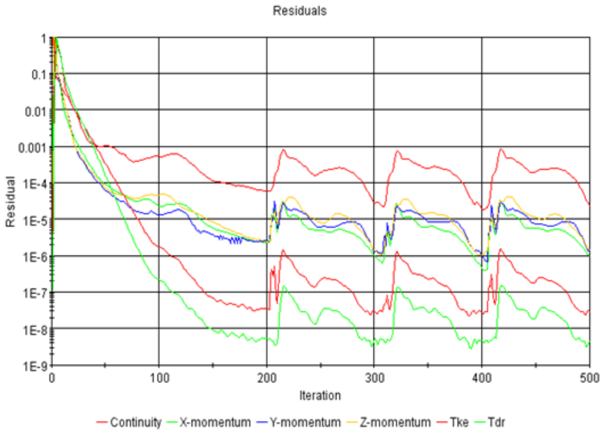


Fig. 5.3.6 Residual plot

5.4: Baffle Design-2

5.4.1: Velocity Contour plot

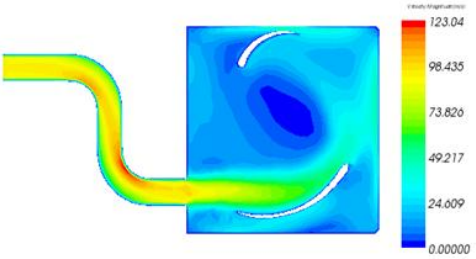


Fig. 5.4.1: Velocity Contour plot

5.4.2 Velocity vector plot

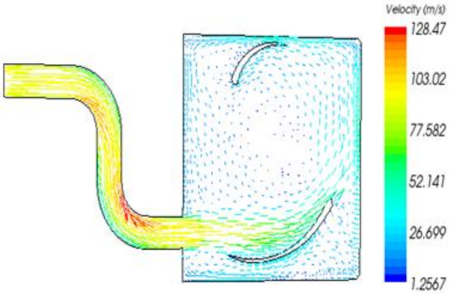


Fig. 5.4.2: Velocity vector plot

5.4.3 Streamlines plot along domain and inlet section

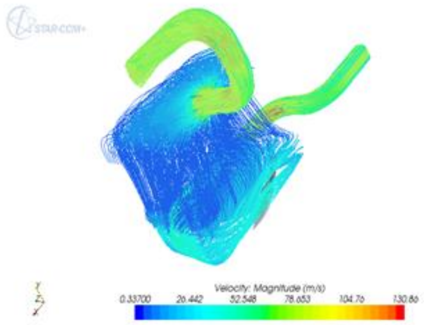


Fig. 5.4.3. Streamlines plot along domain

5.4.4 Streamlines plot for inlet section

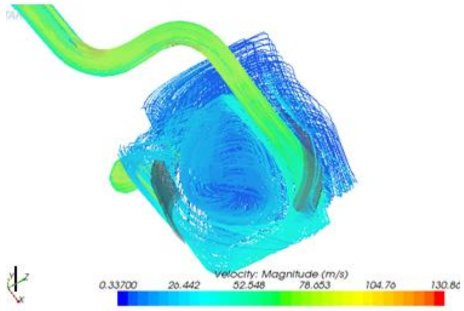


Fig.5.4.4 Streamlines plot for inlet section

5.4.5 Pressure plot along the porous

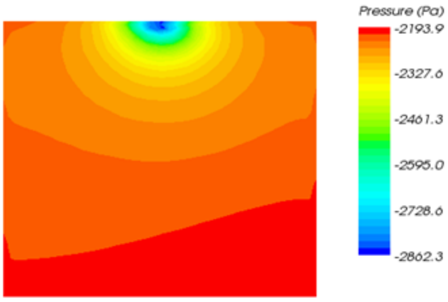


Fig. 5.4.5 Pressure plot along the porous

5.4.5 Residual plot

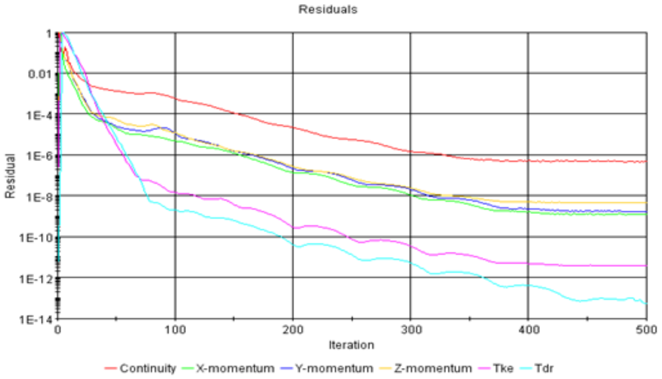


Fig. 5.4.5 Residual plot

5.5: Baffle Design-3

5.5.1: Velocity contour plot

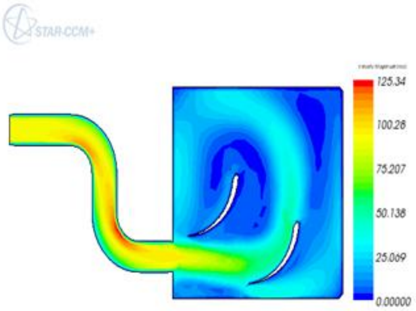
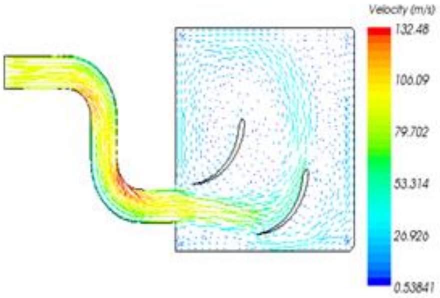


Fig. 5.5.1 Velocity contour plot

5.5.2 Velocity vector plot



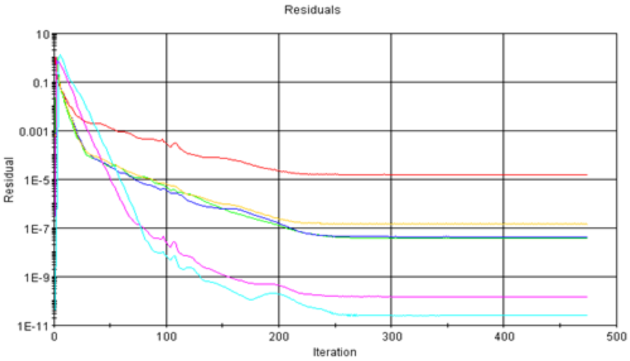


Fig. 5.5.2 Velocity vector plot

5.5.3: Stream lines plot for domain

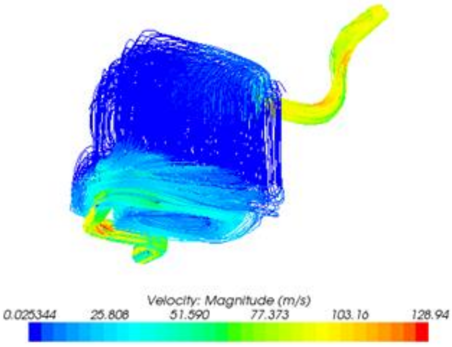


Fig.5.5.3: Stream lines plot for domain

5.5.4 Pressure plot along the porous:

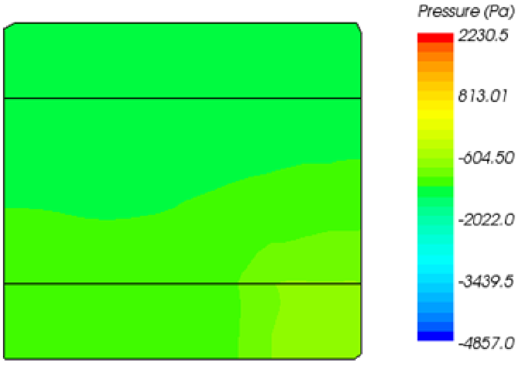


Fig. 5.5.4. Pressure plot along the porous

5.5.5 Residual plot

Fig.5.5.5 Residual plot

5.6: Baffle Design-4

5.6.1: Velocity contour plot

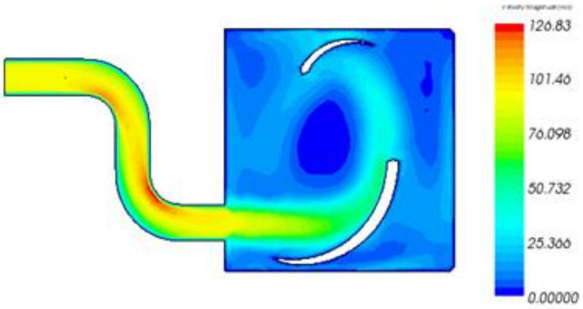


Fig. 5.6.1 Velocity contour plot

5.6.2 Velocity vector plot

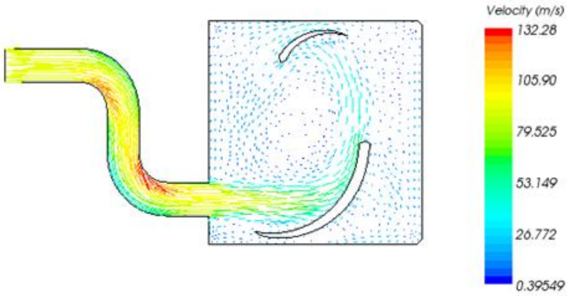


Fig. 5.6.2 Velocity vector plot

5.6.3: Stream lines plot for domain

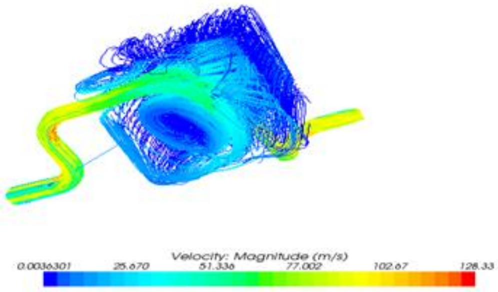


Fig.5.6.3: Stream lines plot for domain

5.6.4 Pressure plot along the porous:

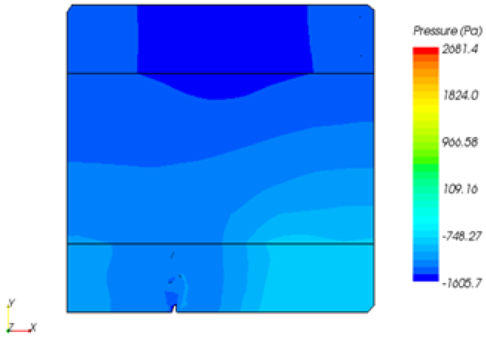


Fig. 5.6.4. Pressure plot along the porous

5.6.5 Residual plot

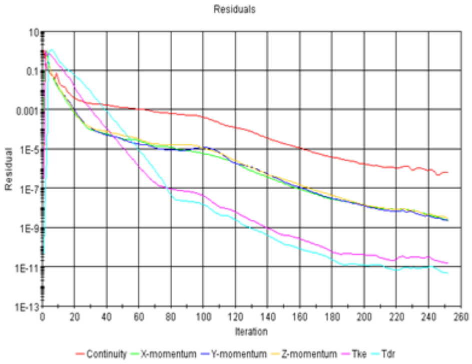


Fig.5.6.5 Residual plot

VI. Results

The pressure drop values for the standard case A and other baffle plate arrangement or other designs (case B,C,D and E) are tabulated below.

Table:6.1 Comparative pressure drop values at different cases

case	Pressure drop(pa)	Improvement(reduction) %
A	437.456	0
B	409.08	6.485695
C	392.677	10.23623
D	384.342	13.52613
E	372.798	14.78046

VII. Graphs

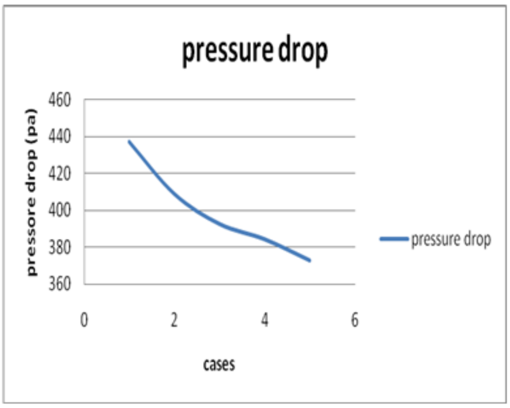


Fig.7.0 Cases Vs Pressure drop

VIII. Conclusions

In this Project simple filter with out having any baffles in the inlet portion was analyzed by using CFD STAR-CCM+. From the result of this test shows clearly the large pressure drop was presented with large recirculation zone. But to reduce the large pressure drop in the existed design of simple filters, here baffle plates are proposed in different positions in order to improve the percentage of reduction in pressure drop up to 14%.

From the above five cases, the case E giving less pressure drop with smaller recirculation zone. This because of this baffle design has more curvature gradual slant height, so that the flow gets more guidance.

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Text Books

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2. Computational Fluid Dynamics by T.J.Chung.