

Manufacturing Elements affecting the Performance & Durability Characteristics of Catalytic Converter

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ABSTRACT: Manufacturing elements that are affecting design parameters, the performance and durability of exhaust catalytic converter was analyzed. Catalytic converters with different outlet pipe insertion lengths were designed and adopted for virtual analysis. Prediction from Computational Fluid Dynamics(CFD) modeling shows insertion length of outlet pipe is inversely proportional to UI & ΔP characteristics. However, required minimum insertion length need to maintain to achieve optimum FOS for the system. According to American Weld Standard(AWS) the minimum overlap of parts in stress carrying lap joints overlap length for lap joint for fillet weld should be five times of its thickness. In this paper what happens when the performance and durability of catalytic converter varies with increase in overlap length of the outlet cone. These prediction of performance data's were verified using bench tests. The paper will discuss in detail the experimental procedures, data acquisition and data handling that were followed.

KEYWORDS: Pressure drop, Uniformity index, Durability, CFD, FEA, Cold flow bench.

I. INTRODUCTION

In an automobile exhaust system catalytic converter and muffler are important components to reduce emission. Diesel oxidation catalyst (DOC) has been proved that it is playing an important role in converting harmful gas of automotive emission [1]. Catalytic converter contains honey comb structure, the surface is coated with wash coat. Precious metal loading, wash coating thickness, substrate material (Ceramic or metal), geometric configuration and position of catalyst converter are playing major role in designing of DOC [2, 3]. In this paper the outlet pipe insertion length contribution in Uniformity index, and pressure drop were studied. Three different profile converters were selected, contour substrate with oblique outlet cone (Sample-1), round substrate with straight outlet cone (Sample-2), and round substrate with oblique outlet cone (Sample-3) respectively. Each model has six outlet pipe insertion length (5, 9, 15.5, 17, 22.6 and 30.5mm). Those models were analysed in STAR CCM+ (CFD) to predict the pressure drop and uniformity index [4]. The pressure drop and uniformity index results are plotted in the graph below. The insertion length is directly proportional uniformity index of converter assembly in all models. From base samples, sample-1 is selected and created with four outlet pipe insertion length 15.5, 17, 22.6 and 30.5mm respectively. Those samples are tested in cold flow bench to measure the pressure drop [5]. Those results are converted into hot flow test results using 1D calculation [6]. Same like CFD results, test results are plotted in the graph below. In sample-1 the maximum and minimum insertion length models are selected to measure the durability analysis. Maximum insertion length has maximum durability compared with minimum insertion length. Outlet pipe insertion length impacts on pressure measurement and uniformity index and durability were validated in experimental and virtual analysis.

A. CFD ANALYSIS

CAD model of the Sample-1 converter which will be examined in the paper is shown in Fig.1. The converter consists of inlet and outlet pipes, two cones, substrate (Porous), Support mat, and Shell. A three-dimensional model of converter is generated in CFD tool Star CCM+ v11.02 for the analysis.

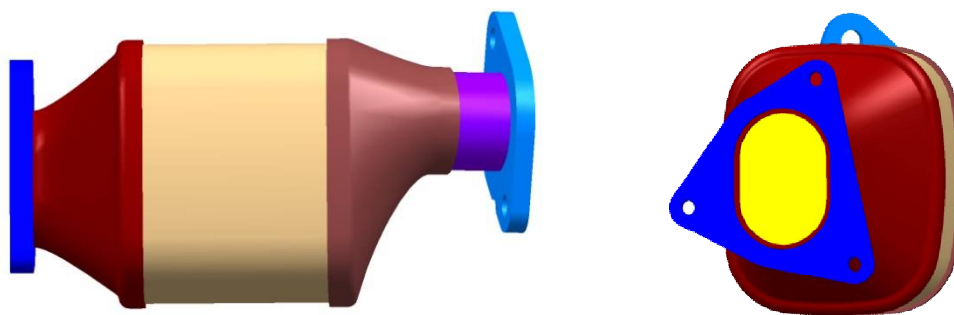


Fig.1 Converter CAD Model

II.1.1 MODELLING AND MESHING

The CAD model is imported in Star CCM+ and the surface preparation was carried out. The parts are merged to one another to create regions such as fluid or solid etc. The solid region was separated and deleted and the remaining fluid region is shown in Fig. 2.

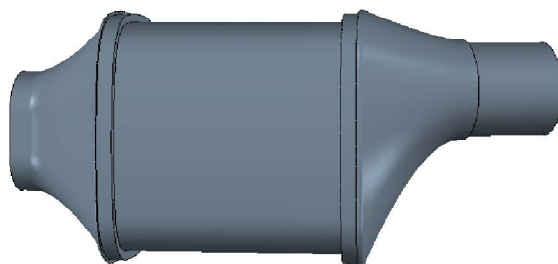


Fig.2 Converter - Fluid region



Fig. 3 Converter - Meshed fluid region

The fluid region of the converter is surface meshed and then polyhedral mesh was performed, with a refined prism layer mesh near the wall. The k-ε turbulence model is used, with standard wall functions for near-wall treatment. The model has approximately 1.1L cells with maximum skewness angle of 83 degree. The fluid region with mesh is shown in Fig. 3.

I. BOUNDARY CONDITIONS

Air is used as fluid media, which is assumed to be steady and comparable. High Reynolds number k-ε turbulence model is used in the CFD model. This turbulence model is widely used in industrial applications. The CFD analysis of this model would be passing air at fixed mass flow rate through the converter assembly. The time conditions implemented are steady state. Converter substrate is considered as porous region. The inertial and viscous resistances are calculated with respected to the tested converter substrate dimensions. The inertial and viscous resistances are 2.68kg/m⁴ and 1833kg/m³.s at 240kg/h respectively. The Pressure drop across the converter assembly is measured. The mass flow rates and temperature are maintained at 240kg/h and 300K. The outlet pressure of converter assembly is kept at 1atm.

II. POST PROCESSING RESULTS

The CFD flow analysis is conducted on converter assembly. The inputs of the converter assembly are mass flow rate 240kg/hr, and air temperature is 1123K. The pressure, velocity vector and uniformity index plots are shown in Fig. 4&5 respectively.

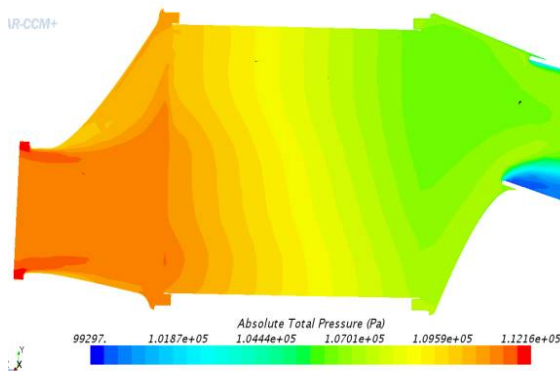


Fig.4 Pressure plot

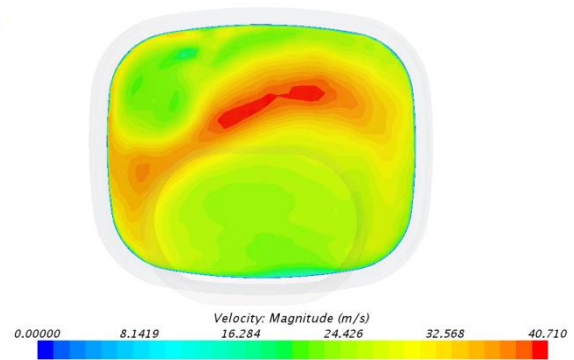


Fig. 5 Uniformity index

Same like sample-1, analysis were conducted, those pressure drop and uniformity index results are listed in Table: 1 and graphical representation is shown in Fig. 6 & 7.

Table: 1 CFD results

S.No.	Insertion length (mm)	Pressure drop (mbar)			Uniformity index		
		Sample-1	Sample-2	Sample-3	Sample-1	Sample-2	Sample-3
1	5.0	59.98	47.95	79.56	0.92	0.94	0.88
2	9.0	61.33	49.49	84.06	0.92	0.94	0.89
3	15.5	64.77	58.83	93.63	0.92	0.92	0.89
4	17.0	65.19	61.22	94.67	0.92	0.92	0.88
5	22.6	67.47	66.48	103.47	0.92	0.92	0.88
6	30.5	69.34	71.40	122.76	0.92	0.91	0.88

Pressure drop of the converter is gradually increased with respected to the insertion length of outlet pipe in outlet cone. That changes also reduce the uniformity index of the converter.

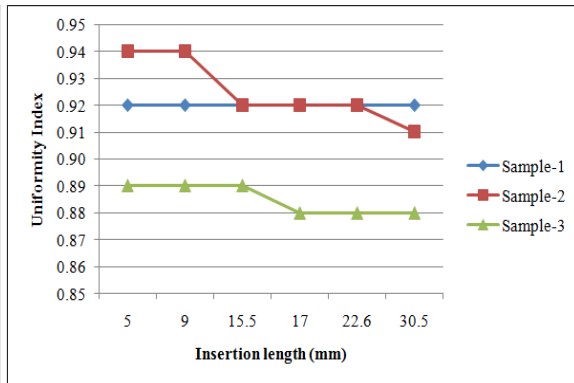
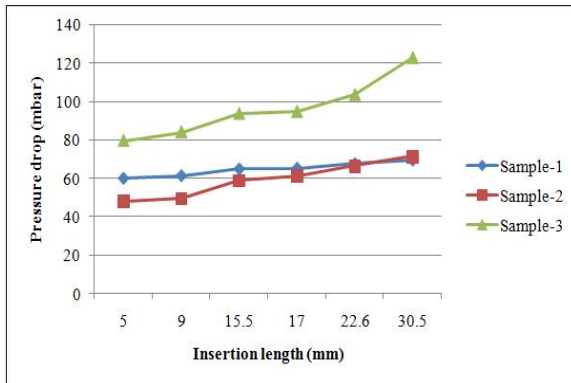


Fig. 6 Graphical representation of Pressure drop-CFD results

Fig.7 Graphical representation of Uniformity index-CFD results

B. EXPERIMENTAL ANALYSIS

I. TEST SAMPLE

The substrate with oblique outlet cone (Sample-1) is selected and created with four outlet pipe insertion length 15.5, 17, 22.6 and 30.5mm respectively. The Test sample and cut section of outlet cone and outlet pipe is shown in Fig. 8 & 9.



Fig. 8 Converter - Sample-1





Samples				
Insertion length	15.5mm	17mm	22.6mm	30.5mm

Fig. 9 Converter - outlet cone & pipe (Cut section)

II. TEST SETUP

The cold flow bench is used to measure the pressure drop of converter assembly. The cold flow bench maximum mass flow rate and temperature are 1200kg/h and 318K respectively. The simple model of converter assembly is selected for

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pressure drop measurement test. The converter assembly is mounted on cold flow bench with appropriate setup. The test setup is shown in Fig. 10.



Fig. 10 Converter - Pressure drop measurement test setup

Pressure drop across the systems are analysed with the aid of two number of pressure sensors. Pressure sensor one is placed 50mm before the inlet flange of the converter assembly. The pressure sensor two is placed open to the atmospheric pressure. The mass flow rate is maintained at 240kg/h. The remaining air temperature is maintained with 303K and the measurements are acquired for two minutes time span at all stages. The outlet pressure of the converter assembly is kept at 1atm.

III. TEST RESULT

The pressure drop measurement in cold flow bench is totally different from hot flow test bench this is because it has more than 60% of deviation based on temperature difference. The following parameters are contributed to make difference in pressure drop measurement in cold flow bench compared to hot flow bench.

1. Air density (kg/m^3), and
2. Gas constant (J/kg/K).

From reference paper :6, The cold flow results are converted into hot flow results. Those converter results are shown in Table:2 and graphical representation is shown in Fig. 11.

Table: 2 (Test & Extrapolated results)

S.No.	Mass flow rate (kg/h)	Pressure drop (mbar)			
		15.5mm	17mm	22.6mm	30.5mm
1	50	13.79	14.11	14.43	14.75
2	100	17.96	18.28	18.60	19.62
3	150	30.14	31.10	32.77	35.97
4	200	46.17	47.45	50.02	53.99
5	240	60.92	62.84	67.20	73.62

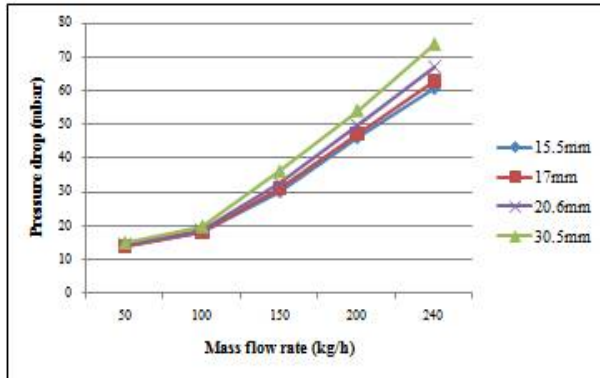


Fig. 11 Graphical representation of results

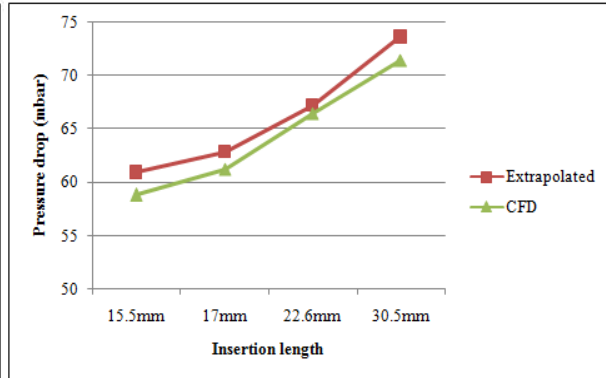


Fig. 12 CFD vs. Extrapolated results

The extrapolated results from cold flow bench are correlated with CFD prediction results. Here, the maximum mass flow rate is selected for each sample. Those are shown in Fig. 12 and its having maximum deviation of 3.5%.

III. DURABILITY ANALYSIS

The same CAD model which was used in CFD analysis, is carried over for durability analysis (FEA). It has following insertion lengths 2, 4, 6 & 8mm respectively.

A. PRE-PROCESSING

In pre-processing Hyper mesh is used. Inlet flange bolt holes are connected to the engine C.G point and all brackets are constrained in all degrees of freedom and it's shown in Fig. 13. For meshing the 4node quad element type is used for exhaust catalytic converter assembly. The maximum element size is 3mm.

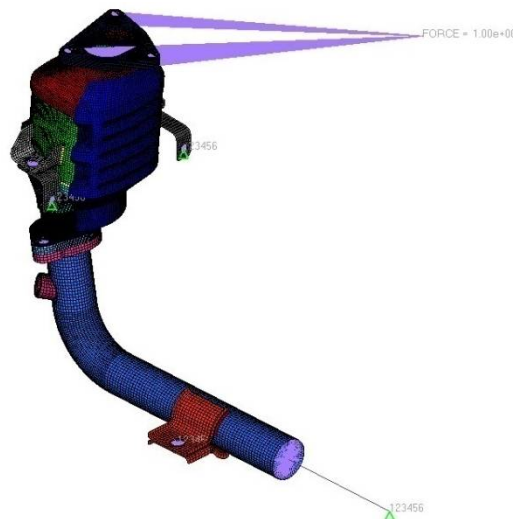


Fig. 13 Converter - FE Model with boundary conditions

B. SOLVING & POST-PROCESSING.

In solving and post processing the MSC Nastran and Hyper view are used. The same boundary conditions are used for all models. The minimum insertion length having maximum stress i.e. shown in Fig. 14. The impact of insertion length in durability is predicted. Those results are listed in Table:3.

Table: 3 (FEA Results)

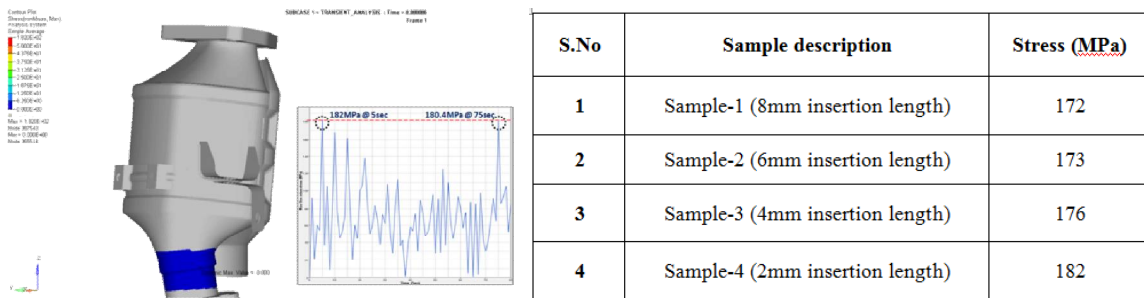


Fig. 14 Min. insertion length stress contributions & transient stress plot

IV. CONCLUSION

The following conclusions can be drawn from the experimental and virtual investigation.

1. By increasing the pipe insertion length from inlet cone, Uniformity Index of the system decreases with increase in back pressure. The same concept was validated with both virtual and experimental analysis.
2. Structural durability of the system by varying the pipe insertion length was analyzed using transient response and found that the von misses stress is increasing, when the pipe insertion length goes below 5mm. Therefore, the pipe insertion length during manufacturing need to be maintained as per the design requirement.

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