ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 5, Issue 5, November 2015

Experimental Investigation of Temperature Variation on the Exhaust Gases of Cylinder Head under EURO 4 Norms by Analytical and FEA

R.Srinu*, ** L.Srinivas Naik,***K.Srinivasa Chalapathi.
*Asst.Professor, **Assco.Professor,***Assco.Professor.
Department of Mechanical Engineering, Anurag Group of Institutions, Hyderabad, TS, India.

Abstract— ***The heat transfer conditions in automotive exhaust piping are only recently being studied in depth because of their important role in the design and the optimization phases of exhaust after treatment systems .With the advent of the EURO 4 norms the design of the exhaust manifold plays a very crucial role.In order to fulfill the above, the temperature of the exhaust gas has to be maintained above a particular level in order to make sure that the catalytic convertor works to its full efficiency. If the temperature of the exhaust gas entering the catalytic convertor reduces less than 550^{0}C reduces the efficiency of the convertor by 80%. Here the exhaust manifold in the cylinder head is modeled in CATIA.The various inputs required for ANSYS and coolant velocity values, for various thicknesses and mass flow rate are calculated. From the resulting tabulation a polynomial expression relating mass flow rate and coolant velocity is formed. Inputs are then given to ANSYS to analyze the stress developed in each case. From this the best possible result is obtained.***

Keywords: **automotive exhaust, catalytic convertor, coolant velocity values, exhaust manifold.**

I. INTRODUCTION

Heat transfer in these systems has only recently attracted the importance they deserve Due to their key role in the design of modern exhaust after-treatment systems. Such studies are today important for better understanding of these systems and, thus, being able to influence cold-start warm-up of the catalytic converter, thermal ageing of the converter. Oncoming automotive exhaust emissions standards focus on the minimization of cold start emissions for catalyst-equipped diesel automobiles. In that context, all passive means of achieving Maximum possible catalyst efficiency must be exhaustively examined. The complex geometry of the exhaust manifold and the special flow conditions complicate the problem of accurately estimating several heat transfer parameters.

The acquisition of useful data for the estimation of heat transfer rates and their application in the optimized design of various exhaust configurations forms the subject of the present work. Here we take advantage of computer models to analyze the effect of the variation of various parameters that govern the heat transfer in the manifold. Selected results are illustrated in form of temperature, stress and deformation distribution plots. Some suggestions for design improvements are therefore also presented.

II. METHODOLOGY

The main objectives of this work. Determine the optimum coolant velocity over the manifold for the varying mass flow rate in order to maintain the temperature of gas entering the catalytic convertor above 550°C .Only if this temperature is maintained will the catalytic convertor work with an efficiency of above 80 percentage.

To obtain a polynomial expression to determine the particular coolant velocity at various mass flow rates for a particular thicknesses. This can be implemented in the cooling system thereby maintaining catalytic convertor efficiency.

To identify and suggest the thickness of the manifold at which the stress developed is minimum and hence reduce the chances of failure.

Material

Most exhaust manifolds are made of Cast iron, which is a brittle, porous, iron-carbon alloy while in some cases other materials such as nodular iron, stainless steel or heavy gauge Steel are used. Silicon-molly cast ductile irons are emerging as the material of choice and the Replacement material for others in order to meet the increasing operating temperature requirements for manifolds.

Properties preferred in a manifold material

Corrosion resistance, low thermal conductivity, low thermal expansion coefficients, high temperature fatigue strength, high temperature creep resistance, anti-oxidation properties and high temperature yield strength.

Desirable characteristics of the manifold

The manifold should provide unrestricted flow of the exhaust gases to minimize the effect on the breathing capacity of the engine. The exhaust manifold must be capable of withstanding extreme temperature and the consequent expansion and contraction, the thermal shock from road splash and the vibration loads due to engine/ vehicle operation. Should ensure leak free gas discharge from the engine to the down pipe. Should ensure durability up to 160,000 km without cracks or other failures. Should minimize heat loss during the warm-up phase to allow quick catalyst light-off; and in hot operation to avoid excessive heating of surrounding components. Minimize weight to improve fuel economy. Provide optimized flow distribution to the oxygen sensor to ensure good air/fuel feedback to the engine management system. Transport exhaust gases well-mixed and free of particles to the EGR (Exhaust Gas recirculation) port.

III. ANALYTICAL METHOD

Heat transfer calculations

Convection loads are to be applied in ansys, it is required that all values of temperatures and heat transfer coefficients be calculated prior to the analysis for mass flow rates of mg=. 014, .015, .016 and the different thickness from 10 to 1mm.
Exhaust gas temperatures: Tags in=650°c, T gas out=550°c
mgas=.016kg/s@1500rpm
• Tbulk=(650+550)/2 =600°c
Internal convection: Properties of exhaust gas at bulk temperature,

Density, ρg=.404kg/m3
Kinematic viscosity, γg=96.89∗10−6m2/s
Prandtl number, Prg=0.699
Thermal conductivity, Kg=62.22∗10-3w/mk
Specific heat Cpg=1.114∗103kJ/kg k
• Heat lost by exhaust gases, Q=mg∗Cpg∗(Tgas in-T gas out)
=0.016 ∗1.114 ∗103 ∗(650 –550)
=1782.4W

Internal convection heat transfer :
• Velocity of exhaust gas , Vg = mg /(ρg∗(∏/ 4) ∗ Di 2)
= 0.016 / (0.404 ∗0.25Π ∗0.0325 2) = 47.73 m/s

• Reynolds number,Reg= (Vg ∗Di)/ γ g
= (47.73 ∗0.0325)/ (96.89∗10-6) = 16013.5

•Nusselt number, Nu st= 0.023 ∗Reg0.8∗Prg0.3
= 0.023 ∗16013.5 0.8∗0.6990.3 = 47.71 23
• (Nu bent / Nu st) = 1+(21∗Di) / (Reg0.14∗Dbend)
= 1+(21∗0.0325) / (16013.5 0.14∗0.070) =3.51
Corrected Nusselt number, Nu bent =167.65
• Internal heat transfer coefficient, Hi= (Nu bent/(Di/Kg))
=(167.65/(0.0325/(62.22∗-3))) =320.97 w/m

Heat lost by exhaust gases= Heat transferred by internal convection=Q
• Heat transferred by convection, Q= Hi∗Ai∗(Tbulk –Tsi)
= Hi∗Π∗Di∗li∗(Tbulk –Tsi)
1782.4=320.97∗Π∗0.0325∗0.183∗(600−Tsi)
Tsi =302.79°c

Conduction heat transfer:
Heat lost by exhaust gases= Heat transferred by conduction
Thermal conductivity of wall , Kw=54.47
For a thickness of 10mm,Dext =0.0525m

• Heat transferred by conduction,
Q= [Tsi −Tsext]/[ln(Dext/ Di)/(2Π∗li∗Kw)]
1782.4= [302.79−Tsext]/[ln(0.0525/ 0.0325)/(2Π∗0.183∗54.47)]
Tsext=289.14°c

External convection heat transfer: Heat lost by exhaust gases= Heat transferred by external convection
Coolant initial temperature, T∞ =70°c , li=lext

• Film temperature, Tf=(Tsext + T∞)/2
=(289.14 + 70)/2 =179.57°c
For =179.57°c for water,
Kinematic viscosity, γl =0.173∗10−6m2/s
Prandtl number, Pr l=1.044,
Thermal conductivity, K l=675.7∗10-3w/mk

Heat transferred by External conduction,
• Q=Hext∗Ao∗(Tf - T∞)
Q=Hext∗Π∗Dext∗lext∗(Tf - T∞)
1782.4=Hext∗Π∗.0525∗0.183∗(179.57 – 70)
Hext=538.95w/m2k

• Nu ext= Hext∗Dext/k l
= 538.94∗0.0525/(675.7∗10-3) =41.806

• Nu laminar=0.664∗√ (Re l) ∗3√ (Pr l)=0.673∗√(Re l)
• Nu turbulent=(0.037∗Re l0.8∗Pr l)/(1+2443∗Re l-0.1∗(Pr l2/3-1))
=(0.0386∗Re l0.8)/(1+71.14∗Re l-0.1)
• Nu ext= 0.3+√(Nu laminar2+ Nu turbulent2)
⇒41.806= 0.3+√[(0.673∗√(Re l))2 +((0.0386∗Re l0.8)/(1+71.14∗Re l-0.1))2]
⇒Re l =3826.21

Reynolds number of coolant,
Re l =(V l∗Dext)/(γl)=3.0345∗105∗V l
⇒coolant velocity required l = .01246m/s

m=.016 (kg/s)						
Thickness (m)	Ts_{ext} (°c)	Hext (w/m^2k)	T_f (°c)	Nu ext	Re_l	V_l (m/s)
.010	289.14	538.95	179.57	41.82	3826.21	0.01246
.009	290.24	557.51	180.12	41.61	3788.35	0.01282
.008	291.39	577.47	180.71	41.38	3748.12	0.01321
.007	292.59	599.06	181.31	41.16	3708.11	0.01363
.006	293.84	622.49	181.92	40.92	3664.71	0.01408
.005	295.15	647.99	182.57	40.69	3623.35	0.01457
.004	296.52	675.88	183.26	40.44	3578.67	0.01511
.003	297.96	706.51	183.98	40.18	3532.49	0.01568
.002	299.48	740.28	184.74	39.92	3486.61	0.01633
.001	301.09	777.73	185.54	39.64	3437.53	0.01703

Table1: calculated values for m=. 016 kg/s

m=.015 (kg/s)						
Thickness (m)	Ts_{ext} (°c)	Hext (w/m^2k)	T_f (°c)	Nu ext	Re_l	V_l (m/s)
.010	295.71	490.58	182.85	37.961	3173.36	0.01021
.009	296.74	507.67	183.37	37.795	3145.32	0.01052
.008	297.82	526.11	183.91	37.616	3115.41	0.01085
.007	298.94	546.04	184.47	37.431	3084.64	0.01121
.006	300.11	567.68	185.05	37.241	3053.21	0.01159
.005	301.34	591.24	185.67	37.044	3020.79	0.01201
.004	302.62	617.02	186.31	36.841	2987.39	0.01246
.003	303.98	645.31	186.99	36.622	2951.58	0.01295
.002	305.41	676.55	187.71	36.404	2916.64	0.01351
.001	306.91	711.24	188.45	36.174	2879.65	0.01411

Table2: calculated values for m=. 015 kg/s

ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 5, Issue 5, November 2015

m=.014 (kg/s)						
Thickness (m)	Ts ext (°c)	Hext (w/m²k)	Tf (°c)	Nu ext	Re i	V i (m/s)
.010	302.56	444.37	186.28	34.79	2690.34	0.00851
.009	303.53	460.05	186.76	34.65	2668.11	0.00877
.008	304.53	476.98	187.26	34.51	2644.72	0.00905
.007	305.58	495.28	187.79	34.35	2621.76	0.00936
.006	306.68	515.13	188.34	34.19	2597.36	0.00968
.005	307.82	536.79	188.91	34.02	2571.57	0.01004
.004	309.02	560.47	189.51	33.85	2546.81	0.01041
.003	310.28	586.49	190.14	33.67	2520.05	0.01086
.002	311.61	615.22	190.81	33.49	2491.95	0.01132
.001	313.01	647.14	191.51	33.31	2463.71	0.01185

Table3: calculated values for m=. 014 kg/s

m=.014 (kg/s)					
Thickness	Strain	Deformation	1st principal stress (N/m²)	2nd principal stress (N/m²)	3rd principal stress (N/m²)
10	0.005803	3.84E-04	3.13E+08	5.32E+07	4.97E+06
9	0.00593	3.83E-04	2.95E+08	5.50E+07	5.24E+06
8	0.005538	3.85E-04	2.76E+08	3.93E+07	2.77E+06
7	0.005102	3.87E-04	2.81E+08	3.44E+07	7.67E+06
6	0.005132	3.83E-04	2.77E+08	2.81E+07	2.20E+06
5	0.005216	3.81E-04	2.79E+08	3.41E+07	9.96E+06
4	0.00522	3.80E-04	2.90E+08	3.35E+07	8.80E+06
3	0.005481	3.78E-04	2.88E+08	3.93E+07	1.81E+07
2	0.005832	3.77E-04	3.04E+08	3.59E+07	2.06E+07
1	0.005671	3.77E-04	2.91E+08	7.14E+07	2.63E+07

Table4: results from ansys for m=.014 kg/s

m=.015 (kg/s)					
Thickness	Strain	Deformation	1st principal stress (N/m²)	2nd principal stress (N/m²)	3rd principal stress (N/m²)
10	0.006655	3.75E-04	3.07E+08	5.15E+07	4.72E+06
9	0.00585	3.75E-04	2.89E+08	5.31E+07	5.93E+06
8	0.005979	3.74E-04	2.65E+08	4.13E+07	8.45E+06
7	0.005918	3.76E-04	2.60E+08	2.91E+07	3.82E+06
6	0.005027	3.75E-04	2.72E+08	2.69E+07	2.63E+06
5	0.00511	3.74E-04	2.74E+08	3.28E+07	9.37E+06
4	0.005117	3.72E-04	2.84E+08	3.26E+07	8.33E+06
3	0.005373	3.70E-04	2.83E+08	3.83E+07	1.75E+07
2	0.00572	3.69E-04	2.98E+08	3.50E+07	1.99E+07
1	0.00617	3.71E-04	3.56E+08	7.88E+07	2.64E+07

Table5: results from ansys m=.015kg/s

m=.016 (kg/s)					
Thickness	Strain	Deformation	1st principal stress (N/m²)	2nd principal stress (N/m²)	3rd principal str (N/m²)
10	0.005395	3.70E-04	2.78E+08	4.25E+07	6.25E+06
9	0.005732	3.67E-04	2.84E+08	5.12E+07	6.61E+06
8	0.00567	3.71E-04	2.76E+08	2.40E+07	4.96E+06
7	0.004898	3.71E-04	2.71E+08	3.15E+07	6.24E+06
6	0.004927	3.68E-04	2.67E+08	2.56E+07	3.18E+06
5	0.00501	3.66E-04	2.69E+08	3.18E+07	8.79E+06
4	0.005018	3.65E-04	2.79E+08	3.17E+07	8.50E+06
3	0.00527	3.63E-04	2.77E+08	3.74E+07	1.68E+07
2	0.005609	3.62E-04	2.92E+08	3.41E+07	1.93E+07
1	0.00602	3.64E-04	3.49E+08	7.72E+07	2.58E+07

table 6 : from ansys for m=0.016kg/s

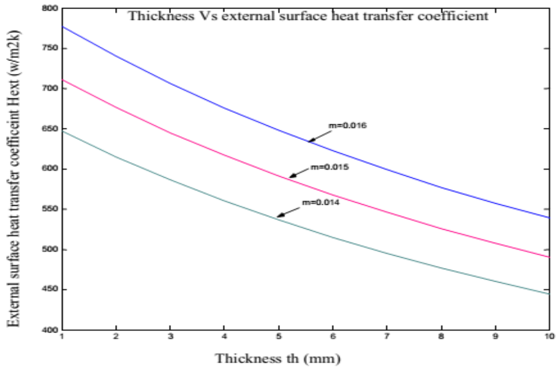

Fig.1 Thickness Vs external surface heat transfer coefficient, comparision

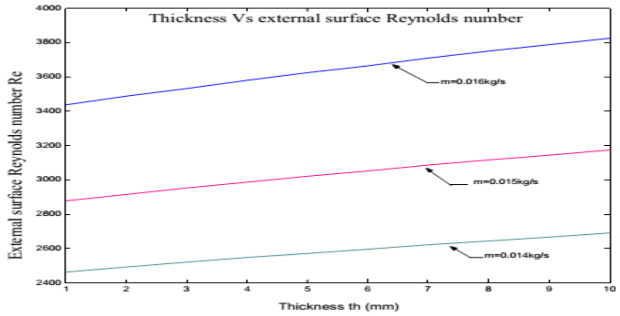

Fig.2 Thickness Vs external surface Reynolds number, comparision

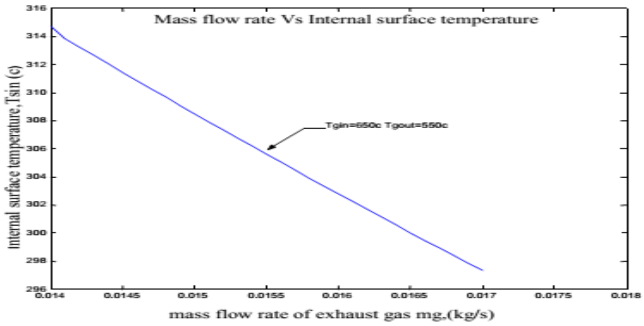

Fig 3 Mass flow rate Vs External surface temperature

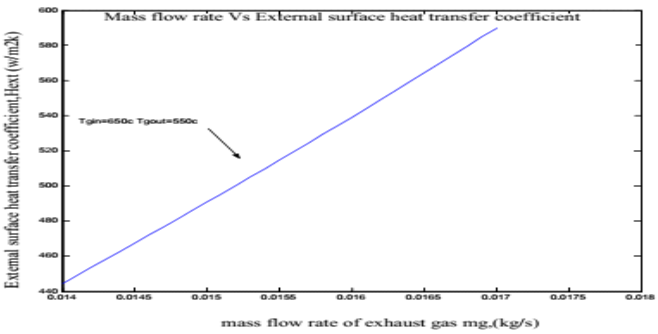

Fig 4 Mass flow rate Vs External surface heat transfer coefficient

IV. NUMERICAL METHOD

The model of the exhaust manifold is created using CATIA V5.Since the flow path in the manifold is made up of different cross sections, the loft option is used to draw the model.

The particular case being dealt here is an exhaust manifold that is water-cooled and is inside the cylinder head. Therefore,

ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 5, Issue 5, November 2015

as opposed to other air-cooled manifolds that are tubular and uniform cross section, this manifold is, made of circles and ellipses of varying dimensions. Therefore considerable time and care is taken to model the component. One another problem faced is that the central axis is bent.

Lofting

After all the cross sections are created, they are all connected using the loft option in Catia which gives us a solid bent structure as shown in the figure.

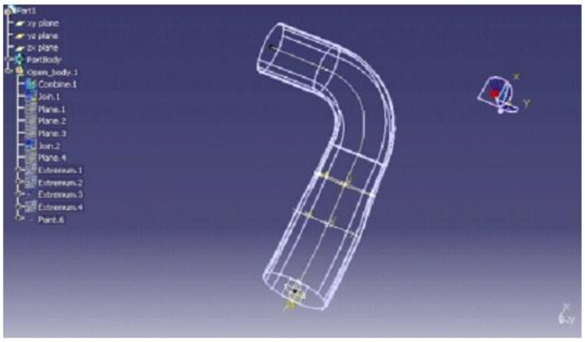

Fig 5. Lofting is created in CATIA

Ansysis Simulation of Exhaust Manifold

Thermal analysis

The thermal loads that act on the body are applied to the model. There are two loads that act here Convection load on internal surface and Convection load on external surface. To apply the loads, first the respective areas on which the load is to be applied are selected after which the load are applied. Here, for the inner surface, convection film coefficient & bulk temperature of the gas from manual calculations are applied for the respective cases to imitate the flow of the exhaust gas. Whereas, for the external surface, external film coefficient and the film temperatures are input as the load values to imitate coolant flow. This assumption is valid as all manual calculations for internal convection is done for bulk temperature and for external Convection, film temperature is used.

Red and blue wire frames spread across the surfaces to denote that a load has been assigned.

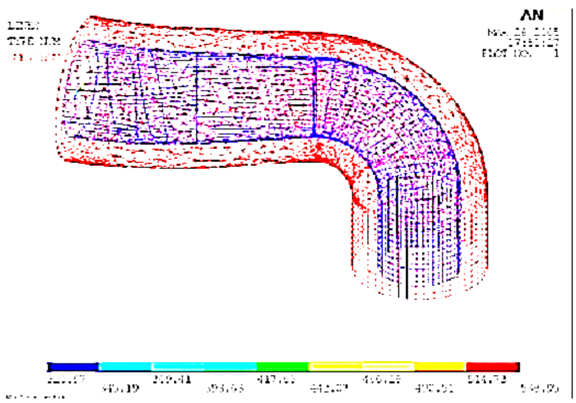

Fig 7. Convection load application

Solution (thermal)

Ansys to solve any problem it is necessary to provide information as to what kind of an analysis is being considered (i.e. static or transient etc). The new analysis menu is selected and static option is selected as only static case is dealt in this project.

Picked on to start solving of all the equations for the current load step. After this step, all the solved data across the model are stored in arth file in the same directory which would function as a temperature input during the structural phase of the analysis.

The first set option is picked to read in all the results generated in the solve process into the model to visualize parameters.

Generate various graphics required for the analysis.3dplots for temperature distribution are Generated and stored in the current working directory and generate the temperature values for every individual node to identify the maximum and minimum temperature on nodes or areas.

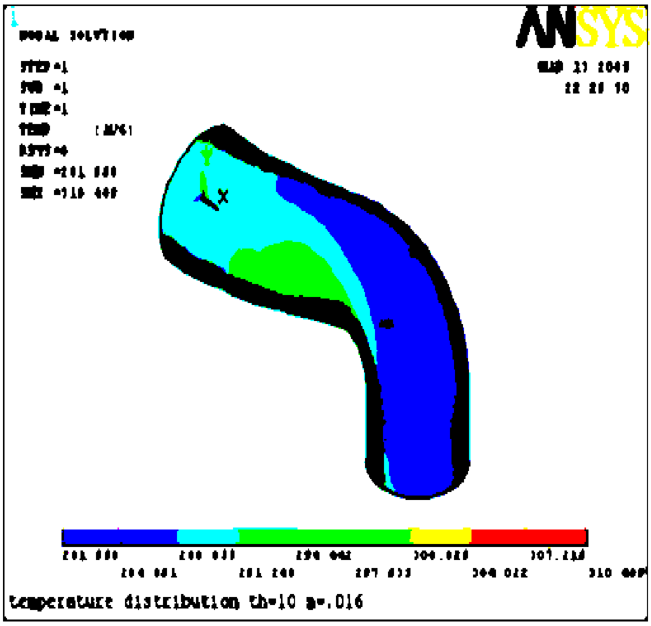

Fig 8.Temperature distribution

Structural analysis

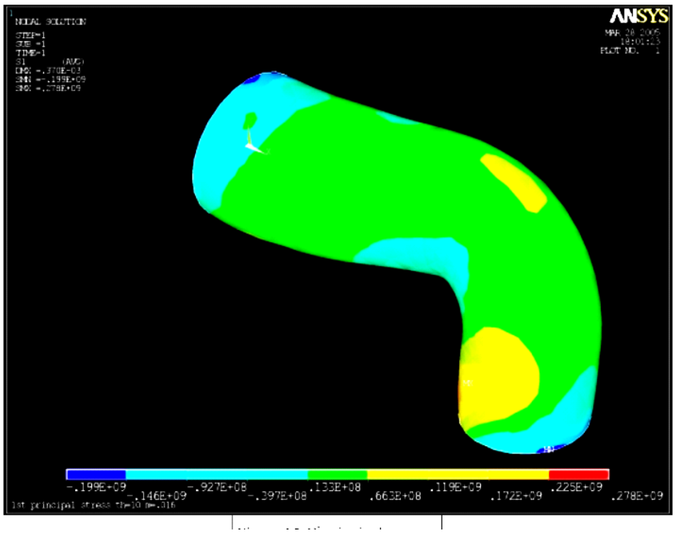

Fig 9. Principal Stress

ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 5, Issue 5, November 2015

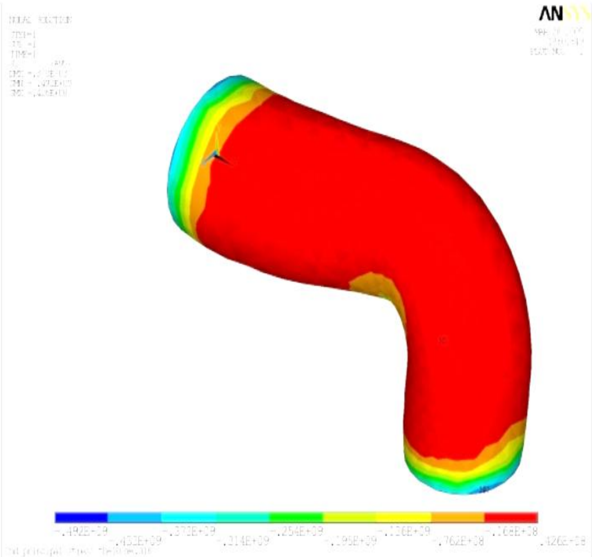

Fig 10. 2nd. Principal Stress

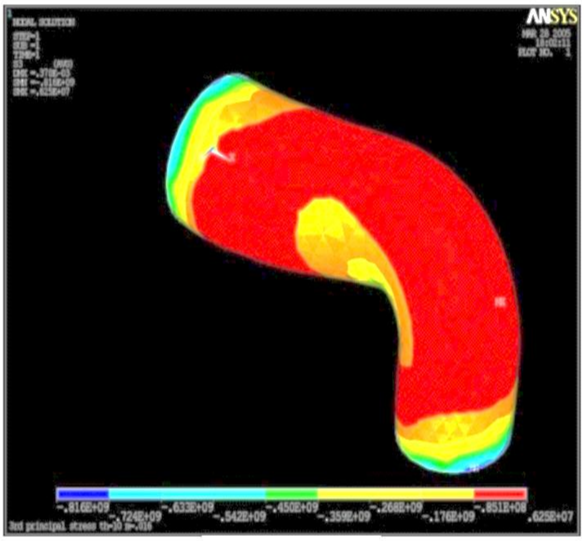

Fig 11. 3rd Principal Stress

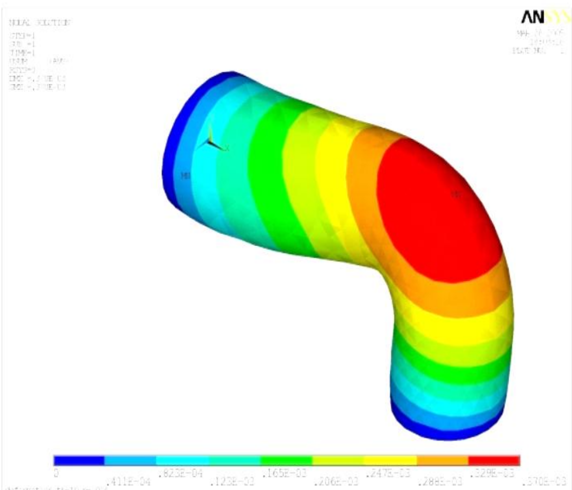

Fig 12. Deformation

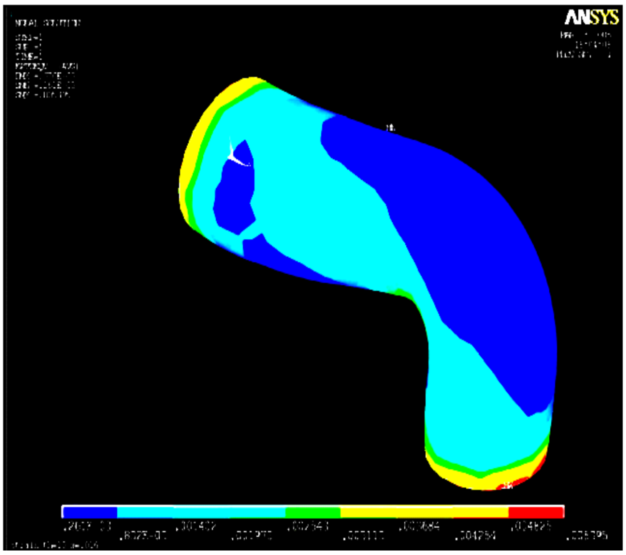

Fig 13. Principal Strain

V. RESULTS AND DISCUSSIONS

For a constant thickness

• With increase in the mass flow rate, the external surface temperature is found to decrease whereas the external heat transfer coefficient was found to increase.

• With decrease in mass flow rate, the coolant velocity over the manifold needs to be decreased.

For a constant mass flow rate

• With decrease in the thickness of the manifold, both the external surface temperature & the external surface heat transfer coefficient are increase. With decrease in the thickness of the manifold, the coolant velocity needs to be increased.

For a thickness of 10mm, the variation of coolant velocity with mass flow rate is found to follow a particular pattern. From the curve fitting operation, a general polynomial expression is derived which signifies the coolant velocity required for every mass flow rate. The above expression is to be implemented in the cooling system to maintain the exhaust temperature at the manifold exit above 550°c for the efficient functioning of the Catalytic converter.

From Ansys and plots

From the tabulations and the graphs plotted, we observe that the stress developed in the manifold with a decrease in thickness:

• Decreases gradually from a thickness of 10mm to 6mm and then

• Increases steeply from thickness of 6mm to 1mm.

Therefore, selection of either too thick or too thin a manifold would result in stress and therefore cracking. From the patterns in the graphs we identify that the 6mm thickness has the minimum stress of all options.

• Thickness 1mm was found to out rightly violate maximum principal stress theory. Therefore would work out to be a failure model.

VI. CONCLUSIONS

The optimum coolant Velocity over the manifold for which the exhaust temperature is maintained above the minimum required for efficient operation of the catalytic converter is determined and the polynomial expression that denotes the coolant velocities required for different mass flow rates of the exhaust is as below

Vl= 0.1- 20*mg + 1.3e+003*mg -2- 2.5e+004*mg3

Further thickness value for the manifold that would result in reduced thermal stress and simultaneously maintain the exhaust temperature is found out to be 6mm. therefore this value of thickness is suggested as a design modification and the polynomial expression for this thickness value is found to be

Vl= 0.12- 2.7e - 23*mg + 1.5e+003*mg2+004*mg3

REFERENCES

[1] Monika weiner (2004) 'Virtual service-life testing', Fraunhofer magazine 1-2004-34_tcm6-10202.

[2] Said Zidat and Michael Parmentier (2003) 'Exhaust Manifold Design to Minimize Catalyst Light-off Time', Delphi, Technical Centre Luxembourg, SAE technical paper series, 2003-01-09403.

[3] I.P. Kandylas, A.M. Stamatelos(1999) 'Engine exhaust system design based on heat transfer computation 'Laboratory of Applied Thermodynamics, Mechanical Engineering Department, Aristotle University of Thessaloniki, Thessaloniki, Greece.

[4] YasarDeger,(2004) 'Coupled CFD Coupled CFD-FE- Analysis for the Exhaust Manifold for the Exhaust Manifold of a Diesel of a Diesel Engine.

[5] Sulzer Technical Review, 10/2003, Germany.