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Experimental Investigation on Titania-Alumina-Zirconia Coated Catalytic Converter for Automotive Application

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ABSTRACT: Nowadays, global warming and air pollution are the major issues across the planet. Significant air pollution caused is due to the combustion of fuels in vehicles causing the emission of Harmful gases such as Nitrogen Oxide, Carbon Monoxide, unburned Hydrocarbon, and particulate matter, increasing global warming. Catalytic converter plays a vital role in reducing harmful gases. On a traditional catalytic converter, rare earth metals like platinum, palladium, and rhodium are used as a catalyst for the reduction of harmful gases. Since they tend to lose their filtration capability within a short period of time, there is a necessity to come up with some advancement in order to extend its lifetime. Therefore, the catalytic converter will be modeled using CATIA software and analyzed by three different oxides such as Aluminum oxide (Al_2O_3), Titanium-di-oxide (TiO_2), and Zirconium-di-oxide (ZrO_2) with the help of ANSYS software. In this Experimental study, Computational Fluid Dynamics (CFD) analysis results will be compared, and the best oxide which provides better results in terms of pressure, temperature, and turbulence will be identified and cast.

KEYWORDS: Catalytic Converter, Alumina, Titania, Zirconia, ANSYS, CFD

I. INTRODUCTION

Internal Combustion engines generate undesirable emissions during the combustion process, which include NO_x , CO, unburned HC, smoke, etc. Apart from these unwanted gases, it produces Particulate Matter (PM) such as lead, soot. All these pollutants are harmful to the environment and human health. They are the main causes of the greenhouse effect, global warming. The simplest and the most effective way to reduce NO_x and PM is to go for the after-treatment of exhaust. Devices developed for after-treatment of exhaust emissions include thermal converters or reactors, traps or filters for particulate matters, and catalytic converters. The most effective after treatment for reducing engine emission is the catalytic converter found on most automobiles and other modern engines of medium or large size. The catalyst and filter materials placed inside the catalytic converter increase backpressure. This increase in backpressure causes more fuel consumption, and in most cases, engine stalling might happen. The filtration efficiency and back pressure are interrelated. If maximum filtration efficiency using very fine grid size wire meshes is achieved, the backpressure will also be increased, which causes more fuel consumption. On the other hand, if larger grid size wire meshes are used, back pressure will be less, but the filtration efficiency will also be reduced, which does not help in meeting the present emission norms. With the help of CFD analysis, it is attempted to find out the optimum solution to get maximum filtration efficiency with limited back pressure developed inside the catalytic converter.



SELECTION OF FILTER MATERIAL

There are many types of filter materials used in the internal combustion engine. Ceramic monolith, ceramic foam, steel wire meshes, ceramic silicon fiber, and porous ceramic honeycomb are the few filter materials. Out of these filter materials, steel wire mesh is selected as filter material because knitted steel wire mesh material is ranked first for its collection efficiency of particulate matter. The other reasons for its selection are,

- Thermal stability during regeneration
- Good mechanical properties
- Long durability
- Easy availability and less cost

II. METHODOLOGY

Modelling and analysis of 3-D models of the catalytic converter were carried out using Catia and Ansys software with and without coating. And also, the thermal analysis will carry out, and the results will compare with that of the existing catalytic converter.

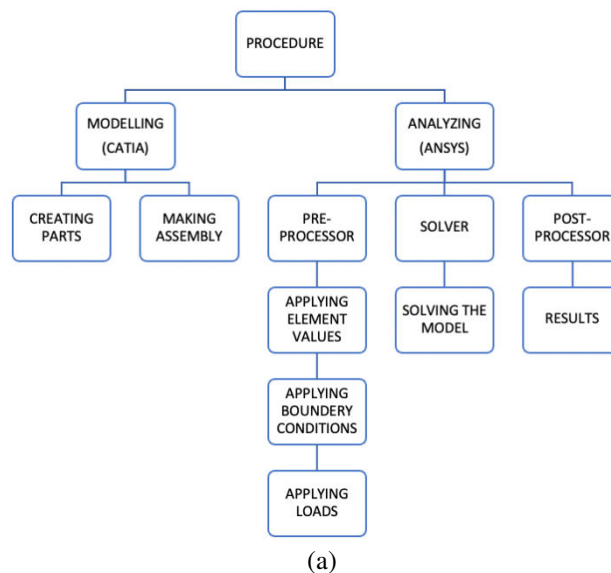


Fig.1.(a) Flow chart of Methodology

III. MATERIAL PROPERTIES

Aluminium oxide is a chemical compound of aluminium and oxygen with the chemical formula Al_2O_3 . It is the most commonly occurring of several aluminium oxides and is specifically identified as aluminium(III) oxide. It is commonly called alumina and may also be called aloxide, aloxite, or alundum, depending on particular forms or applications. It commonly occurs in its crystalline polymorphic phase $\alpha-Al_2O_3$, in which it comprises the mineral corundum, varieties of which form the precious gemstones, ruby, and sapphire. Al_2O_3 is significant in its use to produce aluminum metal, as an abrasive due to its hardness, and as a refractory material. Due to its high melting point Al_2O_3 is an electrical insulator but has a relatively high thermal conductivity ($30 Wm^{-1}K^{-1}$ [3]) for a ceramic material. Aluminium oxide is insoluble in water. In its most commonly occurring crystalline form, called corundum or α -aluminium oxide, its hardness makes it suitable for use as an abrasive and as a component in cutting tools.

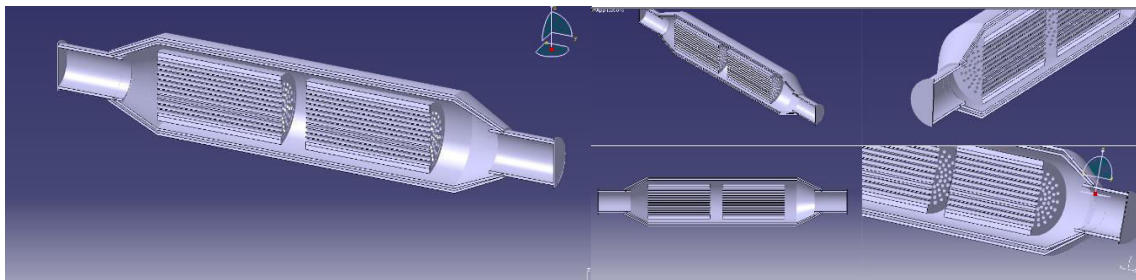
Titanium dioxide, also known as titanium (IV) oxide or titania, is the naturally occurring titanium oxide, chemical formula TiO_2 . When used as a pigment, it is called titanium white, Pigment White 6 (PW6), or CI 77891. Generally, it is sourced from ilmenite, rutile, and anatase. It has a wide range of applications, from paint to sunscreen to food colouring. Titanium dioxide occurs in nature as well-known minerals rutile, anatase and brookite, and additionally, as

two high-pressure forms, amino clinic baddeleyite-like form and an orthorhombic α - PbO_2 -like form, both found recently at the Ries crater in Bavaria. It is mainly sourced from ilmenite ore. This is the most widespread form of titanium dioxide-bearing ore around the world. Rutile is the next most abundant and contains around 98% titanium dioxide in the ore. The metastable anatase and brookite phases convert irreversibly to the equilibrium rutile phase upon heating above temperatures in the range 600°-800 °C.

Zirconium dioxide, also known as Zirconia (ZrO_2) can be found in three crystal structures. These are monolithic (m), tetragonal (t) and cubic (c) structures. The monolithic structure is stable between room temperature and 1170°C while it turns to a tetragonal structure above 1170°C. The tetragonal structure is stable up to 2379°C, and above this temperature, the structure turns to a cubic structure. Zirconia (ZrO_2) is a ceramic material with adequate mechanical properties for the manufacturing of medical devices. Zirconia stabilized with Y_2O_3 has the best properties for these applications. When stress occurs on a ZrO_2 surface, a crystalline modification opposes the propagation of cracks. The compression resistance of ZrO_2 is about 2000 MPa. Zirconia is a crystalline dioxide of zirconium. Its mechanical properties are very similar to those of metals, and its colour is similar to tooth colour.

IV. MODELLING

3D model of a catalytic converter is being designed using Catia consisting of two parts, one the outer shell and the other named porous medium, which plays a vital role during the filtration of toxic gases emitted for the engine.

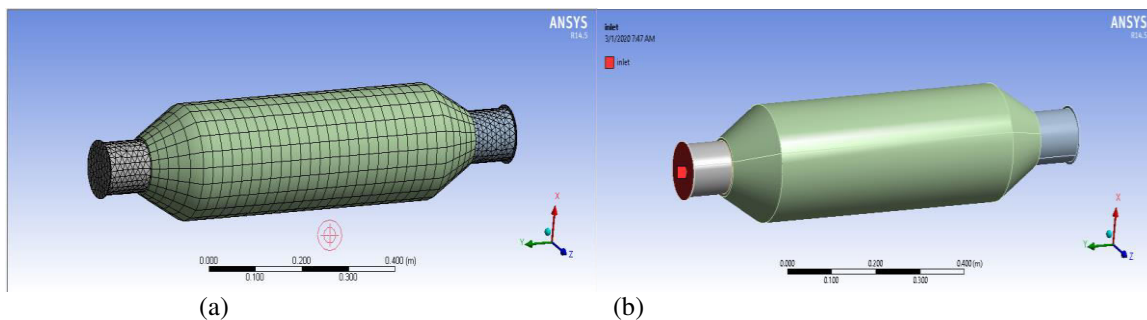


(a)

(b)

Fig. 2.(a) 3D Model of a Catalytic converter (b) The sectional view of the Catalytic converter

V. RESULTS AND DISCUSSION



(a)

(b)

Fig.3.(a) Tetrahedral Mesh (b) Boundary Conditions

UNCOATED

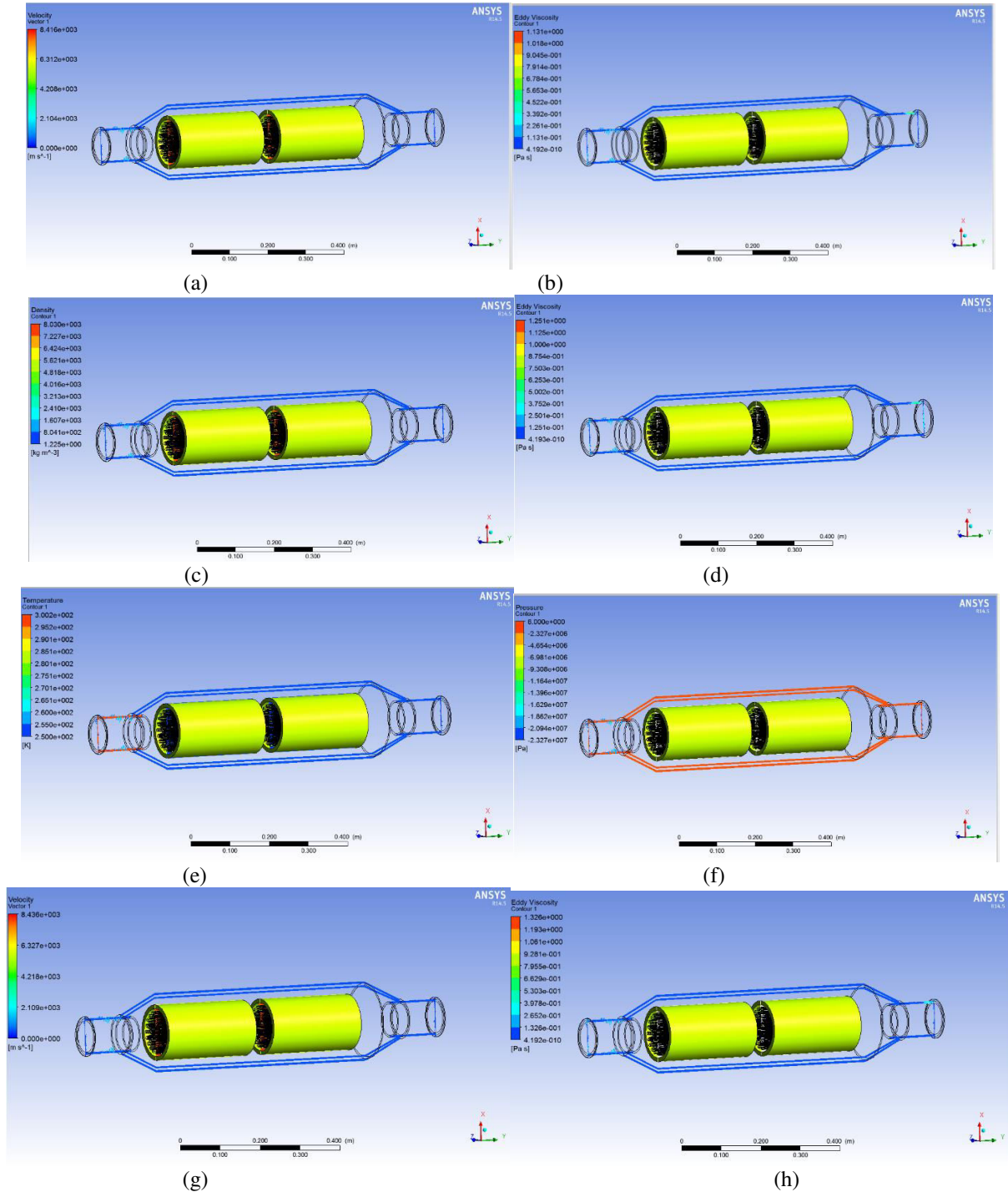


Fig.4 (a) CO₂ Velocity (b) CO₂ Eddy Viscosity (c) HC Density (d) HC Eddy Viscosity (e) HC Temperature (f) HC Pressure (g) Sulphur Density (h) Sulphur Eddy Viscosity

ALUMINA (ALUMINIUM OXIDE)

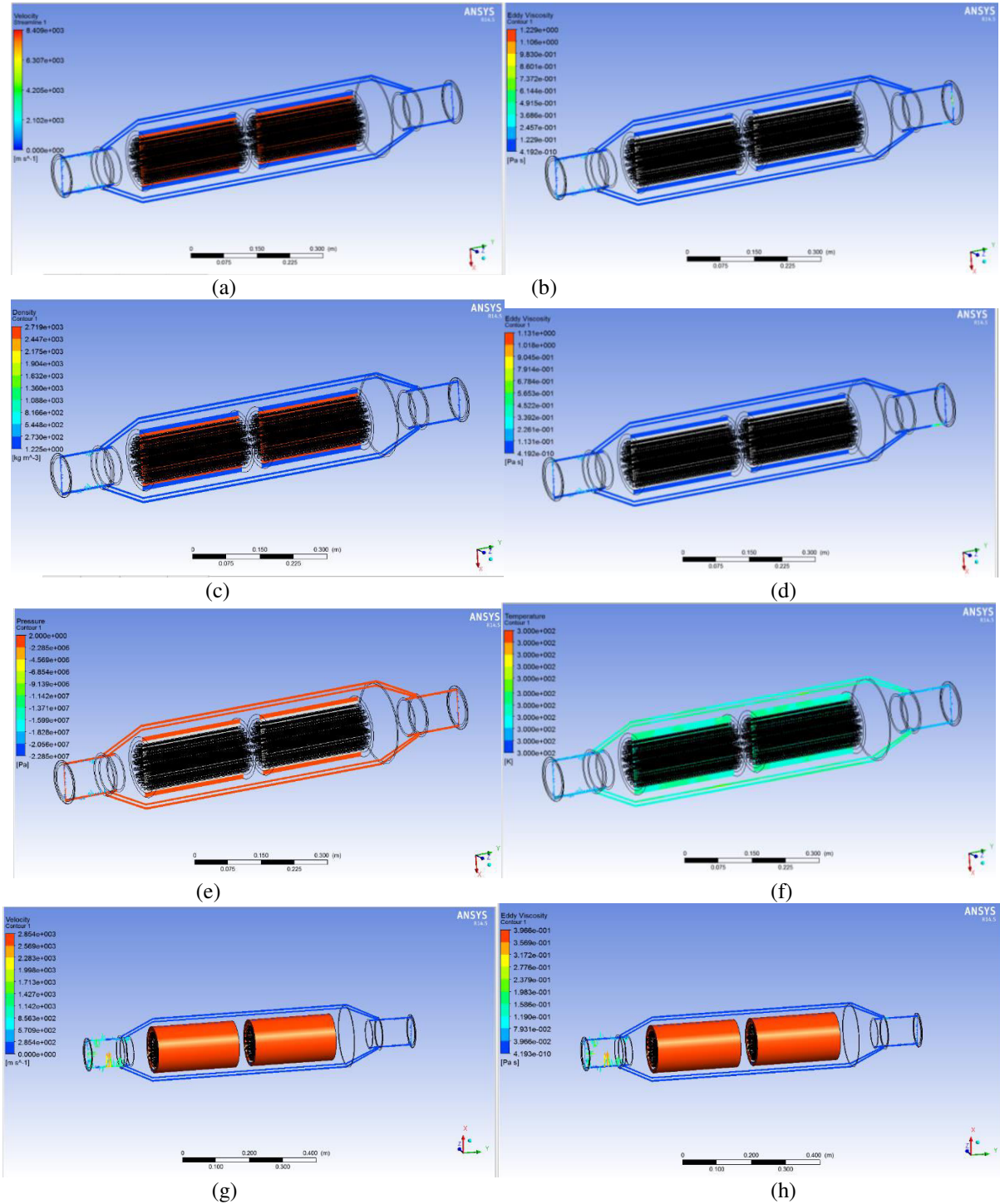


Fig.5(a) CO₂ Velocity(b) CO₂ Eddy Viscosity (c) HC Density (d) HC Eddy Viscosity (e) HC Temperature (f) HC Pressure (g) Sulphur Density (h) Sulphur Eddy Viscosity

TITANIA (TITANIUM DIOXIDE)

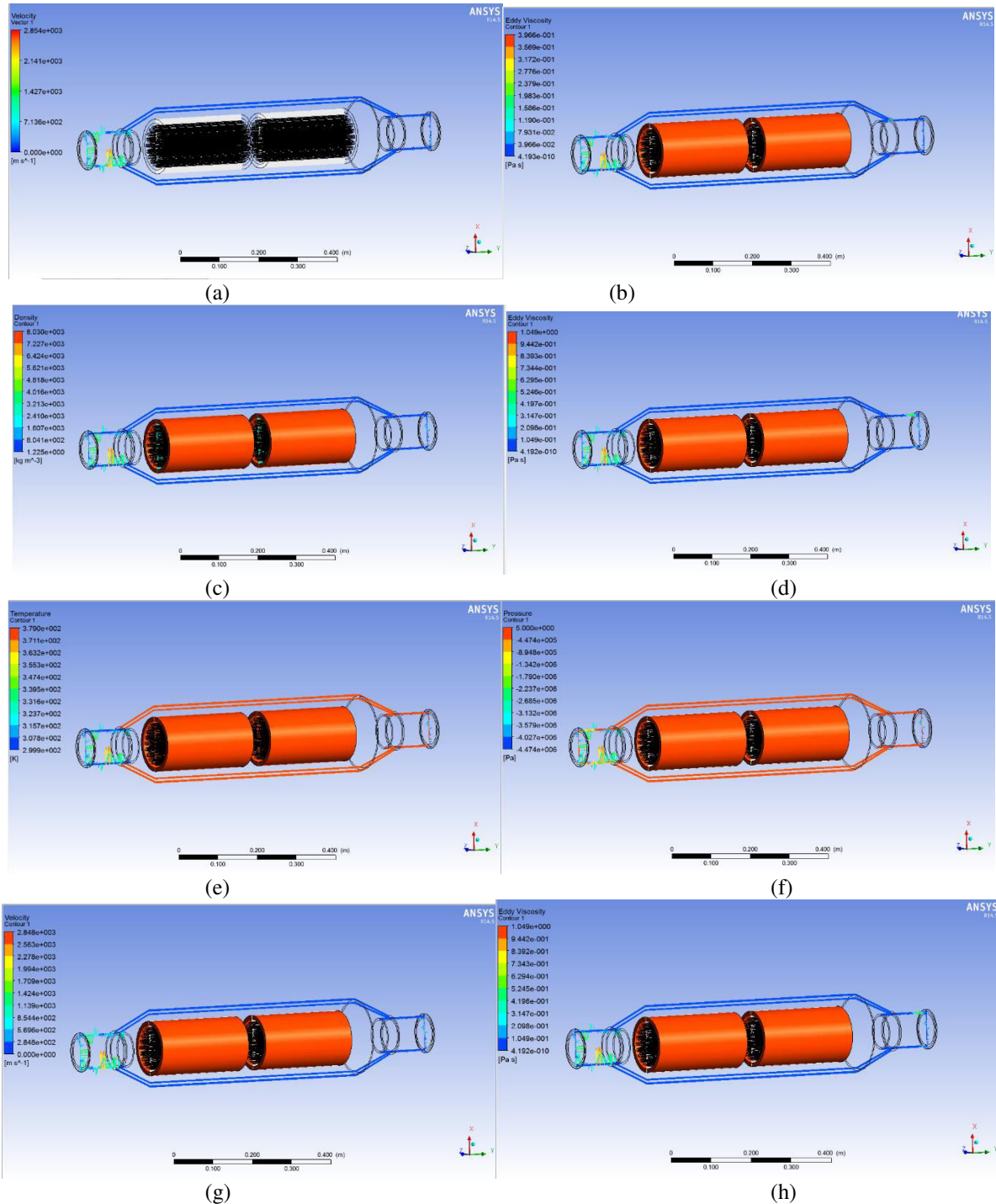


Fig. 6 (a) CO₂ Velocity(b) CO₂ Eddy Viscosity (c) HC Density (d) HC Eddy Viscosity (e) HC Temperature (f) HC Pressure (g) Sulphur Density (h) Sulphur Eddy Viscosity

ZIRCONIA (ZIRCONIUM DIOXIDE)

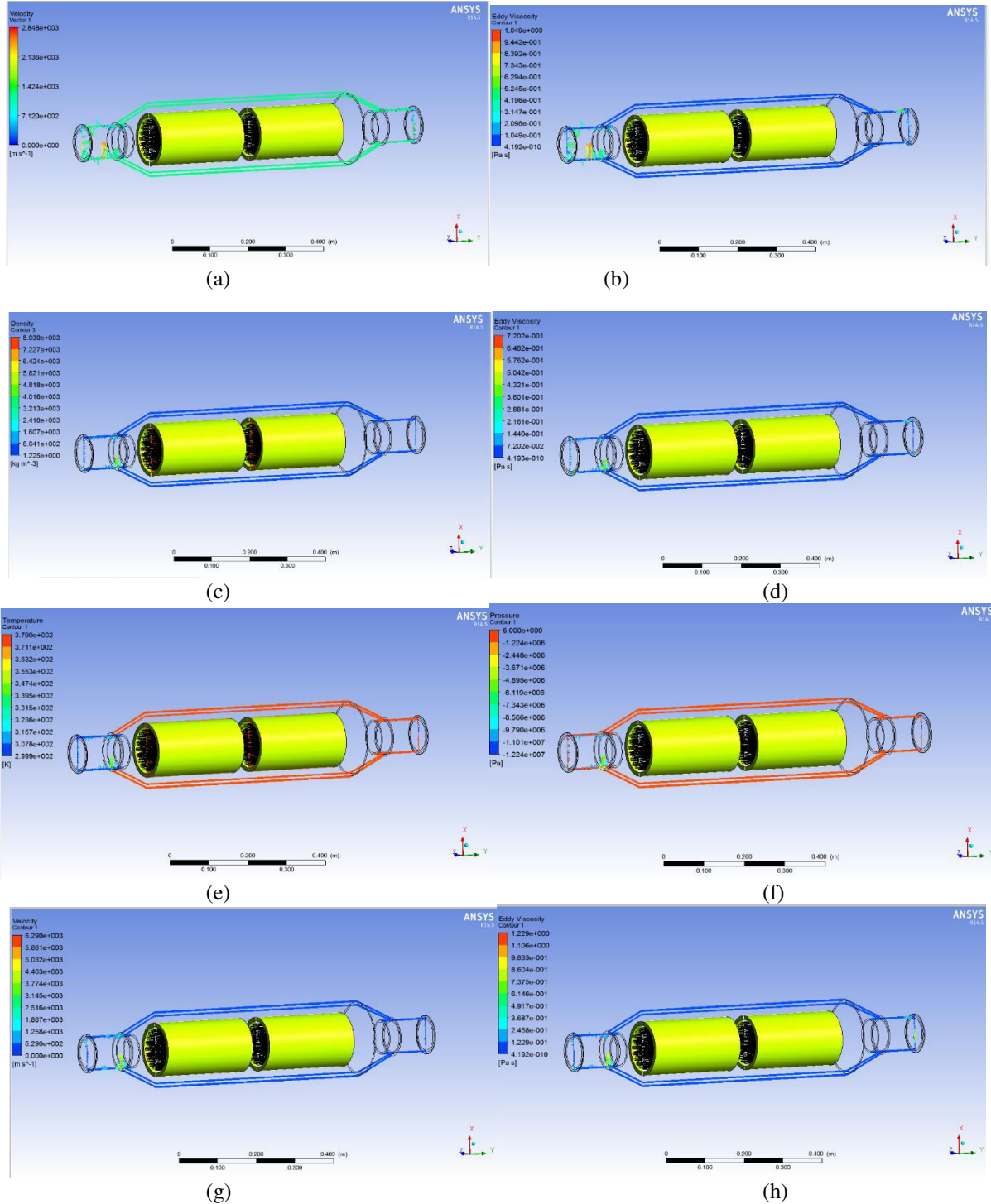


Fig. 7 (a) CO₂ Velocity(b) CO₂ Eddy Viscosity (c) HC Density (d) HC Eddy Viscosity (e) HC Temperature (f) HC Pressure (g) Sulphur Density (h) Sulphur Eddy Viscosity



The analysis was being carried out with three different ceramic oxides. Temperature, Pressure, Density, and Eddy Viscosity of three different ceramics Oxides were obtained. All the three oxides show different characteristics under various conditions. The temperature was calculated by the amount of heat absorbed during filtration. Pressure is calculated on the porous medium of the catalytic converter. The density is obtained by the amount of particulate travel in the chamber, and the velocity profile calculates eddy viscosity in a turbulent flow.

VI. COMPARISON OF RESULTS

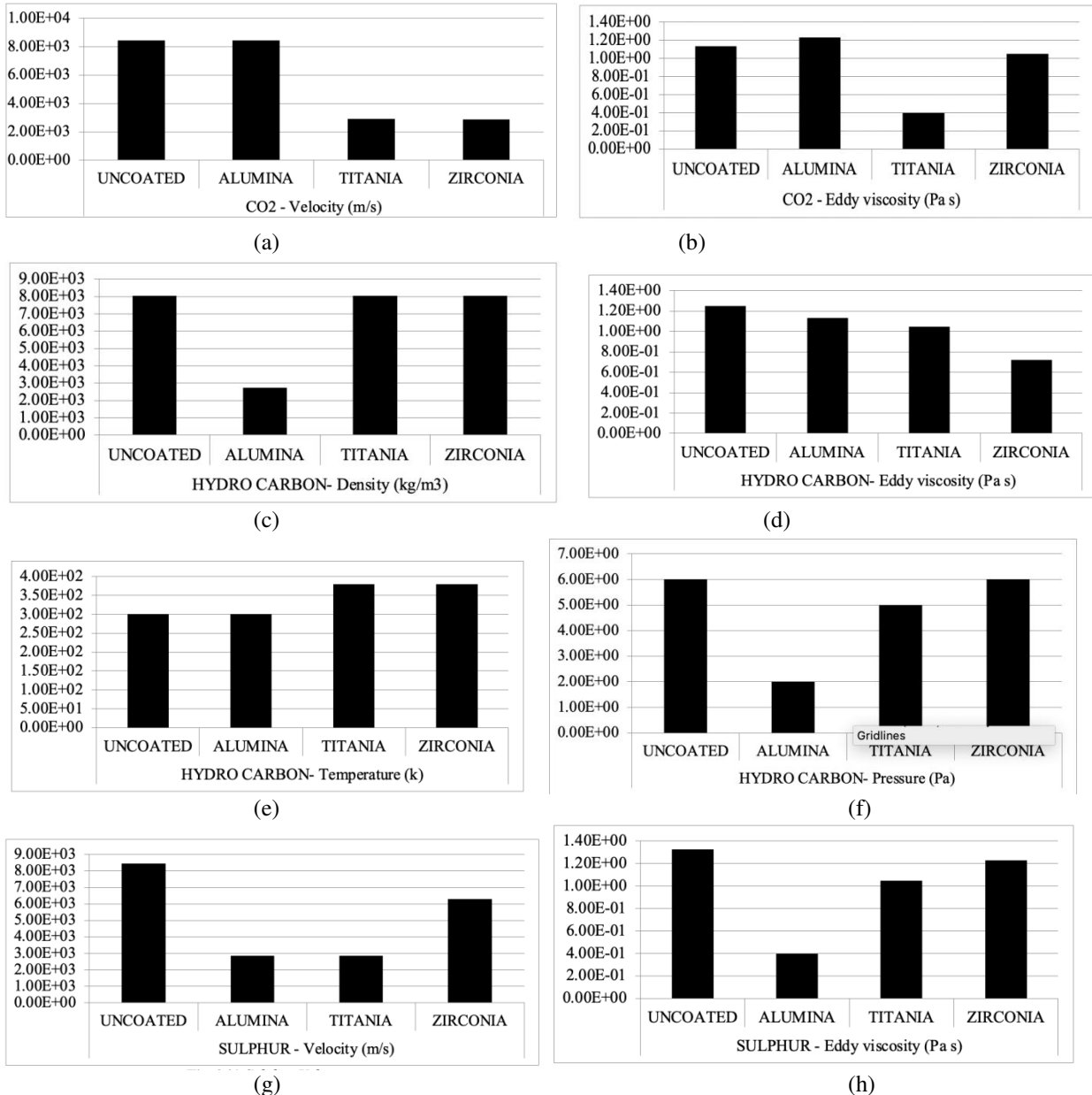


Fig. 8 (a) CO₂ Velocity(b) CO₂ Eddy Viscosity (c) HC Density (d) HC Eddy Viscosity (e) HC Temperature (f) HC Pressure (g) Sulphur Density (h) Sulphur Eddy Viscosity



Under various parameters, charts are prepared for the ceramic powders after the analysis, where the velocity of CO₂ is higher in alumina and lower for titania, whereas the temperature of hydrocarbon is greater in titania and lesser in alumina. The velocity obtained in titania is lesser than other three. Alumina has lesser density comparing other two. Under all the conditions, the alumina and titania are observed as the suitable composite powder for the coating, but the Titania coated catalytic converter has more wear resistance and corrosion resistance than alumina. Hence the titania is considered as the best material for the coating.

VII. CONCLUSION

The CFD analysis of the three-way catalytic converter is done for the IC Engine, the modelling of catalytic converter done in CATIA software, and then the analysis was done for the existing model, the core portion was defined as the porous medium for this analysis, Pressure, Velocity and Turbulence results was taken for this analysis modification of the ceramic coated catalytic converter model also done comparison of the results shows the Titania Coated catalytic converter provide the better reactions and pressure drop in the outlet conditions, temperature value also dropped in that model. Also from the obtained numerical investigation, it was found the following conclusions:

- Alumina coated catalytic converter has reduced CO and other emission when compared to other coated ceramic powders like Zirconia and Titania.
- Also, by means of titania coating on catalytic converter, improved the Wear resistance, corrosion resistance and surface morphology. Which was affect the overall performance and life of the catalytic converter.
- It was found that the carbon monoxide gets reduced.
- Due to the reduction of CO, the NO_x can reduce further.
- The percentage of oxygen has reduced from alumina coated catalytic converter. Without injecting air in to the device it is almost as same as the normal exhaust.

The smoke percentage of our device is little more than the current device. However, the difference is very negligible.

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