Transient Conjugate Thermal Analysis and Validation of the Dosing System for Off-highway Aftertreatment System

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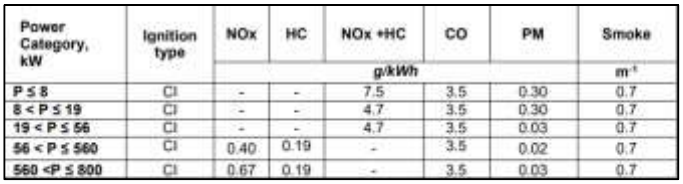
Abstract

Post-BSVI launch of On-highway applications, the next step was taken towards controlling emissions for Off-highway applications. Genset, Tractor and Excavator are one such category that is part of Off-highway applications. The transition to Central Pollution Control Board IV-plus norms from CPCB II is expected to bring transformation in the Genset Industry through technological changes & price revisions. Genset products are going from pure mechanical to complete full scope electronic ones along with Aftertreatment system (ATS). Selective Catalytic Reduction (SCR) is being widely used in On-highway applications, but now the off-highway application is also moving towards it to bring NO_x emission under the required limits. Diesel Exhaust Fluid (DEF) which is a major reductant used to reduce NOx, requires the dosing system to deliver metered quantity into ATS. ATS designers need to ensure that DEF temperature in Dosing system circuit should not go beyond a specified limit for reliable operation of AT system. Off-highway applications have very tight space claim around the ATS with a large canopy over it, making it furthermore difficult to keep airflow around the Dosing system. During Product development, one of the requirements is to check temperatures at key locations on the Dosing system and DEF liquid temperatures for the transient cycle. A few challenges associated with transient thermal analysis are that it is necessary to model surrounding air movement, neighboring part clearances and canopy above the system.

CFD tool was used to analyze risk at critical locations of the dosing system during the cycle. This work discusses details of the modeling approach used in CFD to capture correct physics around the dosing system for the transient cycle. Validation of analysis results with actual application test data is discussed in this work. The stable analysis approach found in this work shows the largest gap between CFD and the test in the range of 30 deg C at the critical location of the dosing system. Transient variation of temperature over the period and its comparison with the test shows a good correlation. The stability of the modeling strategy has been confirmed for different boundary conditions and geometry.

Introduction

Due to rapid urbanization and industrialization, there has been rise in demand of off-highway vehicles. India and China being among the most populous nation have heavy dependence on fossil fuels. There are studies suggesting the peak of pollution level is very near for developing nations **(Becky P.Y. Loo, 2023)**. There has been push from regulatory agencies to layout a plan to target net zero emissions. India is focusing to meet net zero emission by year 2070. There have been drastic steps being taken to put India on track with the future plans. BSVI implementation for On-highway vehicles was one such major change in automobile sector in India. Similarly, now there is huge leap in off-highway emission norms as we move from CPCB II to CPCB IV+ (see Figure 1). There has been approximately 85% reduction in NO_x+HC and 90% reduction in PM permissible levels as compared to CPCB II (see Figure 2), and these are among the most stringent norms for power generation and other stationary applications across the globe for below 750 KVA rating gensets. Due to this change the manufacturers need to do a technological shift from mechanical to electronically controlled after treatment systems. CPCB IV+ norms have been introduced from July 2023. This is in line with the government's plan to reduce overall emissions and meet their 2070 year target of zero emissions. With the advent of urbanization there are many regions such as data centers, office and residential regions where gensets are heavily in use. This technological shift is going to improve environmental sustainability of end users associated in these sectors.



Power Category, kW	Ignition type	NOx	HC	NOx +HC	CO	PM	Smoke
		g/kWh					m⁻¹
P ≤ 8	CI	-	-	7.5	3.5	0.30	0.7
8 < P ≤ 19	CI	-	-	4.7	3.5	0.30	0.7
19 < P ≤ 56	CI	-	-	4.7	3.5	0.03	0.7
56 < P ≤ 560	CI	0.40	0.19	-	3.5	0.02	0.7
560 <P ≤ 800	CI	0.67	0.19	-	3.5	0.03	0.7

Figure 1 CPCB IV+ Emission Norms (Central Pollution Control Board of India, 2023)

Stationary Application Emission Journey				
75 to 560 kW		**CPCB I**	**CPCB II**	**CPCB IV+**
gm/kWh	CO	3.5	3.5	3.5
	PM	0.3	0.2	0.02
	NO_x	9.2	4 (combined)	0.4
	HC	1.3		0.19
Year		2003	2014	2023

Figure 2 Stationary application emission norm evolution journey (Nishant Tyagi, 2013)

SCR technologies has been introduced in power generation and stationary application to meet the tight norms. SCR is now a stable technology being used worldwide and India for on highway vehicles. So, lot of learnings can be taken from it while implementing the same system in genset application. But there are some challenges which are associated majorly with stationary applications. One of that challenge is, available space claim under the canopy of genset. Due to limited space availability and ATS located inside canopy it makes difficult to manage heat and failures associated with it. Ammonia delivery system (ADS) consisting of dosing unit, transfer lines, wiring harness are at risk due to lower temperature acceptance limits. This risk further escalates in scenarios when there is a transient thermal regeneration cycle. During regeneration cycle the exhaust gases are operating at very high temperature and if there is engine shut down after regeneration which is very much a likely scenario for stationary applications, the heat buildup poses a risk to the dosing unit integrated on ATS.

CFD analysis is an effective tool to model this transient behavior and understand risks on critical components of SCR system. This study focusses on evaluation of the strategy used to model the transient heat build behavior and its validation with actual application data. Impact of air flow field around ATS on SCR system has been discussed in detail here. Transient variation of DEF liquid temperature across the cycle shows similar trend as observed in actual test data. ANSYS FLUENT 2021R2 version has been used for this work. Closely correlated and stable modeling approach reduces product development time and risks associated with it. One of the key observations from study has been the criticality of boundary conditions and how it impacts the overall outcome. Challenges associated with transient thermal analysis is mimicking exact ambient behavior around the critical components of ATS. In this paper details of modeling strategies including solver setup and meshing has been discussed which plays a critical role in validating analysis results with actual application test data.

Transient thermal cycle

Particulate matter (PM) is a term used for solid particles. It is a composite matter consisting of dust, dirt, soot or smoke. PM is produced by multiple sources, out of which one of the major source is diesel burning in engines. Diesel particulate filter (DPF) assists in filtering out the soot particles and meet desired PM emission levels. Since, there is constant generation of PM during diesel burning there is constant accumulation of soot in DPF. Due to stringent emission norms now genset application also requires regeneration of accumulated soot in DPF. Regeneration is effective when exhaust gas temperature is above 475-500 deg C. There are broadly two types of PM filter regeneration. Passive regeneration - wherein the soot oxidation takes place at lower temperature in the presence NO_2 coming from oxidation catalyst placed prior to DPF. Passive regeneration is dependent on exhaust gas temperature which must fall in the range of 275-300 deg C. It may not be effective for applications where temperatures will be lower than that band. In such scenario, the soot build up will block the filter causing high backpressure in ATS. Active regeneration are effective at low operating cycles, where with the help of additional energy source increase of gas temperature is achieved and it assists in burning of soot. During both passive and active regeneration, there is increase in temperature of the exhaust gas when DPF regeneration happens ***(Majewski, Diesel Filter Regeneration, 2023)***. This spike in exhaust gas temperature during regeneration causes neighboring components such as dosing unit, temperature to rise. ATS used for genset application typically is stationed inside the canopy as shown in Figure 3 making it difficult for the thermal heat management of auxiliary ADS components during and after the regeneration cycles. This is the major challenge associated with Off-highway genset ATS as opposed On-highway systems which are in relatively open environment. Majorly single module ATS is preferrable in tight space claim for Off-highway application an example shown in Figure 4.

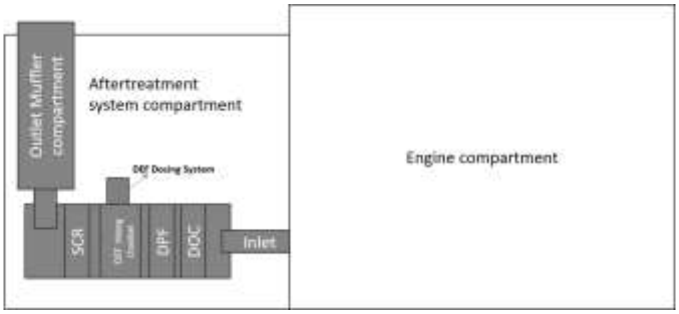


Figure 3 Typical ATS for genset application schematic layout

During regeneration cycle engine is switched ON, there is constant DEF flowing through the dosing system integrated above ATS see Figure 5. But in situation when there is sudden engine shut down the liquid DEF circulating inside dosing unit comes to a halt. Due to which there is rise in temperatures of liquid because there is thermal mass stored on the ATS. So, heat constantly flow from hot ATS surface to cold liquid doser. It can happen due to this huge heat flow on stationary DEF liquid, liquid may boil causing system malfunctioning. This makes it extremely important to evaluate critical temperatures on dosing unit. If there is any risk of high temperatures observed, then design strategy needs to be altered. Below image shows a transient thermal cycle where exhaust temperature ramps up in Event 1, it reaches to a stability regen condition named as Event 2. Then there is sudden shut down of engine followed by a period where due to sudden shut down there is spike in liquid temperatures in event 3, to control this spike coolant flow happens for certain period of time and finally it starts to cool down and reach thermal equilibrium in event 4. This cycle is worst scenario during which if spike in temperature of DEF liquid rises above its boiling point of 130 deg C, then there is high risk to ATS malfunctioning. Stationary applications such as gensets usually run at constant load condition and with this comes the risk of sudden shut down by the end user even in non-regeneration conditions. So, there is high probability that ATS critical component would undergo this cycle very often. In the upcoming sections, details of CFD modeling these transient events and solver settings have been discussed.

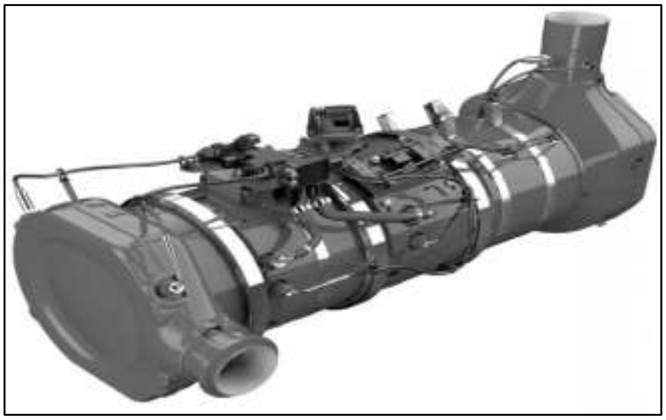


Figure 4 Single module aftertreatment system for off-highway genset application

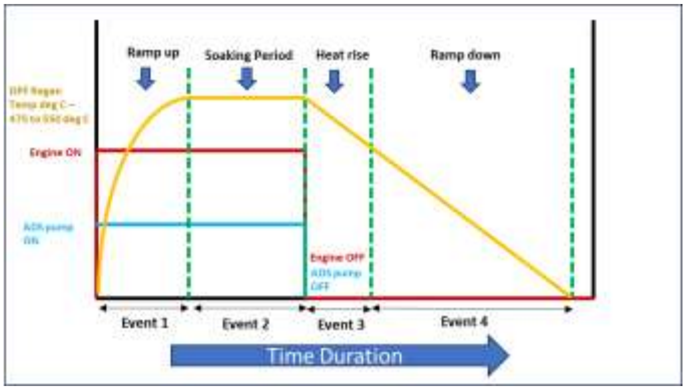


Figure 5 Transient thermal analysis shut down cycle description

Critical Parameters

There are various critical parameters which impact the heat build up of DEF liquid in dosing system as shown in below Figure 6. Dosing system is integrated on ATS due to which risk of heat pushed inside it is highest as compared to other ADS components like DEF transfer lines, supply unit or DEF tank. This transient thermal analysis focuses on evaluating the risk of DEF liquid temperature rise from various heat sources around it.

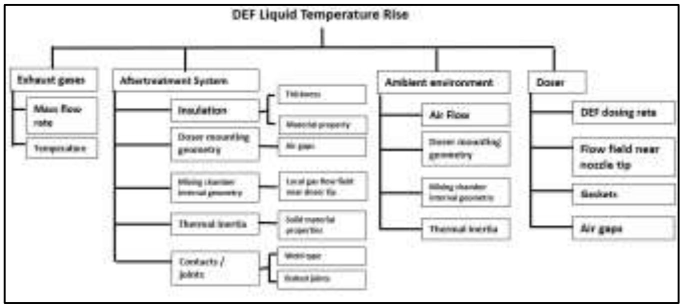


Figure 6 Critical parameters impacting DEF liquid temperature rise inside dosing system

There are various factors which may look trivial but if not modeled accurately may cause huge variation in CFD results. They include air gaps between dosing systems and ATS. For this study conformal mesh approach was used. To ensure proper node to node connectivity, analyst may ignore small gaps and tolerances provided in the CAD model. However, for this analysis small airgaps were defined exclusively, and air properties were assigned to ensure there is accurate heat transfer modeled between surface to surface. Another important factor which plays significant role in DEF liquid heat rise is ambient air flow movement and temperature. In some genset applications radiator air flow is one the source of forced air draft passing on the ATS. It plays a pivotal role while correlating analysis results with test because if we ignore its impact the heat rise would be significantly higher. Also, during event 3 due to sudden engine shut down, radiator air flow also stops causing rise in dosing unit temperature before going for a cool down and reaching thermal equilibrium. Material property accuracy is always an important factor if accurate thermal analysis is needed for correlation. So, as a best practice before commencing CFD analysis for transient thermal analysis the above critical factors must be evaluated deeply. As some of the factors impacts the convective heat transfer around the dosing system and may influence accuracy of results.

Experimental Study and Observations

To deeply understand the physics of heat transfer during transient thermal cycle, multiple tests were done on ATS in controlled environment. The objective of these test were to understand impact of boundary condition change on critical temperatures of dosing system. This test was not done on actual application because of multiple unknowns and uncontrolled ambient behavior makes it difficult to understand the heat transfer behavior. Dosing system consists of very small liquid cavity regions, so thermocouples were placed penetrating inside the metal body touching the liquid. There were five critical representative dosing unit locations were decided at which thermocouples were placed. Out of five (5) locations two (2) locations were in contact with DEF liquid named as DEF inlet and DEF outlet portion of dosing unit. Out of remaining three (3) thermocouples as shown in Figure 7, one (1) was located at the nozzle tip of the dosing unit which is in contact with exhaust gas in ATS. In order to deeply understand heat transfer due to conduction, thermocouple placed at mounting foot area and metal body of the dosing system. Since, major heat source for dosing unit is ATS. Boundary conditions of exhaust gas were varied to understand how does it impact dosing unit critical temperatures. Thermocouples were also added suspended in air to understand natural convection behavior during the transient thermal cycle. An array of thermocouples were used above dosing unit to understand the convective air rising from ATS passing. Each thermocouple from TC 51 to TC 56 were placed at 12mm distance as shown in Figure 8. Thermocouples TC 51, 57, 58 and 60 were strategically placed around dosing unit at 10 mm distance from it. To confirm repeatability of test each condition was repeated three (3) times and average temperature of all three repeats are then considered for comparison. K type thermocouples were used with operating temperature of 600 deg C.

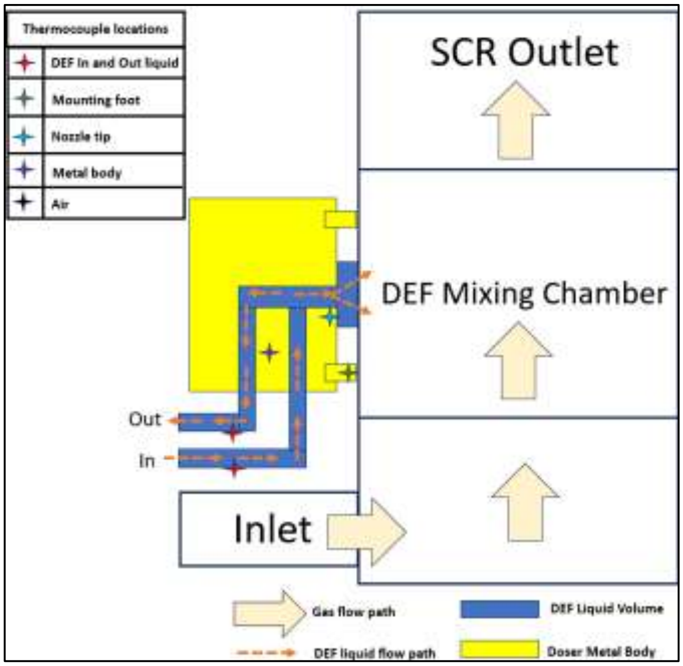


Figure 7 Test setup schematic layout describing dosing system integrated on aftertreatment system with critical thermocouple locations details

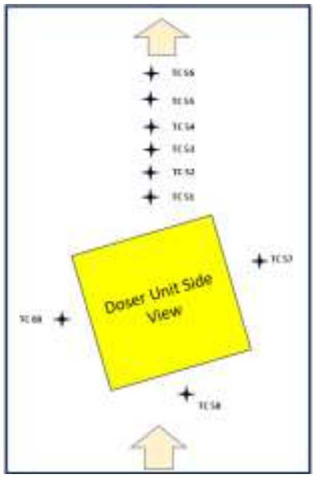
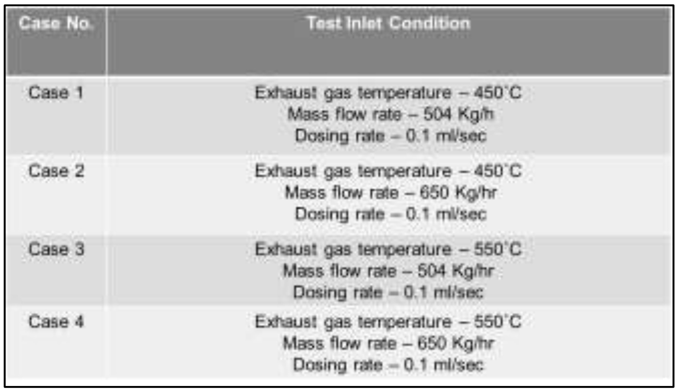


Figure 8 Array of thermocouples placed in vicinity of dosing system

On the basis of historical data collected from past off-highway applications including gensets, construction equipment's, boundary condition was identified to carry out the test. Figure 9 shows the various cases which were run to understand air temperature and dosing unit critical location temperatures.



Case No.	Test Inlet Condition
Case 1	Exhaust gas temperature – 450˚C Mass flow rate – 504 Kg/h Dosing rate – 0.1 ml/sec
Case 2	Exhaust gas temperature – 450˚C Mass flow rate – 650 Kg/hr Dosing rate – 0.1 ml/sec
Case 3	Exhaust gas temperature – 550˚C Mass flow rate – 504 Kg/hr Dosing rate – 0.1 ml/sec
Case 4	Exhaust gas temperature – 550˚C Mass flow rate – 650 Kg/hr Dosing rate – 0.1 ml/sec

Figure 9 Boundary condition details case by case description table

Figure 10 shows transient temperature variation of dosing unit critical temperatures wrt various events. There is a sudden reduction in temperature of all critical location of doser after event 2 but this may depend on application to application. Air flow field around dosing unit will impact the behavior of temperature rise and fall trend in event 2. During event 4 all location try to reach thermal equilibrium, due to which we see them following similar slopes.

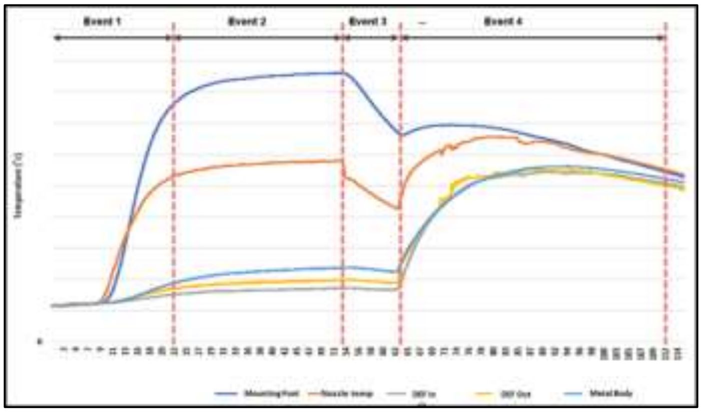


Figure 10 Transient temperature variation of critical dosing system measurement locations

Figure 11 shows that nozzle temperature is the hottest as compared to location of dosing unit. This is expected as heat grows from nozzle tip region. All the temperatures are compared at the end of transient cycle. If we compare results of Case 1 and Case 2, there is rise in temperature of dosing unit critical location due to rise in exhaust mass flow rate. This is happening because gas flow velocity near the mounting region increases due to which heat transfer increases. There is approximately 10% rise in temperature on dosing unit critical temperature by changing mass flow rate from 504 kg/hr to 650 kg/hr.

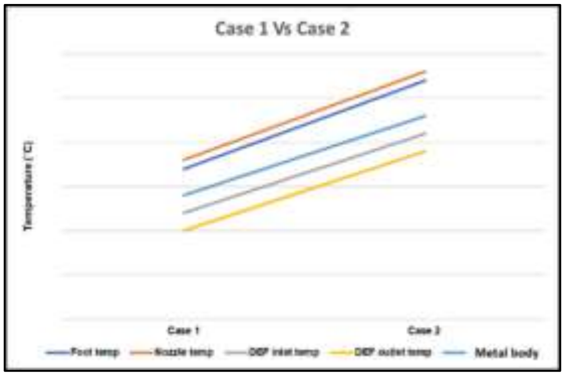


Figure 11 Comparison of dosing system critical temperature between Case 1 and Case 2

Figure 12 shows comparison of case 1 and case 3 where only change is in the exhaust gas temperature. Heat rise of all dosing unit critical temperature is more than 30% (except foot temperature) due to increase in exhaust gas temperature. This is happening because heat source has increased which is causing this significant rise in temperature. Figure 13 shows comparison of air temperature from TC 51 to TC 56. Case 1 and Case 2 showed no significant variation but if we closely observe there is significant rise in hot air temperature surrounding dosing unit in Case 3. This clearly shows due to increase in heat source temperature which is exhaust gas in this case there is sharp rise in neighboring components of doser unit. For genset applications it is difficult to control surrounding temperature but if the doser mounting location is designed in such way that heat is retained underneath dosing unit then temperature can be controlled. Next section we will discuss about key modeling assumptions and best practices to simulate this transient cycle.

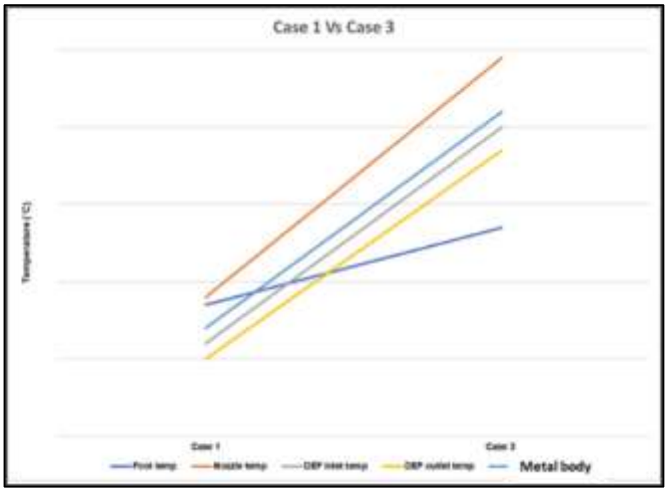


Figure 12 Comparison of dosing system critical temperature between Case 1 and Case 3

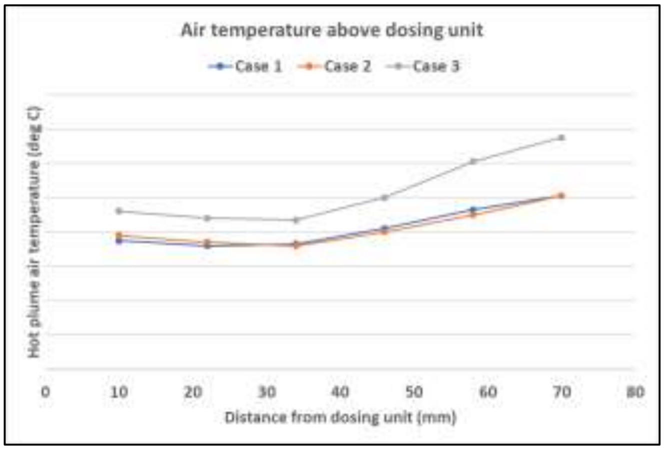


Figure 13 Air temperature comparison of between Case1, Case 2 and Case 3

CFD Modeling Assumptions and Best Practices

Geometry cleanup and meshing strategy

Capturing doser mounting location is very important. Modeling of trapped air volumes as shown in below Figure 14 at multiple contact points helps in accurately predict heat transfer from ATS to DEF liquid.

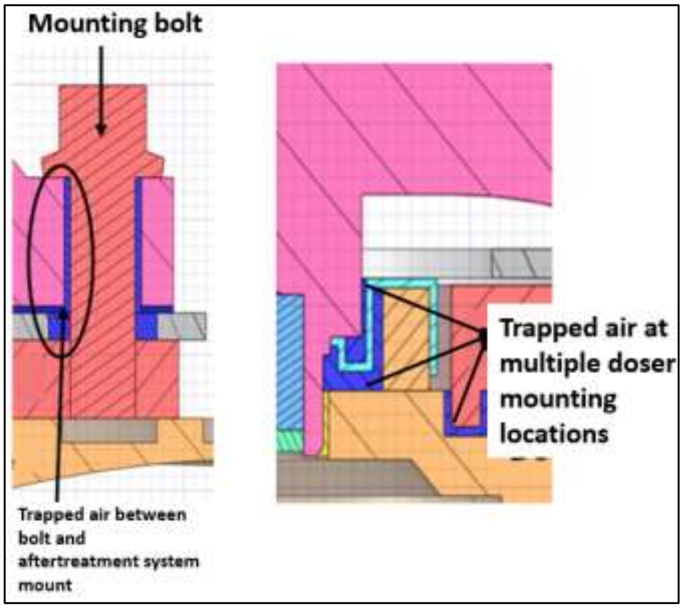


Figure 14 Illustration of trapped air volumes at dosing mounting locations

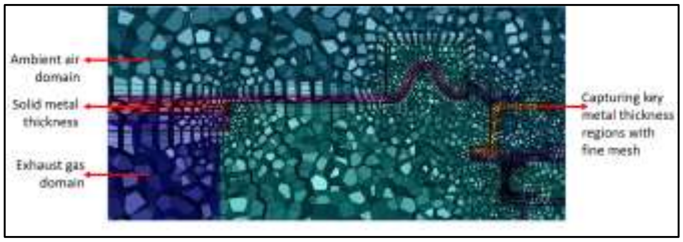


Figure 15 Illustration of prism layer growth inside and outside aftertreatment fluid volume

Figure 15 shows prism layer growth inside and outside fluid region of ATS. On the basis of desired boundary condition, it is important to maintain y-plus less than 1 for fluid domain especially near doser tip region which is key source of heat transfer. As a best practice 5 to 8 prism layers are good to capture high thermal gradients. Fluid domain of dosing unit needs very small first cell height as its cavity channels is significantly smaller than after treatment system gas domain. For conjugate heat transfer it is important to model surrounding ambient box around the aftertreatment and dosing systems, so that natural/forced convection of hot air can be modeled accurately. Body of influence is recommended strategy to ensure thermal gradient near critical components are effectively captured.

Solver settings

- Turbulence model used – k-epsilon realizable with Enhanced wall functions.
- Discrete ordinate with default coefficients to model radiation effects.
- Ambient air density using incompressible ideal gas and exhaust gas density as ideal gas are some of the assumptions used for this application.
- Trapped air regions with piecewise polynomial specific heat and thermal conductivity with Sutherland viscosity is appropriate for this type of analysis.

- All solid material zones were hooked with accurate material properties containing constant or transient thermal conductivity and specific heat properties.
- All fluid zones must have participated in radiation option switched ON.
- To model thermal heat storage inside DPF and SCR, porosity values must be calculated depending on different catalyst properties available from supplier using equation mentioned below. As porous zone option is switched ON for substrate volume then in thermal tab porosity value and material property of substrate can be selected. This is key setting because by default porosity value is 1 which means 100% gas volume, however for substrate it will have lower level of porosity (FLUENT).

$$Porosity = \left[\sqrt{\frac{1}{CPSI}} - \frac{t}{1000}\right]^2 \times CPSI$$

- Based on application DPF regeneration can be modeled using simple volumetric heat generation calculation and that value can be entered for DPF substrate cell zone.
- Defining gravity direction and operating density based on ambient air temperature is another important input required for this specific analysis.
- Exhaust gas inlet, DEF inlet - if mass flow rate is known then mass flow inlet option can be selected.
- Exhaust gas outlet can be modeled as pressure outlet if it is open to atmosphere then gauge pressure can be considered as 0 Pa.
- To model the DEF flow inside the dosing system, it is very complex to model actual DEF injection inside the mixer chamber. Instead at injection outlet we can model void, so that heat transfer from DEF recirculation can be modeled accurately without any simulation complexities.
- All other boundaries of ambient wall may be modeled as pressure outlet or walls depending on the application. For this study ambient walls were considered as heat flux zero walls because of presence of thickness sound absorbing material that have very low thermal conductivity. Figure 16 shows an example of typical genset application ATS canopy.
- Since, it is transient simulation it is necessary to wisely select time step size and number of iteration per timestep. For this study following settings were used
    - Time step size: 5 seconds
    - Number of iterations per timesteps 20

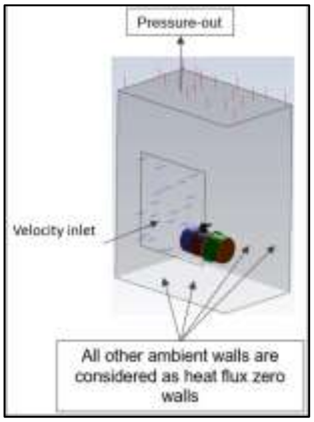


Figure 16 Illustration of enclosure around aftertreatment system for genset application with radiator inlet

Actual Application Test Setup Details

In the above section the CFD modeling assumptions mentioned were applied to model actual genset application ATS. Dosing unit critical location temperatures monitored throughout the transient cycle and compared with analysis results. Thermocouples were applied on dosing unit metal body and DEF in and DEF out liquid cavities as explained in Figure 7. There was radiator air flow field directly pushing air on the dosing system, so those behavior were accurately modeled with velocity inlet through measured inlet duct as shown in Figure 16. Below are details of test setup images see Figure 17. Polyhedral elements with prism were used with 5 boundary layers with total mesh count of 14 million, Figure 18 shows the cross sectional view of mesh. Since, prism is grown both inside fluid domain and in ambient air the thermal gradient capture will be more accurate.

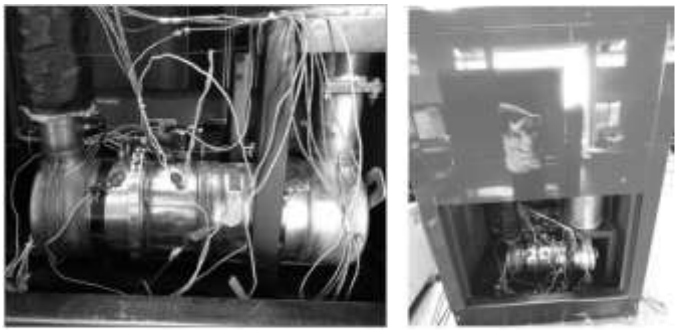


Figure 17 Actual genset application test setup images

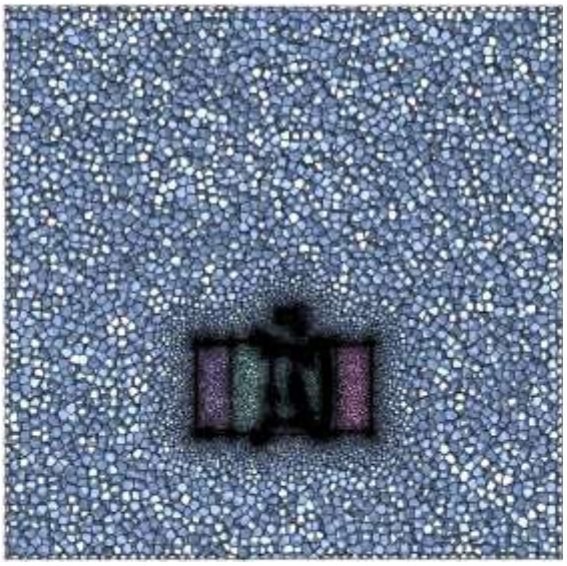


Figure 18 Cross sectional view showing mesh growth from aftertreatment system to enclosure under canopy

For this test skin temperatures on DOC section outer body were also monitored. This was utilized as an input to model the drop in temperature called as temperature decay once engine shut down happens. Transient temperature drop was applied on DOC cell volume so that similar skin temperature of test could be achieved. This is necessary because on actual application the air flow field direction and velocity can get altered. Analysis and test temperature decay showed very close correlation and confirmed the accuracy of input as shown in Figure 19.

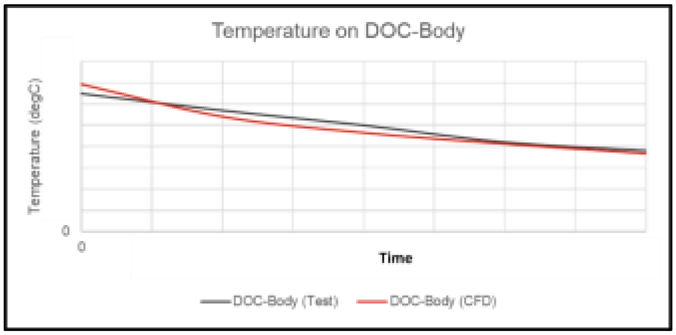


Figure 19 Comparison of DOC outer body temperature between CFD Simulation and Test

Test Data Validation

CFD analysis results were compared for two (2) different genset ratings and two (2) different ATS. Figure 20 shows close correlation of all doser locations between analysis and test. The values reported in the Figure 20 are at the end of transient cycle. Maximum gap between analysis predicted values and test predicted values are 6 deg C.

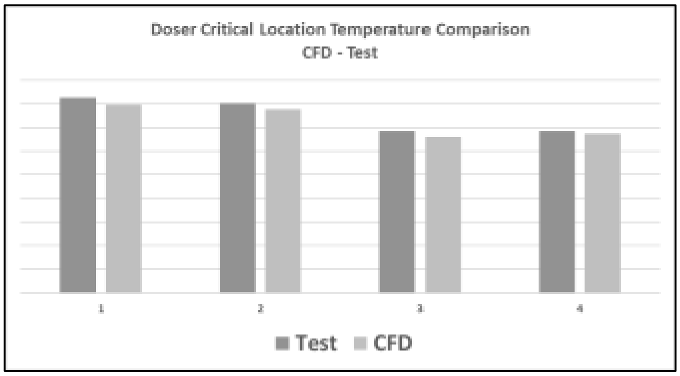


Figure 20 CFD Test comparison of dosing system critical locations for aftertreatment system 1 setup

Figure 21 shows comparison of transient behavior between analysis and test values. Comparison shows that there is close correlation at end of event 2 and event 4 for all critical measurement locations. However, high discrepancy in results is observed at end of event 3. During event 3 there is sudden reduction of air flow field coming from radiator flow and thermal inertia of catalyst, insulations rise the temperature to high levels. Mounting foot and metal body temperatures shows heat build in event 3 whereas liquid temperatures of DEF do not change significantly. This is the major challenge when comparing analysis results with actual application. There are multiple fluctuations coming from engine and air flow field is not controlled.

Figure 22 shows transient trend of each measurement location wrt time. It shows that there is small rise in temperature of metal body at end of event 2 but it is not steep enough to match test behavior. Overall, the transient trend of temperature is as expected and actual ramp up in temperature happen in event 4 when coolant recirculating flow also is switched OFF.

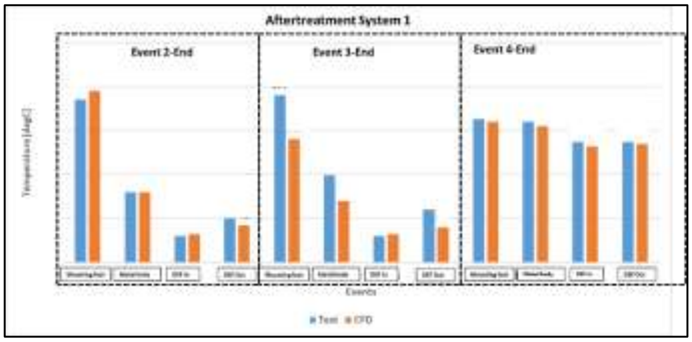


Figure 21 Comparison of CFD and test critical dosing system location at end of each event of the transient thermal cycle

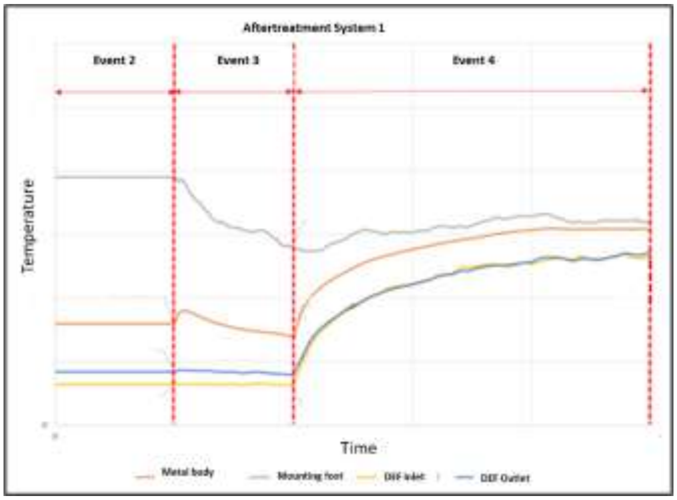


Figure 22 Transient temperature variation of CFD predicted dosing system critical locations for aftertreatment system 1

To understand current modeling approach stability, new test results for different genset application was compared named as aftertreatment system 2 see Figure 23 where layout system used for simulation is illustrated. Figure 24 shows the gap between CFD analysis and test is very close. Maximum gap of 6 deg C can be observed. Radiator air flow inlet was modeled in this case as well, its impact is visible in metal body and mounting foot temperature as shown in Figure 25. There is sudden rise in temperature at end of event 2 when radiator switches OFF. Figure 26 shows test trend, also we can observe the rise in temperature happens on mounting foot and metal body. So, overall if we know the inputs accurately then we can model the transient behavior at critical doser locations. During test, ramp up cycle had step by step increase in load on engine before reaching stable period. Shut down event is highlighted with red dotted box in Figure 26. In this application doser mounting geometry is different than aftertreatment system 1, shut down test data confirms the doser is absorbing lower temperature as compared to aftertreatment system1.

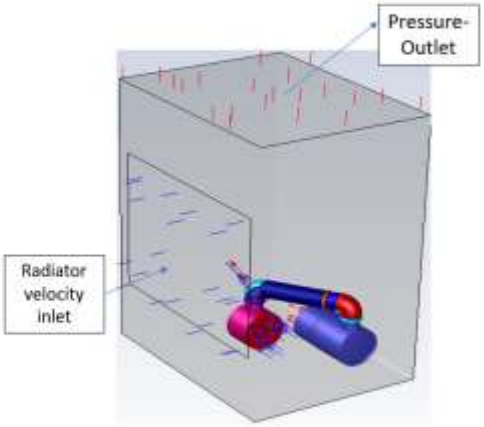


Figure 23 Illustration of enclosure around aftertreatment system for genset application with radiator inlet for aftertreatment 2

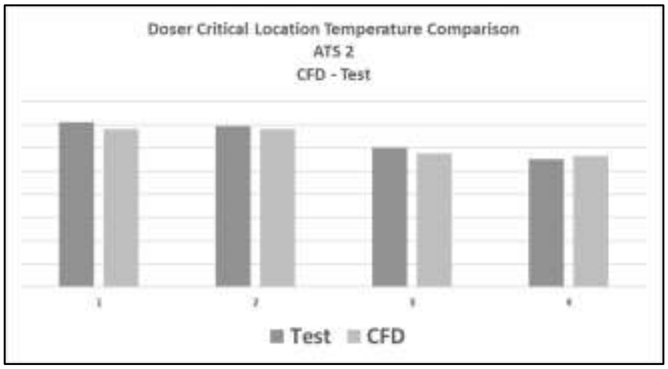


Figure 24 CFD Test comparison of dosing system critical locations for aftertreatment system 2 setup

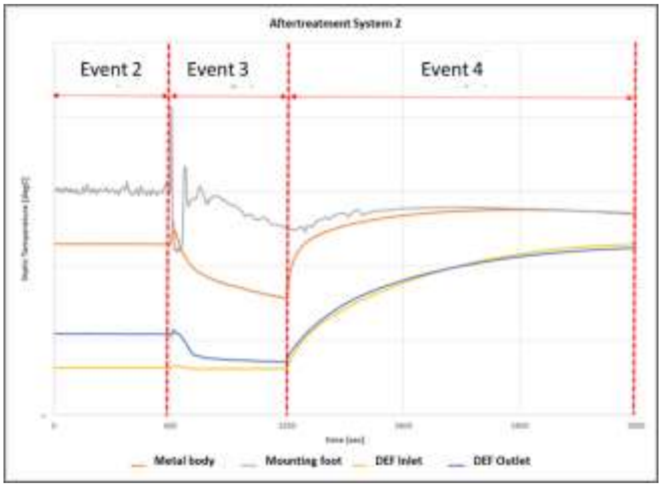


Figure 25 Transient temperature variation of CFD predicted dosing system critical locations for aftertreatment system 2

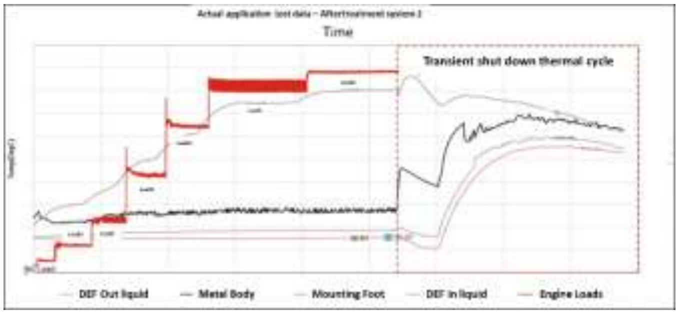


Figure 26 Transient temperature variation of Test predicted dosing system critical locations for aftertreatment system 2

Overall, CFD modeling assumptions are validated for two different designs and boundary conditions. For both systems, the maximum gap between CFD and test is 6 deg C. Transient trend for both systems is similar. However, there is some discrepancy observed during event 3 just after shut down between analysis and test. The gap of discrepancy can be bridged if we try to understand air flow field around doser closely and similar input boundary condition can be created in analysis to mimic actual physics. Mitigation of temperature rise on dosing unit for transient shut down cycle can be done in multiple ways. Some of the best practices are discussed in next section.

Mitigation of Temperature Rise

To mitigate heat ingress from ATS towards DEF liquid inside dosing unit, below are few best practices listed down.

- Strategically providing trapped air volume at dosing unit mounting location to cut down the conduction path.

- Dosing unit mounting location may have insulation or low conductivity material which will have high temperature withstand limits. This will be key in reducing significant heat rising from ATS.

- Coolant flow path near the dosing unit will help carry lot of heat from dosing unit nozzle area. It will also assist in reducing DEF liquid temperature build up during transient shut down cycle.

- Choosing substrate and insulation materials of aftertreatment with low thermal inertia.

- Design features such as deflectors to divert hot air plume rising from ATS away from dosing unit vicinity area will also assists in reducing dosing unit body temperatures.

- Utilizing external forced air draft to cool down doser surface temperatures.

- Minimize contact surface area between dosing unit and ATS. Instead of surface to surface contacts, line contact will be better for dosing unit integration.

- Minimizing exhaust air flow velocities near doser unit tip region, as we have observed heat transfer due to internal convection is significant. Gas velocities near tip must be optimized to reduce heat ingress.

Summary and Conclusion

In this paper transient thermal modelling of ADS, primarily dosing system are discussed in detail. Off-highway applications typically gensets have very less clearances around the ATS. Due to this risk of DEF liquid temperature rising above its boiling point is high. Various critical factors were discussed in detail which play significant role in pushing heat inside dosing systems located above ATS. Doser mounting locations, trapped air around doser tip area are some of the key factors responsible for heat rise of dosing system liquid temperatures. To understand the thermal hot air plume around the dosing system, experimental study was done on Off-highway ATS in controlled environment. Impact of exhaust flow rate change showed 10% rise in temperatures of dosing system critical location, but major impact was observed when exhaust gas temperatures were varied by 22% it resulted in 30% rise in DEF liquid temperatures. Also, array of thermocouples were placed surrounding dosing system to understand natural convection around it. Exhaust gas temperature 100 deg C rise showed significant rise in neighbouring location air temperatures.

CFD modelling methods were discussed in detail. Since, conformal mesh strategy was used for this study. Small trapped air volumes must be modelled accurately to ensure desired body sizing can be provided to small proximity regions. Polyhedral mesh with prism maintaining 5 to 8 layers grown from sheet metal inside of fluid domain and outside from after treatment system to ambient box is important to capture thermal gradient. Prism inside the DEF liquid was also grown to capture sudden temperature changes in DEF cavity. Enhanced wall treatment with prism will help capture near wall gradients accurately. K-epsilon Realizable turbulence model with discrete ordinate radiation model was used for this study. Radiator flow inlet was modelled to capture accurate flow field around the dosing system and neighbouring ambient of ATS. CFD modelling results were compared with actual application test data where thermocouples were placed at various critical locations on dosing system. Below are some of the important conclusions.

1. CFD results when compared with actual test showed close correlation with maximum gap of 6 deg C for two different applications.
2. Radiator air flow sudden shut down shows rise in temperature of dosing system metal body. This rise can be accurately captured in analysis if the air flow field is modelled in simulation.
3. During soaking period and cool down period gap between analysis and test results are close as compared to event 2. Event 2 discrepancy are due to multiple factors one of it is accurate thermal inertia modelling of solid around the dosing system.

Recent launch of CPCB IV+ emission norms has resulted in tight NO_x permissible limits. With introduction of SCR technology in genset application ADS are at high risk because ATS is typically located under canopy. The CFD modelling strategies discussed in this study will help effective designing of ATS and reduce failures associated with DEF liquid boiling.

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Definitions/Abbreviations

BS	Bharat Stage
DEF	Diesel Exhaust Fluid
CFD	Computational Fluid Dynamics
CPCB	Central Pollution Control Board
ADS	Ammonia Delivery System
NO_x	Nitrogen Dioxide and Mono Oxides
PM	Particulate Matter
DOC	Diesel Oxidation Catalyst
DPF	Diesel Particulate Filter
TC	Thermocouple
Deg	Degree

C	Celsius
CPSI	Cells per square inch
ATS	Aftertreatment Systems