

Design and Development of An Integrated Cyclone-Based Cabin Dust Removal System for Automobiles

Jeevan Ealias¹, Arjun K², Ameen Suhail³, Muhammed A M⁴,
Mehzin Muhammed Kabeer⁵

¹Assistant Professor, Department of Mechanical Engineering, Ilahia college of Engineering and Technology

^{2,3,4,5}Undergraduate Student, Department of Mechanical Engineering, Ilahia college of Engineering and Technology

Abstract

One of the problems of the passengers is accumulation dust in cabin. It also affects the internal purity and cleanliness of air. These dust particles build on the air filters of air-condition system and influence the working of air-conditioning system. The conventional technique of dust removal system cannot be applicable because of shortage of time, time deposition and low filtration capacity of the dust. This study focusses on the design and development of an automobile cabin dust removal vacuum system based on the use of cyclone design is proposed with the aim to extract dust periodically in selected areas of the interiors of an automobile with minimal human intervention.

The proposed system in this study is designed using a small vacuum system and a cyclone separator with the centrifugal force separating dust particles in the airflow and the filter does not clog as often. The dust-contaminated air is collected by strategically placed suction inlets, processed in the cyclone unit and dumped in a removable dust collection bin, whereas the clean air is recycled or released in a safe manner. The system is planned to work at irregular intervals, either manually or timed control mechanism, which will necessitate less power use, and minimal effects on the electrical system of the car. It is concentrated on simplicity, cost-effectiveness, and its ability to fit into the current automotive parts. The suggested design will prove the possibility of incorporating an internal dust cleaning system in automobile cabins as the suggested system should provide better cabin hygiene, better passenger comfort, and less reliance on manual cleaning operations.

Keywords: Cyclone Separator, Automobile Cabin Dust Removal, Vacuum Cleaning System

1. Introduction

The health of the internal cabin in automobile is affected by the hygienic air in the cabin, and overall driving experience of the passengers. The modern cars are drawing more attention towards the interior style, thermal comfort, and air conditioning. However, the accumulating dust in the cabin has been a problem that has not been discussed extensively. The dust particles enter in to vehicle through open doors and windows, through ventilation, footwear and exposure to the outside environment. With time,

these dusts accumulate on interior surfaces including seats, dashboards, floor pads, door panels, and air vents among others, as a result of which cabin hygiene is compromised and occupants experience discomfort. The rate of dust deposition is quite high in most regions particularly in the urban and semi-urban areas where the traffic is high and the roads are in poor condition. The long-term effects of dust include allergic reactions, breathing issues, and unpleasant smells in the cabin. Modern vehicles have cabin air filters and air conditioning units, but they are majorly meant to filter the incoming air and not to actively trap dust that has been accumulated in the cabin. Consequently, cleaning of the inside is normally done by hand when they use handheld vacuum cleaners or when they do periodic servicing of their vehicles, which is time consuming and relies on the effort of the person. A dust removal system that is integrated and run intermittently as opposed to continuously will offer a great deal of relief in regard to the amount of manual cleaning surrounding and at the same time keep the interior atmosphere clean. Such a system should be small, power-efficient, and affordable and should be able to work with the current automotive architectures.

This study proposes the design and development of an automobile cabin dust removal vacuum system, which will be based on cyclone. The suggested system makes use of strategically installed suction inlets in the cabin, through which the air full of dust is collected and passed through a cyclone separator system. The cyclone separator uses centrifugal forces to separate dust particles with the air flow and therefore collects dust efficiently without clogging of filters regularly. The dust removed is put in a removable collection bin and the required clean air is either re-circulated into the cabin or made to escape safely. The proposed system is also proposed to operate intermittently, either by a manual control or a time-timed control mechanism unlike the conventional vacuum systems so that the power consumption is minimized and the load imposed on the electrical system of the vehicle is reduced. The design is focused on simplicity, modularity and the utilization of easily available parts thus is applicable in the development of prototypes and could be adopted in future production cars. The main aim of this study is to increase the in-cabin cleanliness, better the quality of air and less manual cleaning process. The incorporation of dust removal capabilities in the vehicle will help add to the comfort, well-being, and the general usability of passengers, as well as prove the effectiveness of innovative interior care methods in the contemporary auto.

2. Literature Review

Several studies are conducted in past years regarding dust removal system. A filter with dust removal system and enhancement of air quality stem were constructed to improve cabin air quality by removing dust and pollutants [1]. Current cabin air filters are ineffective against ultrafine particles; a new filter system has been developed to reduce these particles to very low levels in in-use vehicles [2]. A dust removal system using high-voltage electrostatic adsorption without air filters is proposed, demonstrating effectiveness in reducing PM_{2.5} levels in a controlled environment, potentially adaptable for car cabin use [3]. Creation of particulate filters for car cabin ventilation systems includes detailed analyses and evaluations with the help of theoretical and empirical models, laboratory and field experiments, and standardized test procedures like SAE J1669 [4]. Air recirculation with better efficient air filters is the most effective measure to lower air pollutant concentrations inside vehicle cabins, as supported by a review of over 90 studies covering more than 2000 road trips [5]. The application of air conditioning system in a car can enhance quality of air and remove negative impacts of particulate matter on cardiovascular health, as shown in a study with 60 healthy subjects [6]. A Purification air system was

created and evaluated to filter contaminants in vehicle cabins, showing effectiveness in enhancing air quality and outperforming existing purifiers [7]. Air recirculation in vehicle cabins can reduce nanoparticle recirculation of vehicle cabin air. exposure but may increase CO₂ levels [8]. Air quality in cabin of car is important factor to affect human health and comfort, with HEPA filters and advanced technologies like ionization and UV-based purification used to remove dust and contaminants [9]. Harmful pollutant rate increasing in automobile cabin and affects environment. To protect daily commuters and drivers against the negative effects of air pollution, modern automobiles are commonly equipped with automotive cabin air filters (ACAFs) [10]. Deposition rates of ultrafine particle in car cabins are greater than in indoor environments, increasing with air velocity and surface area, indicating a need for effective dust removal systems [11]. Disinfection agents from medical regions can effectively reduce microorganisms in car air conditioning and cabin surfaces, enhancing air quality [12]. The dust removal system applied in aircrafts for better air conditioning. Aircraft cabin air filters are effective at removing airborne particulate contamination, but the abstract does not address car cabin dust removal systems [13]. Level of particulate matters in car cabin can increased in allowed limit, suggesting a need for better dust removal systems, based on measurements in 18 cars using optical particle counters [14]. These studies are provided clear evidence to scope of implementing dust removal system in automobile cabin. The proposed model more cost effective and better removal of dust from car cabin without any manual effort

3. Problem Definition

Dusts keep on getting in the automobile cabins via door openings, heating systems, movement of passengers, and external environment. With time, such dust settles on the inner surfaces of the seats, dash board, floor mats and air vents bringing down the comfort of passengers and the quality of air in the cabin. Current products such as cabin air filters have the effect of mostly filtering the outside air contaminant but not the dust that has already settled in the vehicle. This has made cleaning time consuming, irregular, and reliant on human effort as it is normally performed manually with the aid of handheld vacuum cleaners. Consequently, there exists a necessity to design a small, effective, and economical in-cabin dust removal system that will be able to remove accumulated dust periodically as well as keep the cabin environment cleaner with the minimum amount of power usage.

4. Objective of the Study

The main focus of the study is to come out with a designed and developed system, which has the ability to effectively eliminate dust deposited in the interiors of cars with least human control. The study has specific goals which are as follows:

1. To investigate the origins and how the dust accumulates in the cabins of cars in a normal operating environment.
2. To develop a comprehensive cabin dust removal system that can be fitted in a car without compromising on passenger comfort or the looks of the car.
3. To develop a dust separation mechanism, which is a cyclone, that effectively separates dust particles and airflow on centrifugal force to minimize filter clogging.
4. To develop a compact vacuum system that can extract dust on a regular basis on specific areas of the car.

5. To reduce the amount of power consumed by allowing intermittent or periodic operation instead of constant operation.
6. To make it compatible with the current automotive electrical systems particularly the 12V DC power supply.
7. To develop a removable and cleanable dust collection unit so that it is easily serviced and reused.
8. To enhance hygiene and in-cabin air quality, in order to increase passenger comfort and well-being.
9. To compare the performance of the system regarding the efficiency of dust removal, energy consumption, and the operational reliability.

5. Methodology

The method of development of integrated cyclone-based cabin dust removal vacuum System is that systematic design, selection of components, fabrication, and assembly and performance evaluation. The overall strategy lies along the lines of simplicity, practicality and efficient dust removal and with minimum power usage. The different phases of the study are discussed below.

Phase 1: System Concept and Design

First, the idea of a built-in dust removal system was worked out based on the analysis of the trends of dust settling in car cabins. Floor mats, seat corners and dashboard edges were also known to be the major areas of dust collection. According to this research, the finalization of the suction inlet points was made to make sure that the dust was extracted successfully and to make sure passengers were not disturbed. A schematic layout and block diagram were drawn to establish the flow of air moving in through the dust inlets all the way to the exhaust outlet. The 2D and 3D image of the proposed system was created using ANSYS space claim software.

Phase 2: Component Selection

The choice of components was made on the basis of availability, cost, and compatibility to automotive systems and performance requirement. A vacuum motor with 12 V DC was selected in order to fit the normal vehicle power supply. Cycle separator was also chosen as the major dust separation unit because it can achieve dust separation by centrifugal force without clogging easily. A fine filter (HEPA or similar) was attached at the end of the line to capture the micro-particles which are left behind and to shield the motor. The suction inlets were connected to the cyclone unit by means of flexible ducts and a removable dust collection bin was also provided to facilitate easy maintenance.

Phase 3. Construction of cyclone separator

A cyclone separator was made by conical body made of plastic tangentially open at both ends. When dust-filled air is introduced in the cyclone chamber it spins with high velocity creating centrifugal force. The heavier dust particles are pushed to the cyclone walls and land in the dust collection bin with clean air flowing through the central outlet. This design enhances effectiveness of separation of dust and lowers the load of the filters

Phase 4: Assembly of Vacuum System

The entire modules were attached to a small base frame so as to create a stable structure. Flexible ducts were used in connecting the suction inlets to the air manifold, and then forced the airflow into the cyclone separator. The fine filter and vacuum motor were attached to the outlet of the cyclone. The spent air was diverted either into the cabin or to the outside by separate vent. Insulated wiring, fuse, and ON/OFF control switch were used to connect electrically.

Phase 5: Installation and Integration.

The installed system was fitted in an appropriate place inside the car like under the seat or in the boot space, making sure that it did not occupy much space. Special caution was observed to ensure that there was no interference with the already existing vehicle parts. The reduction of noise and mechanical stress in operation was achieved by vibration isolation mounts.

Phase 6: Performance Evaluation and Analysis

The performance of the proposed system analyzed with the help of CFD analysis and compares the results with conventional system. The variation in velocity, pressure, mass flux, density, turbulence kinetic energy, eddy velocity and specific dissipation rate are plotted using ANSYS workbench 2026.

6. Development of the system

The suction duct takes in dust and air into the system. A DC motor driven fan forms the suction and is driven by the battery. As a result of such suction, dust-filled air is sucked into the system. Air enters the cyclone separator at the first point. The air moves in a spiral direction creating a centrifugal force inside the cyclone separator. Due to this force, dust particles which are heavier and bigger are drawn towards the outer wall of the cyclone and fall down into the dust bin.

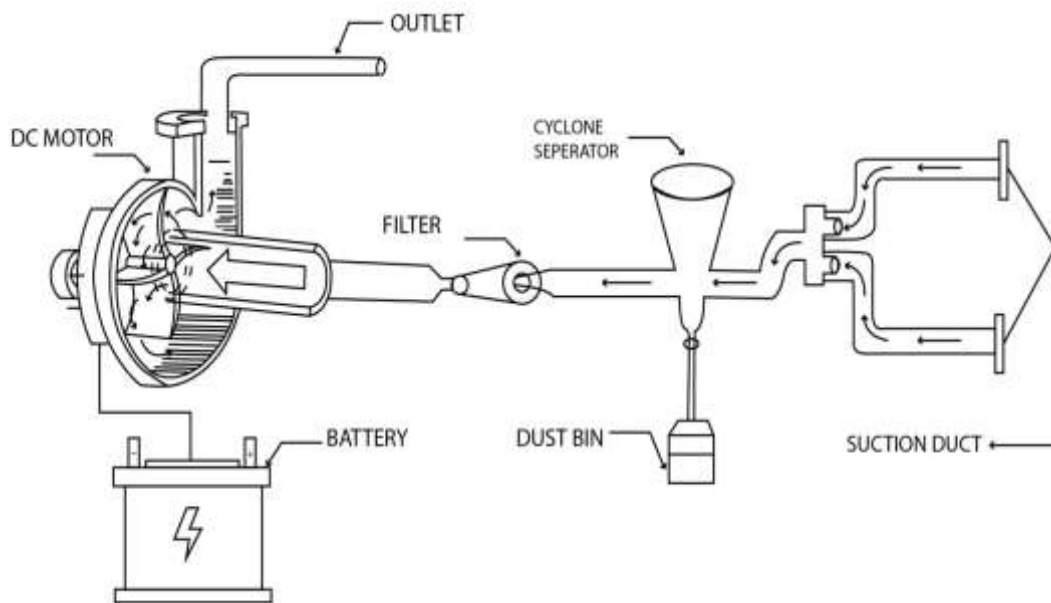


Figure 1: Proposed model of cabin dust removal system

Once the heavy particles have been separated then the resulting air containing fines dust particles is passed over to the filter section. The filter picks up the smaller dust particles which were not taken off by the cyclone separator. Lastly, the clean air flows in the motor outlet and is released into the atmosphere. This cyclone separation and filtration combination enhances the dust removal efficiency and removes the entry of dust to the motor.

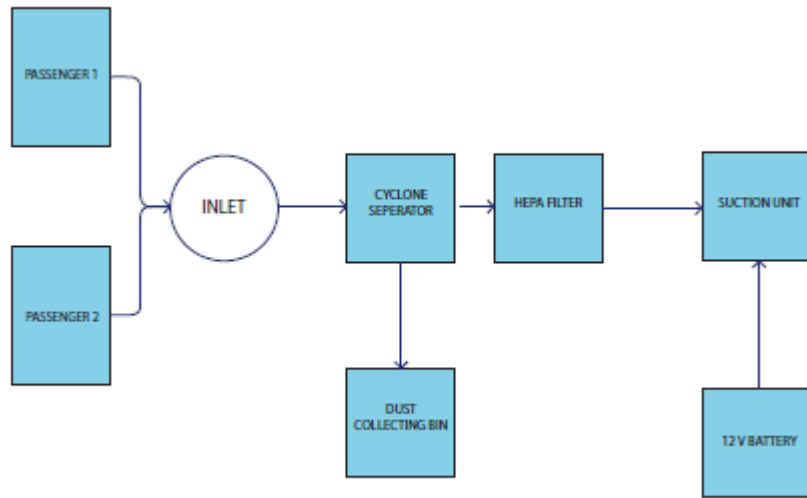


Figure 2: Layout of cabin dust removal system

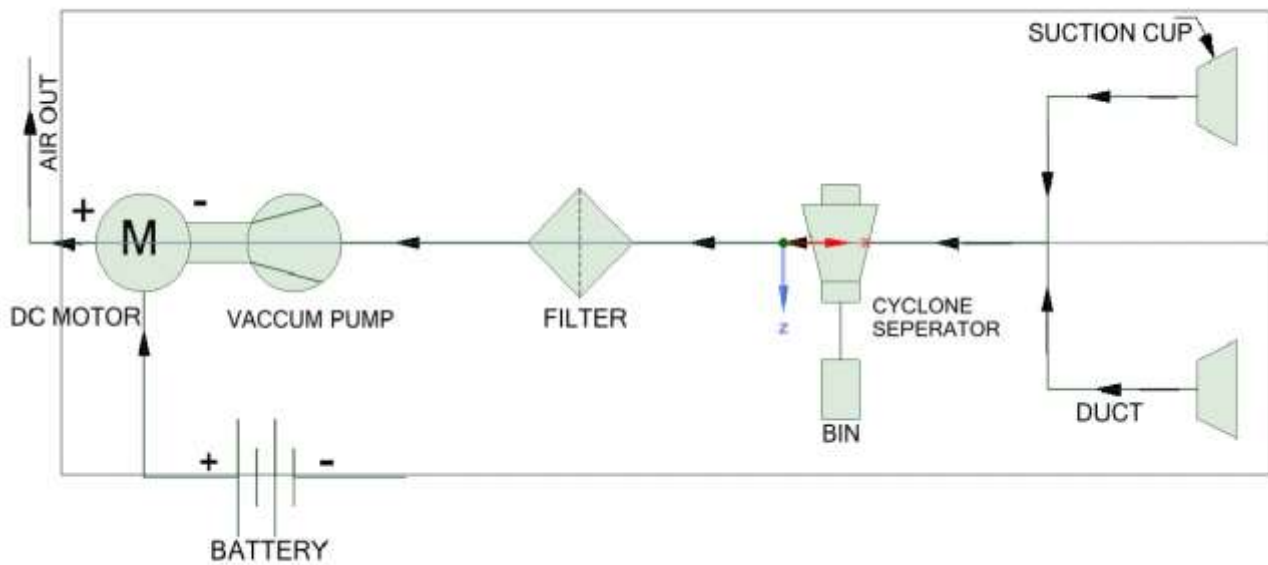


Figure 3: 2D model of cabin dust removal system

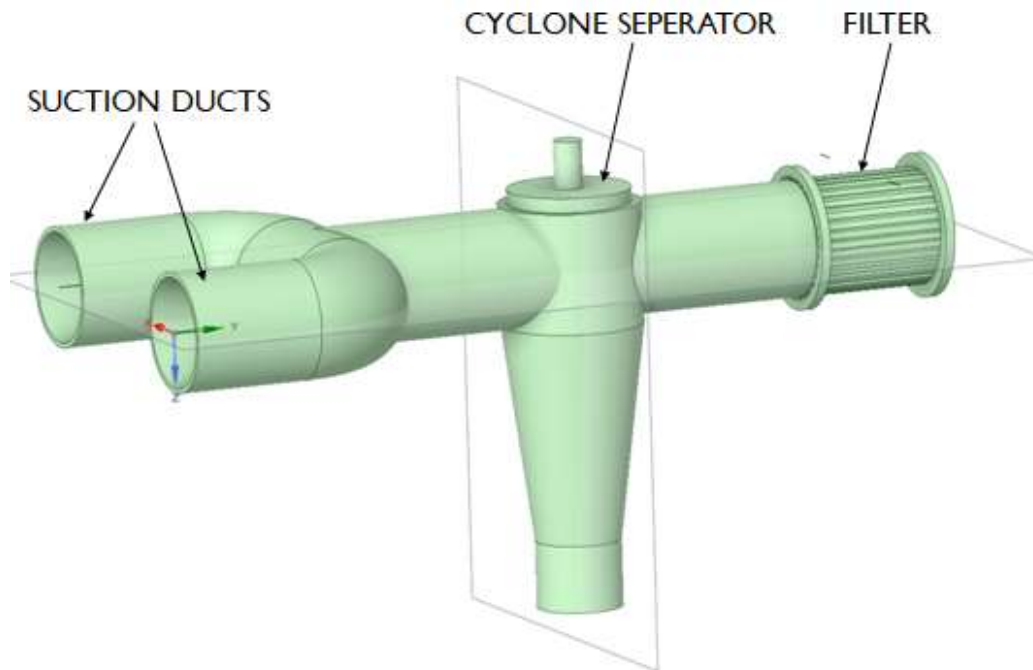


Figure 4: 3D model of cabin dust removal system

7. CFD analysis of proposed system

Computational fluid dynamics, abbreviated as CFD, is a numerical analysis method used to analyze fluid flow, heat transfer, and other physical phenomena by solving equations using computational tools. In a CFD analysis, a physical system is divided into small control volumes, and equations are solved for mass, momentum, and energy to analyze fluid flows. It helps in visualizing parameters like velocity, pressure, and turbulence in a system. CFD analysis is used in many engineering applications to analyze and optimize system designs, reduce experimental costs, and enhance system performance, such as in the analysis of air flows and dust collection in vacuum tubes.

The meshed model depicts the discretization of the vacuum tube, which is divided into small control volumes for numerical analysis. The meshed image of cabin dust removal system shown on figure 5.

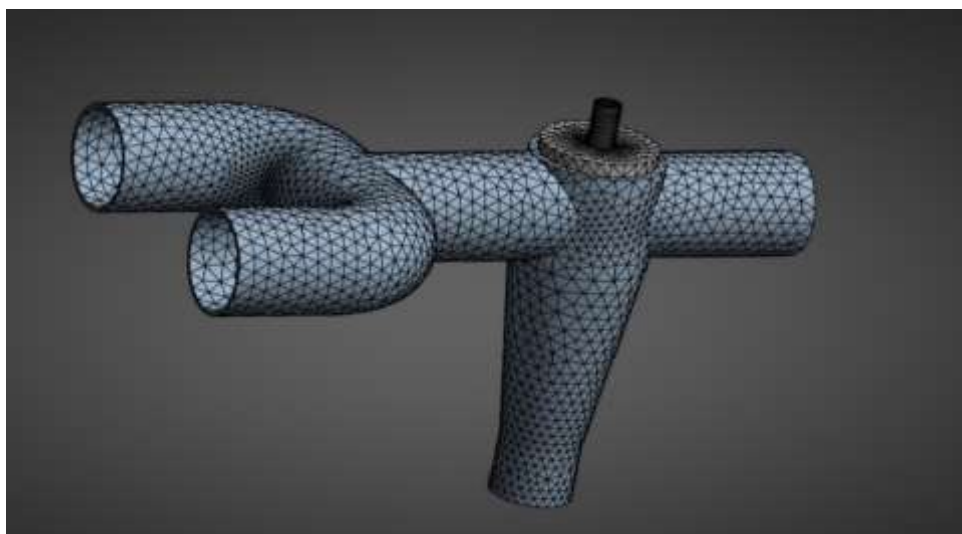


Figure 5: Meshed image model of cabin dust removal system

The mass flux distribution indicates that the mass flow rate per unit area, the higher value near at inlet due to high suction and high or low at tube, indicating a steady flow and efficient capacity to carry dust.



Figure 6: Variation in mass flux of cabin dust removal system

The pressure distribution contour indicates the distribution of pressure from inlet to outlet.

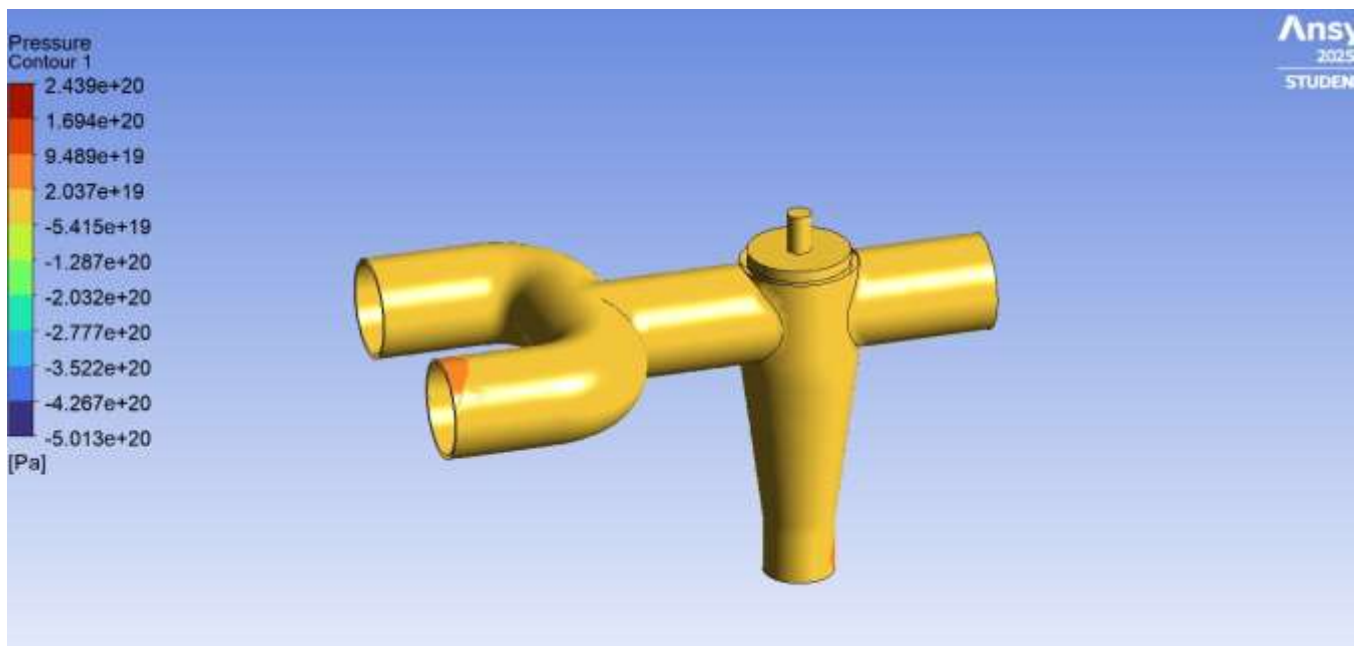


Figure 7: Variation in pressure of cabin dust removal system

The eddy viscosity contour indicates the eddy viscosity, where more in the region of higher mixing, thus showing the effect of increased viscosity on momentum transfer, leading to increased flow resistance and dust dispersion.

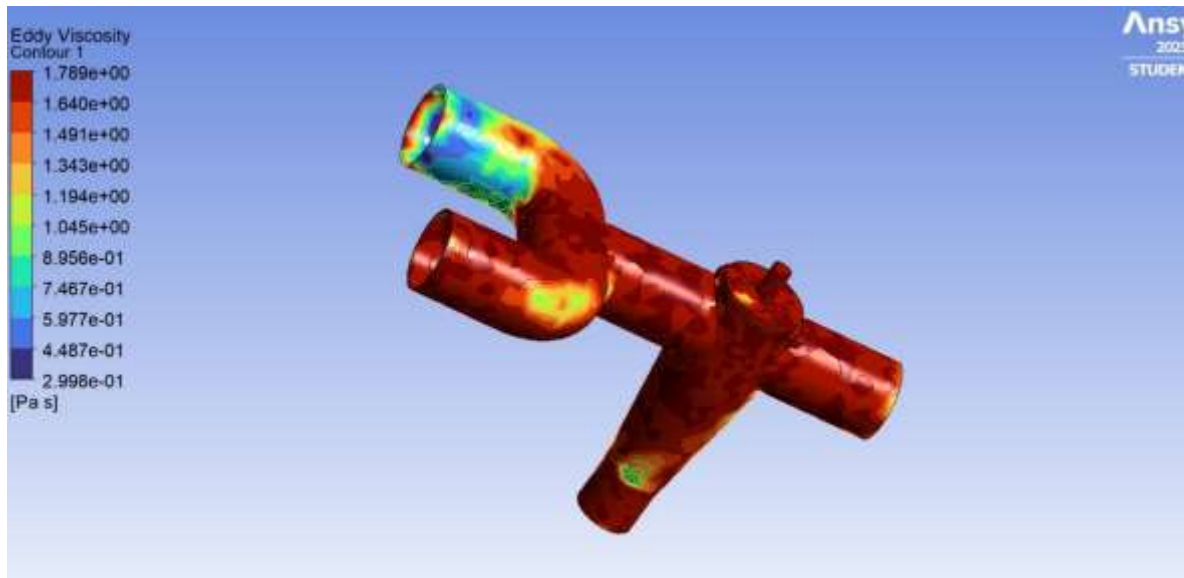


Figure 8: Variation in eddy current viscosity of cabin dust removal system

8. Conclusion

In this study, an integrated cyclone focused cabin dust removal vacuum system specially designed fabricated and tested to address the major issue related to accumulation of dust inside car cabins. The model effectively removes accumulated dust from inner region with controlled vacuum mechanism with cyclone focused dust separation. Practical demonstration is indicating that the cyclone separator more effectively removes dust particles through centrifugal force, decreasing the load using fine filters and ensuring constant airflow. The system working with 12V automotive power supply and required only occasional activation, with less power consumption and low impact on electrical system of vehicle. This design fabricated without affecting the comfort and floor area of car cabin. This model having better maintainability and simple design.

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