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Design and Development of Low-Cost Automotive Catalytic Converter for the Reduction of Exhaust Gas Emissions

Mr. B. Rajesh Babu[1], Mr. D.V. Praveen Kumar Reddy[2], Mr. D. P. Karthik[3], Mr. A. Sai Karthik[4]

[1]M.Tech. (R&A.C), Assistant Professor, Dept of Mechanical Engineering, Sri Krishnadevaraya University College of Engineering and Technology, Anantapuramu, Andhra Pradesh, India
[2]M.Tech. (A.M.S), Assistant Professor, Dept of Mechanical Engineering, Sri Krishnadevaraya University College of Engineering and Technology, Anantapuramu, Andhra Pradesh, India
[3,4]Student, B.Tech. Dept Mechanical Engineering, Sri Krishnadevaraya University College of Engineering and Technology, Anantapuramu, Andhra Pradesh, India

Abstract:
Automotive exhaust gases contain harmful pollutants such as carbon monoxide (CO), hydrocarbons (HC), and nitrogen oxides (NOx).Conventional catalytic converters commonly employ noble metals including platinum (Pt), palladium (Pd), and rhodium (Rh), which provide high catalytic activity but increase cost. This study presents the design and computational analysis of a catalytic converter using a CuMnOx catalyst as a lower-cost alternative. A three-dimensional honeycomb catalytic-converter geometry was developed in SolidWorks and transferred to ANSYS Workbench for CFD analysis.
The numerical model used a pressure-based steady-state solver, An energy equation, species transport, and volumetric reactions. The designed converter was evaluated for flow distribution, temperature Behavior, and pollutant conversion. Under the reported simulation conditions, the predicted conversion efficiencies were 92% for CO, 20.58% for NOx, and 36.888% for CH4/HC.
Comparative results in the project indicate that CuMnOx can provide competitive Performance for CO conversion relative to Pt and can offer a cost-oriented alternative to noble-metal catalysts. The study is Computational and does not include experimental validation; therefore, the results should be considered simulation-based and require Experimental confirmation.

Keywords: CuMnOx; catalytic converter; CFD; ANSYS Fluent; SolidWorks; honeycomb monolith; exhaust emissions; CO; NOx; Hydrocarbons.

I. INTRODUCTION

Increasing vehicle use and industrialization have intensified concerns regarding air pollution from internal-combustion engines. Engine exhaust contains CO, HC, and NOx, which have adverse environmental and health effects. Catalytic converters are used to promote chemical reactions that transform harmful exhaust constituents into less harmful products such as CO2, N2, and H2O. The performance of a converter depends on both catalyst activity and converter geometry.

Conventional systems use Pt, Pd, and Rh because of their high catalytic activity. However, the high cost and limited availability of noble metals motivate investigation of alternative catalysts. Copper-manganese oxide (CuMnOx) is identified in the project as a promising non-noble catalyst because of its redox properties and potential for CO oxidation. In parallel, honeycomb monolith structures provide high surface area and can promote gas-catalyst contact while maintaining practical flow passages.

The objective of this work is to design a catalytic converter using 3D CAD modelling, simulate exhaust flow and reactions using ANSYS Fluent, and evaluate CO, NOx, and HC reduction. The work combines catalyst selection with converter geometry and CFD-based performance assessment. The study is limited to computational analysis and does not include experimental validation.

II. LITERATURE REVIEW AND RESEARCH GAP

1. The project literature review identifies three main research directions: conventional noble-metal catalytic converters, non-noble Transition-metal oxide catalysts, and geometry optimization using computational tools. Noble-metal catalysts are effective but expensive. Non-noble materials such as perovskites, spinels, and hopcalite-type CuMnOx have been investigated as lower-cost alternatives. Previous work cited in the project reports significant CO reduction using manganese-coated copper catalysts and indicates that cell Density, surface area, flow distribution, and inlet-cone geometry influence converter performance.
2. CFD methods such as ANSYS Fluent enable prediction of velocity, temperature, species transport, and reaction behavior inside complex converter geometries. The research gap identified by the project is the limited integration of CuMnOx catalyst selection with CAD-based geometry development and CFD analysis. The present work therefore evaluates a honeycomb converter configuration with CuMnOx using a combined SolidWorks–ANSYS workflow.

III. MATERIALS AND METHODOLOGY

The methodology consists of CAD modelling, geometry preparation, meshing, CFD setup, reaction definition, solution, and post-Processing. The converter comprises an outer casing, inlet cone, honeycomb monolith, and outlet cone. The substrate is specified as ceramic (cordierite), the catalyst coating as CuMnOx, and the working fluid as an exhaust-gas mixture.

The converter geometry was created parametrically in SolidWorks. The cylindrical body and inlet/outlet cones were modelled, followed by a honeycomb structure generated using a hexagonal pattern. The assembled geometry was exported in IGES format and imported into ANSYS Workbench. Named selections were assigned for inlet, outlet, shell, and substrate regions. A fine mesh was applied, particularly to the honeycomb region. The project reports mesh-quality targets of skewness below 0.9 and orthogonal quality above 0.2.

The CFD model used a pressure-based, steady-state solver with the energy equation enabled. Species transport and volumetric reactions were activated. The exhaust mixture included CO, CO2, NO, O2, and HC species, while CuMnOx was represented as the catalyst region. The project specifies a representative analysis condition of 15 m/s inlet velocity and 600 K inlet temperature, with a pressure outlet at 0 gauge pressure. The broader methodology also reports an inlet range of 10–30 m/s and 500–800 K.

IV. CATALYTIC CONVERTER DESIGN AND CFD MODEL

The principal design parameters reported in the project are a converter length of 152.40 mm, diameter of

101.6 mm, channel diameter of 2 mm, cell density of 500 CPSI, and wall thickness of 0.1 mm. The honeycomb monolith was selected to provide a large reaction 2 surface while supporting uniform gas passage. The design objectives were uniform exhaust distribution, high catalytic surface area, low pressure drop, structural stability, and manufacturability.

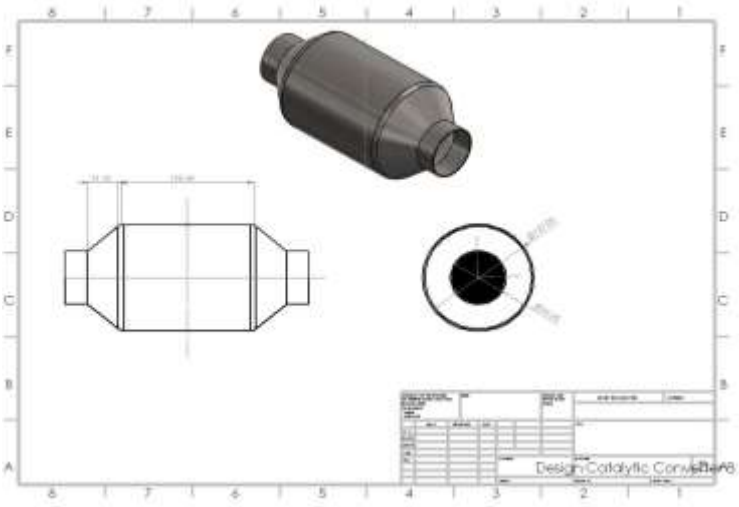


Fig.1. CAD Model of Catalytic Converter

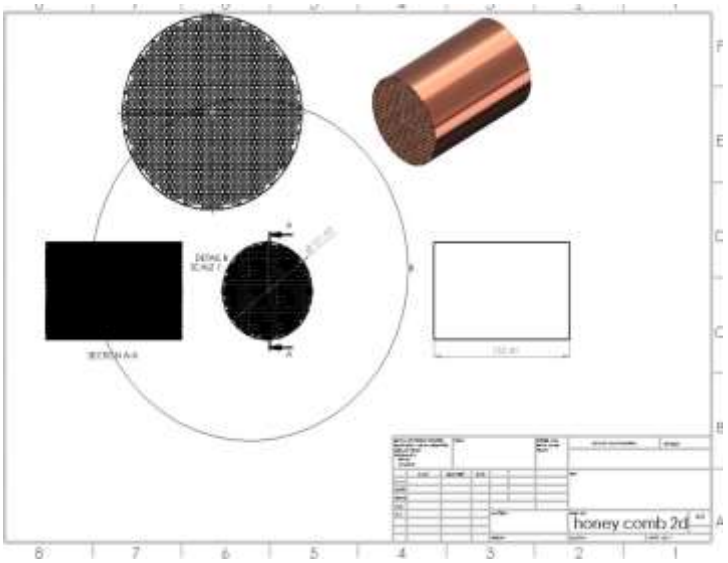


Fig.2. CAD Model of Honey Comb Structure

The chemical reactions defined in the CFD model were CO oxidation, HC oxidation, and NO reduction. The project expresses these reactions as $CO + 0.5O2 \rightarrow CO2$, $CH4 + O2 \rightarrow CO2 + H2O$, and $2NO \rightarrow N2 + O2$. The simple algorithm and second-order discretization were selected, followed by standard initialization. Simulations were run for approximately 100–500 iterations while monitoring residuals with a target of 10^{-6} and checking the stability of outlet concentrations.

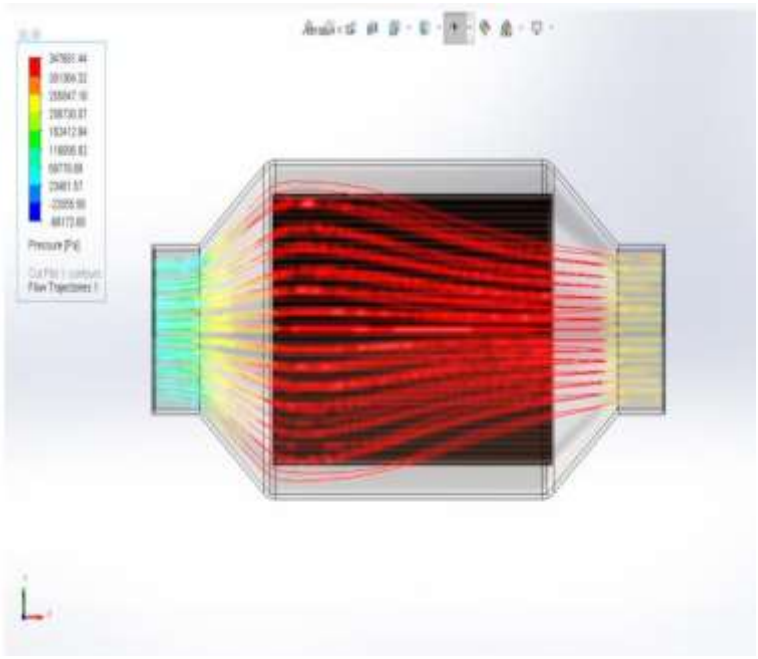


Fig.3. CFD simulation in Ansys fluent

V. RESULTS AND DISCUSSION

The CFD post-processing reported smooth gas movement through the honeycomb channels and relatively uniform velocity distribution from inlet to outlet. The project also reports a temperature increase associated with exothermic reactions, with the highest temperature occurring in the catalyst region. Species concentration contours show a decrease in pollutant concentrations along the converter length.

The reported conversion efficiencies were calculated using $\eta = [(C_{in} - C_{out})/C_{in}] \times 100$. For the selected simulation, CO decreased from 0.015 to $8.3466245 \times 10{-}13$, corresponding to a reported 92% efficiency; NOx decreased from 0.01 to 0.00797416755, corresponding to 20.58%; and CH4 decreased from 0.321 to 0.20258883, corresponding to 36.888%. The values below are reproduced from the project results.

TABLE I REPORTED POLLUTANT CONVERSION RESULTS FROM THE CFD STUDY

S.No.	Species	Inlet	Outlet	Reported efficiency
1	CO	0.015	8.3466245 × 10−13	92%
2	NOx	0.010	0.00797416755	20.58%
3	CH4/HC	0.321	0.20258883	36.888%

VI. CONCLUSION AND FUTURE WORK

A honeycomb catalytic converter using CuMnOx was designed in SolidWorks and analyzed using ANSYS Fluent CFD. The computational study examined flow distribution, temperature behavior, and pollutant conversion. The reported results indicate conversion efficiencies of 92% for CO, 20.58% for NOx, and 36.888% for CH4/HC under the selected simulation conditions. The project comparison also indicates that CuMnOx can achieve competitive CO conversion relative to Pt while offering a potentially lower-cost

catalyst option. The honeycomb structure supports increased reaction surface area and smooth gas flow through the converter.

The main limitation is the absence of experimental validation. Future work should therefore include experimental catalyst preparation and coating, laboratory emission testing, real-vehicle evaluation, geometry optimization, and validation of CFD predictions. Further research may investigate advanced catalyst coatings, CuMnOx–Pt/Rh hybrid systems, nano-catalysts, and AI-based geometry and operating-condition optimization.

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