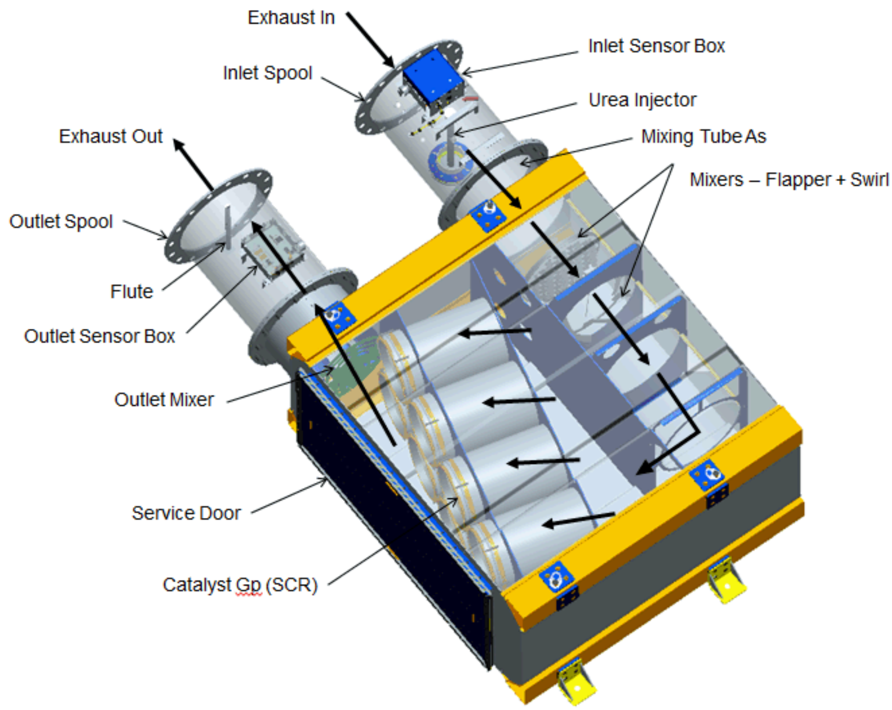
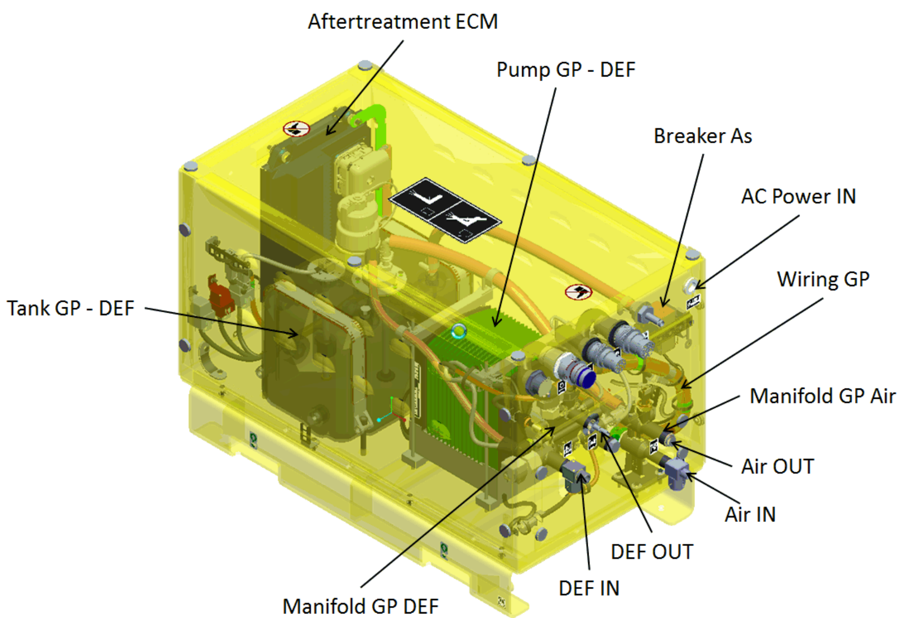
Marine Application of Aftertreatment 3500, C175, C280 Cat Clean Emissions Module (CEM) Application & Installation Guide





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1. Introduction

Purpose

This document is intended as a reference and guide for the correct installation of the Caterpillar Clean Emissions Module (Cat CEM) for Caterpillar Engines. The primary purpose is to assist engineers and designers specializing in engine installations. The Engine Electrical Applications and Installation Guide, Engine Application and Installation Guide, and Engine Data Sheets complement this booklet.

NOTE: *The information in this document is subject to change as engine exhaust aftertreatments are revised, improved and required for emission reduction standards.*

The Exhaust System and Cat CEM are an integral part of Caterpillar's EPA Tier 4, IMO III and Euro Stage IIIB engine solution. Caterpillar Engines are designed and built to provide superior value; however, achieving the end user's value expectations depends greatly on the performance of the complete installation to assure proper function over the design life of the installation. This proper detail will allow the engine to produce its published rated power, fuel consumption and conform to emissions regulations.

Caterpillar exercises all reasonable effort to assure engine and Cat CEM perform properly. However, it is the responsibility of the OEM / installer to properly install the engine and Cat CEM. Caterpillar assumes no responsibility for deficiencies in the installation. It is the responsibility of the OEM / installer to meet all of Caterpillar's requirements, as provided in this Application and Installation Guide. Caterpillar does not guarantee or approve the validity or correctness of any installation. Caterpillar's sole obligation with respect to any product is as set forth in the applicable Caterpillar warranty statement.

It is the installer's responsibility to consider and avoid possibly hazardous conditions, which could develop from the systems involved in the specific engine installation. The suggestions provided in this guide regarding avoidance of hazardous conditions apply to all applications and are necessarily of a general nature since only the installer is familiar with details of the installation. The suggestions provided in this guide should be considered general examples only and are in no way intended to cover every possible hazard in every installation.

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Contact the appropriate application support group for the latest information on Cat CEM guidelines and requirements.

This document serves as Caterpillar’s instructions required by U.S. EPA regulations (40 C.F.R. Part 1068) to facilitate the selection and application of the correct Cat CEM module by the OEM or “installer” based upon engine selection.

Requirements and Agreements

1. Each OEM shall enter into a delegated final assembly agreement with Caterpillar, Inc. as required by 40 C.F.R. § 1068.261. This publication fulfills Caterpillar’s obligation under 40 C.F.R. § 1068.261 (c)(2) to provide installation instructions to ensure the engine will be in certified configuration.

2. OEM is required to follow Caterpillar’s Applications and Installation requirements for proper Cat CEM integration with the Caterpillar engine.

Any deviation from these instructions resulting in improper installation or connection of Cat CEM may be considered an emissions-related defect requiring the OEM or installer to report to U.S. EPA pursuant to 40 C.F.R. § 1068.261 (h). OEM installations are subject to audit by Caterpillar pursuant to 40 C.F.R. § 1068.261 (d)(3), as further set forth in the delegated final assembly agreement.

Note: No aftertreatment component shall be placed between the engine out exhaust and the CEM inlet except for that which this document has specified.

Note: If the available Cat CEM option does not meet the application/installation requirements, the OEM Installer must contact his or her respective Caterpillar sales manager. Any deviation from these instructions resulting in the installation of Cat CEM not included as part of the applicable certified engine configuration will be considered a mis-build and must be reported immediately to Caterpillar.

Cat CEM Identification

Caterpillar will provide Auto-detection to ensure the proper Cat CEM is fitted to the proper engine. The engine will identify the CEM and allow proper operation of the engine and aftertreatment system. Failure to detect proper CEM will result in 100% derated engine performance.

The Caterpillar Clean Emissions Module will be stamped with a Caterpillar part number for identification and part service requirements. No OEM part numbers or supplier part numbers will be stamped on the device.

Document Layout

This document provides application information, specifications and installation procedures to install Cat CEM for selected Caterpillar engines that meet US Tier 4 and IMO III emissions regulations. To determine which module is available for your engine application please review the following Caterpillar Clean Emissions Strategy Table for the emissions technology provided for the selected engine Platform(s). After reading and understanding the Cat CEM technology overview proceed to that Cat CEM Components section for detailed design and installation information. The Appendix contains additional detailed design and installation information and is referenced throughout the document.

This document provides the required information for Cat CEM mounting including electrical, plumbing, and exhaust connections.

Note: There are critical specifications required for proper performance and compliance with U.S. EPA, IMO III and European Commission regulations. Failure to meet these requirements will constitute a "mis-build" and prompt notification to Caterpillar is required. Installation Audits are required for each new application build.

Tier 4 Emissions Strategy Table

<table>
<tr><th colspan="4">Caterpillar Clean Emission Strategy</th></tr>
<tr><th>Power</th><th>Engine Platform</th><th>Aftertreatment Technology</th><th>Applications</th></tr>
<tr><td rowspan="3">>750HP (560KW)</td><td>C140
3500
C175</td><td rowspan="3">AUS / DEF
SCR</td><td>Marine / Petro Offshore
2016</td></tr>
<tr><td rowspan="2">C280</td><td>Marine / Petro Offshore
(2000kW-3700 kW only)
2016</td></tr>
<tr><td>Marine / Petro Offshore
(>3700 kW only)
2017</td></tr>
</table>

Table 1.1 – Caterpillar Clean Emissions Strategy Table

Safety

Most accidents that involve product operation, maintenance, and repair are caused by failure to observe basic safety rules or precautions. An accident can often be avoided by recognizing potentially hazardous situations before an accident occurs. An OEM Installer must be alert to potential hazards. An OEM

Installer should also have the necessary training, skills, and tools in order to perform these functions properly.

The information in this publication was based upon current information at the time of publication. Check for the most current information before you start any job. Caterpillar dealers will have the most current information.

> ***Warning:*** **Improper operation, maintenance, or repair of this product may be dangerous. Improper operation, maintenance, or repair of this product may result in injury or death. Do not operate or perform any maintenance or repair on this product until you have read and understood the operation, maintenance, and repair information. Burn and fire hazards are possible. Failure to properly connect the After-treatment, or properly route the exhaust gases away from the module may result in personal injury or *death*.**
>
> ***Notice:*** **Failure to properly connect the after-treatment will result in poor engine performance, engine and after-treatment system damage.**

Caterpillar cannot anticipate every possible circumstance that might involve a potential hazard. The warnings in this publication and on the product are not all inclusive. If a tool, a procedure, a work method, or an operating technique that is not specifically recommended by Caterpillar is used, you must be certain that it is safe for you and for other people. You must also be certain that the product will not be damaged. You must also be certain that the product will not be made unsafe by the procedures that are used.

Pressurized Air and Water

Pressurized air and/or water can cause debris and/or hot water to be blown out. This could result in personal injury. Always wear a protective face shield, protective clothing, and protective shoes when cleaning components. The maximum air pressure for cleaning purposes must be reduced to 205 kPa (30 psi) when the air nozzle is deadheaded and used with effective chip guarding (if applicable) and personal protective equipment. The maximum water pressure for cleaning purposes must be below 275 kPa (40 psi).

High Pressure Wash

Notice: High-pressure wash systems, including high pressure spray washers and water cannons, are now in frequent use by maintenance people. Connector seals will fail when hit directly with high pressure spray. Many connection systems have adapters available that can be attached to the back of the connector to protect the wire seals from direct high pressure wash. **Where direct exposure to high pressure wash systems cannot be avoided then protective shields will need to be designed and installed.** For the benefit of service, connectors should be placed in accessible locations.

Welding

WARNING Notice — Welding on Cat CEM frame/chassis is prohibited.

Painting

Painting of Caterpillar CEM is **NOT** recommended and strongly discouraged. Some components skin temperatures on the CEM can get to as high as 525 degrees Celsius during operation and will cause charring or burning of the paint.

Cleanliness

Air lines, Fuel lines, coolant lines and oil lines that connect to the CEM or engine should meet Caterpillar cleanliness specification contained in A&I Guide LEBW0019.

Replacement Parts

When replacement parts are required for this product, Caterpillar recommends using Caterpillar replacement parts or parts with equivalent specifications including, but not limited to, physical dimensions, type, strength, and material.

⚠ WARNING

When replacement parts are required for this product Caterpillar recommends using Caterpillar replacement parts or parts with equivalent specifications including, but not limited to, physical dimensions, type, strength and material.

Failure to heed this warning can lead to premature failures, product damage, personal injury or death.

Tier 4, IMO III - Emissions Requirements

This Installation Guide is intended for use for engines that must comply with Tier 4 or IMO III emission requirements. Proper fluids must be used to meet these requirements. Refer to the specific Operation and Maintenance Manual (OMM) for the Caterpillar engine model being installed for the proper fuel, lubricants, and coolants that are to be used. The proper fuels, lubricants and coolants must be used to enable the engine to produce its published rated power, fuel consumption and conform to emissions regulations.

JP8 Diesel fuel is **not** compatible with Caterpillar Tier 4 and IMO III Cat CEM. U.S. EPA Tier 4 regulations require the use of commercial ULSD that conforms with the ASTM D975 specification of 15 ppm max sulfur fuel per US EPA Tier 4 requirements. IMO III requires that the fuel sulfur levels are below 1,000ppm. Using any fuel which is not equivalent to ASTM D975 or EN590 may damage engine and Aftertreatment systems. In this case, consult Caterpillar or your Caterpillar dealer for further direction. Biodiesel is compatible with the Cat CEM up to B20 but can have an affect on some CEM components (Refer to SEBU 6251 – Caterpillar Fluids Recommendations). The following table summarizes the engine operating fluids requirements for engines equipped with the Cat CEM

Engine Operating Fluids	
Fuel Tolerance – Sulfur (ppm)	Tier 4 15 or less IMO III 1,000
Oil Tolerance (ash content)	CJ4 or better
Fuel Tolerance – biofuels (ASTM 6751-075 B100)	B20 or less

Table 1.2 - Tier 4 Engine Operating Fluids Limits

NOTICE:

Oils that have more than 1% total sulfated ash should not be used in Aftertreatment device equipped engines.

In order to achieve expected ash service intervals, performance, and life, Aftertreatment device equipped diesel engines require the use of Cat DEO-ULS or oils meeting the Cat ECF-3 specification and the API CJ-4 oil category. Oils that meet the Cat ECF-2 specification and that have a maximum sulfated ash level of 1% are also acceptable for use in most aftertreatment equipped engines. Use of oils with more than 1% total sulfated ash in aftertreatment device equipped engines will cause the need for more frequent ash service intervals, and/or cause loss of performance. Refer to your engine specific Operation and Maintenance Manual, and refer to your aftertreatment device documentation for additional guidance.

Warning: Use of Oil Renewal System (ORS) is strictly forbidden. Any ORS that extends the oil life through the combustion process and toping off the oil reservoir with new oil will damage the aftertreatment device. Failures that result from the use of any oil are not Caterpillar factory defects. Therefore, the cost of repair would NOT be covered by the Caterpillar warranty for materials and/or the warranty for workmanship.

Note: The U.S. Forest Service operates a national laboratory that provides spark arrester qualification testing pursuant to U.S. Forest Service Standard 5100-1c, “Spark Arresters for Internal Combustion Engines,” which is currently being revised so as to extend its assessment beyond particle capture measurement.

The CAT CEM with DPF is being validated per SAEJ350, “Spark Arrester Test Procedure for Medium Size Engines,” which will not result in a formal qualification by U.S. Forest Service, but will document spark arresting particle capture capabilities**.**

All other CAT CEM’s are pass through aftertreatment devices and can not be validated to SAEJ350. If spark arresting is needed for these applications a dedicated device meeting SAEJ350 will need to be installed after the CEM.

Recorder

EPA recognizes that it is unsafe and unacceptable to significantly derate or shut down a marine engine for an aftertreatment failure. So in the EPA regulations 40 CFR 1042 does not require engine derates or shutdowns. To answer this issue in the engine control panels a recorder of certain faults will be recorded and stored. If this fault codes are logged on the recorder than the customer has 30 day to inform the EPA on what cause the recorder to recorder the one of those critical codes.

Caterpillar will provide an A5N2 recorder ECM which will record the required codes in in non-volatile memory. It then will be the end user responsible to respond to EPA if a code is record on the A5N2. The codes that will be recorder are in AUS/DEF quality is below the spec, if vessel ever ran out of AUS/DEF and if the system was ever turned off.

Caterpillar will alarm and record in standard engine ECM memory all other incidents relating to engine and aftertreatment operation. Active codes will be displayed, and recordings of the first and last incident date and time and the number of occurrences will be recorded in standard engine ECM memory.

Terminology

The terminology used throughout this document will be as follows:

- **AMOX** Ammonia Oxidation Catalyst
- **API** American Petroleum Institute
- **ARD** Auxiliary Regeneration Device
- **ASTM** American Society for Testing and Materials
- **AT** Aftertreatment
- **ATAAC** Air to Air After Cooler
- **AUS** Aqueous Urea Solution
- **AUS32** Aqueous Urea Solution per ISO Standard 22241
- **AWG** American Wire Gauge
- **BPV** Back Pressure Valve
- **CAN** Controller Area Network
- **Cat CEM** Caterpillar Clean Emissions Module
- **Cat ECF** Cat Engine Crankcase Fluid
- **Cat RS** Caterpillar Regeneration System
- **CCW** Counter Clockwise
- **CDPF** Catalyzed Diesel Particulate Filter
- **CEPRU** Caterpillar Electric Priming and Regeneration Unit

- **CFD** Computational Fluid Dynamics
- **C.F.R**. Code of Federal Regulations
- **CG** Center of Gravity
- **CISD** Compliance and Innovative Strategies Division
- **CO** Carbon Monoxide
- **CW** Clockwise
- **DEF** Diesel Exhaust Fluid (also referred to as AUS32)
- **Delta P** Differential Pressure
- **DOC** Diesel Oxidation Catalyst
- **DPF** Diesel Particulate Filter
- **DPI** Delta Pressure Indicator
- **ECM** Electronic Control Module
- **EH&S** Environment of Health & Safety
- **EPA** Environmental Protection Agency
- **FEA** Finite Elemental Analysis
- **FMEA** Failure Modes & Effects Analysis
- **GND** Ground
- **HC** Hydro Carbon
- **ID** IDentification or Inside Diameter (Dimensional Reference)
- **IEC** International Electro-technical Commission
- **ISO** International Organization for Standardization
- **JIC** Joint Industry Council
- **MAF** Mass Air Flow
- **MSDS** Material Safety Data Sheet
- **NOx** Nitrous Oxides – NO and NO^2
- **OEM** Original Equipment Manufacturer
- **OMM** Operations & Maintenance Manual
- **ORS** Oil Renewal System
- **PM** Particulate Matter
- **P/N** Part Number
- **PSIg** Pounds per Square Inch gauge
- **PSPS** Product Software Programming System
- **SAE** Society of Automotive Engineers
- **SCAC** Separate Circuit After Cooler
- **SCR** Selective Catalytic Reduction
- **SOF** Soluable Organic Fraction
- **STOR** Straight Thread O-Ring
- **S/N** Serial Number
- **TBD** To Be Determined
- **ULSD** Ultra Low Sulfur Diesel

2. Cat CEM Overview

Caterpillar Clean Emissions Module (Cat CEM) Systems

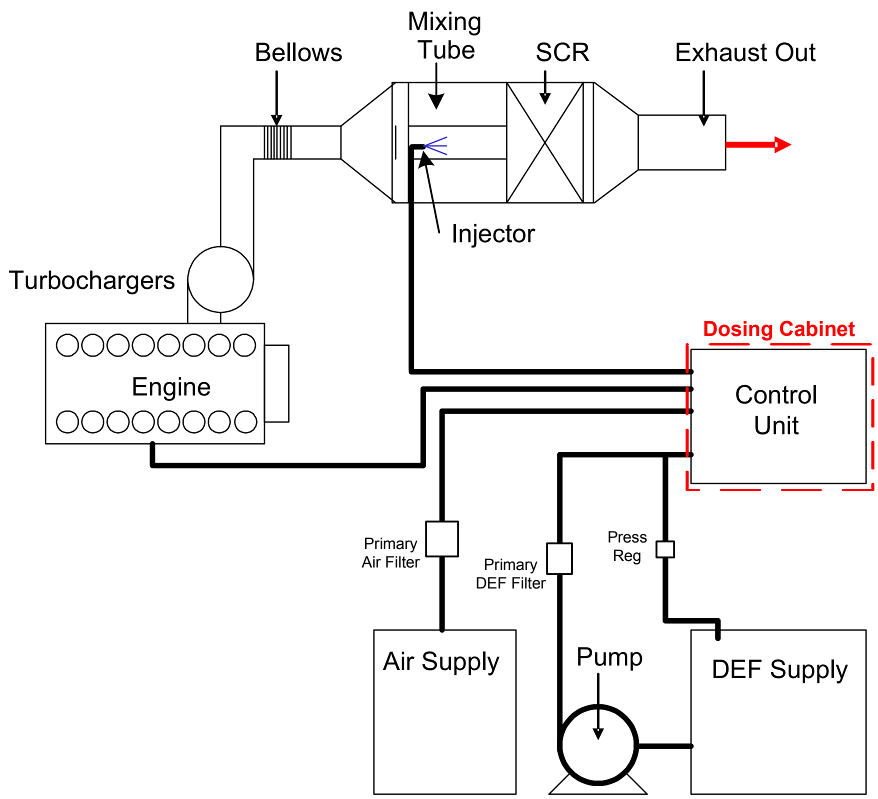
The Cat CEM consists of the key components necessary to support an engine arrangement for emissions compliance. Caterpillar Tier 4, IMO III and Euro IIIB engine systems use a variety of technologies for the reduction of particulate matter and NOx emissions. Selection of the optimal module combination is based upon engine rating and application. Each of the emission reduction technology combinations is listed in the Cat CEM Strategy table in section above and described in this document.

Technology Component Descriptions

SCR (Selective Catalytic Reduction) System

SCR is one of a combination of several components. SCR units will require the use of urea or DEF (Diesel Exhaust Fluid also referred to as AUS32) along with flow-through honeycomb substrate catalysts.

AUS / DEF fluid is injected into the exhaust stream before entering the SCR. When injected into the exhaust stream, the AUS / DEF is atomized into fine droplets and then sent through a mixer. The mixer disrupts the exhaust flow and allows the AUS / DEF to be well distributed throughout the exhaust gas. The water evaporates due to the high temperature of the exhaust and releases the NH_3 that was chemically bound up in the AUS / DEF. The NH_3 is then free to react with the NOx and the oxygen present in the exhaust stream. This reaction occurs on the SCR catalyst. The NH_3 and NOx are converted into harmless gas particles of nitrogen and water.



SCR CEM System Diagram

Working Principle

$$CO(NH_2)_2 + H_2O \rightarrow 2NH_3 + CO_2$$
$$NO + NO_2 + 2NH_3 \rightarrow 2N_2 + 3H_2O$$

3. SCR Clean Emissions Modules

Introduction and Purpose

Caterpillar's SCR emissions approach combines emission reduction technologies to comply with Tier 4 emissions requirements. Selective Catalyst Reduction (SCR) catalyst technology is used to reduce NOx emissions and particulate matter (PM), carbon monoxide (CO), hydrocarbons (HC) and soluble organic fraction (SOF).

Caterpillar's SCR is packaged in a module that contains the components necessary to support the specific engine configuration for emissions compliance. OEM installation will require connections between OEM module, engine, AUS / DEF tank and air source. These connections will include engine exhaust piping, electrical harness, air, and AUS / DEF lines.

System Hardware Overview

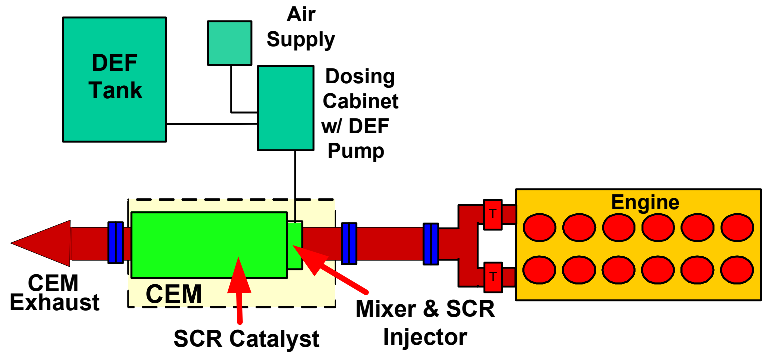


Fig. 4.1 – System Block Diagram

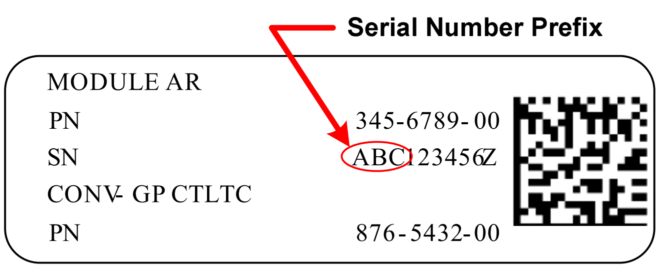
CEM Application Guide

The following table provides applicable CEM for a given application and engine platform. There will be several CEM illustrations for these applications below in the following subsections of this SCR CEM Technology section.

CEM Application Guide		
Engine Platform	CEM Prefix	Application
***3500/C175**	ECF	Marine / Petro (U Flow & Z Flow CEM Designs)
C280-8	ECK	Marine / Petro Offshore (2000kW-3700 kW only)
C280-12	ECH	Marine / Petro Offshore (>3700 kW only)
* The CEM Prefix indicates the 16 brick version of CEM for these engine platforms. Currently the prefix designation for the 12 & 20 brick version of CEMs are not available		

Each CEM has a Serial Number that is compatible to a particular engine platform and is shipped as a set. This S/N must be verified at installation for compatibility to the engine. The serial number prefix will identify the CEM for correct application. The prefix on the CEM serial number label is indicated on the example below.

Example:



Refer to “**Appendix B: Initial Startup Procedures**” for location of serial number on CEM and dosing cabinet, documentation and first fit detection.

Cat CEM Mandatory Interface Connections:

Doc Loc	Connection Point	Description	Fitting Type
Fig. 4.6 & Table 4.6	Dosing Cabinet to CEM	AUS / DEF Line from dosing cabinet to CEM	N0. 6 Female STOR (straight thread O-ring)
Fig. 4.6 & Table 4.6	Dosing Cabinet to CEM	Air line from Dosing Cabinet to CEM	No. 8 Female STOR
Fig. 4.6 & Table 4.6	Dosing Cabinet to CEM	Electronic harness from Dosing Cabinet to CEM	Quantity 1 24 Pin Connectors
Fig. 4.6 & Table 4.6	Dosing Cabinet to Engine ECM	Electronic harness from Dosing Cabinet to Engine ECM	Quantity 1 24 Pin Connectors
Fig. 4.6 & Table 4.6	Dosing Cabinet to Main AUS / DEF Tank	Electronic harness from Dosing Cabinet to Main AUS / DEF Tank	Quantity 1 24 Pin Connectors
Fig. 4.6 & Table 4.6	Air Source to Dosing Cabinet	Air line into dosing cabinet from air source	3/8" Male NPT
Fig. 4.6 & Table 4.6	Customer AUS / DEF tank to Dosing Cabinet	AUS / DEF line into dosing cabinet buffer tank from main tank	1/2" Male NPT
Fig. 4.6 & Table 4.6	Dosing Cabinet Drain	AUS / DEF buffer tank manual drain	N0. 6 Female STOR (straight thread O-ring)
Fig. 4.6 & Table 4.6	Dosing Cabinet Vent	AUS / DEF buffer tank vent & overflow	½" Hose Bead SAE AS5131
Fig. 4.6a	CEM to Dosing Cabinet	Air line from CEM to dosing cabinet	JIC Flare, SAE J514 ¾ X16
Fig. 4.6a	CEM to Dosing Cabinet	AUS / DEF line from CEM to dosing cabinet	JIC Flare, SAE J514 9/16X18
Fig. 4.14	CEM to Dosing Cabinet	Electronic harness from CEM to Dosing Cabinet	24 Pin Connector
Fig. 4.8	120V AC source to Dosing Cabinet	Electrical harness from Dosing cabinet to 120V AC source	Bus Bar (Inside Dosing Cabinet)
Fig. 4.16	CEM to Turbo	Exhaust pipe into CEM from engine	1 - 18" Bolted Flange
Fig. 4.16	CEM to Atmosphere	Exhaust pipe from CEM to atmosphere	1 - 18" Bolted Flange

Table 4.1 - Interface Connections

Air System

Compressed Air is used:

- To assist in the atomizing of the liquid AUS / DEF as it is injected into the exhaust stream
- To shield the liquid AUS / DEF in the injector from the exhaust heat until injection, so that no crystallization occurs which could plug the injector nozzle
- To purge the AUS / DEF line during shutdown in order to prevent crystallization

Typically, compressed air will carry some oil from the compressor and some sediment from the piping. This debris can collect in the nozzle and clog the unit. Use a coalescing filter/separator that is 90 percent effective that is rated for 1069 kPag (155 psig) and 849.5 liter/min (30 CFM).

Reference Air Filter Requirements in the sub section "Air Filter Recommendations" for details. An air dryer is recommended to keep relative air humidity below 10%.

The air supply delivered to the dosing cabinet must meet the specifications in Table 4.2 when engine is running and any non-parasitic load.

Air Supply	
Air quality	ISO 8573.1 Class 4
Oil Content (mg/m^3) (Max.)	25 (mg/m^3)
Particle Size (Max) (micron)	40 micron
Particle Density (Max) (mg/m^3)	10 (mg/m^3)
Relative Air Humidity	<10%
Air delivery (compressor capability):	
Air Temperature	-40 to 50 C
Air Flow Capacity	10 CFM
Air Consumption	Continuous when system is dosing
Air Pressure	70 to 155 PSIg
Air Pressure at Engine Startup	70 PSIg at start up OR 70 PSIg within 3 minutes maintaining <30% load or CEM outlet temp <250C
Purge Air Press/Vol at Shutdown	>70 PSIg /10 SCFM for 30 sec
Selected filter should meet the filter performance test per ISO 12500.3	

Table 4.2 – Air supply delivery requirements at Dosing Cabinet Inlet

Note: An optional air compressor system is available from Caterpillar that is designed specifically for use with the Caterpillar CEM (SCR). Please refer to the air compressor A&I guidelines for requirements.

Air Supply Line Requirements:

The air line that is used for delivering air from the dosing cabinet to the injector is to be sized and routed such that the pressure loss across the line is no greater than 1.0 PSI at the maximum flow capacity.

Note: Routing of this air line must progress **continuously** without air locks or line bends that would allow condensation to form and freeze preventing air supply to Dosing Cabinet air valve.

Secondary Air Filter

The AUS / DEF dosing cabinet requires customer to provide compressed air to the dosing cabinet which meet ISO 8573.1 Class 5 requirements specified in Table 4.2 above.

A cabinet contains a secondary air screen filter at the dosing cabinet air inlet.

Air inlet port on the screen filter is Male 3/8" NPT. It is recommended to have a dryer installed on the compressed air system to maintain the <10% relative air humidity. See Air & AUS / DEF Filter Installation figure below for interface connection location on dosing cabinet.

See maintenance schedule for service interval of air filter. See service manual for service procedure.

AUS / DEF System

AUS / DEF Specifications

For SCR applications the required AUS / DEF solution to be used is SCR Grade AUS32, or Aqueous Urea Solution of 32.5% or 40% concentration with quality properties per ISO 22241-1. A solution 32.5% concentration provides the lowest possible freezing point, -11°C (12^{o}F) while 40% concentration freezing point is at 0°C (32°F). The solution is homogeneous, allowing partial or total freezing and thawing without changing the concentration. The solution is basic, with a pH of about 9.0, and is slightly corrosive. Reference ISO 22241-3 standard for "Handling, Transportation, and Storage of AUS32 (AUS / DEF)".

Fertilizer or technical grade urea may contain elements that will clog the injector nozzle. It should not be used to supply the dosing cabinet.

The AUS / DEF supply to the dosing cabinet inlet should be filtered. The filtration requirement is 40 microns to protect valves inside the dosing cabinet. Caterpillar offers a AUS / DEF filter part number 370-6215.

Customer needs to have onsite AUS / DEF filters with filtration capability of 40µ (microns) using differential pressure gauges across the filters for service.

Cabinets will include a AUS / DEF filter screen assembled and mounted on the front of the cabinet using all stainless steel fittings.

AUS / DEF inlet port on the screen filter is Male 1/2” NPT. If the system will be shut down in freezing conditions or put into storage, the screen filter and supply line should be drained. Customer is responsible for protecting the supply line from freezing and damage from foreign objects (stainless steel supply line is recommended).

See maintenance schedule for service interval of AUS / DEF screen filter. The filter is reusable and can be cleaned using an ultrasonic bath. Refer to figure below for interface and installation on dosing cabinet.

Air & AUS / DEF Strainer Locations:

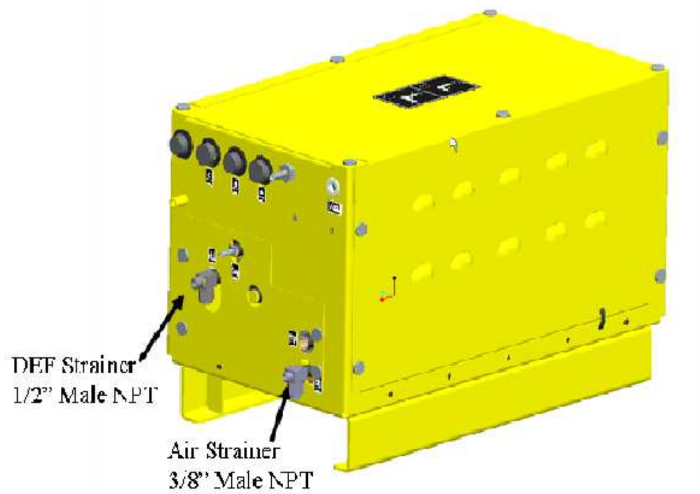


Fig. 4.2 – Dosing Cabinet Air & AUS / DEF Interface Connections

ISO 22241-3 has comprehensive list of AUS / DEF compatible materials including 300 and 400 series stainless steel, Ethylene Propylene Diene Monomer (EPDM), Polyethylene, Polypropylene, and etc.

Any O-rings must be EPDM. Reference "Material Selection for Tank and Piping" found later in this section for details regarding tank material, size, piping, fittings, etc.

CAUTION: Base material and their alloys of copper, zinc, aluminum and magnesium are not compatible. Also soldering material containing silver and nickel coatings are considered not compatible with AUS / DEF. Carbon steels, zinc coated carbon steels, and mild iron are not to be used with AUS / DEF Do not store AUS / DEF in a tank or use supply lines or fittings that are made of the above materials.

The 40% urea solution will have the advantage of smaller storage tanks, while maintaining the freezing point of water. Caterpillar recommends AUS 32.5% solution per ISO 22241-1. AUS / DEF must be kept below 50 °C (122 °F) to keep it from decomposing too quickly and above – 11 °C (12 °F) to prevent it from freezing during cold operation. According to Caterpillar specification 1E4413, storage near 25°C provides a shelf life of approximately 18 months while storage around 35°C reduces storage life to approximately six months. Other storage and handling methods have to be followed.

The best operating temperature for the urea solution is – 5°C to + 50°C (23 °F to 122 °F). If ambient temperature goes below -11 °C, AUS / DEF inside tank and lines outside dosing cabinet need thawing before starting AUS / DEF dosing.

The thawing time requirement is defined in the EPA SCR guideline (CISD-09-04). The dosing cabinet has a freeze prevention strategy.

Dosing Strategies:

The dosing cabinet requires a AUS / DEF supply of 5-10 psig with a max of 10 psig at the dosing cabinet AUS / DEF supply inlet. There is no AUS / DEF return line back to the remote tank from the tank located inside the dosing cabinet. A vent in the dosing cabinet release purged air & AUS / DEF vapor during purge event. The vent line connected with the dosing cabinet should be below the AUS / DEF injector mounting location at the CEM. The exit location should meet OSHA safety requirements. Please contact local EH&S organization for related concern.

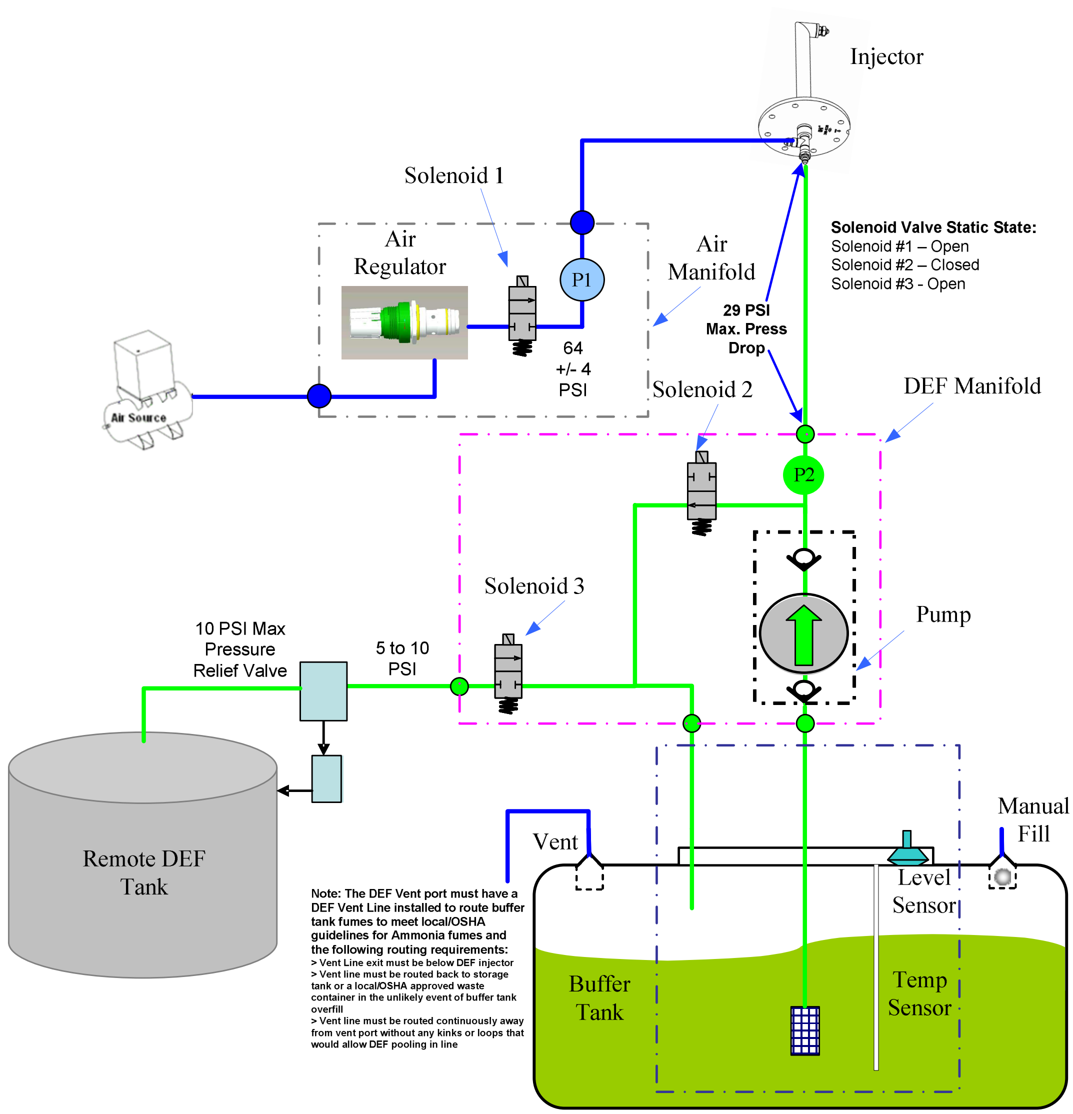


Fig. 4.3 – Dosing system schematic

Dosing System Operations

As shown in Fig. 4.3 air pressure must be present at the input to the dosing cabinet before dosing can begin. This air pressure is regulated to 64 psig. +/- 4 psig. at Solenoid Valve #1. When dosing conditions are met the Aftertreatment

ECM energizes Solenoid Valve #1 which looks for the required psig using P1 sensor. If pressure is present Solenoid Valve #2 is energized to close and allows AUS / DEF to be supplied to the AUS / DEF Injector via the AUS / DEF Dosing Pump. The AUS / DEF Dosing Pump pulses AUS / DEF from the Dosing tank to AUS / DEF injector controlled by the Aftertreatment ECM. The P1 pressure signal is fed to the Aftertreatment ECM that in turn inhibits dosing without the required psig pressure from the P1 sensor signal. Purging is accomplished by energizing Solenoid Valve #1 and de-energizing Solenoid Valve #2 providing compressed air back through AUS / DEF Injector via Solenoid Valve #2 to Dosing Tank when dosing is not required.

The AUS / DEF fill is controlled by Aftertreatment ECM to the buffer tank for the cabinet shown in Fig. 4.3 When the buffer tank AUS / DEF level is lowered and the AUS / DEF Level Sensor detects a low level condition the Aftertreatment ECM energizes Solenoid Valve #3 which fills the Dosing Tank to maintain adequate supply of AUS / DEF to the injector. The maximum AUS / DEF pressure allowed at the input to Solenoid Valve #3 is 10 psig. The allowable range of AUS / DEF pressure and flow rate is 5 to 10 psig and 1.25.to 2.5 gallons per minute respectively. AUS / DEF pressure from the AUS / DEF Supply Tank is typically 5 to 8 psig. A 10 psig maximum pressure relief valve is recommended in series with AUS / DEF Supply Tank.

Dosing Cabinet

Normal functions/operations of a dosing cabinet include:

- Monitor and dose AUS / DEF
- Monitor and regulate compressed air
- House Electronic Control Module (ECM)
- Provide customer connections

The Aftertreatment ECM in the dosing cabinet will communicate with the engine over J1939 data link via the electronic connector on the cabinet interface illustrated below. Dosing cabinet is shipped fully calibrated to work within specified operating conditions. If the operating conditions change beyond the specification, additional care needs to be taken to address these issues. Whenever a critical component is replaced, recalibration might be required. The dosing pump comes with a tamper evident sticker. If this sticker is damaged due to normal wear and tear, please contact the local Caterpillar dealer for replacement. If this sticker is tampered with this implies EPA violation.

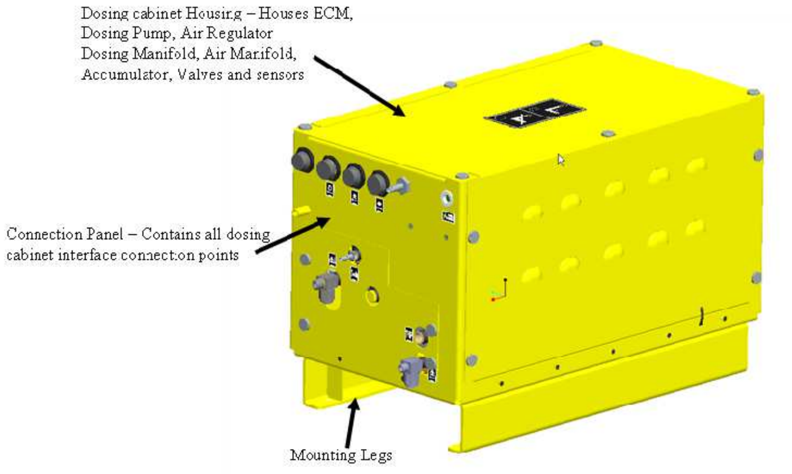


Fig. 4.5 – Dosing Control Cabinet

Dosing cabinet connection points:

Dosing cabinet communicates with external components via its connection points. These connections could be electrical, air and AUS / DEF. For descriptions about the connections and their meaning see Table 4.3.

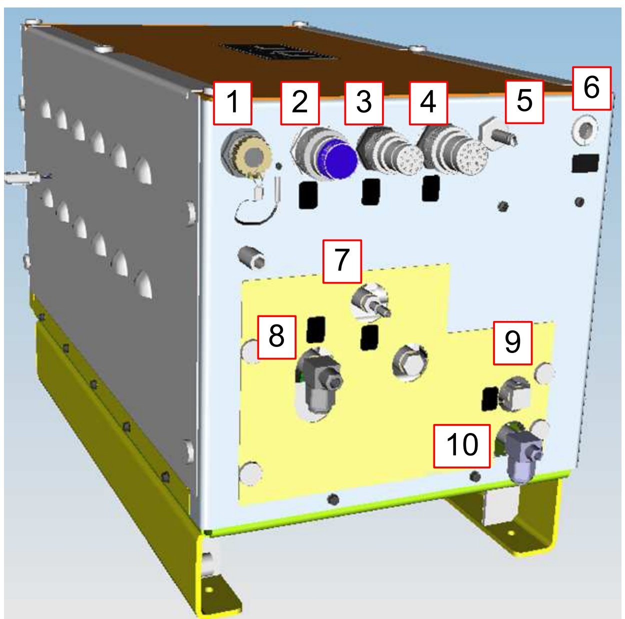


Fig. 4.6 – Connection to Dosing Cabinet

Connection Point *	Description	Fitting Type
1	Service tool connector	
2	Electrical harness from Dosing Cabinet to Engine ECM	24 Pin Connector
3	Electrical harness from Dosing cabinet to main AUS / DEF tank (level sensor/transfer pump???)	24 Pin Connector
4	Electrical harness from CEM to Dosing cabinet.	24 Pin Connector

5	AUS / DEF Vent Port (see Note below)	½" Hose Bead SAE AS5131
6	Electrical harness from Dosing cabinet to 120V AC source	Grommet for wiring & 3 Terminal Blocks
7	AUS / DEF line from Dosing Cabinet to CEM	No. 6 STOR (Straight Thread O-Ring)
8	AUS / DEF inlet line to strainer on Dosing Cabinet.	1/2" NPT
9	Air line from Dosing Cabinet to CEM	No. 6 STOR (Straight Thread O-Ring)
10	Air line into Dosing cabinet	3/8" NPT

Table 4.3 – Dosing Cabinet Connection Points

Note: The AUS/DEF Vent port of item 5 above must have a AUS/DEF Vent Line installed to route buffer tank fumes to meet local/OSHA guidelines for Ammonia fumes and the following routing requirements:

1. **Vent Line exit must be below AUS / DEF injector**
2. **Vent line must be routed back to storage tank or a local/OSHA approved waste container in the unlikely event of buffer tank overfill**
3. **Vent line must be routed continuously away from vent port without any kinks or loops that would allow AUS / DEF pooling in line**

Dosing Cabinet to AUS / DEF Injector

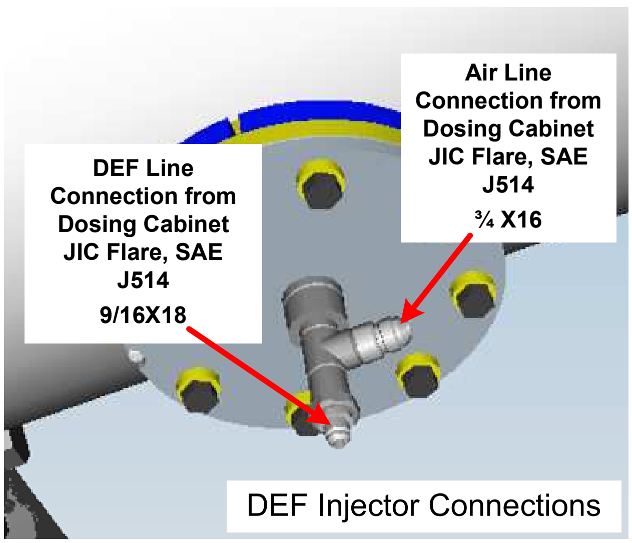
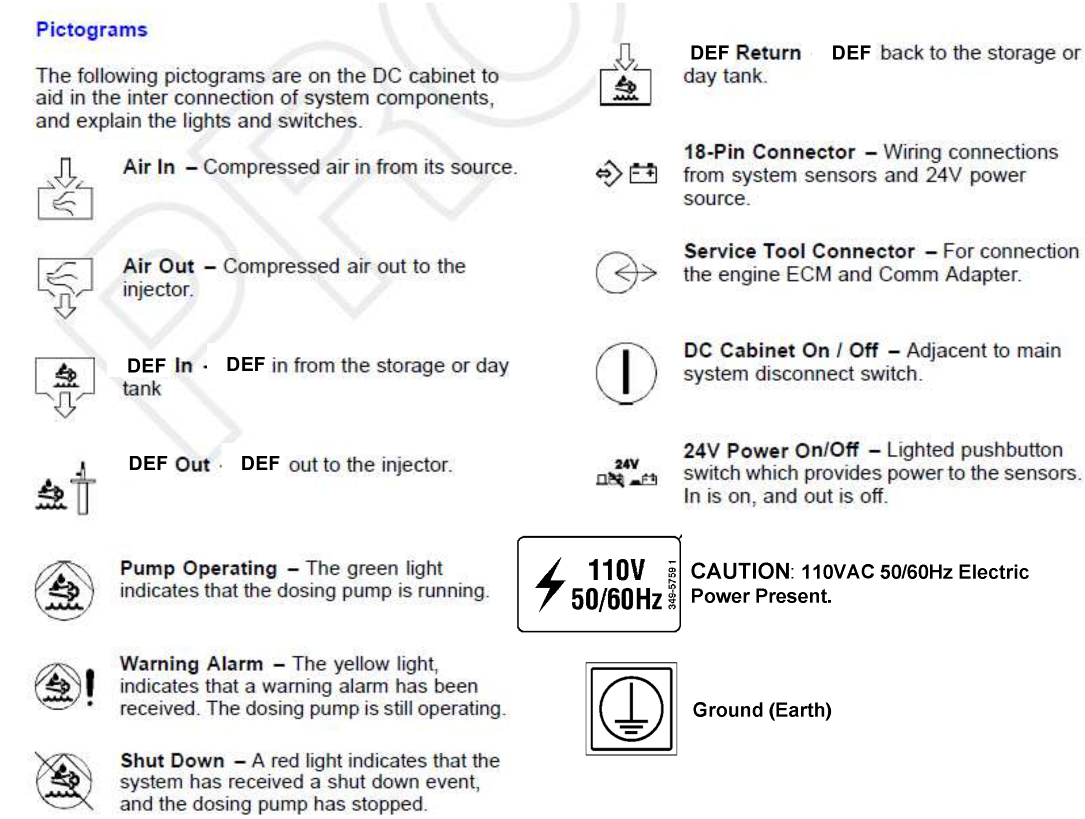


Fig. 4.6a – AUS / DEF Injector Connections

Dosing cabinet symbols:



Pictograms

The following pictograms are on the DC cabinet to aid in the inter connection of system components, and explain the lights and switches.

Air In – Compressed air in from its source.

Air Out – Compressed air out to the injector.

DEF In · **DEF** in from the storage or day tank

DEF Out · **DEF** out to the injector.

Pump Operating – The green light indicates that the dosing pump is running.

Warning Alarm – The yellow light, indicates that a warning alarm has been received. The dosing pump is still operating.

Shut Down – A red light indicates that the system has received a shut down event, and the dosing pump has stopped.

DEF Return **DEF** back to the storage or day tank.

18-Pin Connector – Wiring connections from system sensors and 24V power source.

Service Tool Connector – For connection the engine ECM and Comm Adapter.

DC Cabinet On / Off – Adjacent to main system disconnect switch.

24V Power On/Off – Lighted pushbutton switch which provides power to the sensors. In is on, and out is off.

CAUTION: **110VAC 50/60Hz Electric Power Present.**

Ground (Earth)

AC Power Connection

During the installation of the dosing cabinet, external power supply (AC power only) has to be routed inside the cabinet via appropriate opening. The termination of these power lines are inside the cabinet at the junction block as shown below.

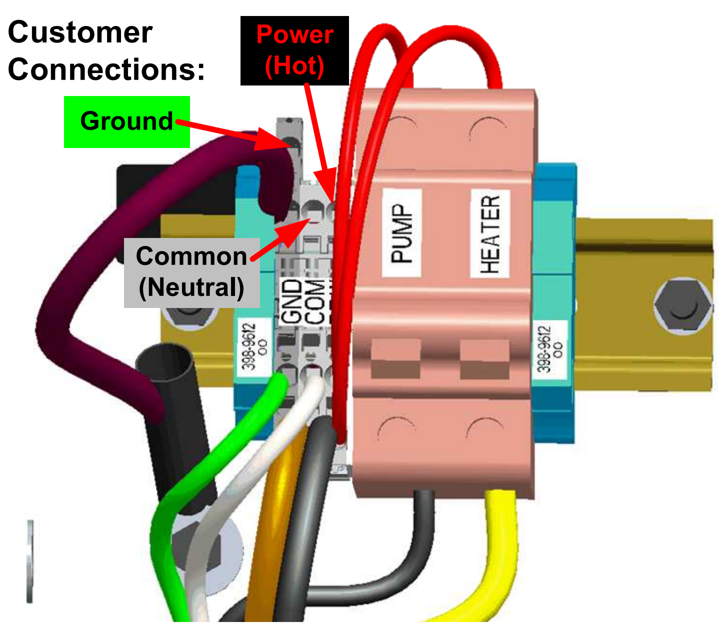


Fig. 4.8 – Example AC Power Connection to Dosing Cabinet

AUS / DEF Supply to the Dosing Cabinet

Desired fill rate is about 1.5 gallon per min at 5-10 psig AUS/DEF supply pressure at the dosing cabinet fill port. For example a 10 feet height difference generates 4.7psi AUS / DEF pressure. Fill rate and overall flow restriction in valves, lines, and filters upstream to the dosing cabinet need to be accounted for when designing the AUS / DEF supply.

AUS / DEF supply to the dosing cabinet must be supplied by a transfer pump. The transfer pump must be sized to provide 5-10 psig with max of 10 psig AUS / AUS / DEF pressure at the dosing cabinet fill port based on the flow rate and total flow restriction in the line from the remote tank to the cabinet.

Dosing cabinet provides a 24VDC (max amp: 300 mA) signal via aftertreatment ECM connector to control a relay used to control the power supply to the transfer pump as shown in Fig. 6.10. Aftertreatment software will energize the relay at fill and turn it off when the fill is done. This relay is not provided with the dosing cabinet. To use this feature, the customer needs to wire the relay. In addition, the customer also need connect a wire from the pin J1-31 of the aftertreatment ECM connector inside the dosing cabinet to the pin 14 of the connector for Cabinet to Engine, i.e. item 1 shown in Fig. 4.6. The wiring diagram for the optional installer provided transfer pump example is shown below.

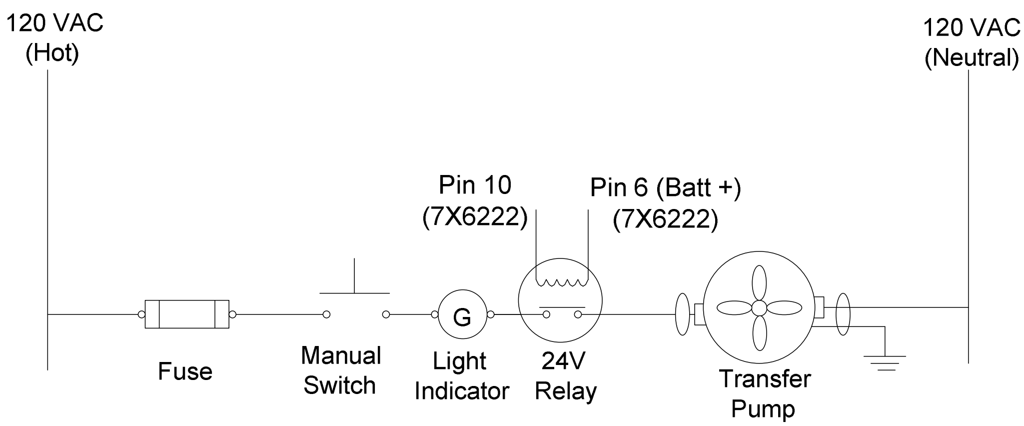


Fig. 4.10 – Transfer Pump Wiring Diagram with ECM and Relay

Weight and Dimensions:

	3516 Dosing Cabinet	***C280 Dosing Cabinet***
Length (mm)	***940***	***1010***
Width (mm)	***500***	***553***
Height (mm)	***585***	***634***
Weight without AUS / DEF (kg)	***95***	***95***

Both the 3516 & C280 Dosing Cabinet have identical interface connections. However the C280 application has a larger footprint and space claim. The figure below shows these dimensions and differences.

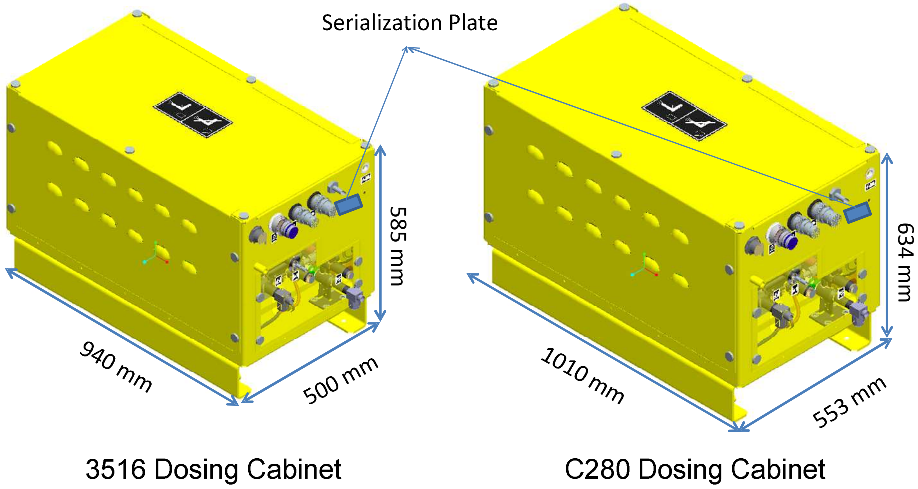


Fig. 4.11 – 3516 & C280 Dosing Cabinet Space Claim & S/N Location

Lifting and Mounting:

The preferred method of lifting the dosing cabinet is to use two straps through the openings in the base frame as shown in Fig. 4.12.

The cabinet can be mounted by the use of bolts. The cabinet frame rails have 4 M 10 bolts holes that are to be used to mount the cabinet to the vessels mounting structure.

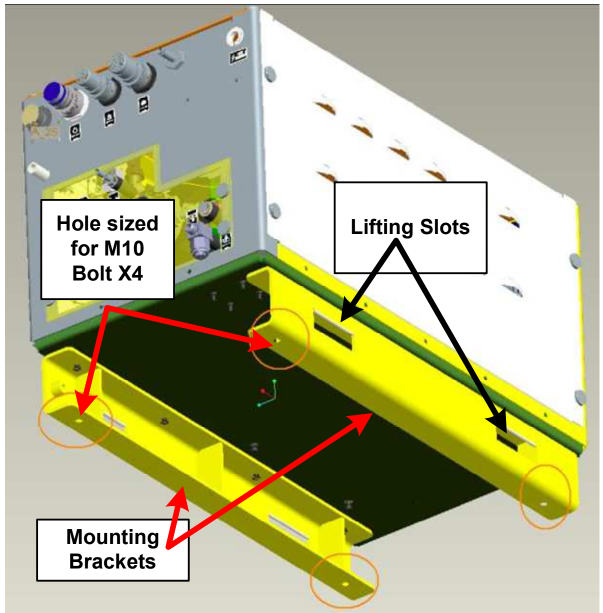


Fig. 4.12 – Mounting Dosing Cabinet

Refer to **Section 5** – Mounting Considerations for additional mounting guidelines.

Clearance:

Dosing cabinet is required to have clearances around the outside of the box per Fig. 4.13. If one of the sides with 2 ft of clearance is not accessible then it is required to have 4 ft of clearance on the side that is accessible and is not necessary to maintain the 2 ft of clearance on the inaccessible side.

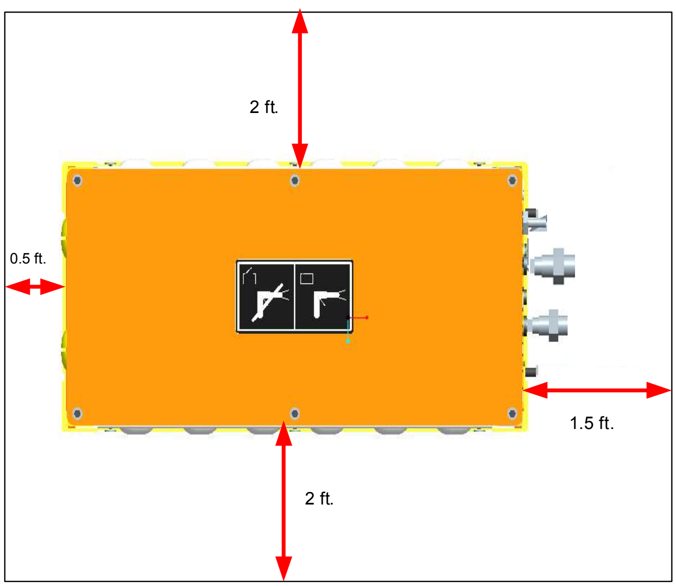


Fig. 4.13 – Dosing Cabinet Mounting Clearance Requirements

Orientation:

The dosing cabinet has to be mounted per Fig. 4.12 in the vertical position. The cabinet needs to be mounted with the top of the cabinet parallel with the horizon. The dosing cabinet should not be tilted by more than 18 deg from the vertical position.

Location:

Mounting location of the Dosing cabinet must be within 10 meters (30ft) of the CEM injector and the top of the Dosing cabinet must be at or below the bottom of the CEM Mounting pads. The maximum pressure drop in the AUS / DEF Line between the Dosing Cabinet and CEM injector nozzle is 29 psi or 200 kPa.

Environment:

The dosing cabinet needs to be located so that it will not be subjected to ambient temperatures higher than 55 C or lower than -40 C. The components within the dosing cabinet are designed to operate in temperatures per the above specifications.

AUS / DEF Delivery System

Caterpillar's Selective Catalyst Reduction (SCR) system is contained in a module and utilizes AUS / DEF to reduce engine-out NOx. AUS / DEF is a solid at room temperature, but is typically placed into a de-ionized water solution to facilitate high resolution metering which is necessary for the DEF/SCR system to operate at high efficiencies without inducing ammonia slip. Also note that DEF ($CO(NH_2)_2$) itself is simply a safe "transporter" of ammonia (NH_3) which is what ultimately drives this SCR process. This is described in the global equations below.

$$CO(NH_2)_2 + H_2O \rightarrow 2NH_3 + CO_2$$
$$NO + NO_2 + 2NH_3 \rightarrow 2N_2 + 3H_2O$$

An onsite, or in the case of a Marine Vessel, an on board AUS / DEF storage must be provided by the installer and the piping to deliver the AUS / DEF water solution to the pump on the module which will inject the AUS / DEF into the engine exhaust stream where the AUS / DEF then decomposes into NH3 and reacts with NOx primarily in the presence of the SCR catalyst.

AUS / DEF Handling

Refer to Appendix D: "AUS / DEF Handling" for appropriate handling methods.

Material Selection for Tank and Piping

Material compatibilities must be considered in the AUS / DEF storage and delivery system due to the caustic corrosive nature of the liquid.

- Highly alloyed austenitic Cr-Ni and Cr-Ni-Mo Steels or Stainless Steel (304, 304L, 316L, 409, 439) materials are recommended for use with AUS32 (urea water solution).

- Titanium is recommended for use with AUS / DEF water solution

- Metals & Plastics coated with nickel are not recommended because nickel coating inner diameters of components and durability (resistance to flaking) of nickel coating are not consistent.

- Polyethylene, Polypropylene, Polyisobutylene, Perfluoroalkoxyl alkane (PFA), Polyfluroethylene (PFE), Polyvinylidenefluoride (PVDF), Polytetrafluroethylene (PTFE) are all recommended materials

- Seal/Hose Materials – EPDM (1E0712B) and NBR (1E0741) are suggested materials for use with AUS32.

- Aluminum and its alloys are not recommended for use as tank material for DEF tanks. Only certain grades of anodized aluminum are acceptable but due to variability of anodizing quality, it is not recommended as tank material either.

- Non-ferrous metals and alloys (copper, copper alloys, zinc, lead) are strongly not recommended

AUS / DEF Lines

Connections

Typical fittings have mild steel as the base material, which will not be compatible with AUS / DEF. All connection points and fittings for the AUS / DEF lines are required to be stainless steel or AUS / DEF compatible material.

Line Specifications

Dosing Cabinet to CEM AUS / DEF line

Inside Diameter – Greater than 5.5mm and Less than 7.5mm

Length – Less than 6.1 meter (20 ft.) in length
Oil resistant
Connections per Table 4.1

AUS / DEF Lines from storage tank to buffer tank

A minimum of 5 PSI head pressure on AUS / DEF in line and a maximum of 10 PSI is required at all times during operation to assure that the buffer tank can be filled when it runs low.

AUS / DEF line must be capable of delivering AUS / DEF in atmospheric conditions down to -40C without AUS / DEF freezing and impeding filling of buffer tank when required.

<u>AUS / DEF Lines Installation & Routing</u>

AUS / DEF lines are to be installed following instructions based on DIN 20066 part 4. General routing and clipping rules should include keeping these lines from coming in contact with sharp edges that would fatigue and fail the line from vibration or system operating movements. Other considerations should include continuous routing without kinks, extreme bends and loops that would restrict AUS / DEF flow throughout the operating temperature extremes.

If there is more than one engine/PETU/CEM installed on a vessel, than a shut off valve must be installed before the dosing cabinet/PETU in the AUS/DEF line from the transfer pump. The valve will allow that one PETU to be turned off for service, while other engines and PETU are still running. The valve can also be used to if a leak would occur in one of the PETU to compete its repair.

Thermal Control

AUS / DEF storage and delivery systems must be designed to accommodate freezing as well as perform NOx reduction functionality at ambient temperatures below the freezing point of the fluid.

AUS / DEF Storage Tank

The OEM or installer must provide a AUS / DEF main storage tank and delivery system.

The OEM or Installer must provide a means to sample AUS / DEF in the tank to determine AUS / DEF Quality.

AUS / DEF storage tanks must be designed to the industry best practices for fluid storage tanks, but also with consideration for AUS / DEF you need to watch for ambient conditions for both high and low temperatures. If the tank would have a chance of freezing, then the tank needs to be designed with an effective heat exchanger that is capable of thawing the tank. Unlike other common operating fluids, such as diesel fuel and coolant, AUS / DEF freezes at a temperature within the operating limits of the engine.

AUS/DEF in the tank freezes from the outside to the center. The density of frozen AUS/DEF is lower than the density of the liquid AUS/DEF. This means that the frozen AUS/DEF floats on the liquid AUS/DEF. To ensure that the complete tank of AUS/DEF is thawed, at least part of the heating source has to be located at the bottom of the tank. The AUS/DEF pick-up location has to be very close to the heating source and draw from the bottom of the tank as well. As the AUS/DEF is consumed, the AUS/DEF level in the tank reduces and the cold AUS/DEF approaches the heater.

To facilitate the thawing process, the tank should have a simple rectangular or trapezoidal shape wherein the base of the tank is slightly larger than the top of the tank; a "pyramid" design (no plateaus) is recommended for best thawing performance. Shapes that do not assure the gradual reduction in the level of AUS/DEF have to be avoided. Tank shapes vary from application to application based on design and space limitations. Irregularity in these shapes is acceptable as long as the air pockets and/or stuck chunks of frozen AUS/DEF inside the ridges or any other contours of the tank can be avoided. It is also preferable to have the width of the tank equal or smaller than the height of the tank. Short and long tanks are not favorable for AUS/DEF freeze protection.

Tank Volume

Tank volume should be sized based on required refill frequency, AUS / DEF freeze expansion, and the volume of internal tank components. The AUS / DEF tank size is dependant upon AUS / DEF quality over duration of use and delivery infrastructure. The AUS / DEF tanks must be sized never to run out. Tank sizes will depend on vessel designed operating profile and its normal fueling stops. AUS / DEF tanks must be sized such that sufficient AUS / DEF is always available to adequately operate the SCR system. The amount of AUS / DEF usage can be reasonably estimated as a direct fraction of the engine fuel burn, on an average the amount of AUS / DEF consumed by the engines will be around 10% for the 3500 engines and upwards of 15% for C280 engines. Example for 3500 engine is 1 gallon of AUS / DEF for every 10 gallons of fuel usage. Such, a calculation must be based on the amount of fuel that may be burned by the engine/engines between AUS / DEF fill up opportunities. This value should be based on an operational knowledge of the vessels expected service, and the engines projected fuel usage. The AUS / DEF tank should then be sized to accommodate the requisite fraction of AUS / DEF as outlined in the table below. As an example, if an analysis of the operating profile of a 3500 sized engine shows that it could burn 1,000 gallons of fuel between AUS / DEF fill opportunities, then the AUS / DEF tank would need to be sized to hold at least 100 gallons of 32.5% AUS / DEF over and above any space taken up by any tank inserts, such as level switches." When figure out the fuel usage and AUS / DEF usage the operation profile must be used to determine both fuel tank size and AUS / DEF tank size.

The urea (AUS / DEF) tank placement into a Marine Vessel must be designed into a place where the urea will not be allowed to freeze. Caterpillar's normal tank freeze protection system volume of 2% for freeze expansion volume will not be required. Caterpillar off road capacity safety margin is 5% of the total tank volume. The urea tanks size on Marine Vessels will be designed based on operating load profile of the vessels with a safety factor of "never to run out". Fuel and urea tank volume will be base on operating profile and normal vessel fueling stop.
Instances where insufficient AUS / DEF is available will be recorded in nonvolatile memory by the engine, and the end user must report these instances to the EPA.

Tank Connections

The AUS/DEF line suction or pick-up connection should be placed at the bottom of the tank, and as close to the heat exchanger as possible if installed. This location has the greatest potential for the first available liquid AUS / DEF during thawing. Adequate protection of the pickup tip is recommended to keep unthawed AUS / DEF from blocking port. On the return side, melted AUS / DEF returning from the pump has the potential to help thaw the remaining frozen AUS / DEF. To take advantage of this potential, the return port on the tank should be at the top of the tank.

Tank mounting location in Marine Vessels

The ideal location of the AUS/DEF tank is as close as possible to the center of gravity of the Vessel. This would result in the least sloshing possible. Proximity to heat sources should also be considered in tank placement, as prolonged exposure to elevated temperatures causes thermal degradation of AUS / DEF in the tank. The tank should be located in the Vessel where the tank temperatures will not freeze and not exceed the high temperature requirements for proper storage. The proper storage temperature range for AUS/DEF is between 15°F and 77°F (-9°C and 25°C) that is stored above the 95°F (35°C) for longer than one month must be tested to make sure quality is not degrading and AUS/DEF meets required spec. Tank must be location on Vessel to meet the temperatures requirements to avoid degradation of AUS/DEF. If location of the tank within a Vessel can't meet the temperature requirements for AUS/DEF than a way to cool or heat the fluid must be installed in the main AUS/DEF tank. Use of thermal insulation is another way of keeping the tank temperatures within the proper temperature requirements for storage.

Although high-density polyethylene is a poor conductor of heat, additional insulation will help to protect AUS/DEF from thermal degradation.

Tank Materials

Non-cross linked polyethylene (PE) is the material of choice for AUS/DEF tanks. It provides a wide temperature range of operation, has good strength properties, allows for flexibility in "shaping", low in weight, and has been used other AUS/DEF applications.

In-Tank Filtration

In-tank filtration is required to protect the AUS/DEF delivery system.

An inlet strainer is required to prevent large debris from entering the tank. The strainer should be made of stainless steel with 30-mesh/500 micron filtration. (Ref. Cat PN 108-3730).

An "Iceberg Catcher" must be located at the end of the AUS/DEF pickup line in the tank to keep frozen chunks of AUS/DEF out of the delivery system. This will act as secondary filtration into the AUS/DEF delivery system, but will not provide enough filtration to meet the requirements for the AUS/DEF delivery systems. Functional specification for the iceberg catcher is consistent with Euro 4 (ES-2084). Technical requirements of the filter are for AUS/DEF flow capacity for the delivery system (area of the mesh) and the filtration requirements (size of the mesh - 100 um).

Tank Sensors

AUS/DEF tank designs must provide for appropriate interfaces with tank sensors. The ultrasonic AUS/DEF level sensor needs to be installed perpendicular to the fluid (when level) with a minimum of a 2" space between the sensor and the fluid. This requirement drives the placement of the sensor to the top of the tank. Additionally the AUS/DEF level sensor should be placed as close to the center of the AUS/DEF tank as possible and have line of sight to the bottom of the AUS/DEF tank. The sensor is salt and AUS32 corrosion resistant, with an operating temperature range of –40°C to 85°C.

AUS / DEF Temperature Sensor

The AUS/DEF temperature sensor probe functionally needs to be located very close to the AUS/DEF suction line in order to determine if there is liquid AUS / DEF available for the system.

Temperature sensor requirements based on the reference sensor include: operating temperature range –40C and 150C (probe end), –40C and 120C (connector end), vibration limits: 30GrmsX3sigma for 0.03% of operational lifetime, and it is salt & AUS / DEF corrosion resistant.
If an electrostatic painting process is used, then proper grounding must be in place during the paint process.

AUS / DEF Level Sensor

A low level urea tank sensor must be placed in the main urea tank. The sensor will send a signal to the dosing cabinet ECM when the AUS/DEF level in the tank drops to 13.5% left in the tank. The dosing cabinet will warn the vessel operator when the AUS/DEF main tank reaches the sensor. No faults are recorded unless the tank runs empty of AUS/DEF. The sensor inside the dosing cabinet will record when the system is completely out of AUS/DEF. The low level sensor in the main AUS/DEF tank will only supply a warning to the operator that his AUS/DEF tank is running low. The low level sensor input into the dosing cabinet ECM is a switch input to GND. These two points are required to comply with EPA 1042 rules.

It is recommended that along with the level sensor a warning light is provided to indicate when AUS/DEF level is low. The warning light should be set at a level that will provide adequate time to acquire quality AUS/DEF and refill the tank.

Tank Heating

Heating of the AUS/DEF tank for thawing can be carried out in various ways. Heat can come from an electric heater, or a heat exchanger using one of the various working fluids on a Marine Vessel, including coolant, engine oil, hydraulic oil, and exhaust. Out of these sources, a heat exchanger using coolant is the optimal solution. Electricity is also acceptable for performance, but the amperage requirement is very high. Although other fluids may have equal or higher temperatures, coolant's high specific heat enables it to outperform the others. Mass flow rate also plays a major role in determining the heating potential of a fluid.

While a heat exchanger using coolant has many advantages, it also has one major performance disadvantage compared to an electric heater. While an electric heater can begin thawing AUS/DEF almost immediately after startup, engine coolant warms up more slowly.

Heat Exchanger Design

Based on the highest rate of consumption, the heat exchanger (a stainless steel coolant line) can be sized to provide thawing. The sizing is accomplished by utilizing the following equation:

$$mC_{p,\ solid\ DEF}dT_{solid\ DEF} + mH + mC_{p,liquid}dT_{liquid\ DEF} = UA\ (T_{coolant}-T_{DEF})$$

where:

m = 2 x DEF consumption, kg/s

$C_{p,\ solid\ DEF}$ = specific heat of frozen DEF solution, kJ/kg-K

$C_{p,\ liquid\ DEF}$ = specific heat of liquid DEF solution, kJ/kg-K

$dT_{solid\ DEF}$ = -11C - Initial temperature of DEF, C

H = Latent heat of fusion of AUS / DEF solution, kJ/kg

$dT_{liquid\ DEF}$ = Final, required temperature of DEF - -11C, C
U = Overall heat transfer coefficient, kW/m^2-K

A = Heat transfer area, m^2

$T_{coolant}$ = AECD Coolant temperature, C

T_{DEF} = Required temperature of AUS / DEF, C

The overall heat transfer coefficient, U can be obtained from the following equation:

$$\frac{1}{UA} = \frac{1}{h_{coolant} A_{coolant}} + \frac{l_{ss}}{K_{ss} A_{ss}} + \frac{1}{h_{ice} A_{ice}}$$

Where:
$h_{coolant}$ = Convective heat transfer coefficient of the coolant inside the coolant line, which can be obtained from the equation

$$Nu = hD/K$$

$A_{coolant}$ = Surface area of the coolant, m^2

l_{ss} = thickness of the stainless steel tube, m

K_{ss} =Thermal conductivity of stainless steel, kW/m-K

A_{ss} = Mean surface area of the stainless steel tube, m^2

h_{ice} = Convective heat transfer coefficient of the frozen AUS / DEF solution surrounding the tube, kW/m^2-K

A_{ice} = Surface area of the OD of the tube, m^2

The heat transfer area, A, can be calculated from the above equation. This area can be translated into an equivalent length and diameter of the coolant line.

Insulation Requirements

Although non-metallic AUS/DEF tanks are a very poor conductor of heat, depending on the proximity of the AUS/DEF tank to a heat source, additional thermal insulation may be required. For metallic tanks, thermal insulation is required to help improve the AUS/DEF thawing process in addition to heat protection. AUS 32 freezes at –11°C and starts to degrade at elevated temperatures above 50 °C.

The main storage tank location in a Vessel needs to be taken into consideration for both high and low temperature requirements of urea. If the tank is located in a high temperature area of the vessel then insulate the tank or design in some type of cooling design to keep the urea below the maximum temperature limits. If Marine Vessel will be spending time in cold operating areas then the urea tanks needs to be keep from freezing. This can be accomplished by insulating the tank or by adding heater to the tank to keep the temperatures from freezing.

Energy Source

Energy Requirements

For AUS/DEF thawing, the recommended melt rate for frozen AUS/DEF is twice the maximum consumption rate. This gives a brake-specific melting rate of 34 g/kW-hr and 21 g/kW-hr for ratings 175-750 hp and greater than 750 hp, respectively. These numbers should be used when sizing a heat exchanger or electric heater.

- Heat Exchanger Design
- Pickup/Return Location
- Flow rate/Thaw rate min.

Electrical

Block Diagram

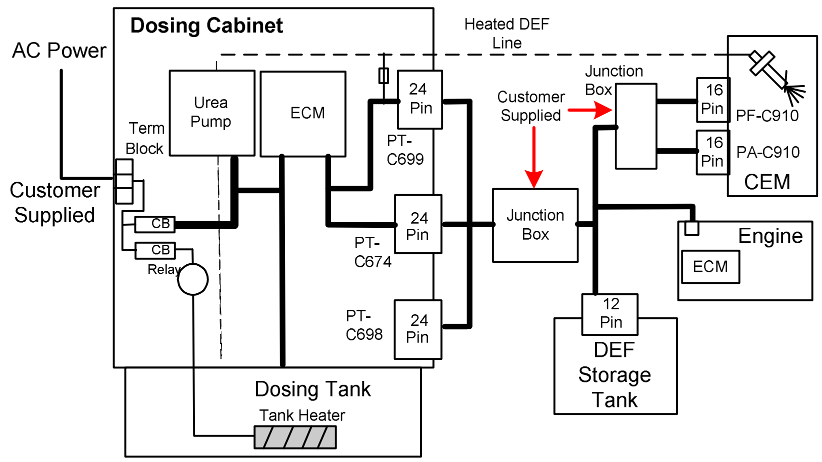


Fig. 4.14 – Dosing Cabinet Block Diagram – 3516CHD/C175

Electrical Connections

Interconnect Harness Connectors

Dosing Cabinet Side

All Applications

Dosing Cabinet PT-C674 to Engine via Junction Box			
23 Way Interconnect Harness Connector: 433-0308 (Mating: 388-6613)			Term: Pins
Connector Pin	ECM Pin Function	Wire ID	Wire Size (AWG)
A	Cat Data Link (-)	945-BR	18
B	Cat Data Link (+)	944-OR	18
C	J1939 - Global CAN A (-)	K990-GN	18
D	J1939 - Global CAN A (+)	K900-YL	18
E	--------	-	-
F	--------	-	-
G	J1939 - Local CAN B (-)	R976-GN	18
H	J1939 - Local CAN B (+)	R970-YL	18
J	AUS / DEF Line Heater Relay HI Sw Batt +	P830-PU	18
K	AUS / DEF Line Heater Relay Lo Sw Batt -	L838-OR	18
L	AUS / DEF Transfer Pump Sw	Y719-BU	18
M	ECM J1 – Battery +	101-RD	14
N	ECM J1 – Battery -	A250-BK	14
O	--------	-	-
P	ECM J1 – Battery +	101-RD	14
Q	--------	-	-
R	ECM J1 – Battery -	A250-BK	14
S	AUS / DEF Line Heater Relay HI C547-1	103-YL	18
T	AUS / DEF Line Heater Relay Lo C548-1	229-BK	14
U	AUS / DEF Manifold Heater Relay C546-1	103-YL	14
V	AUS / DEF Manifold Heater Return	229-BK	14
W	Keyswitch	105-BR	18
X	--------	-	-

Dosing Cabinet PT-C698 to Tank **via Junction Box**			
14 Way Interconnect Harness Connector: 425-4537 (Mating: 433-0310)			Term: Sockets
Connector Pin	ECM Pin Function	Wire ID	Wire Size (AWG)
A	AUS / DEF Level Sensor	H857-PK	18
B	AUS / DEF Tank Temperature	K811-BL	18
C	Analog Sensor Return	Y947-BR	18
D	AUS / DEF Tank Heater Relay Supply	K839-BU	18
E	AUS / DEF Tank Heater Relay Return	T791-BR	18
F	AUS / DEF Line Heater Relay HI Sw Batt +	P830-PU	18
G	AUS / DEF Line Heater Relay Lo Sw Batt -	L838-OR	18
H	AUS / DEF Transfer Pump Sw	Y719-BU	18
J	Tank High Sw	410-WH	18
K	Tank Low Sw	A487-PU	18
L	AUS / DEF Transfer Pump Relay Batt +	101-RD	18
M	-------------	-	-
N	--------------	-	-
P	-------------	-	-

Dosing Cabinet PT-C699 to CEM **via Junction Box**			
23 Way Interconnect Harness Connector: 433-0309 (Mating: 425-4540)			Term: Pins
Connector Pin	ECM Pin Function	Wire ID	Wire Size (AWG)
A	AFTM #1 ID Module	K895-BU	18
B	------------	-	-
C	+5V Analog Sensor Supply	997-OR	18
D	------------	-	-
E	------------	-	-
F	Analog Sensor Return	T993-BR	-
G	------------	-	-
H	J1939 - Local CAN B (-)	R976-GN	18
J	J1939 - Local CAN B (+)	R970-YL	18
K	DOC 1 Delta Pressure	P938-WH	18
L	AFTM 1 SCR Inlet Gas Temp	J890-BU	18
M	SCR 1 Outlet Gas Temp	J891-GN	18
N	Inlet 1 NOx Sensor	L920-BR	18
P	Outlet 1 NOx Sensor	L921-YL	18
R	Outlet 2 NOx Sensor	L922-BU	18
S	NOx Sensor Return	J807-BK	18
T	AUS / DEF Line Heater Relay HI Sw Batt +	P830-PU	18
U	AUS / DEF Line Heater Relay Lo Sw Batt -	L838-OR	18
V	------------	-	-
W	------------	-	-
X	------------	-	-

CEM Side

CEM Inlet Box PA-C910 to Dosing Cabinet via Junction Box			
18 Way Interconnect Harness Connector: 331-3598 (Mating: 331-3592)			Term: Sockets
Connector Pin	ECM Pin Function	Wire ID	Wire Size (AWG)
1	--------------	-	-
2	J1939 - Local CAN B (-)	R976-GN	16
3	J1939 - Local CAN B (+)	R970-YL	16
4	Gnd – Intake NOx Sensor	J807-BK	16
5	VS – Inlet Temp Sensor	997-OR	16
6	--------------	-	-
7	--------------	-	-
8	--------------	-	-
9	Signal – CEM Inlet ABS Pressure Sensor	P938-WH	16
10	VS – Inlet NOx Sensor	L920-BR	16
11	VS – CEM Inlet ABS Pressure Sensor	997-OR	16
12	Gnd – Inlet Temp Sensor	T993-BR	16
13	Gnd – CEM Inlet ABS Pressure Sensor	T993-BR	16
14	Signal – Inlet Temp Sensor	J890-BU	16
15	--------------	-	-
16	--------------	-	-
17	--------------	-	-
18	--------------	-	-

CEM Outlet Box PF-C910 to Dosing Cabinet via Junction Box			
19 Way Interconnect Harness Connector: 197-7359 (Mating: 197-7261)			Term: Sockets
Connector Pin	ECM Pin Function	Wire ID	Wire Size (AWG)
1	Signal - Outlet Temp Sensor	J891-GN	16
2	+5V - AFTMT ID Module	997-OR	16
3	Output Signal - AFTM ID Module	K895-BU	16
4	Gnd – AFTMT ID Module	T993-BR	16
5	J1939 – Local CAN B (+)	R970-YL	16
6	J1939 – Local CAN B (-)	R976-GN	16
7	VS – Outlet NOx Sensor	L921-YL	16
8	--------------	-	-
9	Gnd – Outlet NOx Sensor	J807-BK	16
10	--------------	-	-
11	J1939 – Local CAN B (-)	R976-GN	16
12	--------------	-	-
13	J1939 – Local CAN B (+)	R970-YL	16
14	--------------	-	-
15	Gnd – Outlet Temp Sensor	T993-BR	16
16	--------------	-	-
17	VS – Outlet Temp Sensor	997-OR	16
18	--------------	-	-
19	--------------	-	-

120V Power Connection

The dosing pump requires 120V AC power to operate. The connection for the power is made inside the dosing cabinet on a bus bar with the cable routing through a wiring grommet on the dosing cabinet. The hot and neutral wire coming into the cabinet will hook to the terminal strip connectors. Then the ground wire needs to be hooked up to the grounding stud. This will allow the dosing cabinet to meet the grounding requirements. Refer to wiring example in Fig. 4.8.

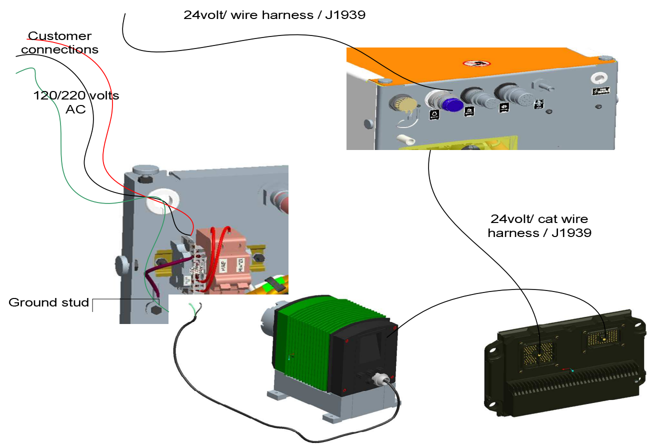


Fig. 4.15 – 120V AC Connection Diagram

Electrical Loads

SCR Component Electrical Load (Assume Cold Ambient Temps)								
Component	Power	AC		DC				
		AC max amp	AC max amp	DC max amp	DC Ave amp	DC max amp	DC Ave amp
		Engine Running	Engine Stopped	Engine Running	Engine Running	Engine Stopped	Engine Stopped
Dosing pump	AC	0.7	0.0				
Buffer Tank Heater	AC	2.9	2.9				
Manifold heater	DC			8.3	4.2	8.3	4.2
12V power conditioner	DC			1.0	0.2	1.0	0.2
Line heater (dosing/tank 2.6 m)	DC			15.0	5.0	15.0	5.0
ECM & connected items Total:	DC			11.4	3.7	4.2	2.0
1. ECM	DC	0		0.3	0.3	0.3	0.3
2. NOx Sensors	DC	0		7.0	1.0	0.0	0.0
3. Air supply enable solenoid	DC	0		2.0	0.5	2.0	0.0
4. Reagent return solenoid	DC	0		0.2	0.1	0.0	0.0
5. Pump fill solenoid	DC	0		0.2	0.1	0.2	0.0
6. Pump motor Heater	DC	0		1.7	1.7	1.7	1.7
7. AUS / DEF Transfer Pump Relay (Optional – Customer Supplied)	DC	-	-	0.3	0.1	0.3	0.1
Total Component Current (Amps)		3.6	2.9	36.0	13.2	28.8	11.5
NOTE: Power consumption w/SCR Aftertreatment system. This does not include air compressor and air dryer.							

Table 4.5 – Electrical Loads

Electrical Component temperature limits

There are components on the CEM that are required to stay under specified temperature limits. The sensor box on the CEM contains the critical electrical components such as the NOx sensors and temperature sensors. The pressure sensors may or may not be located in the sensor box. It is necessary that the components in Table 4.6 do not exceed the listed specifications during operation of the engine system.

Component Temperature Limits	
Component	**Temp Limit (C)**
Temperature Sensor	120
NOx Sensor Control Box	85
Delta Pressure Sensor	125

Table 4.6 – Electrical Component Temperature Limits

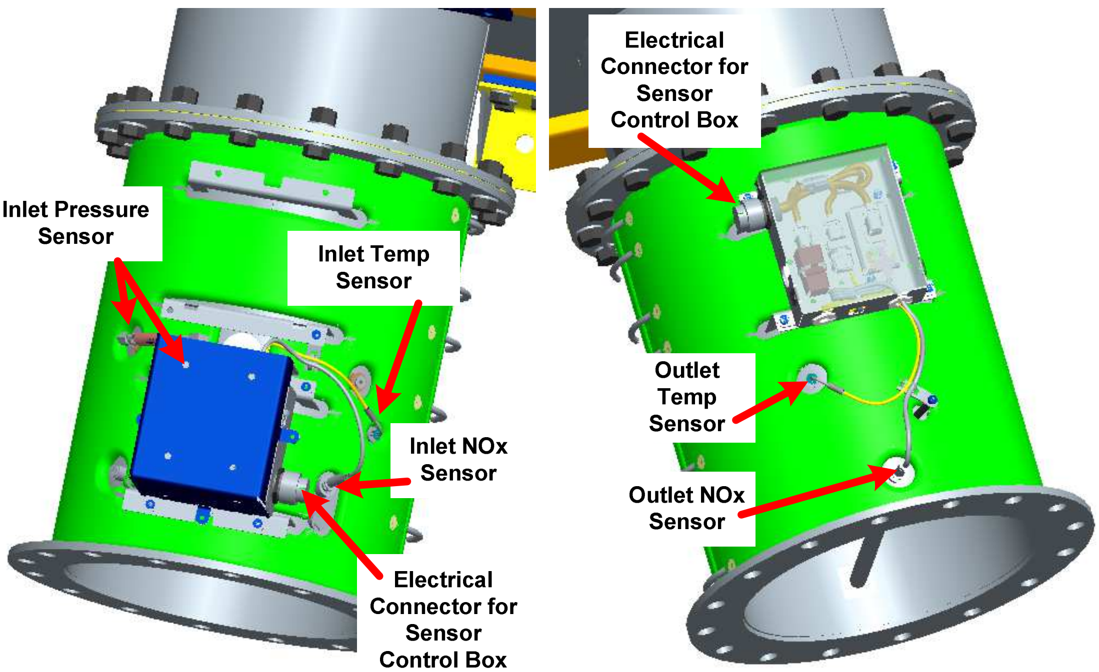
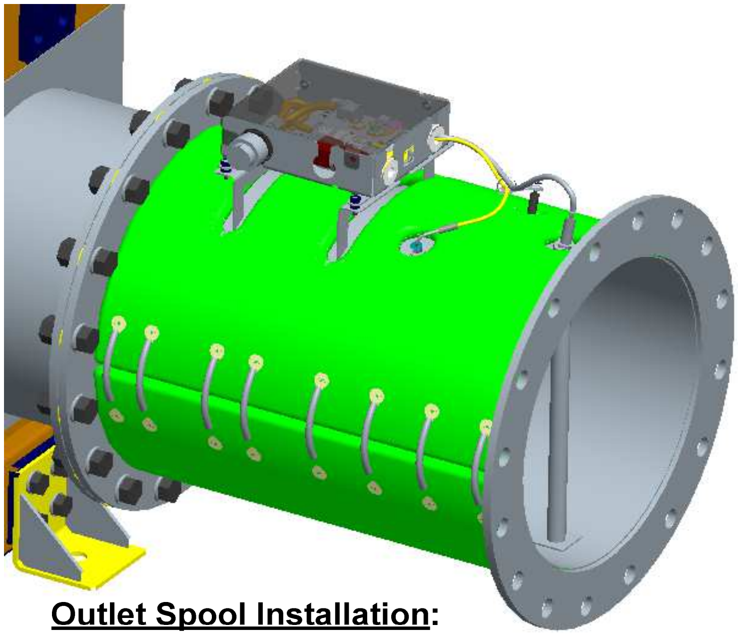


Fig. 4.16 - 3516CHD Inlet/Outlet Spool Electrical Component Locations

The above figure shows the electrical component locations for the inlet and outlet exhaust spools that attach to the CEM both U and Z flow configurations.



<u>Outlet Spool Installation</u>:

- **Sensor Box should always be on top.**
- **Vertical Installation - the spool should be oriented where there is access for servicing the sensor.**

Figure 4.16a – Outlet Spool Orientation

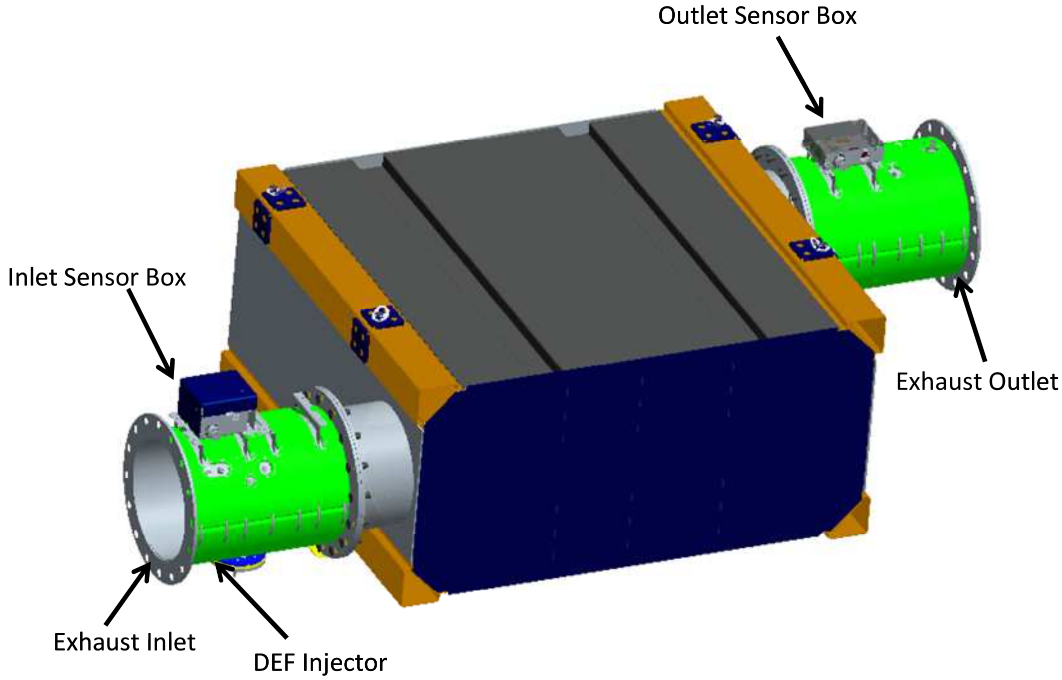
The installation of the outlet spool requires the Sensor Box to be on top in horizontal installations with adequate clearance to allow service of the NOx sensor. CEMs mounted vertically (on its end) the spool must be oriented to allow easy access to NOx Sensor for service. Refer to the Mounting & Lifting installation subsection below for Horizontal and Vertical installation examples.

Exhaust System

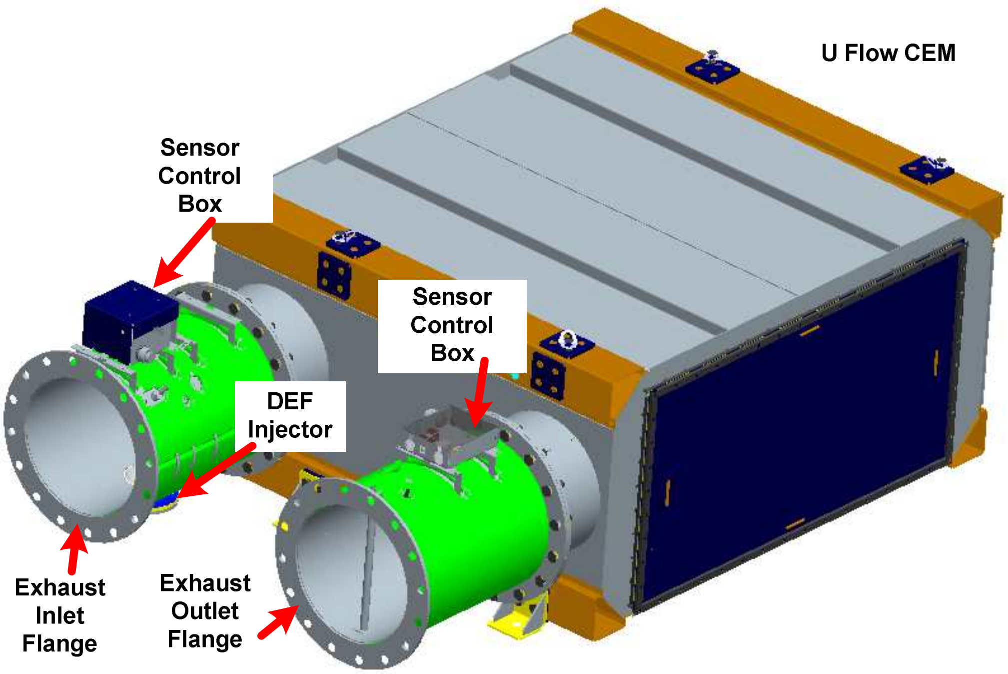
Exhaust Connections

Both the inlet and outlet exhaust connections to the CEM utilize a bolted flange connection. A gasket and standard bolt torques are required to maintain a leak tight seal. Any connections for the exhaust that are between the turbo out and CEM inlet are required to be leak tight and utilize industry standard exhaust connection components.

For further Exhaust System Requirements reference “Section 4 – Exhaust System.”



Top front view of "Z" Style SCR CEM for 3516CHD



Top front view of "U" Style SCR CEM for 3516CHD

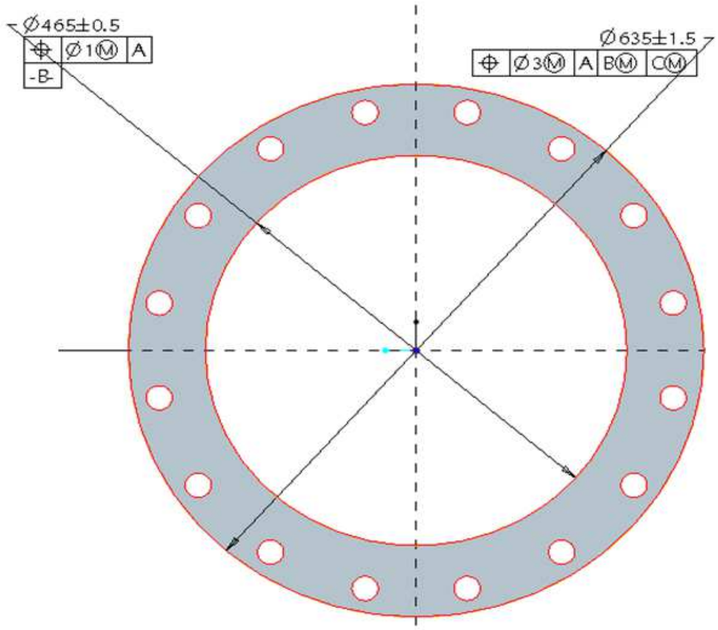


Fig. 4.16 – 3516 CEM Exhaust Inlet & Outlet Flange Dimensions

Sound Attenuation

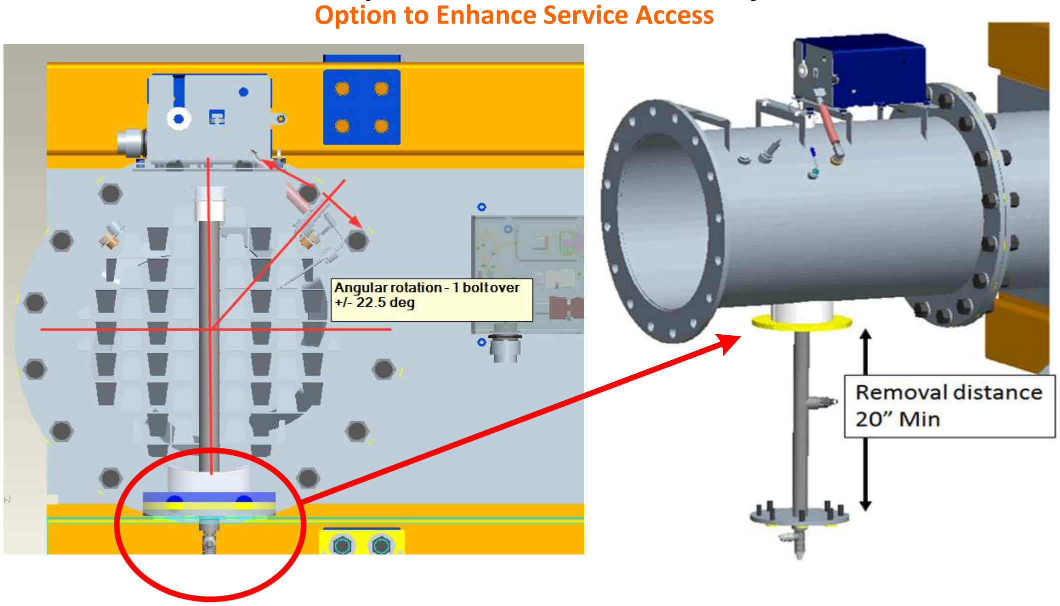
See TMI for sound attenuation data.

Installation

CEM installation considerations should be based on application, location, environment and serviceability. Serviceability includes but not limited to repair and maintenance of CEM System components. This may include dosing cabinet, sensors, catalyst and dosing injectors. The inlet spool on the CEM that houses the AUS / DEF injector is flexible through orientation for better serviceability. Careful attention to details such as this will enhance service and maintenance of Caterpillar aftertreatment systems.

Inlet Spool Orientation Flexibility

Option to Enhance Service Access



Note: Clearance for servicing the AUS / DEF Injector must be maintained by providing 20 inches (508 mm) clearance for injector access and removal. Spool orientation option above may assist you when designing for CEM installation.

Enclosure Temperature Limits

Ventilating air should enter near the bottom of the enclosure and then flow upward around the engine and/or Cat CEM module before exiting above the engine.

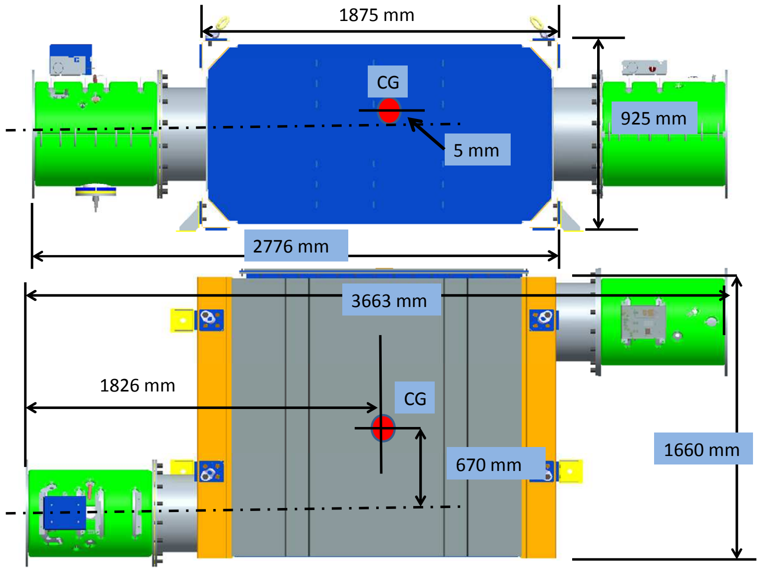
Room/Building ventilation should be designed to bring the coolest air to the Cat CEM module. If the engines and modules are placed in a building that has a pitched roof then ventilating air should flow out at the peak or near the top of the gable ends. The source of the air must be low in the room and rise across the engine and Cat CEM and other equipment.

For personnel comfort, maintain air velocity at 1.5 m/sec (5 ft/sec) in areas of heat sources or areas that exceed 38°C (100°F). Potential dead air spaces should be checked for temperature rise during engine operation. Check all electrical and mechanical equipment in the dead air space for any detrimental effects caused by excessive temperatures. Require corrections if necessary. Engine room pressure should not become excessively negative. This would indicate a shortage of ventilating air or excessive ventilating fans if equipped.

Installation Dimensions and General Views:

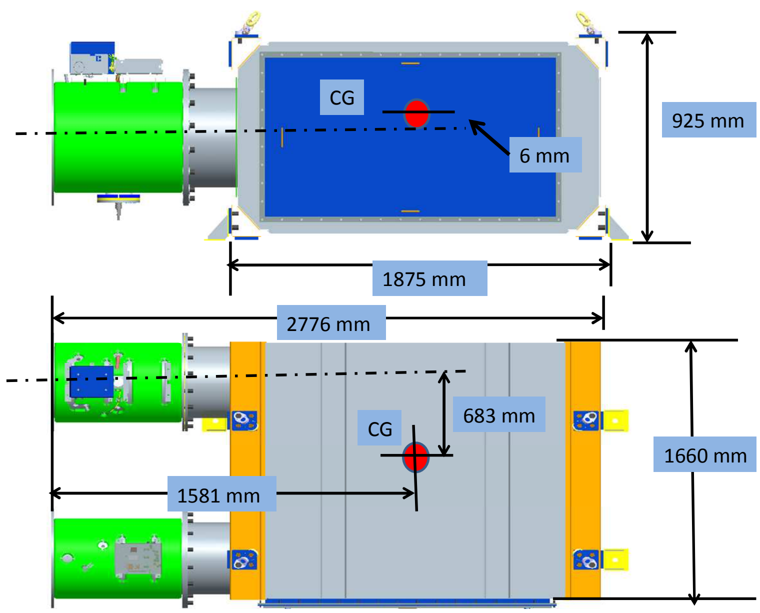
Refer to TMI data for weights of CEM.

Center of Gravity Location: 3516 Z flow 16 brick design CEM



Mass of the Z flow is 1399 kg. The catalysts are arranged in an 8 x2 stack design.

Center of Gravity Location: U flow 16 brick design CEM



Mass of the U flow is 1390 kg. The catalysts are arranged in an 8 x2 stack design.

Mounting & Lifting

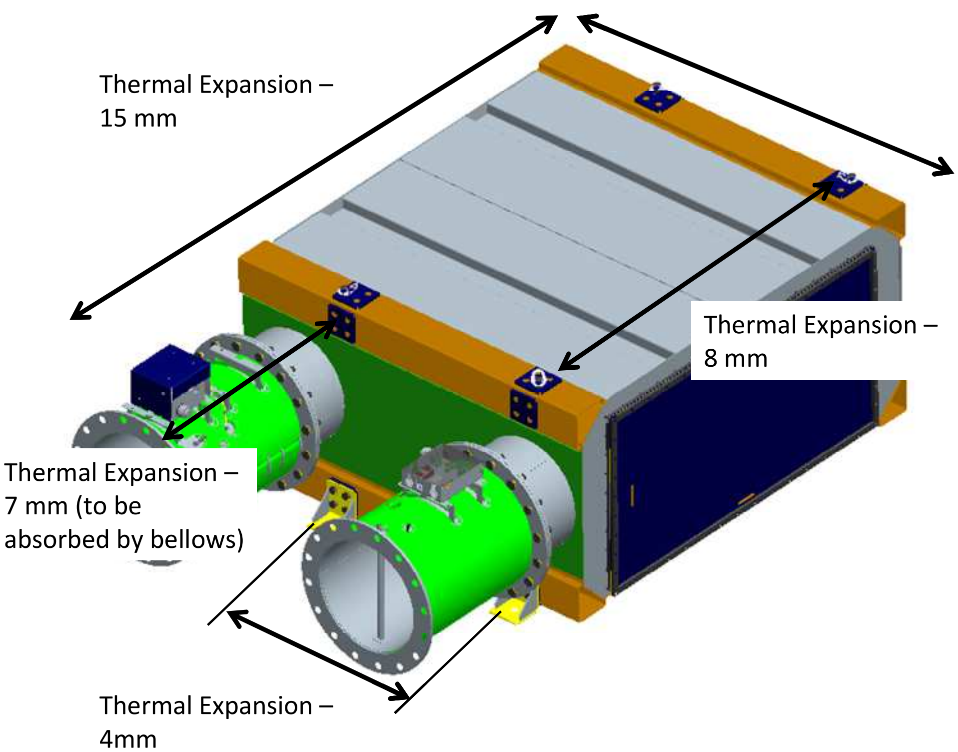
For requirements Reference Section 5 – Mounting Considerations.

In addition to the above requirements, please note the g-load requirements for the following CEM families:

1. **3500 and C175: U and Z flow design CEM**
    a. **Fore/Aft – up to 2 G's**
    b. **Vertical – up to 2 G's**
    c. **Side to Side – up to 2 G's**
2. **C280 CEM design:**
    a. **Fore/Aft – up to 2 G's**
    b. **Vertical – up to 2 G's**
    c. **Side to Side – up to 2 G's**

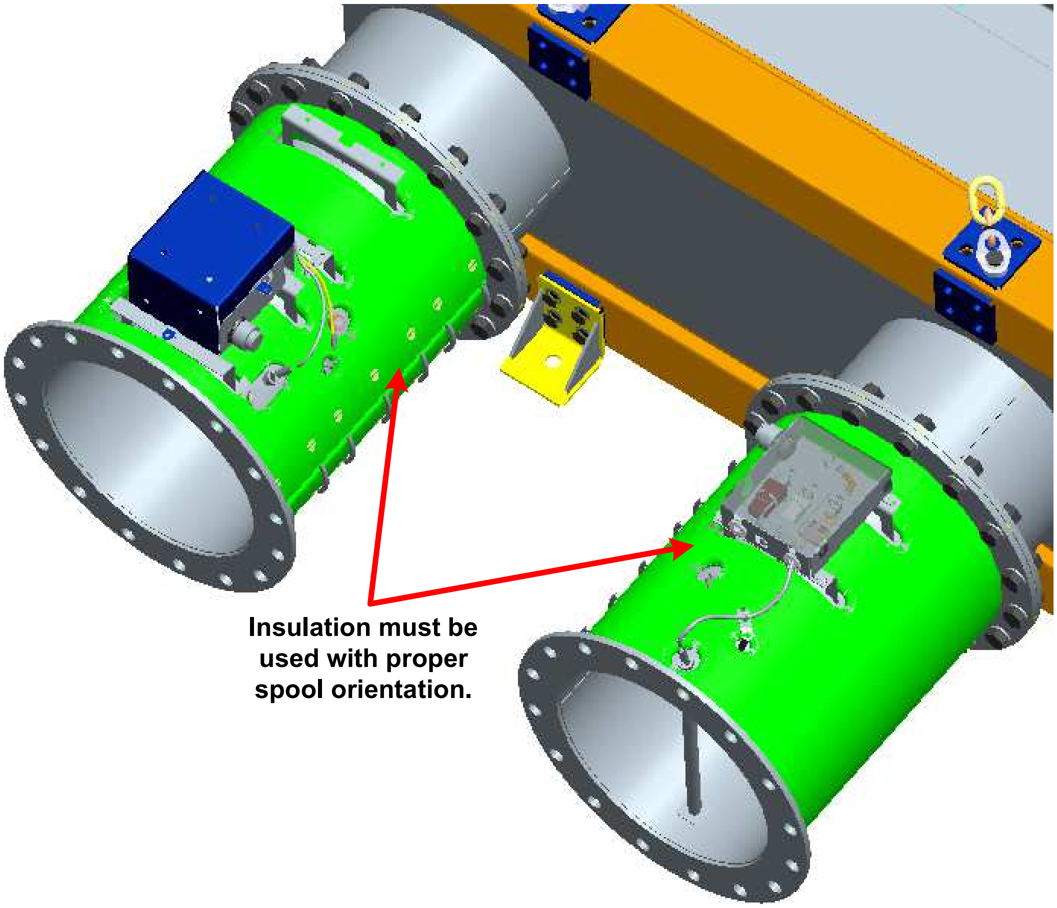
Warning: Standing on top of the CEM and using the top of the CEM as work platform is strictly prohibited.

Marine Aftertreatment Mounting - Thermal Expansion



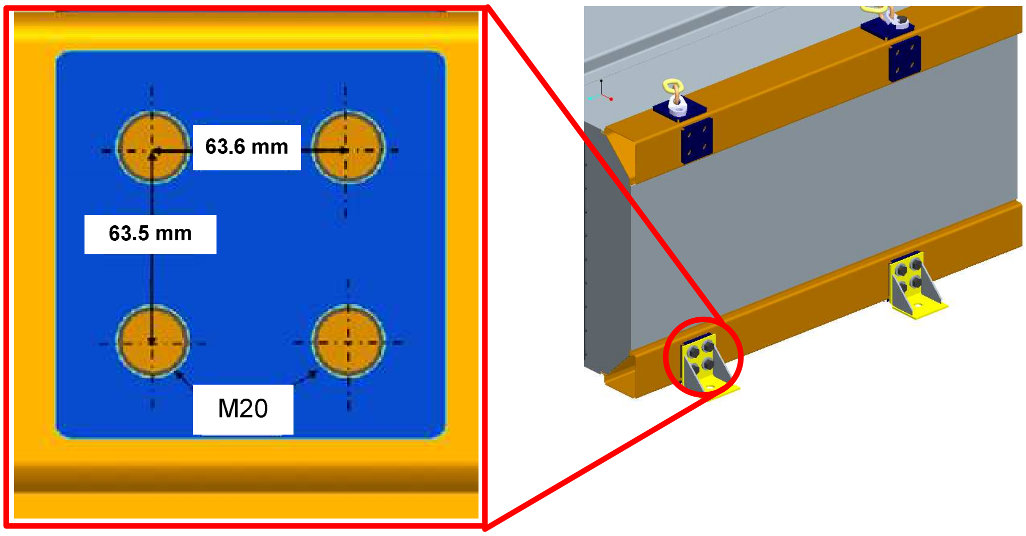
Thermal Insulation

Insulation is required for Aftertreatment inlet and outlet. Refer to Section 6: Thermal Management for insulation details.



3500 and C175: U and Z Flow CEM Mounting

Cat CEM provisions for mounting are a 4 bolt pattern per pad. There are a number of pad locations depending on which way the CEM is mounted in the Vessel. Mounting requires the use of at least four mounting pads when mounting in the vessel. Bolt requirements are M20 grade 10.9 Bolts.



There are two types of CEM which are based on the exhaust flow direction. One type is U-flow and another one is Z-flow. In U-flow configuration, both the inlet and outlet of exhaust gas are on same side of the CEM.
Whereas, in case of Z-flow configuration, the inlet and outlet of exhaust gas are on opposite sides of the CEM.

The mounting components should be able to meet the following requirements:

1) Mount should be able to support the weight of the CEM
2) It should be able to withstand the high temperature of exhaust gases
3) It should be able to limit the stresses on bellows from displacement and thermal growth, which necessitates the fixed mount on the inlet side.
4) There should be flexible mount on the outlet side to take care of dynamic conditions and allow thermal expansion of CEM

- L-bracket needed for mounting and add to the stiffness
- Pipe length has no influence if the weight change is less than 5%.

There are mainly three types of mounts: cushion mount, cable mount and stabilizer. Cushion mount falls under the fixed mount category, whereas, cable mount and stabilizer fall under the flexible mount category.

The pros and cons associated with the stabilizer and cushion/cable mount options are as follows:

1) Stabilizer option is more prevalent than the cushion and cable mount options.
2) Stabilizer is around 20% cheaper than cushion and cable mount.
3) Noise and vibration is more with stabilizer option.

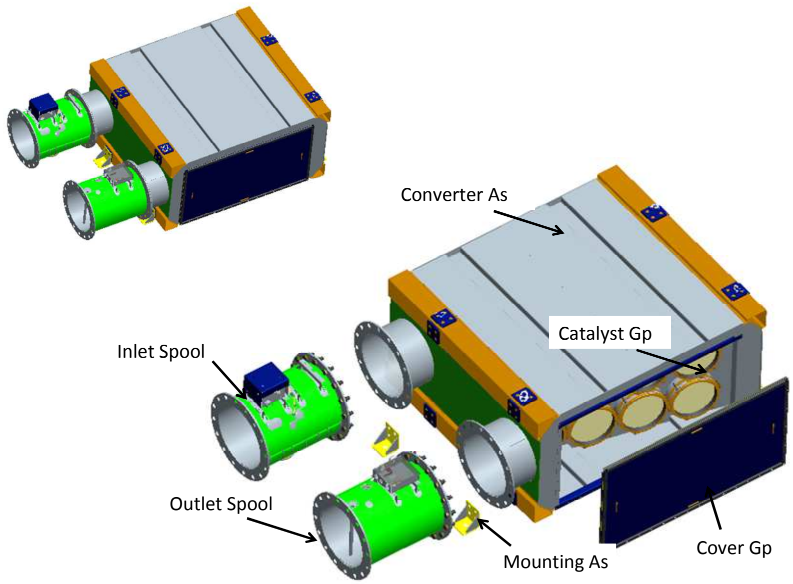
In order to isolate the vibration from the mounts, the mount stiffness requirements are as follows:

1) The mounting bracket should be at least 10 times stiffer than the mounts (fixed and flexible).
2) Foundation should be 10 times stiffer than the mounts (fixed & flexible).

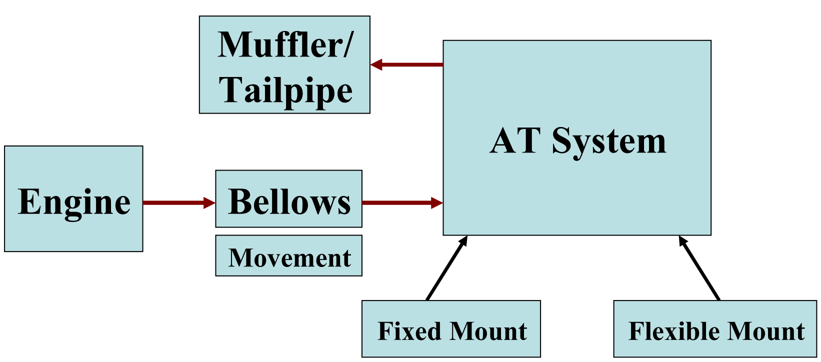
Otherwise, no vibration isolation from the mounts.

U Flow System Level Schematic

As shown in the schematic below, for U-flow, the exhaust gas inlet and outlet are on the same side of the CEM. The CEM is supported with fixed mount on the inlet & outlet side to keep this side of the CEM rigid limiting the stresses on the bellows on upstream side of CEM. However, the other side of the CEM is supported on flexible mount to take care of dynamic conditions and allow thermal expansion of the CEM.



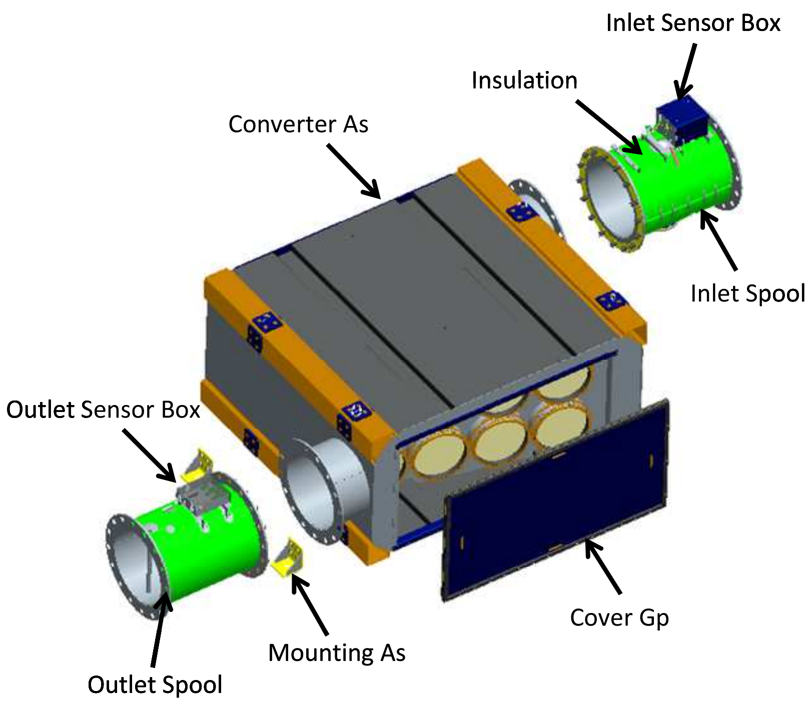
System Level Schematic – U Flow



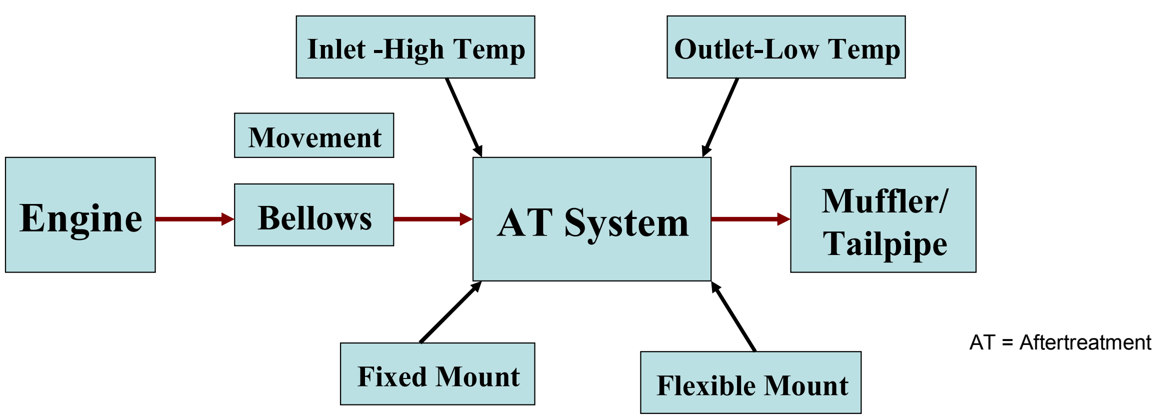
AT = Aftertreatment

Z Flow System Level Schematic

As shown in the schematic, for Z-flow, the exhaust gas inlet and outlet are on the opposite side of the CEM. The CEM is supported with fixed mount on the inlet side to limit stresses on bellows and flexible mount on the outlet side of the CEM to allow flexibility and thermal expansion of CEM.



System Level Schematic – Z Flow



Mounting Support

There are three types of CEM support mounts:

- **Fixed Support:** Exhaust Equipment Category
  - SS Cushion Mount (semi-custom) – compression mount

- **Flexible Support:** Shock Mounting Category
  - SS Cable Mount – Compression mount

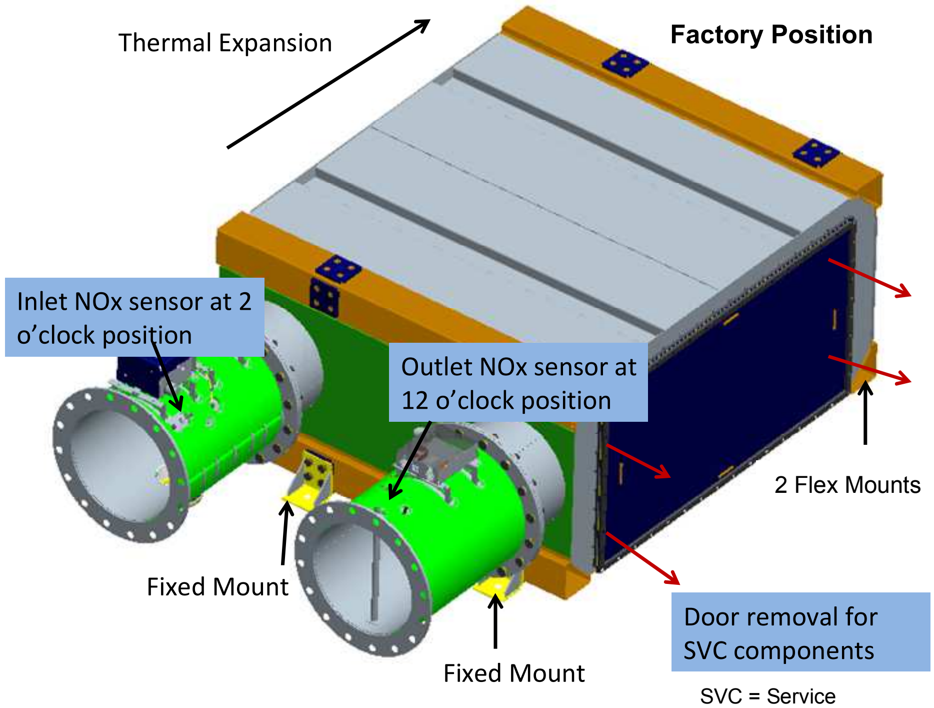
- **Flexible Support (hanging):** Exh. Equipment Category
  - Flexible Suspension – Tension mount

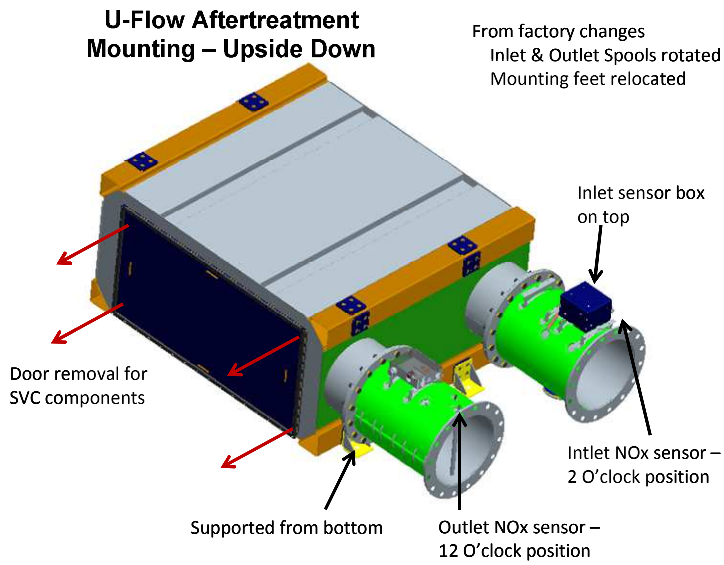
The fixed support, which is compression mount, falls under the exhaust equipment category. The flexible support, which is also compression mount, is categorized as shock mount. However, the hanging option, which is tension mount, is categorized as exhaust equipment.

U Flow Mounting Configuration

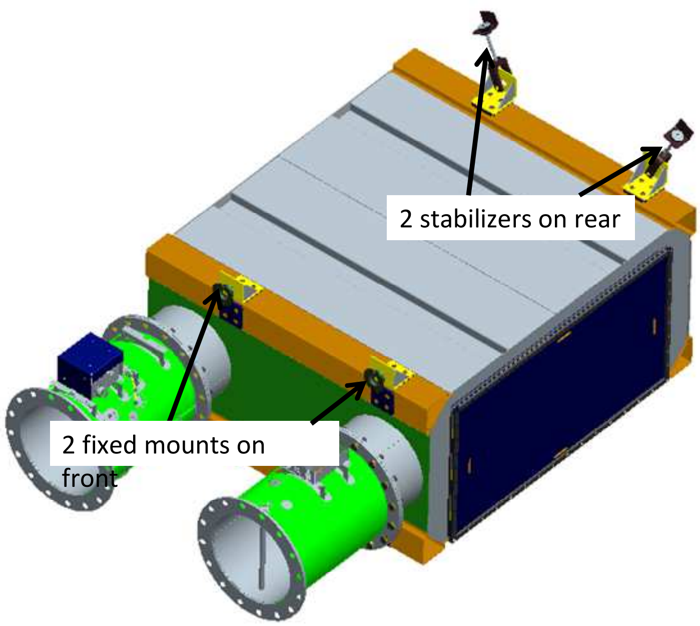
Horizontal Mounting (Mounted on Floor)
The basic U-flow CEM mounting configuration is the horizontal mounting as shown below. The two mounting feet on inlet and outlet sides are fixed and that on the opposite side are allowed to move using flexible mounting.

U-Flow Aftertreatment Mounting - Horizontal

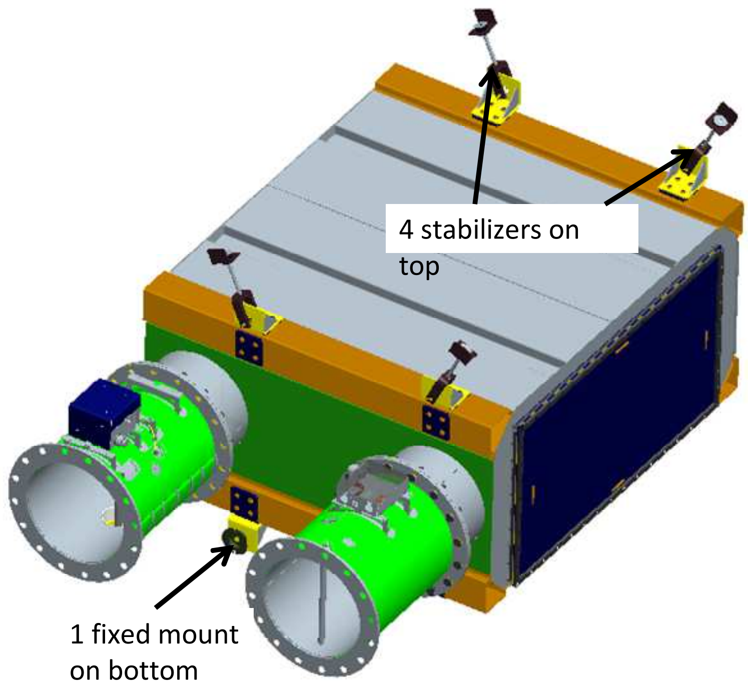




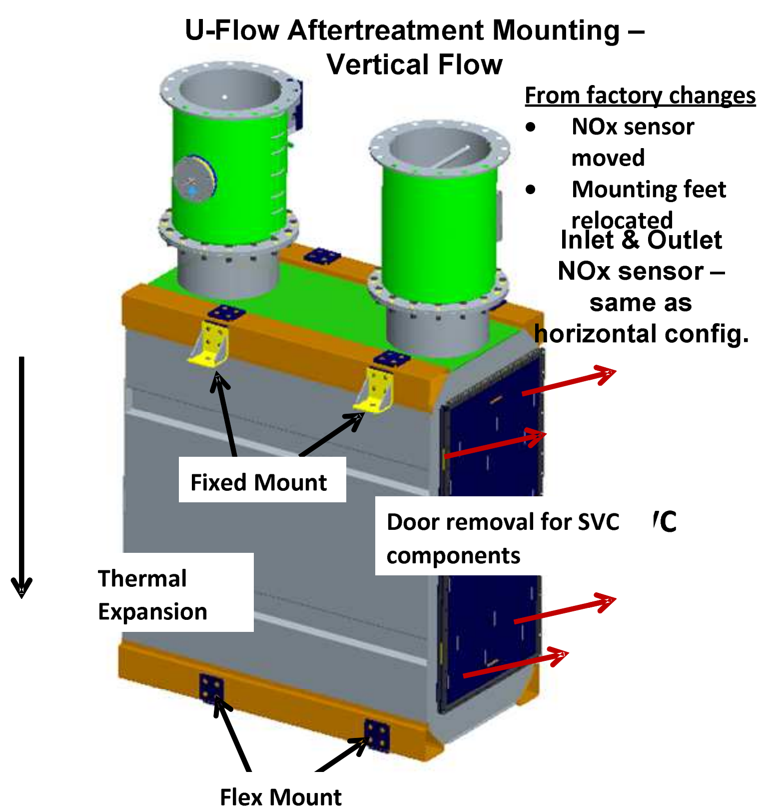
Horizontal Mounting (Hanging)
The U-flow CEM can also be mounted horizontally with two fixed support on the inlet and outlet sides whereas other side is allowed to move using two stabilizers on top.



In another configuration, the aftertreatment can be mounted horizontally with four stabilizers on top allowing flexibility to CEM while one fixed support on bottom front prevents excessive movement of the CEM.

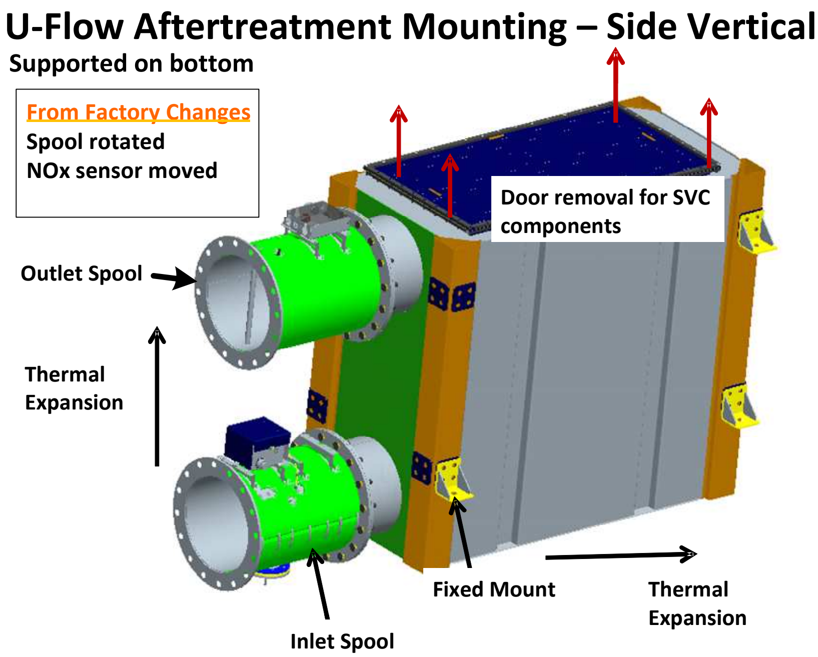


Vertical Mounting (Vert Flow)
The U-flow aftertreatment can be mounted on rear end with fixed mount on exhaust end and flex mount on rear end. This is a vertical exhaust flow.



Side Vertical Mounting (Mounted on Floor)

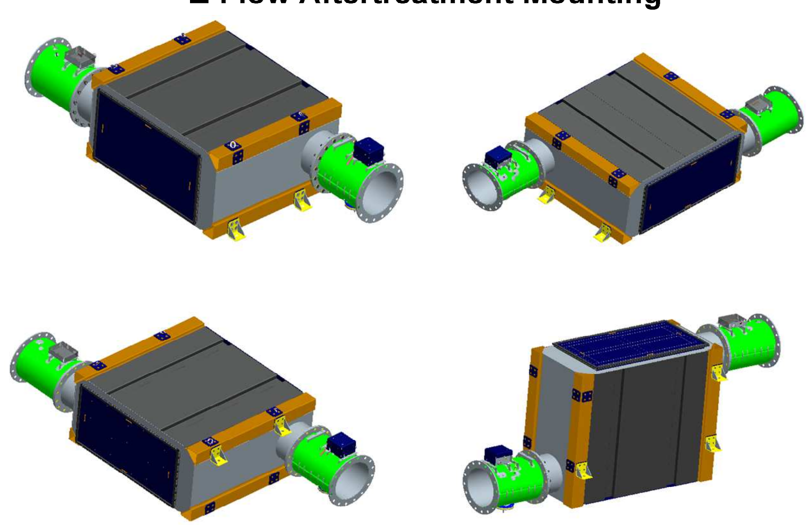
The U-flow aftertreatment can be mounted on side vertical with two fixed on bottom front and two flexible on the bottom rear. The height of the CEM can be supported using two flexible mounts on rear top of the CEM.

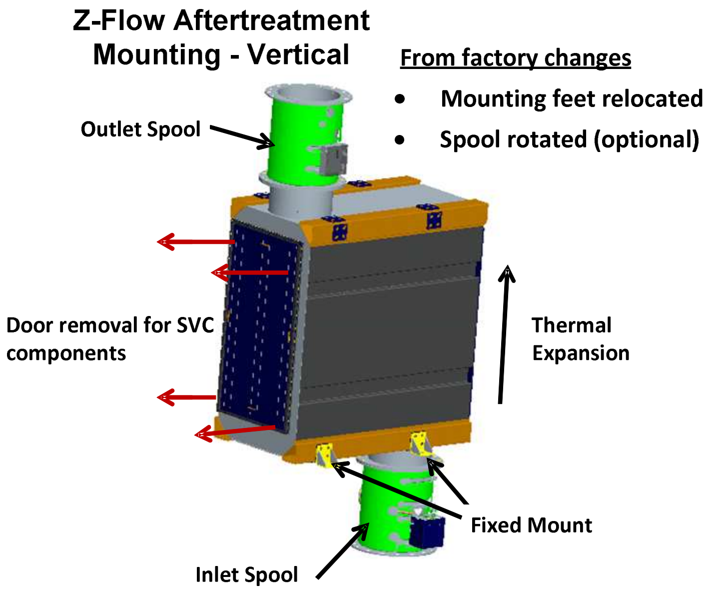


Z Flow Mounting Configuration

Z Flow mounting has similar mounting requirements as U-Flow mounting but the exhaust flow is from end to end instead of in and out at the same end. This difference should drive more consideration for exhaust interface and use of bellows to align engine exhaust to CEM. Refer to U-flow fixed and flexed mounting. The vertical mounting will require additional capabilities for bellows movement.

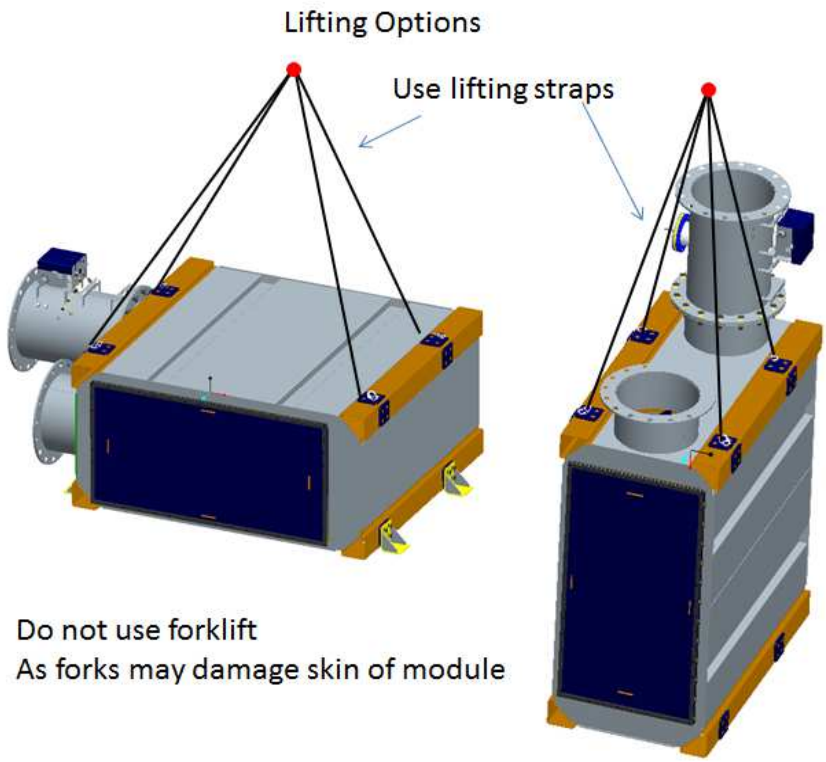
Z-Flow Aftertreatment Mounting





Lifting

Four lifting links are to be bolted to the CEM assembly and lifted as illustrated below. Spreader bar might not be required if lifting straps are used and straps are kept away from all sensors and wiring harness on the inlet spool and CEM.



C280 CEM Installation

Guidelines for Lifting and Installation:

- Use all lifting lugs when lifting the CEM (Clean Emission Module or Reactor) into place.

- Use all mounting feet when securing the CEM housing into its operating position.

- Make sure all ports; openings and connections are clear from obstruction.

Lifting Instructions:

1. The CEM should be delivered lying on its side in the horizontal position; the lifting eyes must be used to remove from the bed of the shipping or delivery truck.
2. Use 2 or more sets of lifting eyes to rotate the reactor into the upright position while keeping the bottom secured but free to rotate. A safety chain can be used on each of the bottom opposing feet to prevent the unit from slipping. **Do not lift the CEM off of the ground with only 2 lifting eyes.**
3. Rotate it into the upright position first and only after it is flat on the ground, secure all of the lifting eyes to remove off of ground.
    a. **Warning: Failure to follow these instructions could result in accidents, potential injury and equipment damage.**

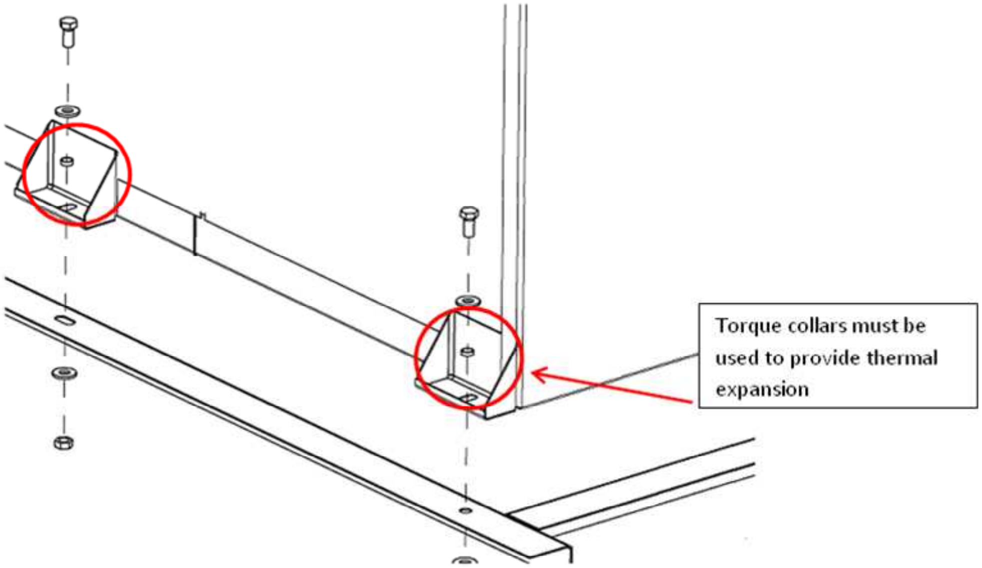
Note: The feet are not to be used for lifting.
Note: Unit is shipped without the modules block catalysts installed; these blocks will need to be installed after the unit is in its permanent location.

Mounting the CEM - Bolting Instructions

Bolting the CEM to the pedestal using the mounting feet provided, include 7/8 in. slotted holes running parallel to the short axis of the unit. The customer installed mounting platform that the unit rests on should have pre-fabricated 7/8 in. slotted holes running parallel to the long axis of the unit. When the mounting feet are set on the mounting frame the slots will form a cross. This allows the unit to thermally expand sideways and long ways. Flat washers should be used on both the bottom and top when tightening down the unit. A torque collar or spacer installed between the two flat plains (bolt holes) enables the unit to move thermally back and forth or left and right discouraging structural impact on the housing of the SCR reactor. Both top and bottom must be secured. Secure the top once the bottom has been bolted in place.

Note: Failure to install the torque collar could cause metal fatigue in the SCR housing and cracked welds where exhaust gas leakage is eminent.

Example of Bolting Method



Note: Unit must be bolted to the mount utilizing the Bolts, washers, torque collars and nuts shown in the diagram. Torque collars must be used. Bolt Torque is set at 200 ± 40 N-m (118-177 lb ft). This will ensure proper freedom for thermal expansion and contraction.

Initial Startup

See **Appendix B:** Initial Startup Procedures

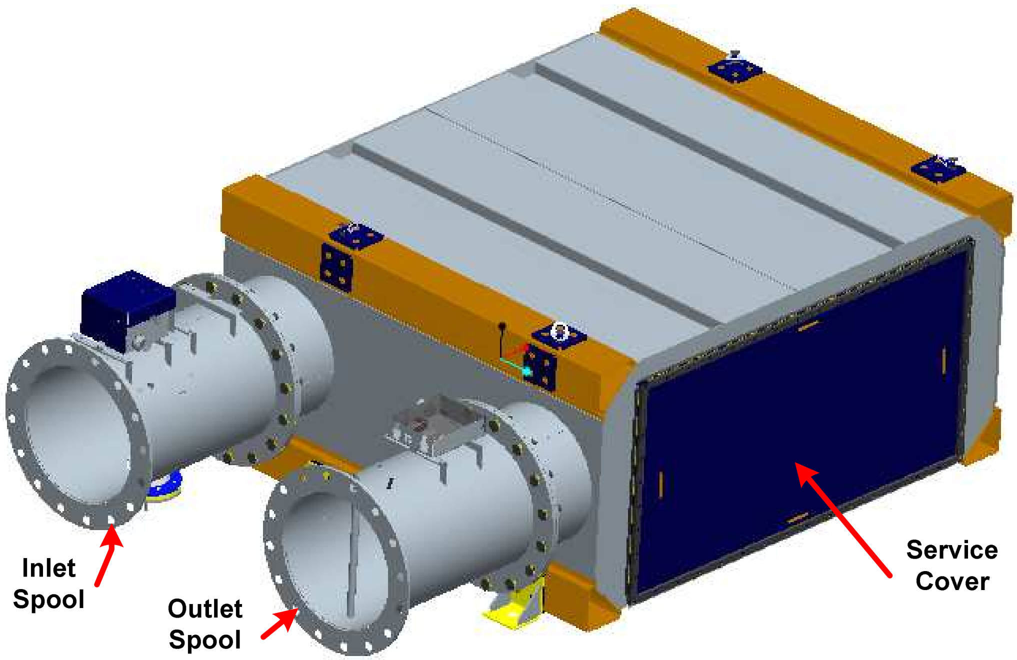
Service and Maintenance

Catalyst storage

Caterpillar requires that if the catalyst are not installed in the CEM right away, then the catalyst need to be stored indoors out of the weather. The shipping pallets that the C280 catalyst arrive on are not totally sealed and are not totally impervious to rain water.

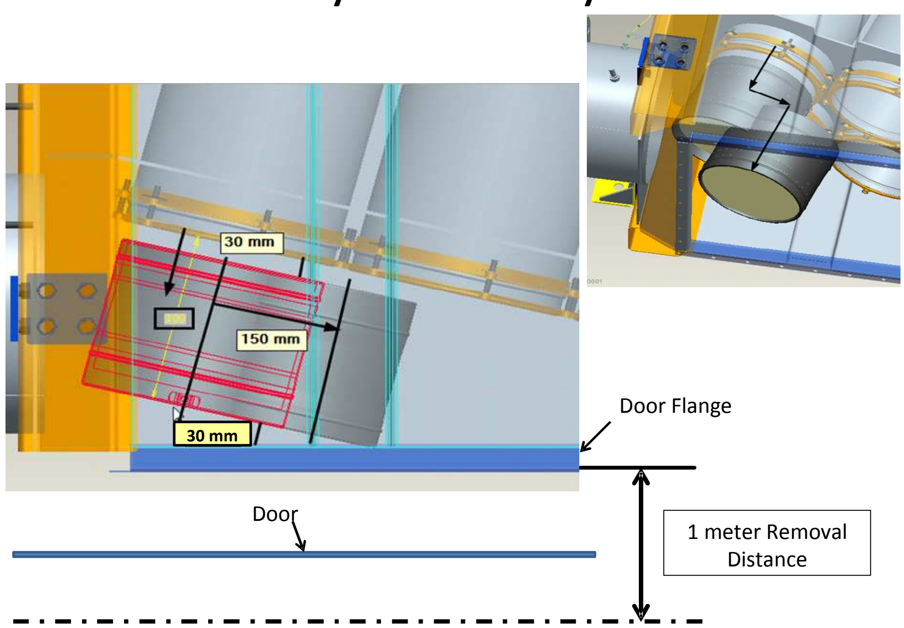
3500 and C175 SCR Access:

SCR catalyst cover access needs to be considered when designing the installation of the CEM. The ability to remove the service cover and the SCR catalyst is required. The minimum catalyst removal length is 450mm which includes the handle and the catalyst. The handle is used for pulling the catalyst out of the CEM and the ability to carry the catalyst. The minimum length shown below is only needed on the service side cover side of the CEM. The service cover is the only access point into the CEM besides the inlet and out ports. Refer to the Assemble and Dissemble guide for complete instructions on to remove the catalyst from the CEM.



The figure above shows the inlet, outlet and the service cover for the catalyst. The figure below shows the required removal distant to pull the catalyst out of the CEM.

Catalyst Serviceability



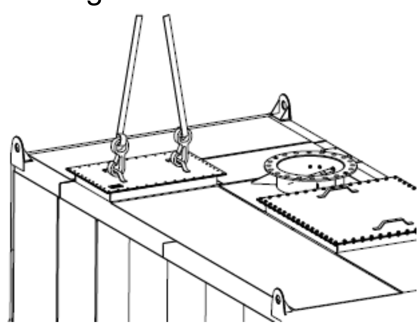
To service the catalyst the service cover needs to be removed, and then each catalyst can be removed with the service tool by removing the retention bolts and pulling the catalyst out. When replace the catalyst all new retention hardware will be required to install the new catalyst.

<u>Important Note:</u> Non-Caterpillar supplied SCR system components (Ex. AUS / DEF Filter, Air Dryer / Filter, etc) that are an integral part of the SCR system must meet the Tier 4 interim EPA requirements for maintenance service intervals. The key criteria for meeting the regulation is that any regularly scheduled adjustment, replacement, cleaning or repair of components must be at a minimum of 4500 engine hours. Component life must meet 10,000 engine hours for 3500 and C175 engines and 20,000 engine hours for C280 engines.

C280 SCR Access:

Special Instructions
Access Hatch Removal

Reactor hatches can weigh up to 250 lbs. (113 kg). To avoid injury use a hoist when lifting components weighing 50 lbs (23 kg) or more. The hatch handles must be used to attach the lifting hooks. The lifting hooks must be equipped with a spring latch; ensure that the lifting hooks are positioned correctly. Ensure that the hoist, chains or slings and lifting hooks are in good working condition and can withstand the hatch weight.
See Fig below.



Reinstallation of the hatch:
1) Align the hatch, gasket and flange to the holes. These parts need to lay flat against one another with their holes lined up so the bolts can go straight in. Apply anti seize compound to all the threads to avoid thread galling.
2) The bolts with washers should then be placed through the holes, secured using washers and locknuts. The bolts must be hand-tightened to the point where the hatch, gasket and flange are held together. The bolts may need to be gently tapped through the holes before the parts are completely lined up. See Fig below:

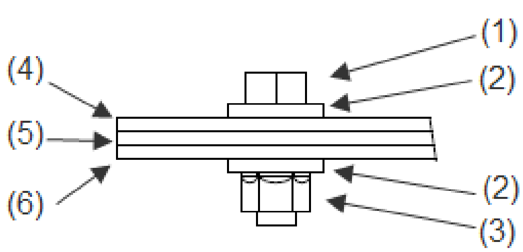


Fig 2. Fasteners used in the Hatch.
1) Hex Head Bolt

2) Washer –Hard
3) Lock Nut
4) Hatch
5) Gasket
6) Flange

3) The bolts should be tightened to a torque of 47 **Nm (35 lb-ft).**

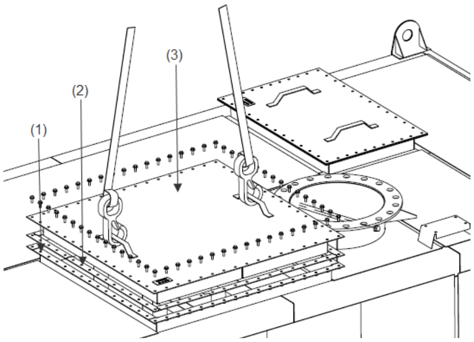


Fig 3. Hatch Installation.
Flange
Gasket
Hatch

The recommended torque sequence is as follows: start in the center of the hatch then work toward the outside. At the end do a second round to verify the torque in all the bolts. See Fig 4.

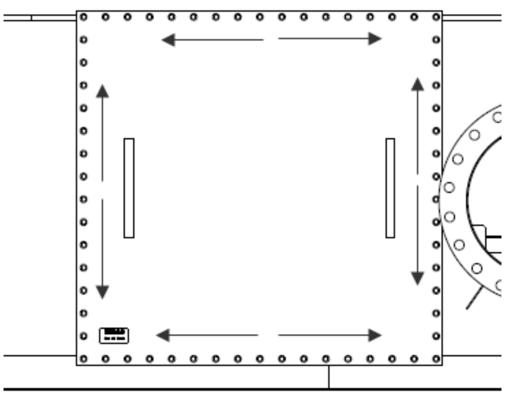
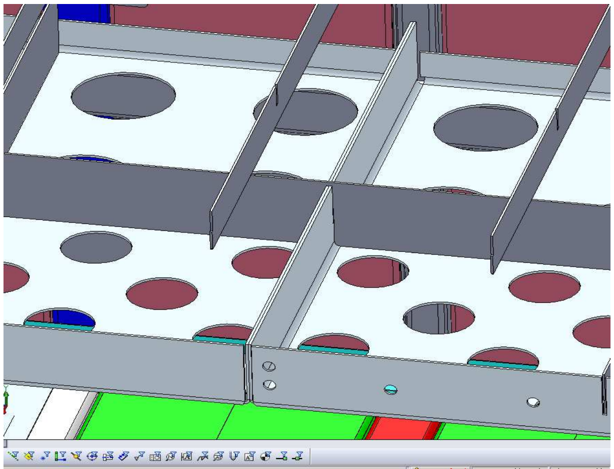


Fig 4

C280-8 & 12

SCR Block Installation
Grid Installation

The C280 Selective Catalyst Reactor Housing has been specially designed to utilize the whole cavity of the CEM/reactor without having to wrestle with or stuffing ceramic fiber insulation in and around the SCR blocks. This new design makes the installation of the canned blocks much easier to handle and secure in place with little or no tools.

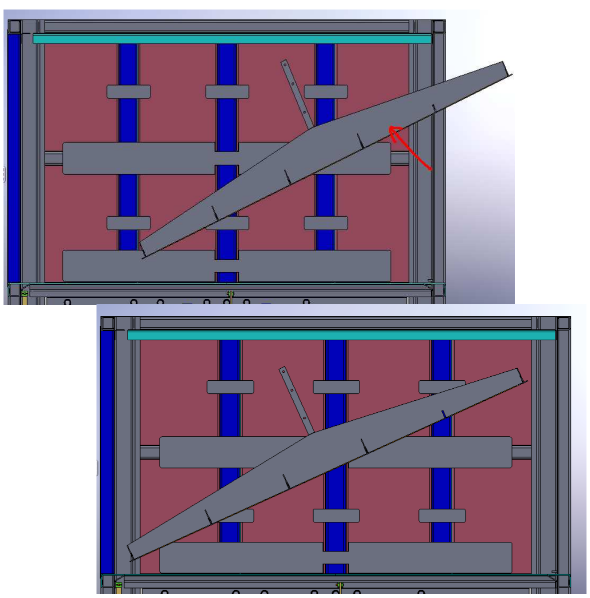


The bottom most part of the reactor has a diffuser pan, this pan which allows the exhaust to flow through while keeping the back pressure of the exhaust low.

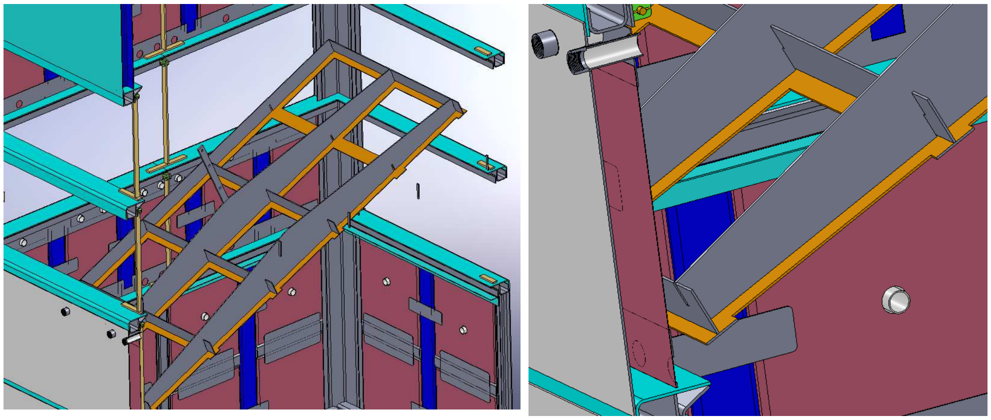
This pan can be stood on to install the first grid layer.

Installing the grid

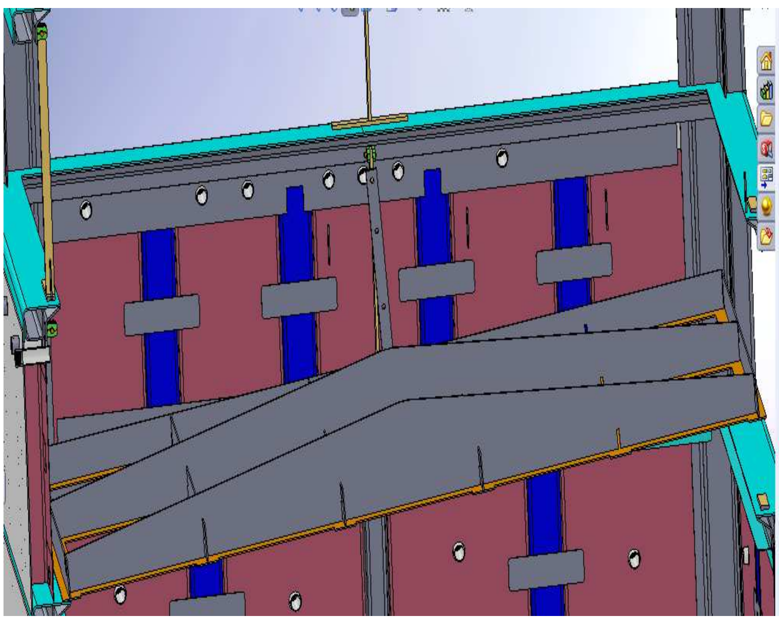
For the bottom most layer, bring 1 grid half in rotated as shown to fit in the door. The channel support on the ceiling can be used to hoist the grid into place. To make installation easier, the quarter inch “T” pinned anchors on the sides can be removed and re-pinned after the grids are in place.



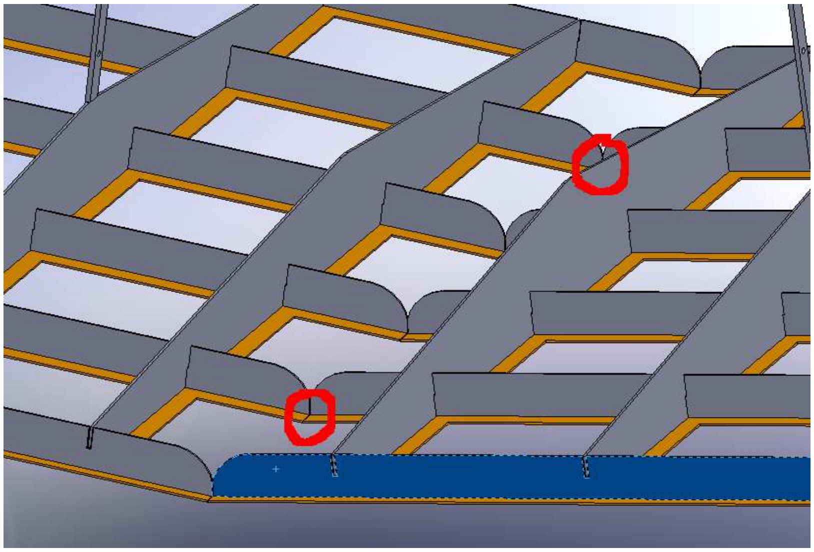
Note: The vertical quarter inch beam with the 3 holes in it is located on the inner most triangular support on the grid. In the corresponding images it is shown located on the outside, which will be the case in the production builds.



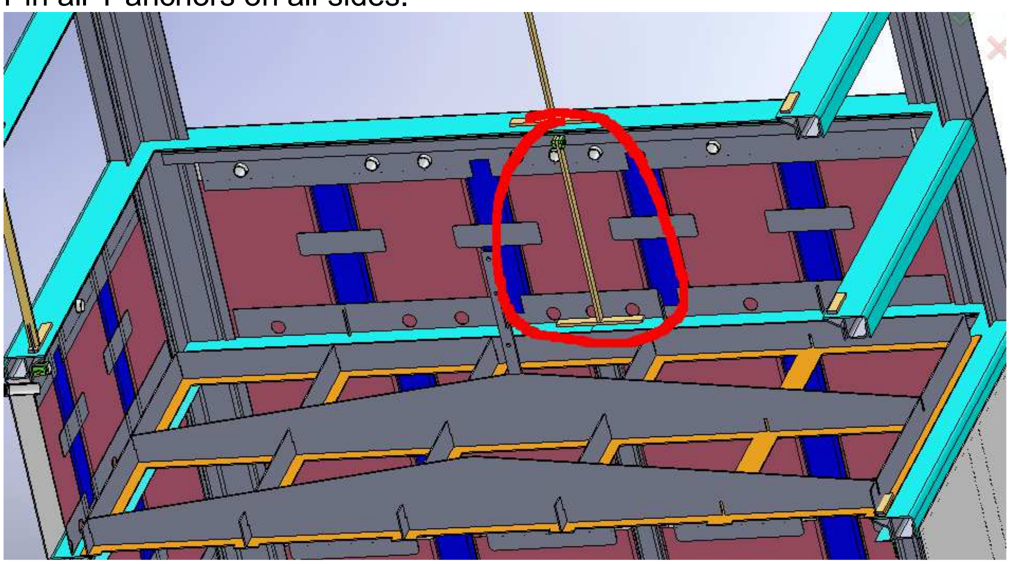
Lower the grid half into place by keeping it rotated as shown. Once the grid edge is resting on the bottom grid support ledge, push the grid edge into this corner and allow the grid to rotate until the other flat surface hits the other side of the ledge. Start from the back working your way out towards the hatch opening.



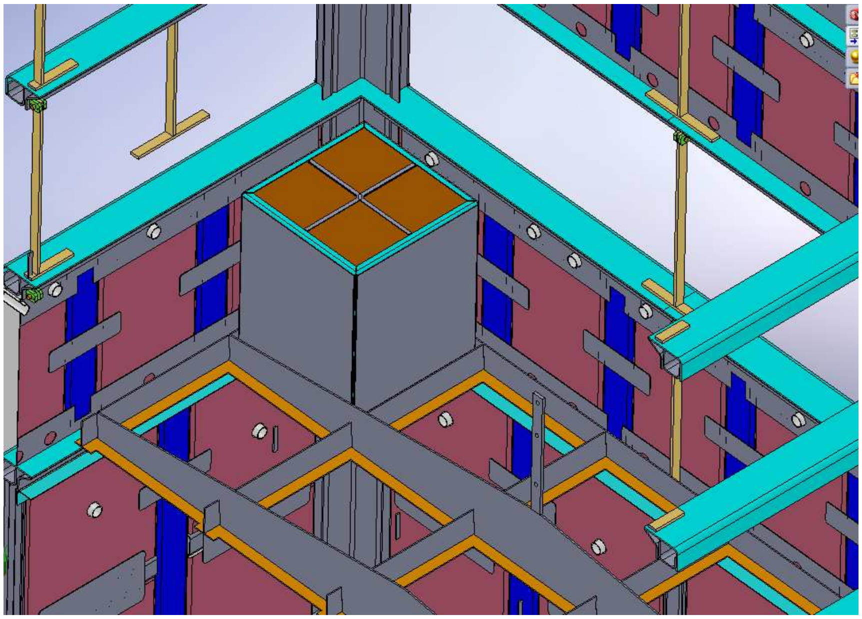
With one grid in place, repeat the procedure to bring in a second grid half that has the corresponding number posted on its triangular beam section. Rotate the grid so that the slotted connections align. Use the clevis pins to join the two sections together. Remove any tape that remains on the grid halves.
A rubber mallet can be used to adjust the grids into place.



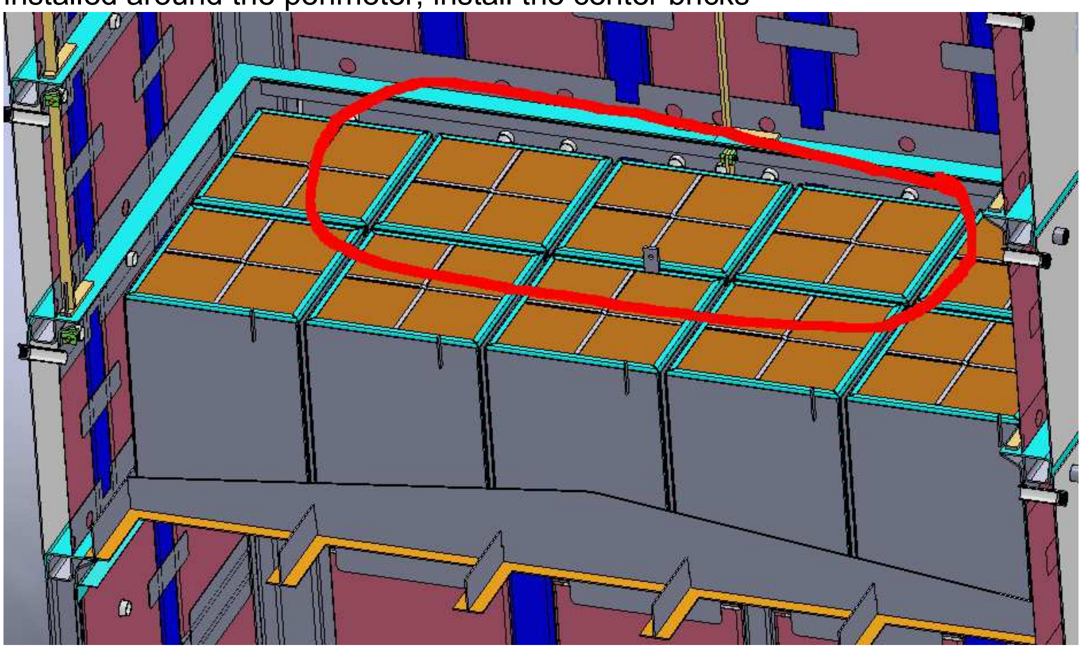
Once the grids are in place, the T shaped anchors are pinned into place. Ensure that the lanyards remain looped through the T anchors.
Pin all T anchors on all sides.



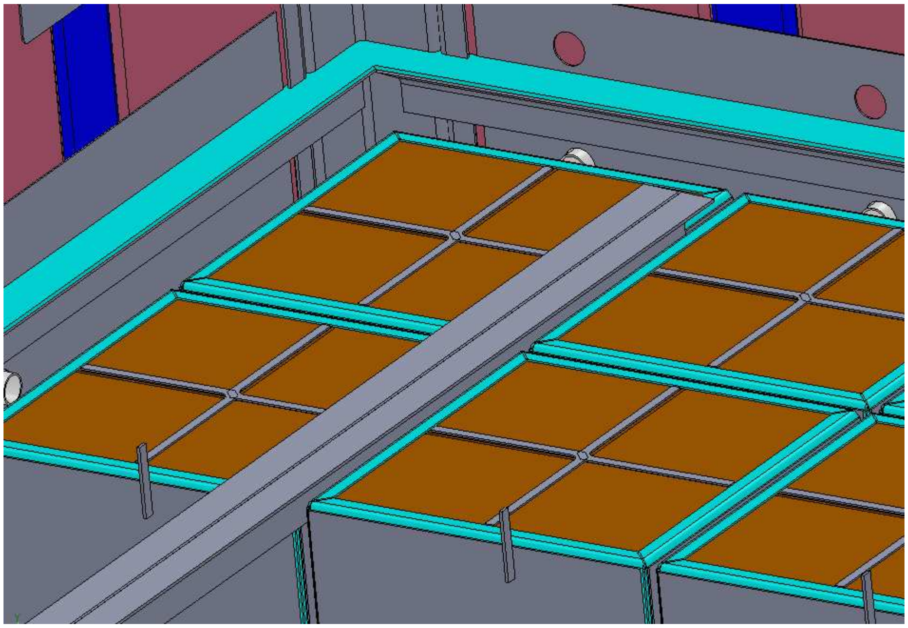
Once the grid is on the first ledge, with two pins secured beneath the grids and the T anchors installed, insert the first 4 bricks in each corner.

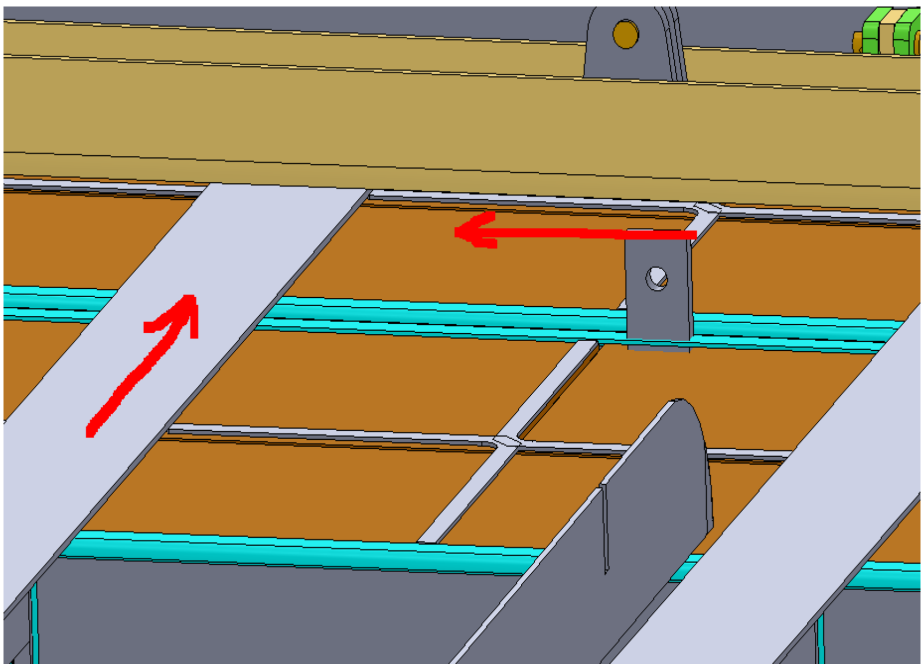


Install the 3 bricks on each side between the corners next. Once all bricks are installed around the perimeter, install the center bricks

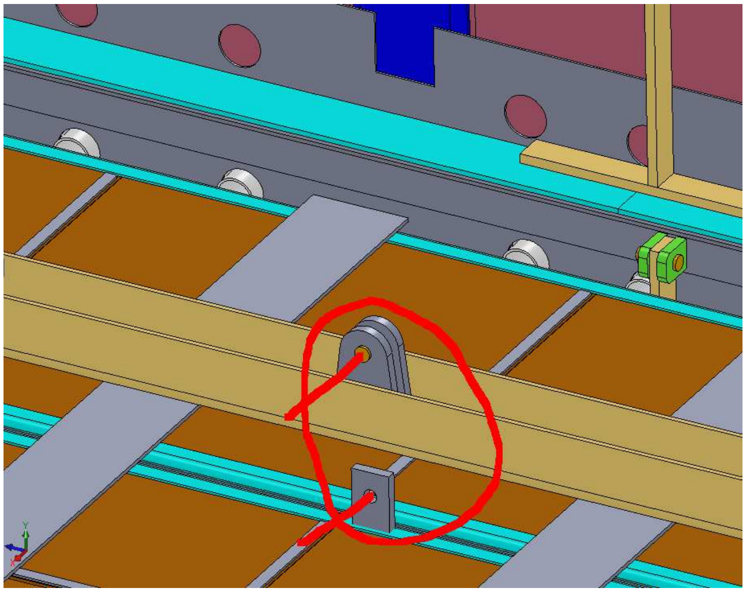


Install the T beams in one direction perpendicular to the vertical quarter inch holed connectors. The T beams are held in place by a U shaped channel that is pinned to these quarter inch holed bars.





Once all of the T beams are placed between the catalyst modules, install the U shaped bars across the top of the T beams on each side.
Insert the clevis pin into each slot on each side.



Perform these steps for each of the 4 layers on the reactor.

4.0 Exhaust System

Introduction

The engine Exhaust System discussed in this section consists of the interface of the turbo exhaust gases to the Cat CEM. This includes Cat Bellows Assembly or flexpipe assembly, Cat CEM or aftertreatment and muffler or exhaust pipe.

Cat CEM exhaust gas inlet receives the engine exhaust gas through flex bellows joints allowing for misalignment that may occur from the many installation arrangements of the Cat CEM. Caterpillar recommends the combination of bellows, ball and slip joints. Particular attention must be taken to ensure proper design and placement of the Cat CEM to maintain alignment with the engine exhaust and stay within the vibration and industry standard leak tight connection requirements.

The engine and aftertreatment should be considered as a system. The mounts for the engine limit pitch and roll and therefore reduce the requirement on the bellows assembly. Refer to Engine A&I guide for information on Engine Mounts.

Exhaust System Overview

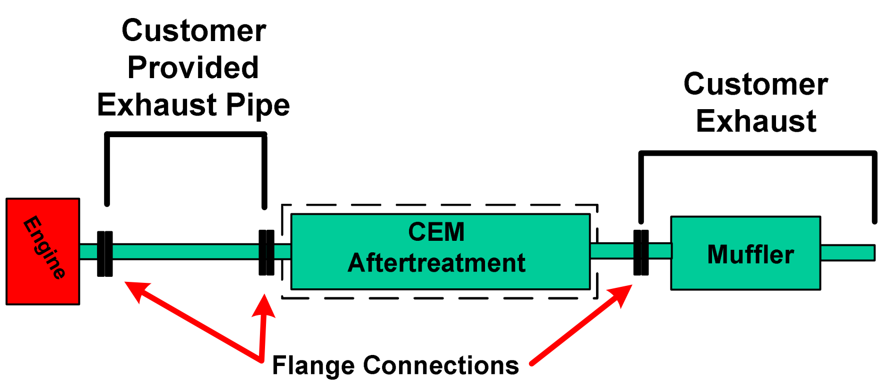


Fig. 7.1 – Exhaust System Example

Mandatory Requirements:

- Flexpipe Design
- OEM Supplied Exhaust Pipe Requirements
    - Pipe Size
    - Pipe Material
    - Backpressure Apportionment
    - Exhaust Gas Temperature Loss Through Exhaust Pipe
    - Water Ingress Prevention
    - Exhaust gas sampling port

Flexpipe Design

Each application requires understanding of the installation requirements for proper location of the Cat CEM relative to the engine exhaust. The actual flexpipe (bellows) will account for movement during engine operation. The following application parameters should be considered before selection of flexible joint that accommodates the application needs:

- Tolerance Stack-Up (static)
- Worst Case Engine Operation/Duty Cycle
- Vibratory- High cycle low displacement
- Thermal Growth
- Shock Loading- Low cycle high displacement
- Temperature
- Pressure

Flange-pipe Design Requirements (Vee Engines – 3500, C140, C175):

The Vee Engine design requirements are included in the following sections where appropriate when interfacing with a flange-pipe connection.

> Note: Additional general guidelines for Exhaust Systems A&I is available in Media Number LEBW4970 "Exhaust Systems".

Engine Exhaust Flange Loading

Careful consideration must be given to the load external piping may induce on the exhaust flange. To minimize the load carried by the flange, downstream exhaust piping should be self supporting. The thermal growth of horizontal piping connected to the flange exhaust must also be accounted for in the design.

Maximum allowable vertical load and bending moment limits are provided for each engine model. Consult the Technical Marketing Information (TMI) for the appropriate information.

Flexible Joints

Flexible joints are needed to isolate engine movement, vibrations, and Marine Vessel frame deflection. Bellows take up dynamic axial and lateral movement. Ball joints compensate for radial misalignment. Slip joints compensate for axial misalignment. Additionally they are needed to offset assembly tolerances and thermal expansion and contraction of the main exhaust. Great care should be taken to ensure that these factors are accounted for in the design and development of the flexible sections of these systems.

From its cold state, 304L Stainless Steel will expand 0.3mm (.0119in) per 305mm (1ft) per 50° C (122°F) temperature rise. If not accounted for, the thermal growth can exert undue stress on the engine and Cat CEM connections, as well as the pipe supports. See the Allowable Joint Loading section for specific requirements

The Cat CEM exhaust outlet piping with additional components such as exhaust temperature cooling devices, exhaust stacks and long lengths of unsupported pipe should be designed and reviewed per Caterpillar, OEM and installer agreement. All installation requirements per this A&I guide must be complied with per agreement outlined in the introduction of this document.

It is important that the flexible sections continue to meet the pressure drop and leakage specs throughout the life of the installation in order to ensure compliance with emissions regulations. A robust flexible joint will accommodate all the various movements of these routings through the many thermal, vibration and loading cycles experienced by the application.

Proper assembly of the flange is necessary to form a strong seal that provides a leak tight joint.

OEM Supplied Exhaust Pipe Requirements

1) Pipe Material

Material

The material selection is an important part of ensuring that the system will continue to perform over the life of the Marine Vessel. Traditional steel and aluminized steel, have lower thermal stability and corrosion resistances than higher-grade stainless materials. 300 series stainless steel material is required to be used for OEM supplier exhaust piping between the turbo out and CEM inlet. CEM and turbo connections are ductile iron and have similar thermal expansion coefficients as the 304SST.

Required: OEM Pipe Material: 304 Low carbon Stainless Steel (SAE30304L)

2) Exhaust Backpressure

Exhaust System Apportionment

Commercial Engines

If apportioned exhaust backpressure is higher than specified in table below it can result in poor engine performance. Refer to TMI for maximum backpressure requirement.

Engine	Power Rating		Apportioned Max Press Drop
	HP	KW	KPA
C175/3500	>1207	>900	6.7
C280			2.5

Table 7.5 – Commercial System Backpressure Table

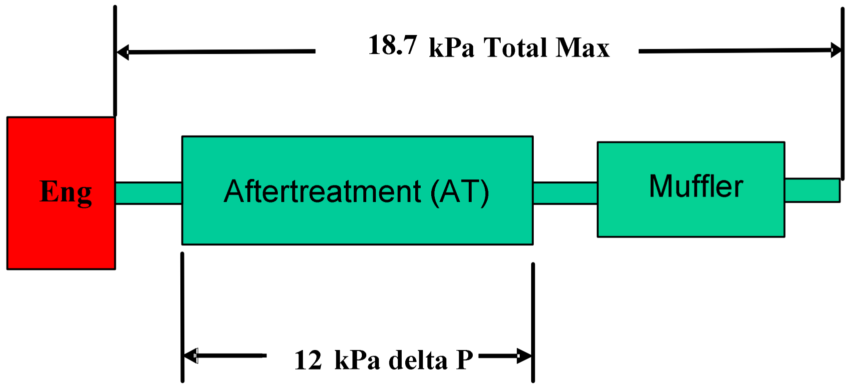


Fig. 7.13 – Exhaust System Example for Cat Aftertreatment

Example of Apportioned Pressure Drop Calculation: (Reference figure and table above)

OEM/Installer (kPa) = Total Backpressure (kPa) – Cat CEM (kPa)
OEM/Installer (kPa) = 18.7 – 12 = 6.7

Where:
Total Backpressure = 18.7 kPa
Cat CEM = 12 kPa

<u>Calculating Exhaust Restrictions</u>

Estimation of the OEM piping backpressure can be done with this formula:

$$P = \frac{0.22 L_{eq} Q^2}{(460 + T) D^5}$$

P = Pressure drop (backpressure) measured in inches of water.
L = Total equivalent length of pipe in feet.
Q = Exhaust gas flow in cubic feet per minute at rated conditions
D = Inside diameter of pipe in inches.
T = Exhaust temperature in °F.

Nom Pipe Dia. (in.)	Actual ID (in.)*	D^5 (in.^{5})
5	4.87	2740
6	5.87	6970
8	7.87	30192
10	9.87	93671
14	13.87	513328
21	20.87	3959319

Table 7.6 – Pipe Diameter D^5 Calculations

*Based on a tube width of 1.65mm. Calculation will vary if thickness is different, such as 1.8mm.

To determine values of straight pipe equivalent length for smooth elbows use:

Standard 90° elbow = 33 x pipe diameter
Long sweep 90° elbow = 20 x pipe diameter
Standard 45° elbow = 15 x pipe diameter

To determine values of straight pipe equivalent length for flexible tubing use:
L = Lf x 2

Important considerations

- Sharp bends in the exhaust system will significantly increase exhaust backpressure. The piping size decision assumes a minimum number of short radius bends. If a number of sharp bends are required, it may be necessary to increase the exhaust pipe diameter. Since restriction varies inversely with the fifth power of the pipe diameter, a small increase in pipe size can cause an appreciable reduction in exhaust pressure.

- It is essential that the system does not impose more than the allowable maximum backpressure. The maximum backpressure must not exceed the limit while certifying each engine model for conformity to exhaust smoke and exhaust gas emissions under Federal, California, and other agency regulations. To avoid this problem, exhaust system backpressure should be calculated before finalizing the design. Testing should be done to validate design is compliant with A&I requirements.

- Exhaust piping is a critical component in the Cat CEM operation required to meet emission standards. Care should be exercised in configuring and designing the exhaust piping to meet packaging and exhaust component load and operational limits.

- OEM pipe diameter has a significant impact on the pressure drop through the system. The engine and Cat CEM connections have been configured for the recommended pipe diameter in order to meet the pressure drop requirements.

3) Exhaust Temperature Loss

Exhaust Temperature

Introduction

The Caterpillar CEM relies on a minimum average temperature during operation to provide the necessary emissions reduction. Control of the temperature loss through the exhaust pipe from turbo out to CEM inlet is required to maintain this average temperature. There are two methods that can be used to determine if this temperature loss is acceptable.

- Meeting Maximum exhaust length requirements
- Meeting the exhaust temperature loss requirements

Maximum exhaust length
One method to meet the temperature loss requirement is to not exceed the specified maximum exhaust lengths. Table below provides the maximum allowable OEM exhaust pipe length to maintain an acceptable temperature loss.

Engine Platform	Application	Max Length (Meter)	Max Length (Inches)
3512	Commercial	1.52 m	60 in
3516	Commercial	1.52 m	60 in
C175	Commercial	3.66 m	144 in

Table 7.7 - Maximum allowable exhaust length*

Some commercial installations may require an exhaust pipe that is longer than the maximum. If the maximum exhaust pipe length requirement cannot be met then the installation must meet exhaust temperature loss requirements. Providing insulation of the exhaust pipe in most cases will maintain the necessary exhaust temperature loss requirements.

***Maximum lengths in table above are provided for installations in which the exhaust pipes are not in the direct path of any fan air flow. If any portion of the exhaust pipe is in the direct path of fan air flow the exhaust temperature loss requirements must be met.**

Exhaust temperature loss requirement
The second method to meet exhaust temperature loss through the exhaust pipe requirements is to meet temperature loss requirements in table below.

<table>
<tr><th rowspan="3">Engine Platform</th><th colspan="2">SCR</th></tr>
<tr><th colspan="2">10% Rated Load</th></tr>
<tr><th>Max Allowable Temp Drop (C)</th><th>Allowable Engine RPM range during test</th></tr>
<tr><td>3500</td><td rowspan="2">10</td><td rowspan="3">Rated Speed</td></tr>
<tr><td>C175</td></tr>
<tr><td>C280</td><td>15</td></tr>
</table>

Table 7.8 – Allowable temperature loss from turbo to CEM

4) Joint Loading & Supports

Loading

Flange load limit, CEM connection flange load limit for either end of the exhaust pipe connection has a maximum allowable load limit. This load is a function of the material and geometry of the flange exhaust outlet and the CEM exhaust inlet.

The flexible joint should typically be positioned to minimize cantilever type loads to the turbo exhaust outlet connection and CEM inlet and outlet.

The following table provides guidelines for Dynamic loading of the connection interface at the engine turbo exhaust and Cat CEM inlet and outlet. All reference to turbo outlet load must be verified with TMI load requirements for the engine of your application.

Exhaust Component Connection	Joint Type	Size	Maximum Allowable Dynamic load
CEM Inlet/Outlet (3512)	Cat Pattern Flange	2X8”	**400 N-m/100 N-m**
CEM Inlet/Outlet (3516)	Cat Pattern Flange	2X10/12“	**400 N-m/100 N-m**
CEM Inlet/Outlet (C175-16)	ANSI/DIN	2X16” 1X20”	**100 N-m/60 N-m**

Table 7.9 - Exhaust Joint Loading Table Guidelines

Determining Allowable Joint Loading

Joint loading is complicated by several factors that fall within OEM design control. Application installation design should be designed to protect the Cat CEM devices from dynamic loading in addition to the resonance concerns that would cause system overload.

- Exhaust pipe Supports
  - Support Locations
  - Type of exhaust support
- Pipe Considerations from closest support to Cat CEM connection points
  - Weight
  - Length
  - Center of Gravity (CG)
- Location of Flex Joint

The allowable joint load should be evaluated using dynamic load. The dynamic load is the combination of factors including weight, length of pipe, center of gravity and maximum acceleration rate. Maximum acceleration rate is typically the maximum anticipated G-load. As a reference point, 5 G is often used in cases where the maximum dynamic load is not well known.

CEM or Turbo flange loading will be calculated one of two ways depending upon how the exhaust pipe is supported.

Method #1: Simple Cantilever Loading:

If the pipe is simply connected to the:

- Inlet or Outlet (CEM or Turbo connection)
- To the flex joint

Without any other support points, then this method can be used to determine the Estimated loading:

$$\mathbf{M = maL}$$

Where:

M = Dynamic load in Newton-Meter (pound-foot), N-m (lb-ft)

m = Mass of the pipe supported by the joint in kilogram (pound), kg (lb)
a = Acceleration, maximum amplitude of the CG location of the supported pipe in meters/second squared (feet/second squared), m/s2 (ft/s2)
L = Distance from the CG of the supported pipe to the Cat CEM joint in meter (feet), m (ft)

Method #2: Supported Exhaust Pipes:

If the pipe is connected to the:

- CEM Inlet or Turbo Outlet connection
- Flex joint
- And is supported in some way off of the engine or CEM or it's mounting structure

This alternative method must be used to evaluate the flange loading.

Some form of rigid support is recommended on both sides of the flexible joint to prevent joint failure at the CEM or engine.

- If supporting between the bellows and engine the support structure should be mounted on the engine.
- If supporting between bellows and aftertreatment system the support structure should be mounted from the aftertreatment system.
- This will insure the bellows functionality and not induce undue stress in the flexpipe system components.

It is critical that exhaust pipe support be done in such a way that thermal growth of the exhaust pipe does not result in loading either the turbo exhaust outlet or the CEM inlet. This may mean that the pipe be supported for typical static weight and G-loading while also allowed to move such that the exhaust pipe thermal growth is taken up by the flex joint rather than exerting a force on the turbo exhaust outlet or the CEM inlet.

Allowable loads must not be exceeded when designing the flexpipe interface connections.

A tri-axial mounting support is recommended within 915 mm (3 ft) of the Cat connections. A tri-axial support provides support to the X-Axis, Y-Axis, and Z-Axis planes.

The flexible joints that isolate the CEM from the engine vibrations should be positioned to prevent cantilever arm type loads to the CEM connections. Cantilever arm type loads due to pipe weight can easily create vibration/resonance that can overload the connection on the CEM causing a joint failure.

Method 3
The force method is another way to determine if you are exceeding the limits on the turbo and CEM inlets and outlets.

The external pipe and flanges can be replaced by a combination of a force, F, and moment, M. The values of F and M can be obtained using the following expressions:

$$F = W_{pe}L + 2W_{fl}$$

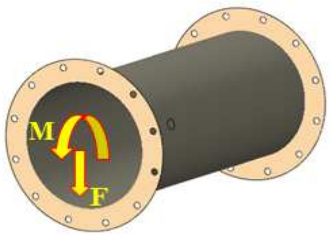
$$M = \frac{W_{pe}L^2}{2} + W_{fl}\left(\frac{t_{fl}}{2} + L\right)$$

where L = Pipe Length

W_{pe} = Weight per unit length of pipe

W_{fl} = Flange weight

t_{fl} = Flange thickness



Refer to the Exhaust Joint Loading Table above for the maximum allowable dynamic load for each specific joint connection.

5) Water Ingress Prevention

Moisture Limits

Introduction

The presence of water in the CEM can cause failures such as cracking of catalyst from freeze/thaw cycles, cracking of catalyst by water causing thermal gradients across the catalyst. Exhaust system outlets must be provided with an appropriate means of preventing snow, rainwater or sea spray from entering the CEM through the exhaust piping. This can be accomplished by several methods, but must be given careful consideration. The selected method can impose significant restrictions that must be taken into account when calculating system backpressure.

For engine applications with >750 HP/560 KW ratings the maximum water ingress is 1 Liter at maximum 5 degree angle.

One simple method, used primarily with horizontal exhaust pipes, is to angle cut the end of the exhaust pipe with the point at the top.

A common method used with vertical exhaust pipes is to angle the pipe at 45 or 90° from vertical using an appropriate elbow, then angle cutting the pipe end as previously described.

Another feature that may be used in conjunction with either of the above methods is Rain/Spray Slots as shown in figure below.

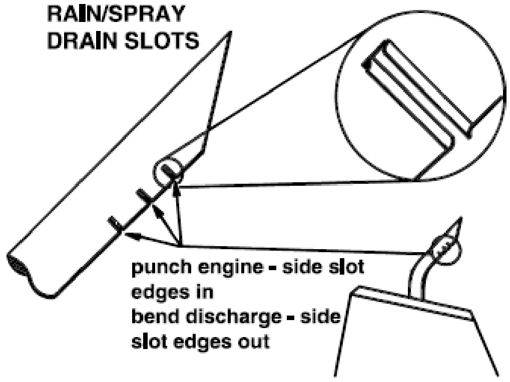


Fig. 7.15 – Rain/Spray Drain Slots

Slots are cut into the exhaust pipe to allow rain/spray to drain harmlessly. The edges of each slot are deformed as shown in the previous graphic. The engine side of the slot is bent inward and the downstream side of the slot is bent outward. No more than a 60° arc of the pipe circumference should be slotted in this way.

For applications where none of the above methods are possible, it may be necessary to fit some form of rain cap to the end of the vertical pipe section. This method can provide a positive means of water ingress prevention, but not without imposing a significant backpressure restriction.

6) Sampling port

In accordance with MEPC 103.49 requirements (ON-BOARD NOx VERIFICATION PROCEDURE – DIRECT MEASUREMENT AND MONITORING METHOD) the exhaust system must provide a sample port located downstream of the last exhaust treatment system to measure gaseous emissions. Please refer to regulations on type and correct location for the sampling port. A copy of the requirement is stated below.

5.9.3 Sampling for gaseous emissions

5.9.3.1 The sampling probes for the gaseous emissions shall be fitted at least 0.5m or 3 times the diameter of the exhaust pipe - whichever is the larger - upstream of the exit of the exhaust gas system, as far as practicable, but sufficiently close to the engine so as to ensure an exhaust gas temperature of at least 343 K (70(C) at the probe.

5.9.3.2 In the case of a multi-cylinder engine with a branched exhaust manifold, the inlet of the probe shall be located sufficiently far downstream so as to ensure that the sample is representative of the average exhaust emission from all cylinders. In multi-cylinder engines having distinct groups of manifolds, such as in a "Vee" engine configuration, it is permissible to acquire a sample from each group individually and calculate an average exhaust emission. Other methods which have been shown to correlate with the above methods may be used. For exhaust emission calculation, the total exhaust mass flow must be used.

5.9.3.3 If the composition of the exhaust gas is influenced by any exhaust after-treatment system, the exhaust sample must be taken downstream of this device.

7) Exhaust System Verification

Verification Introduction

The exhaust system must be designed to be leak tight and comply with the minimum EPA useful life requirements. During the useful life, the piping cannot contribute to plugging, abrasion, exhaust gas leakage, or other damage to Cat CEM.

To ensure proper operation of the engine / Cat CEM package during the life of the Marine Vessel, care must be taken to ensure these systems are constructed of proper materials with reliable joints, flexible sections, and mountings. Exhaust piping must provide for movement and thermal expansion to ensure undue stresses are not imposed on Cat CEM components or engine connections.

General Requirements Summary

Attention should be given to exhaust gas flow restriction with the following recommendations:

- The exhaust backpressure must not exceed the limits given for each engine family and Cat CEM installation. Reference TMI System Data or Engine Sales Manual for Commercial applications and Engine Technical Specifications.

- The exhaust piping must allow for movement and thermal expansion so that undue stresses are not imposed on the turbocharger structure or exhaust manifold.

- Never allow the turbocharger to support more than allowable loads. Reference TMI System Data or Engine Sales Manual for Commercial applications and Engine Technical Specifications.

- Allowable Distance from Turbocharger to Cat CEM is restricted by the maximum backpressure and maximum length for engine application.

To determine values of straight pipe equivalent length for smooth elbows use:

Standard 90° elbow = 33 x pipe diameter
Long sweep 90° elbow = 20 x pipe diameter
Standard 45° elbow = 15 x pipe diameter

Backpressure Verification

Excessive pressure drop (backpressure) in the exhaust will adversely affect the performance of the engine and the Cat CEM system. It is required that the systems meet these criteria for optimal performance. Excessive pressure drops can yield higher than expected exhaust temperatures, lower fuel economy, reduced altitude capability, and less than rated power. The maximum pressure drop for these systems is shown in the backpressure Table 7.5 – Commercial System Backpressure Table.

Measuring Backpressure:

Exhaust backpressure is measured as the engine is operating under full rated load and speed conditions (High Idle for Naturally Aspirated engines). Either a water manometer or a gauge measuring inches of water may be used. Refer to Fig. 7.16 or Fig. 7.17.

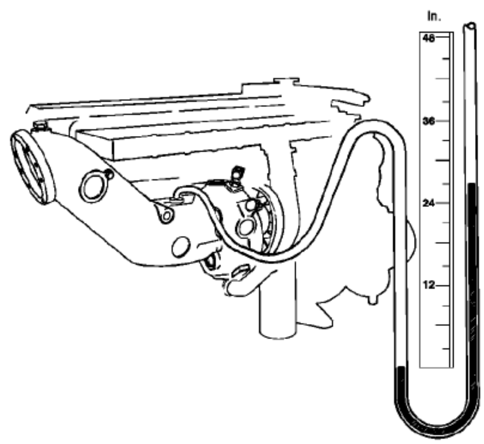


Fig. 7.16– Manometer used to Measure Exhaust Backpressure

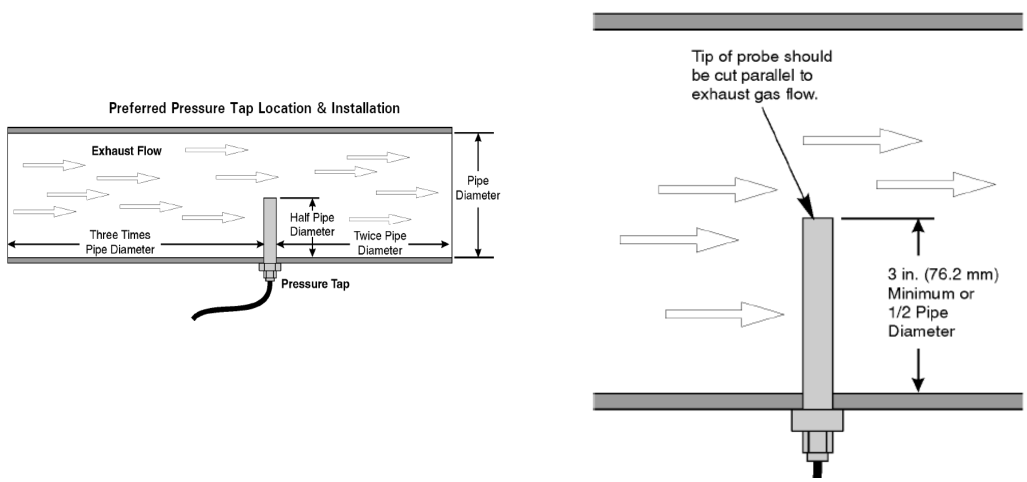


Fig. 7.17 – Exhaust Backpressure Sensor Recommended Location

<u>Pressure Drop Measurement (testing procedure)</u>

Exhaust system pressure drop is measured while the engine is operating at rated speed and full load conditions (refer to the Engine Data Sheet for rated RPM and load conditions). Either a water manometer or a pressure gauge can be used. If not equipped, install two pressure taps on a straight length of exhaust pipe. The first tap should be located as close as possible to the beginning of the pipe section, but at least 12 in. downstream of a bend. The second tap should be located just before the end of the pipe section. If an uninterrupted straight length of at least 18 in. is not available (12 in. preceding and 6 in. following the tap), locate the probe as close as possible to the neutral axis of the exhaust gas flow. For example, a measurement taken on the outside of a 90° bend at the pipe surface will be higher than a similar measurement taken on the inside of the pipe bend. A 1/8 NPT half coupling can be welded or brazed to the exhaust pipe to create a pressure tap. After the coupling is attached, drill a 3-mm (1/8 in) diameter hole through the exhaust pipe wall. If possible, remove burrs on the inside of the pipe so the gas flow is not disturbed. The gauge or gauge hose can then be attached to the half coupling.

This procedure can be repeated for each pipe section. (Reference SEBD6729 for additional information.)

Information that can be used for CFD analysis of the exhaust piping systems is contained in the engine data sheet for the engine rating that the exhaust is being designed. The data sheet will contain information required for CFD such as exhaust flow and exhaust stack temperatures.

Sound Pressure Level

Reference TM7080 for procedure in TMI – Definitions/Performance Def of how to obtain data.

A muffler may be added if sound attenuation is required in addition to the aftertreatment. The muffler or resonator must meet the backpressure requirements described in exhaust backpressure sub section above and must be installed after the Cat CEM.

The Cat CEM noise attenuation data can be found in TMI for the CEM selected.

5. Mounting Considerations

Introduction

This section is comprised of two parts, Mounting Requirements and Mounting Guidelines. The first part describes metrics that a mounting system must meet for the CEM installation to be successful. The second part gives some tips about how to approach the design and validation of a mounting system that should make it easier (though not guaranteed) to meet the requirements in the first part. Every installation is unique, so individual customers may have to adapt the methods described here to better fit an individual application.

The CEM has been designed and validated to provide acceptable durability in a wide variety of applications with load frequencies less than 60 Hz without the use of isolation mounts. However, certain applications may still require the use of isolation mounts for one of the following reasons:

- The CEM hard mounted to a particular structure would be exposed to vibrations greater than 60Hz.
- The mounts supporting the CEM move independently of each other and would cause damage to the CEM or mounting supports.
- The noise generated by a hard mounted CEM would be objectionable
- Some flexibility in the attachments may make assembly easier and/or reduce assembly stress.
- The volume is low enough where it may be preferable to add component cost in order to reduce validation cost.

Notice: Engine mounting of aftertreatment is not recommended.

Mounting

Mounting Requirements

The CEM may be attached with or without the use of rubber isolation mounts. Regardless of the style of design or the method used to validate it, any successful CEM attachments must meet the following criteria:

- CEM vibration (during operation, shipping, etc) must not exceed required limits for CEM component durability for load input frequencies of less than 60 Hz. A majority of applications will operate with frequencies less than 60 Hz.
- If load frequency input is greater than 60 Hz, the CEM must use tuned isolation mounts to reduce loads at greater input frequency than 60 Hz or work with a Caterpillar A&I engineer to design/select a CEM suited for the particular application.
- Any brackets, bolted joints, mounts, welds or other structural elements supporting the CEM must be able to withstand all mechanical loads seen during operation (including thermal growth) or shipping. Each of these elements may have different load limits, and the limits may depend on the direction of loading or number of load cycles expected during the products

lifetime. **For non-Cat applications the CEM G-Loading limits have been evaluated up to +/- 5G's.**

- Any structural elements must provide acceptable strength and durability over the entire temperature range expected to be experienced in the application.
- Motion of the CEM during operation must not exceed what can be accommodated by the flexible connections attached to the CEM and the clearances between the CEM and surrounding objects.

Caterpillar strongly recommends keeping the mounting contact points within the perimeter of the cradle mounting feet. If the mounting structure extends beyond the cradle mounting feet perimeter, care must be taken to ensure that the structure does not interfere with other components on the CEM that may extend below the cradle mounting feet plane.

Mounting Guidelines

There are a number of (sometimes conflicting) goals and criteria to keep in mind when designing a CEM mounting system. It's important to check several criteria for any given mounting system. The specific criteria to check depend on whether or not soft mounts are used in the design.

Hard mounted

A hard mounted design should be evaluated with a stress-quality FEA model. The model should have at a minimum all structural components meshed between the CEM cradle and whatever is acting as "ground." An experienced analyst should be involved to ensure that all the important sources of stiffness, mass, and loads are being accounted for in each application. At least the following analyses should be run:

- Modal analysis: Check natural frequencies and compare with the firing frequencies of the engine over the operating engine speeds and other sources of strong vibration (for example, if the primary load on the engine is a pump, compare to the pumping frequency). If one of the system natural frequencies is close to a frequency of excitation, a harmful resonance condition could occur.
- Static g-loading: The model should be run with a number of load cases to simulate both low-cycle and high-cycle (fatigue) shock events. The specific loads to apply will depend on the application. Predicted stresses should be compared to material limits (endurance limit for high cycle, yield strength for low cycle). Loads through bolted joints should be compared to joint capacity. **For non-Cat applications the CEM G-Loading limits have been evaluated up to +/- 5G's.**
- Hard mounting is recommended if the load input frequency is less than 60 Hz. A majority of applications will operate with frequencies of less than 60 Hz. Some examples of exceptions to this could be Rock Ripper, Rock Drilling and certain track type tractor applications. **In these applications, properly tuned isolation mounts should be used to reduce all vibration inputs into the CEM to less than 60 Hz.**

Some applications may need additional analyses run or additional criteria checked. Consult with your Caterpillar A&I Engineer if you require assistance.

Soft mounted

Soft mounted systems must meet the same requirements as hard mounted systems, so the same techniques described above can be helpful. In practice, some additional screening tools can be useful to evaluate soft mounted systems more efficiently using a lower level of detail than a full FEA model. One such tool is a rigid body analysis. This type of analysis assumes that everything is rigid except the mounts, and just uses six degrees of freedom to describe the motion of the CEM. Also, the mounts are assumed to be the only connection between the CEM and ground (i.e. the pipes, hoses, and wire harnesses are assumed to contribute negligible stiffness). This tool is often used at the early stages of mounting system design in order to quickly evaluate several possible mounting configurations before moving on to more thorough analysis such as FEA. This analysis can be run by individual customers on their own commercial or in-house software.

The analyses run with a rigid body code are identical to those described above for FEA. The only differences are that the rigid body analysis can be built, run, interpreted, altered, and rerun much faster than FEA, and that some additional model outputs need to be checked. In particular, the static g-loading results should be checked in the following ways:

- Peak loads through mounts should be compared with limits associated with the bolted joints.
- High cycle mount deflections should be compared to the deflection (strain) limits for the mounts being used.
- Motion across the exhaust bellows should be compared to their limits.
- Motion of other critical parts of the CEM (extremities near tight clearances, for example) should also be checked.

Once a design has been found which meets all the criteria that a rigid body model check can, the next step is to move on to a FEA model to check the same things (plus stresses of metallic structures) with more precision.

Using analysis results to guide design changes

If a particular design did not pass all the criteria after running rigid body or FEA analysis. The results of the failed design can help determine what changes are necessary to improve the design. Some examples of corrective actions are listed below.

- If component stresses are too high: Try using a material with higher stress limits, strengthening the section, or changing the relative stiffness of different members in order to adjust how the loads are distributed.
- If mount strain is too high: Consider using a stiffer mount, using a larger mount, or changing relative stiffness or mount pattern in order to change the distribution of loads.

- If motion is too high at bellows: Consider using a stiffer mount, spreading out the mount pattern, putting the plane through the mounts closer to the CEM center of gravity, or putting the bellows closer to the CEM center of gravity.

CEM Vibration Acceptability Overview

CEM vibration capability is difficult to assess. When vibration isolation mounts are used and properly specified, it is understood that CEM vibration will likely be acceptable. In some cases, extensive vibration measurements may be required. Each of the scenarios discussed in this section will designate the need for vibration measurements.

Exhaust Flexpipe and CEM Vibration Design Considerations:
Each Installation may have an established choice for engine mounting. Considering Tier 3 engine installations, either hard or vibration isolation mounts have been used for the engine. This choice should be used as a starting point in the design process. This design process may be iterative in order to satisfy both exhaust flex pipe and CEM vibration considerations.

Scenario	CEM Mounting	Engine Mounting	Preferred Scenario?
1	Hard	Hard	No
2	Vibration Isolation	Hard	Yes
3	Hard	Vibration Isolation	Yes*
4	Vibration Isolation	Vibration Isolation	No*

* See notes with regard to scenario #3 & #4 in the detail below.

Scenario #1: CEM Hard Mounted, Engine Hard Mounted

This is a not preferred scenario. Although this scenario often provides the best case in terms of flex pipe capability, it is not preferred because the CEM is exposed directly to engine vibration. In some cases this scenario may be used however extensive vibration testing will be required. This scenario should be not used if at all possible.

Scenario #2: CEM Isolation Mounted, Engine Hard Mounted

This is a preferred scenario. When the CEM is attached to the master structure using vibration isolation mounts, it is preferable to hard mount the engine to the master structure. This scenario allows the CEM to be isolated from engine and Marine Vessel vibration sources. A Marine Vessel vibration source may originate from rotating equipment associated with trenching, drilling, chipping & grinding, road building equipment etc. Cat typically prefers to supply these isolation mounts as part of the engine package. Flex pipe relative movement due to isolation mounting is minimized since isolation mounts are only used for the CEM.

Scenario #3: CEM Hard Mounted, Engine Isolation Mounted

This can be a preferred scenario. When the engine is attached to the master structure using vibration isolation mounts, it is preferable to hard mount the CEM to the master structure. This is typically preferred for installations that do not have Marine Vessel vibration sources (see Scenario #2 for examples of Marine Vessel vibration sources). If this scenario is to be used with Marine Vessel vibration sources, then extensive vibration testing may be necessary.

In this scenario, only 1 of the 2 components is isolation mounted. Flex pipe relative movement due to isolation mounting is minimized since isolation mounts are only used for the engine.

Scenario #4: CEM Isolation Mounted, Engine Isolation Mounted

This is not a preferred scenario. When the engine and CEM are both attached to the master structure using vibration isolation mounts CEM vibration will tend to be acceptable. However, exhaust flex pipe relative movement capability may be difficult or impossible to satisfy. In this scenario, relative movement will originate at both the engine and CEM. The relative movement at the exhaust flex pipe will be equal to the movement allowed by the isolation mounts at the engine and CEM and their component's relative position to the exhaust flex pipe. If the engine and CEM are not in close proximity then achieving flex pipe capability requirements in this scenario may be impossible.

This scenario may be required for installations that:

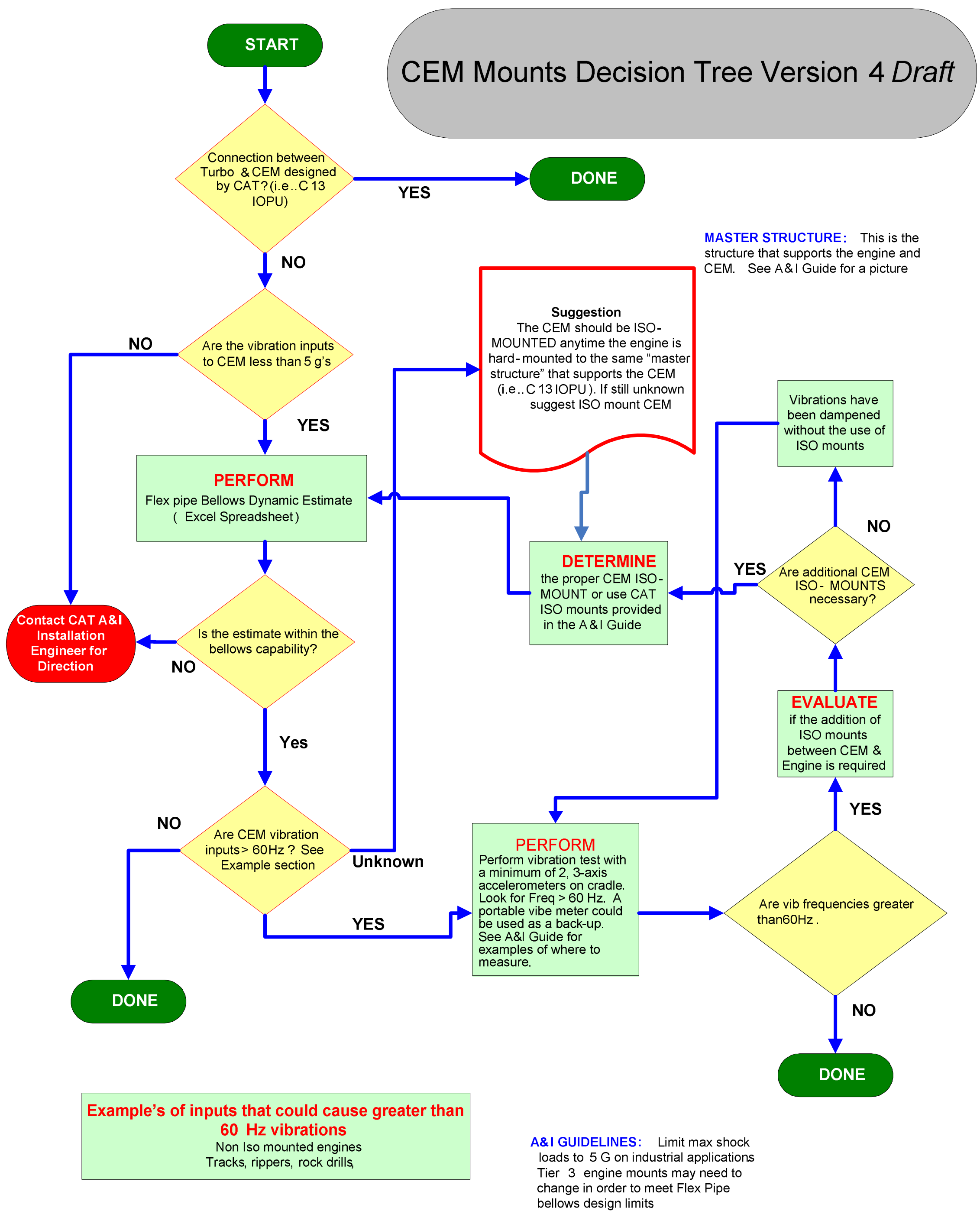
- Require the engine to use vibration isolation mounts
- Have Marine Vessel vibration sources present (see Scenario #2 for examples of Marine Vessel vibration sources).

Scenario #1-4 Summaries:

Now that each scenario has been discussed, the chart from above as been updated with CEM vibration, Exhaust pipe Capability and Vibration measurement requirements.

Scenario	CEM Mounting	Engine Mounting	Preferred Scenario?	Preferred for CEM vibration?	Preferred for exhaust flex pipe capability?	Vibration Measuring Req'ed?
1	Hard	Hard	No	No	Yes	Yes
2	Vibration Isolation	Hard	Yes	Yes	Yes	No
3	Hard	Vibration Isolation	Yes*	No*	Yes	In some cases*
4	Vibration Isolation	Vibration Isolation	No*	Yes	No*	No

* See notes with regard to scenario #3 & #4 in the detail below.



Bellows-Mount Displacement Calculator:

The Bellows-Mount Displacement calculator should be used to determine if the installation satisfies the required flex pipe capability. This calculator must be used with the CEM Mounts Decision Tree to determine CEM vibration acceptability. The flex pipe calculator is available in Engipedia - Tool Box – A&I Guides.

The installer designed engine and CEM installed system must satisfy 2 criteria to ensure acceptable flex pipe durability.

1. Radial Capability
2. Axial Capability

The flex pipe calculator requires several inputs including:

- Engine
    - ✓ Installed mass of the engine and all loads cantilevered off the flywheel housing
    - ✓ Installed center of gravity for the engine and all loads cantilevered off the flywheel housing
    - ✓ Number of Engine mounts
    - ✓ G-Load
    - ✓ Engine Mount positions
    - ✓ Engine mount stiffness
- CEM
    - ✓ Mass
    - ✓ Center of gravity
    - ✓ Number of CEM mounts
    - ✓ G-Load
    - ✓ CEM Mount positions
    - ✓ CEM mount stiffness

The calculator uses this information to determine radial and axial movement at the flex pipe. Based on this movement the calculator will designate the radial and axial flex pipe capability as acceptable or unacceptable. **All installations must achieve flex pipe radial and axial acceptability.**

Installation

Handling and shipping

The Cat CEM unit will be packed in order to protect the assembly during shipping and delivery. Shipping covers will be installed on all flange connections. These MUST be removed before the unit is placed into service.

Lifting Links

Lifting Links are available to facilitate handling of Cat CEM units. Refer to appropriate Service Manual and OMM for lifting details.

Important: Lifting links are rated to support the weight of the Clean Emissions Module unit **ONLY! Remove any lifting links after installation is completed!**

Warning: Care must be used when lifting the CEM. Lifting at adverse angles to the lifting bracket may cause damage to the CEM and potential injury to the handler. Always lift in line with the bracket. Spreader bars are mandatory for lifting the CEM when inline lifting cannot be achieved with chains/strap.

Mounting Pads

The SCR units will have 6 Mounting Pads using M16X2 weld nuts for the 3516 and 4 mounting pads using SAE ¾ - 10 X 3 in. clearance holes.

The Cat CEM assembly should be mounted in a location that provides air circulation around the can and yet protects it from possible debris or foreign object damage. Only a protective heat shield located away from the Cat CEM allowing airflow around it is acceptable. Unless approved by CAT, protective heat shields should not be used as they can cause localized heating.

Note: The Cat CEM should be mounted in a location that allows access and removal for service requirements. A minimum of 200 mm is required between the engine valve covers and Cat CEM when mounted above the engine for engine service. See the Caterpillar Operation and Maintenance Manual (OMM) for actual service requirements and procedures.

Notice – Welding mounting brackets to the Cat CEM is not permitted; this could lead to failure of the unit and emissions non-compliance.

All mounting brackets must be properly adjusted so that the inlet and outlet of the Cat CEM line up properly with the existing inlet and outlet pipes of the installation application. Designated clamping zones will be provided with Cat CEM models to avoid damaging the filter within the can. Refer to **"Section 5 - Exhaust System"** for Flexpipe Bellows Coupling Requirements.

6. Thermal Management

Introduction

The main exhaust piping routes exhaust gas from the engine to the Cat CEM. Normal operating temperatures can reach up to 525°C at peak torque for C140 through C280 engine families including 3500 series. Therefore, thermal insulation on the surface of the main exhaust piping may be required. Proper precaution should be taken to ensure that the Cat CEM is not mounted in close proximity to components that may be damaged by heat.

In addition, Marine Class Societies have a 220 C skin temperature requirement, per SOLAS regulations Chapter II-2, Regulation 4, Paragraph 2.2.6.1.

Thermal Protection

The main exhaust piping routes exhaust gas from the engine to the Cat CEM. Normal operating temperatures can reach up to 525°C at peak torque. Therefore, thermal protection from the surface of the main exhaust piping may be required. Proper precaution should be taken to ensure that the aftertreatment device is not mounted in close proximity to components that may be damaged by heat.

Note: The aftertreatment skin temperature and the gas temperature are difficult to measure and/or simulate and are dependent upon many factors including the following: the nature of the engine/aftertreatment failure, the design and packaging of the aftertreatment, the engine speed/load conditions, the condition of the aftertreatment, and the ambient conditions. Therefore, the potential temperatures are provided as a guideline for safe design of the installation even under conditions of unexpected engine and/or aftertreatment failure; and proper precaution should be taken to insure that the aftertreatment device is properly shielded and not mounted in close proximity to surrounding components that may be damaged by heat.

In general surface temperature will increase with emissivity assuming all else being equal. Geometry also plays a role. The Rubber Hose has lower surface temperature than the Nylon Strip because of its size and shape and surface orientation to the heat source relative to the CEM.

Various types of insulation and shielding are readily available and can be applied according to the requirements of the specific application. Insure that the chosen thermal management device is adequate for the application under all conditions. Special consideration must be given to conduction, as well as radiation effects due to each option.

Thermal Wrapping

Caterpillar strongly recommends wrapping the engine exhaust aftertreatment. Applications must look into alternative means of reducing radiated heat effects from the aftertreatment device such as increased air

flow around the aftertreatment and/or heat shields to protect heat sensitive devices.

There are components and areas on the Cat CEM that require protection from high temperatures. Follow the component temperature limit requirements found in this A&I document to ensure adequate thermal protection is adhered to.

If the CEM Exhaust Tubes need to be wrapped in an application:

- Maintain the temp limits of electronics as listed in the A&I guide, Component Temperature Limits
- Clearance must be maintained both inside and outside of soft wrap to avoid points where wear abrasion can take place
- Wraps must have openings to allow sensor probes to pass through and openings must be sufficient to prevent sensor contact with wraps. Do not place wraps over wires or sensor leads.

7. Appendices:

Appendix A: Cat CEM Harness Installation Guide

Back to TOC

Wiring Harness Components

Deutsch DT Jumper Harness Connectors (C3,C4)

The DT connector is the low-cost preferred choice for inline applications. The connector is available in 2, 3, 4, 6, 8, and 12 terminal configurations. It is also intended for SAE J1939 application use. The wire size range the connector will accept is 0.8 mm^2 (18 AWG), 1.0 mm^2 (16 AWG), and 2.0 mm^2 (14 AWG). The plug assembly with interface seal accepts socket terminals and the receptacle assembly accepts pin terminals. Sealing plugs are to be used in unused wire cavities.

The DT connector has a wedge that locks the pins and the sockets in place. The wedge can be removed and replaced without cutting the wires. The wedge removal tool (p/n 147-6456) can be used to aid in the removal of the wedges. When the receptacle is inserted into the plug, a click should be heard as the two halves lock together. The connector should not be able to be pulled apart.

The following table contains the Caterpillar part numbers for DT inline connector plug and receptacle kits for all available number of pin positions. The kit is comprised of the plug or receptacle and the respective locking wedge.

Standard DT Connectors		
	Cat Part Number	
Positions	Plug Kit	Receptacle Kit
2	155-2270	102-8802
3	155-2260	102-8803
4	155-2271	197-7565
6	155-2274	102-8805
8	155-2265	102-8806
12	155-2255	102-8801

Contact the local Deutsch sales contact for more information on these connectors.

Deutsch AEC Jumper Harness Connectors (C1,C2)

The connector is available in 24, 40, and 70 terminal configurations. It can be used for inline or bulkhead mountings. The connector is frequently used in electronic box applications. The wire size range the connector will accept is 0.8 mm^2 (18 AWG), 1.0 mm^2 (16 AWG), and 2.0 mm^2 (14 AWG). The plug assembly with interface seal accepts socket terminals and the receptacle (header) assembly accepts pin terminals. Sealing plugs are to be used in unused wire cavities.

The Caterpillar OEM/Installer harness uses the AEC14-40PAE-E019 terminal configuration. OEM/Installer interface with this harness is the 40-position plug connector (Caterpillar part number 324-6267). This connector is labeled as PJ-C1 and PJ-C2 on Jumper Harness. The AEC connectors are keyed to align correctly when the two parts are mated together. An Allen head screw holds the two connectors in place. Ensure that the Allen head screw is tightened to a torque of 6 +/- 1.0 N•m (4.4 +/- 0.7 lb-ft.).

Connector Terminal Contacts

There are two types of terminal contacts available for production use: machined, and stamped and formed. Machined terminal contact, also referred to as a solid contact, is used for low volume harness production and for field repair. Stamped and formed contact is used for high volume harness production and is the lowest cost terminal contact option.

Terminal contacts are available with nickel or gold plating. Gold plating should be used for applications of 5 volts or less and/or less than 100 milliamps. Typically these low level circuits require low resistance at the pin/socket connection and gold plating is the best low-cost choice. Nickel-plated contacts can be used in power-type circuits or circuits where low resistance at the pin/socket connection is not a concern.

Gold-plated contacts can be used in all circuit applications regardless of the voltage and current requirements. Gold plating provides some marginal improvement in vibration versus nickel plating. Caterpillar requires that only Gold-plated sockets are used in the ECU connector (J1).

Note: ***Deutsch nickel-plated stamped and formed terminals are not recommended for use because of excessive voltage drop experience in laboratory tests.***

Wire Type and Gauge Size

Wire Selection

Wire must be of a type suitable for the application. Wire must be selected so that the rated maximum conductor temperature is not exceeded for any combination of electrical loading, ambient temperature, and heating effects of bundles, protective braid, conduit, and other enclosures. Typical factors to be considered in the selection are voltage, current, ambient temperature, mechanical strength, connector sealing range, abrasion, flexure, and extreme environments such as areas or locations susceptible to significant fluid concentrations.

Wire Size

The minimum conductor size used on Caterpillar products is 0.8 mm^2 (18 AWG). Smaller conductors are susceptible to breakage and fatigue failures. SAE J1614, wiring distribution systems for construction, agricultural, and off-road work machines require wire sizes no smaller than 0.8 mm^2 (18 AWG).

Jumper harness wire size requirements per connection are defined in the Cat CEM and Engine Jumper Harness Definition tables below.

Wire Insulation

NOTE: ***Thermoplastic Polyvinyl Chloride (PVC) insulation shall not be used in wire harness designs because of its low operating temperature range (-40 to 85° C), and melt and flammability characteristics.***

Cross Linked Polyethylene (XLPE) is the primary wire insulation type used in chassis, cab, and engine compartment locations. It has a temperature rating of -50 to 120° C. The voltage rating for Caterpillar 1E0815 wire and SAE J1128, Type GXL is 50 volts. The circuit voltage shall be considered when making wire selections. This wire insulation is also available with 50, 150, 300, or 600-volt ratings.

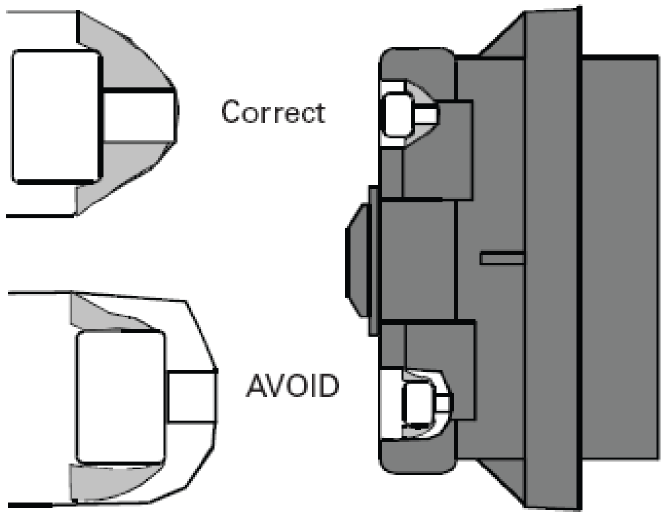
Outside diameter insulation range is 2.26 to 3.33 mm (0.089 to 0.131 in.). The table below provides insulation diameter range for each gauge and wire type.

PJ Connector Wire Insulation and Gauge Size		
Wire Type	**Wire Gauge**	**Insulation Diameter**
GXL	14	0.114 – 0.125
	16	0.098 – 0.112
	18	0.089 – 0.098

Metric Equivalents for AWG Wire Numbers							
AWG	**20**	**19**	**18**	**16**	**14**	**12**	**4**
Diameter (mm^2)	**0.5**	**0.65**	**0.8**	**1**	**2**	**3**	**19**

Connector Seal Plug

All unused cavities for sockets and pins must be filled with seal plugs in order to ensure that the connector is sealed. Two options are available for plugging unused connector cavities. Either the Deutsch 114017 (Caterpillar part number 8T-8737) or PEI Genesis 225-0093-000 (Caterpillar part number 9G-3695) sealing plugs can be used.



Plug Insertion in Unused Connector Cavity

The seal plugs are installed from the wire insertion side of the plug or receptacle. Correct installation of either of these cavity plugs is critical to maintain connector sealing integrity. Figure above illustrates the correct insertion of the plug. The seal plug cap is designed to rest against the seal, not inserted in the hole in the seal.

Harness Routing

Wiring shall be routed to ensure reliability and to offer protection from the following:

1. Chafing/rubbing/vibrating against other parts.
2. Use as handholds or as support for personal equipment.
3. Damage by personnel moving within the Marine Vessel.
4. Damage by impact, or thrown or falling debris.
5. Damage by battery acid fumes, engine and hydraulic oil, fuel, and coolant.
6. Abrasion or damage when exposed to rocks, ice, mud, etc.
7. Vandalism damage (to the maximum extent practicable).
8. Damage by moving parts.
9. Harsh environment such as nitrite mines, high temperatures, or areas susceptible to significant fluid or fume concentration.

Wire harnesses shall not be located in close proximity to oil and fuel fluid fill areas or below fuel and oil filter locations. If these locations cannot be avoided, additional protective covers and shields must be provided to protect the harness.

Harnesses shall be located a minimum of 50 mm from high heat sources (e.g. exhaust manifolds, turbochargers, hydraulic components, etc.) to avoid insulation and/or connector deterioration.

Harness Maintenance Considerations

The maintainability of the wiring system shall be an important consideration in the selection, design, and installation of harnesses, cable assemblies, and other wiring system components. All wiring components shall be accessible, repairable, and replaceable (i.e. connector terminals).

High-pressure wash systems are now in frequent use by maintenance people. When locating electrical connectors, place them in accessible locations while using other physical elements for protection and prevention of direct exposure to wash systems (e.g. brackets, housings, sheet metal structure, etc.). Where direct exposure to high pressure wash systems cannot be avoided, protective shields will need to be designed and installed.

Harness Appearance

The primary purpose for the wiring system is to provide electrical and electronic component function. There is, however, another important and intangible value to consider when designing the wiring system.

The appearance of the wire harness and its routing path should reflect an orderly, well-thought-out design plan. A poorly executed plan can have a negative impact on OEM/Installer perceptions of the entire product. Use the product's horizontal and vertical lines for routing paths. Design preformed bends into large harnesses to facilitate product assembly and improve appearance. Use other product elements to shield or hide the harness from view. Benchmark new automotive product applications for ideas.

Harness Bends

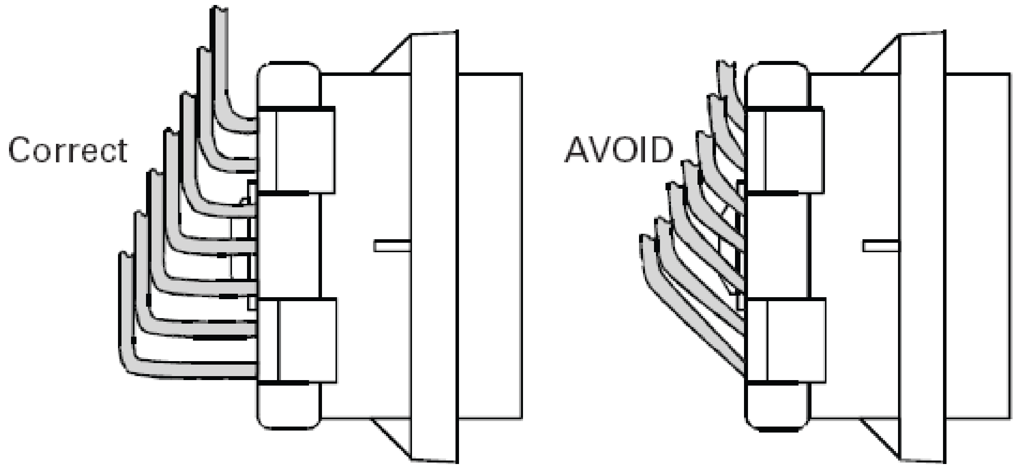
Routing of the harness should insure connector seals are not stressed because the harness curvature is too close to the connector. This applies to routing of OEM/Installer lines on or near the engine harness as well as the ECU OEM/Installer connector (J1/P1).

The minimum bend radius for a braided wire harness as measured from the inside of the bend shall be four times the outer diameter of the harness. Tighter bends are possible if the bend is preformed during harness manufacture. The bend radius size and location must be specified on the wire harness drawing. Bends in jacketed cables shall be based on manufacturer recommendations. A bend must not adversely affect the operating characteristics of the cable. For flexible coaxial cables, the bend radius must not be less than six times the outside diameter. For semi-rigid coaxial cable, the bend radius must not be less than ten times the outside diameter of the cable.

The minimum bend radius for flexible conduit must be six times the outer diameter of the conduit. Conduit bends shall not cause internal chafing of the wiring.

Harness Bends near Connectors

Avoid wire harness bends within 25 mm (1.0 in.) of the connector. When a harness bend is too close to the connector, the connector seal is stretched away from the wire, providing an opening for moisture entry. The wire should exit perpendicular to the connector before curving as necessary for routing. Refer to illustration in Figure below.



Example of Wire Harness Routing at the PJ-C1,C2 Connectors

Wire harness bends near a connector must be no less than twice the wire harness diameter. Special consideration shall be given to connectors with large wire counts. Stresses placed upon the retention system of the connector can cause contact retention failures and wire pull-out. In order to avoid this problem consider the following options:

1. Pre-form the harness to the required bend. The harness assembly drawing shall detail the harness bend requirements (e.g. location and radius). The harness braid protection should be applied up to the tangent point of the bend furthest from the connector. Connector orientation to the bend may be necessary and should be specified on the harness print.
2. If harness braiding is used, increase the unbraided harness length to 150 mm. This will allow the wires to fan out when the harness is bent, greatly reducing the forces placed on the connector contact retention system. The connector should also be oriented properly with respect to the harness so that upon installation to the product the harness will not need to be twisted to align the connector.

Drip Loop

When a harness is routed downward to a connector, terminal block, panel, or junction box, a trap or drip loop shall be provided in the harness. This feature will prevent fluids or condensate from running into the above devices.

Sealing Splices and Ring Terminals

Caterpillar requires all ring terminals and splices connected to the engine ECU be sealed using Raychem ES2000 adhesive lined heat shrink tubing or equivalent. Refer to Table below for heat shrink tubing sizing information.

Cat Part Number	I.D. Before Shrink		I.D. After Shrink	
	(mm)	(inch)	(mm)	(inch)
125-7874	5.72	0.225	1.27	0.050
125-7875	7.44	0.293	1.65	0.065
119-3662	10.85	0.427	2.41	0.095
125-7876	17.78	0.700	4.45	0.175

Heat Shrink Tubing Reference Table

Wire Connection Guidelines

The following requirements ensure the correct installation of solid contacts into connector terminals:

- Do not solder the contact (socket or pin) to the wire.
- Never crimp more than one wire into a contact. Connector contacts are designed to accept only one wire of a specified gauge or gauge range, do NOT insert multiple wires of a smaller gauge.
- All contacts should be crimped on the wires. Use the Crimp Tool (Caterpillar part number 1U-5804) for 12 to 18 AWG wire.
- Perform the pull test on each wire. The pull test is used to verify that the wire is properly crimped in the contact and the contact is properly inserted in the connector terminal. Each contact and connector terminal should easily withstand 45 N (10 lb) of pull such that the wire remains in the connector body.

SAE J1939/11 — Data Bus Wiring

J1939 Data Bus Harness Design

The data bus connector that Caterpillar uses is a modified DT connector, special wedge, cable, and extended socket. The harness assembly requirements are unique to typical Caterpillar wire harnesses. Caterpillar recommends 2 conductor shielded cable from Raychem Corp (Raychem part number 2019D0309-0/Cat part number 153-2707) for all J1939 data link wiring. This is twisted pair wiring. If the Caterpillar recommended cable is not used, the cable must meet J1939 specifications for conductors. For additional information regarding the electrical system design see the SAE publication J1939/11 Physical Layer.” The minimum bend radius for the data bus cable is 40 mm.

Table 2: J1939 Conductor Specifications

J1939 SPECIFICATIONS FOR CONDUCTORS			
	Minimum	Nominal	Maximum
Impedance (ohm)	108	120	132
Capacitance between conductors (pF/m)	0	40	75
Capacitance between the conductors and the shield (pF/m)	0	70	110

In order that the data bus will function as intended the following requirements must be identified on the customer wire harness print.

1. Remove 75 mm of the outer jacket of data link shielded cable. (Reference Cat part number 153-2707)

2. Remove the foil shield from the exposed wires to within 3 mm of the cable jacket end.

3. Crimp gold-plated socket terminals to the wires and the extended socket terminal to the drain wire.

4. Slide heat shrink tube over the cable end. (Reference Cat part number 125-7876)

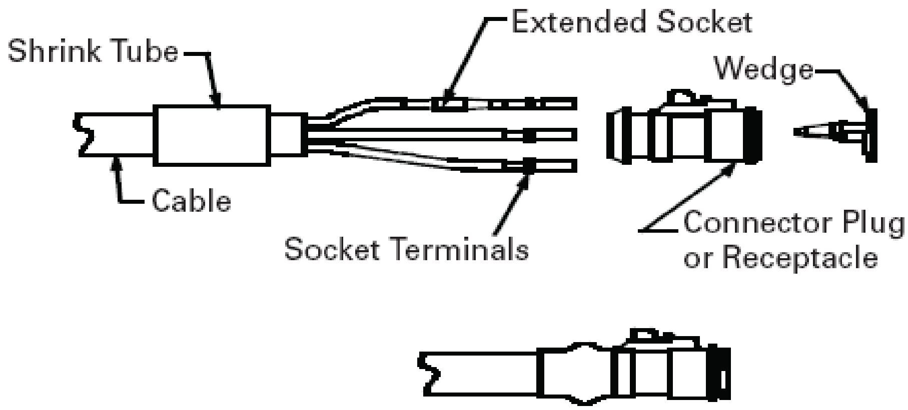
5. Install the terminals into the appropriate connector cavity positions.

6. Install the wedge into the connector.

7. Apply the heat shrink tube over the back of the connector body and the jacket of the cable.

The above components and assembly procedures must be used to ensure the cable to connector joint will be sealed. Failure to conform to these requirements will result in cable contamination and result in loss of shield performance. See Figure 6.

Figure 6: SAE J1939 Connector Assembly



NOTE: *Refer to SAE J1939-11 "Physical Layer" document for more information.*

Connecting Modules to the CAN Data Link

The SAE J1939 data link is used to communicate engine information to an SAE J1939 compatible display or other desired SAE J1939 compatible modules. Refer to SENR9764 "Installation Guide for Industrial Electronic Engine Displays" for more information on connecting J1939 displays to Caterpillar industrial engines. The illustration in Figure 7 shows two J1939 modules properly connected to the J1939 data bus. The key components to note are as follows:

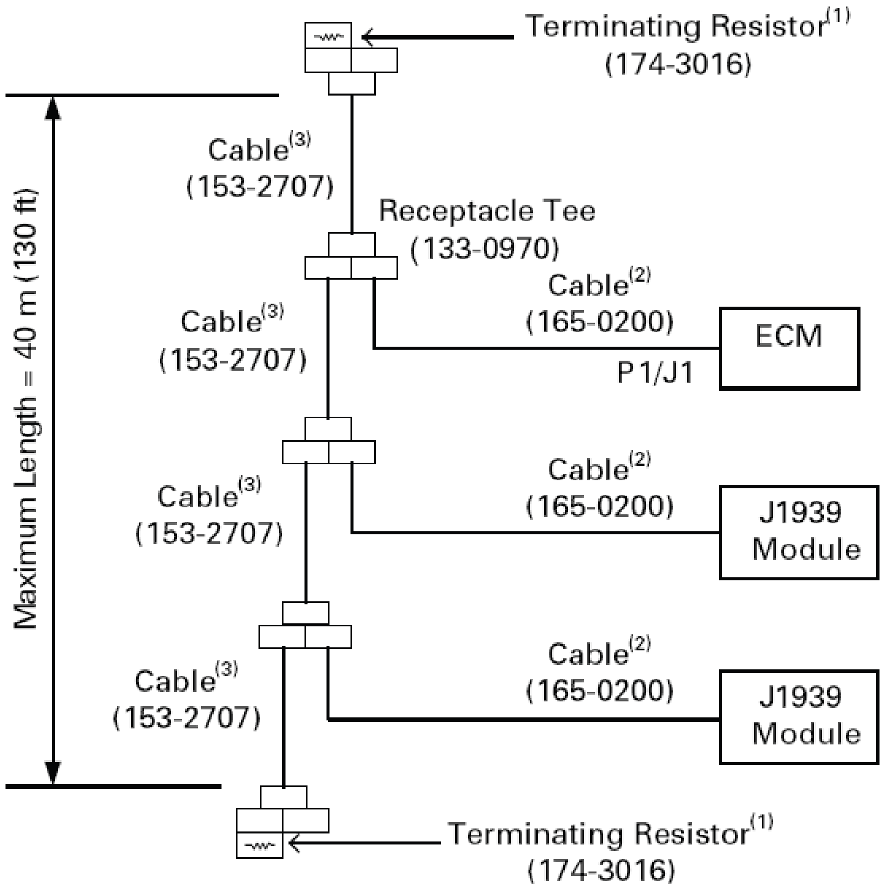
- The total length of the data link between terminal resistors must not exceed 40 m (130 ft).

- Length of each branch, or stub length, must not exceed 1 m (3.3 ft). Reference cable assembly (Cat part number 165-0200) that is .15 m long with Deutsch DT 3 pin plug on one end and J1939 signal and shield wires with appropriate crimped socket on the other end for insertion into J1939 module connector.

- All splices and end nodes can be implemented using a connector tee. (Reference Deutsch DT receptacle assembly — Cat part number 133-0970).
- Two terminal resistors must be installed. One resistor is required at each end of the data link in order to ensure proper operation. These two terminal resistors are critical for the proper operation of the network.

(Reference Deutsch DT plug with integrated termination resistor — Cat part number 174-3016).

Figure 7: J1939 Multiple Module Installation Example



(1) Two terminal resistors are required. Optional Customer Harness provides the resistor at the ECM if installed
(2) Maximum stub length = 1 m (3.3 ft)
(3) Fabricate 153-2707 cable to length

NOTE: *If the requirements for J1939 data link connections are met, any number of display modules or service tool connectors may be connected to the J1939 data link.*
NOTE: *One terminal resistor for the J1939 data link is included in the optional customer harness. If the optional customer harness is not present, two terminal resistors must be installed. Any J1939 data link must have a terminal resistor at each end of the data link.*
NOTE: *A terminal resistor is required at the terminal ends of the data link cable. A terminal resistor is not required at each node on the data link.*

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Appendix B: Initial Startup Procedure

Engine and Aftertreatment Compatibility Check

After completing installation of the aftertreatment hardware, a hardware compatibility check is required. There are three criteria for meeting aftertreatment compatibility check.

1. Automatic compatibility check at key on
2. Verifying that the CEM and Dosing cabinet serial numbers match
3. Documentation of CEM and Engine serial number

Automatic compatibility check at key on

All CEM's contain a chip that will check for proper compatibility with the engine. At first start up the engine ECM will read the CEM chip and write the serial # information to the engine ECM. The engine ECM will then determine if a compatible CEM and dosing cabinet has been installed with the engine.

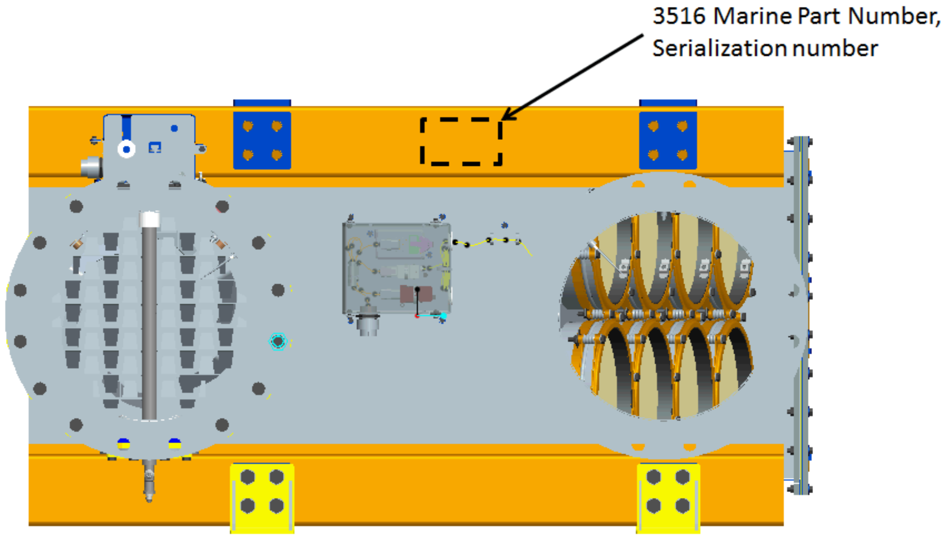
- If the CEM and/or dosing cabinet are not compatible with the engine, the engine will derate and trigger an active fault. A compatible CEM and/or dosing cabinet for the engine will need to be installed to resolve this issue.
- If the CEM and dosing cabinet is compatible the engine will not derate and there will be no fault code. No further action for the automatic compatibility check is required.

The engine will continue the compatibility check of the CEM for the first 25 hours of operation of the installation. If for any reason the engine ECM is replaced or aftertreatment is replaced within the first 25 hours of operation the engine ECM will rewrite the CEM serial# from the CEM chip. The 25 hour clock for compatibility check will also restart after initial compatibility check of the new hardware.

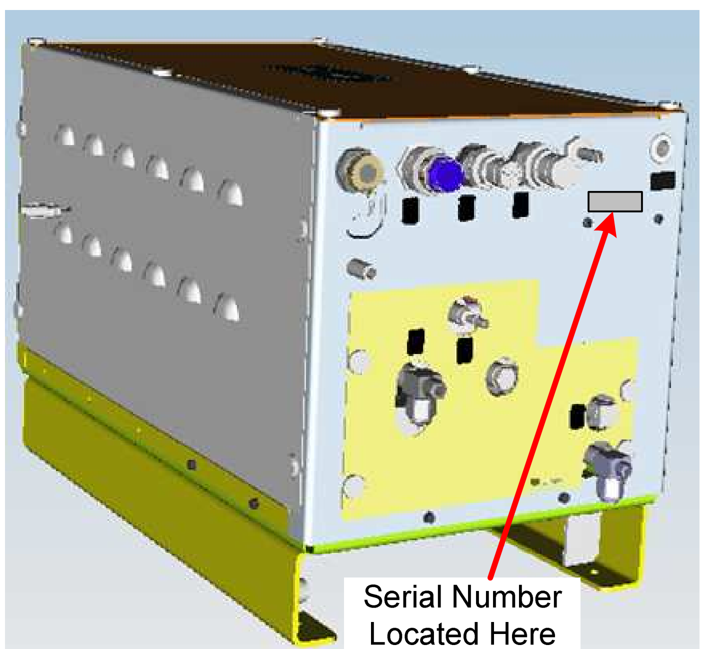
Verifying that the CEM and dosing cabinet serial numbers match

CEM and dosing cabinet are shipped as a matched set from Caterpillar. It is required that the installer use a CEM and dosing cabinet with matching serial numbers for any installation. Verify that the serial numbers are identical for both the CEM and dosing cabinet.

Location of CEM Serial Number:



Location of Dosing Cabinet serial number:



Documentation of CEM and Engine Serial Number

Documentation of engine serial number and CEM serial number is a requirement for all installations

The final installer of the engine and CEM will be required to document the engine and CEM serial number and provide that information to Caterpillar. The Dealer will follow the standard reporting requirements through the Web Portal Tier 4 Commercial Engine Application. This site requires an Installation Audit and

Serial Number pairing entry on either an individual engine system basis or part of a mass upload performed by the Dealer.

Engine and Aftertreatment Assembly documentation

Documentation of the engine and CEM serial number is to be done to be reported back to Caterpillar to meet the EPA requirements. The engine and aftertreatment serial numbers are to be required within the DFA.

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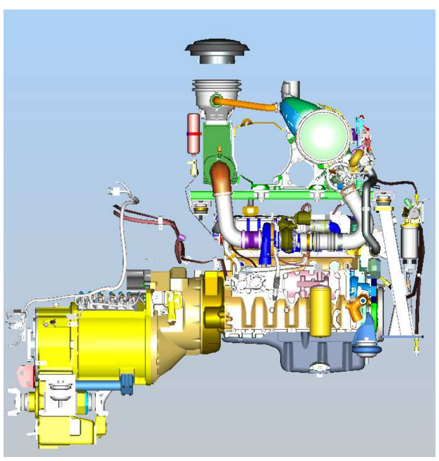
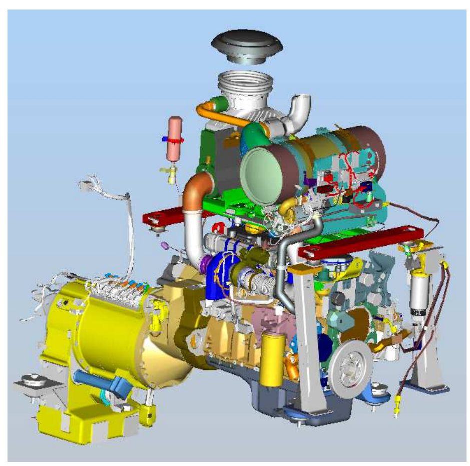
Appendix C: Bellows-Mount Displacement Calculator Process

Purpose:
This procedure is provided to assist in determining the Bellow-Mount capability of the T4 aftertreatment application installation and the need for hard or soft mount CEM. This process should be used in concert with the Bellows-Mount Calculator, Cat CEM A&I Guide in section 5 – Exhaust System/Installation Design & Assembly Instructions and Section 5 – Mounting Considerations/CEM Vibration Acceptability Overview. This tool provides guidance for calculation of bellows-mount displacement both axially and radially using distance measurements and engine & CEM mount information from a typical application installation design. Process procedure follows:

Process:
- Calculate bellows relative movement axially & radially using distance measurements and engine & CEM mount information.
    - Independently moving engine
    - Independently moving CEM
    - How does the bellows move to compensate?





Spreadsheet Preview

Bellows Input	
Nominal Tube OD (Inches)	4

Bellows Movement Output		Acceptable
Max Bellows Capability Radial	8	M
Max Bellows Capability Axial	12	
Max Movement Radially Calculated	7.735352886	
Max Movement Axially Calculated	8.730111443	

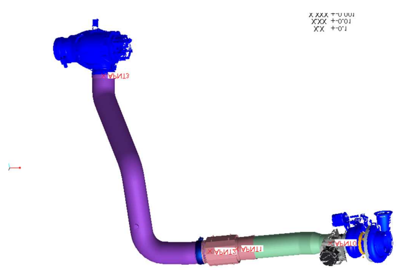
ENGINE INPUTS	
Mount Specifications	
Engine Mass (kg)	2200
# of mounts	4
G-Load	5
Calculation (Do not edit)	
Load per mount @ G-Load (N)	26977.5
Lookup (Input)	
Mount axial displacement @ above load (mm)	2.8
Mount lateral displacement @ above load (mm)	1
Measurements (Input)	Value (mm)
(AM)x (negative if to the left of engine A mount)	-40
(AM)y (negative if to the front of the engine A mount)	350
(AM)z (negative if below the engine A mount)	560
(AT)x (negative if to the left of engine A mount)	-40
(AT)y (negative if to the front of the engine A mount)	380
(AT)z (negative if below the engine A mount)	560
Shortest distance between mounts across width of engine	600
Shortest distance between mounts across length of engine	1890
Background Calcs	

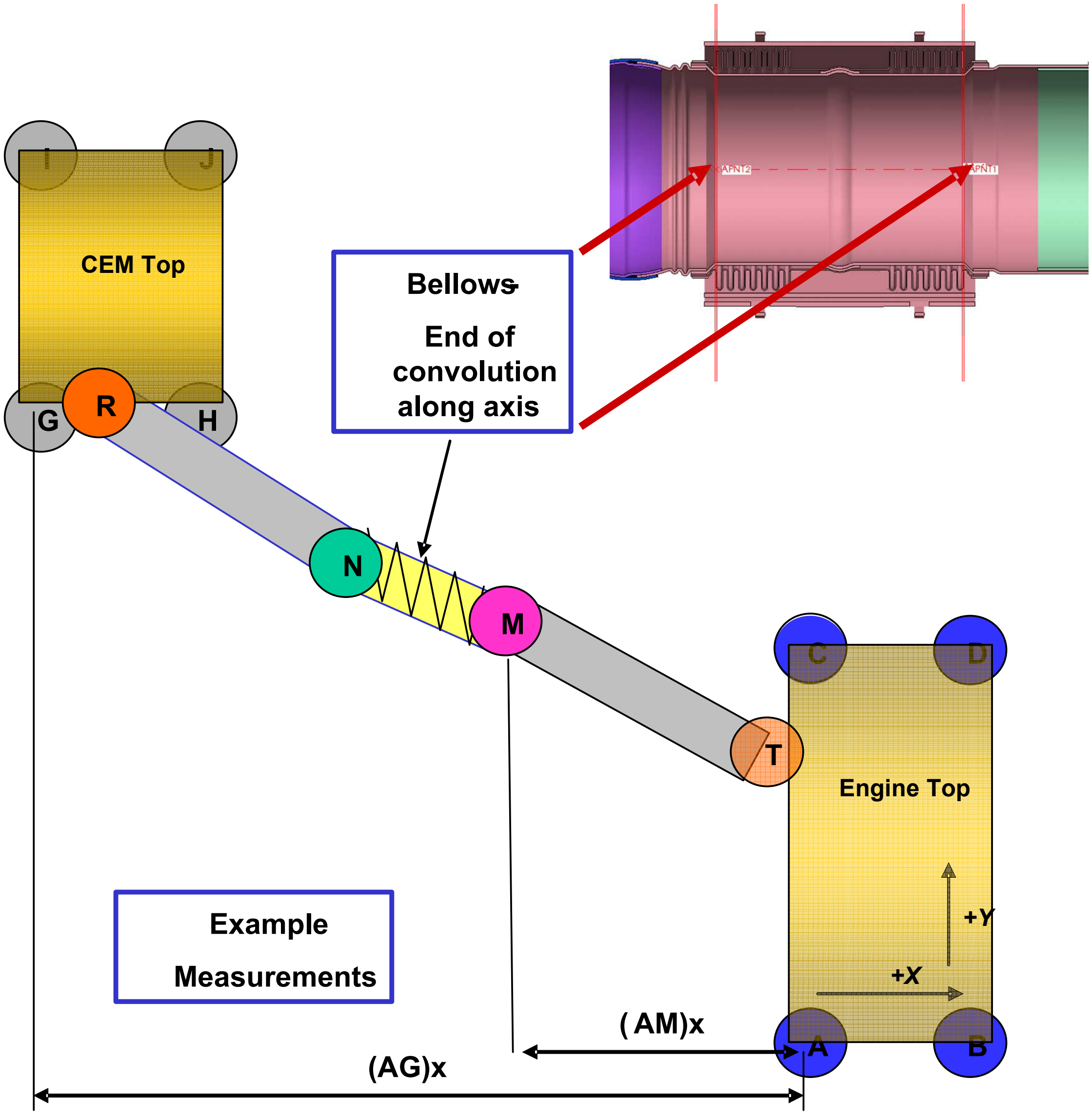
CEM INPUTS	
Mount Specifications	
Mass (kg)	300
# of mounts	4
G-Load	3
Calculation (Do not edit)	
Load per mount @ G-Load (N)	2207.25
Lookup (Input)	
Mount axial displacement @ above load (mm)	0.9
Mount lateral displacement @ above load (mm)	2.5
Measurements (Input)	Value (mm)
(AN)x (negative if to the left of engine A mount)	-40
(AN)y (negative if to the front of the engine A mount)	170
(AN)z (negative if below the engine A mount)	530
(AR)x (negative if to the left of engine A mount)	-40
(AR)y (negative if to the front of the engine A mount)	80
(AR)z (negative if below the engine A mount)	850
(AG)x (negative if to the left of engine A mount)	-40
(AG)y (negative if to the front of the engine A mount)	-140
(AG)z (negative if below the engine A mount)	800
(AH)x (negative if to the left of engine A mount)	700
(AH)y (negative if to the front of the engine A mount)	-140
(AH)z (negative if below the engine A mount)	800
(AI)x (negative if to the left of engine A mount)	-135
(AI)y (negative if to the front of the engine A mount)	1000
(AI)z (negative if below the engine A mount)	800
(AJ)x (negative if to the left of engine A mount)	700
(AJ)y (negative if to the front of the engine A mount)	1000
(AJ)z (negative if below the engine A mount)	800
Background Calcs	

The spreadsheet consists of data input from engine and CEM application and installation parameters to determine bellows-mount capability.

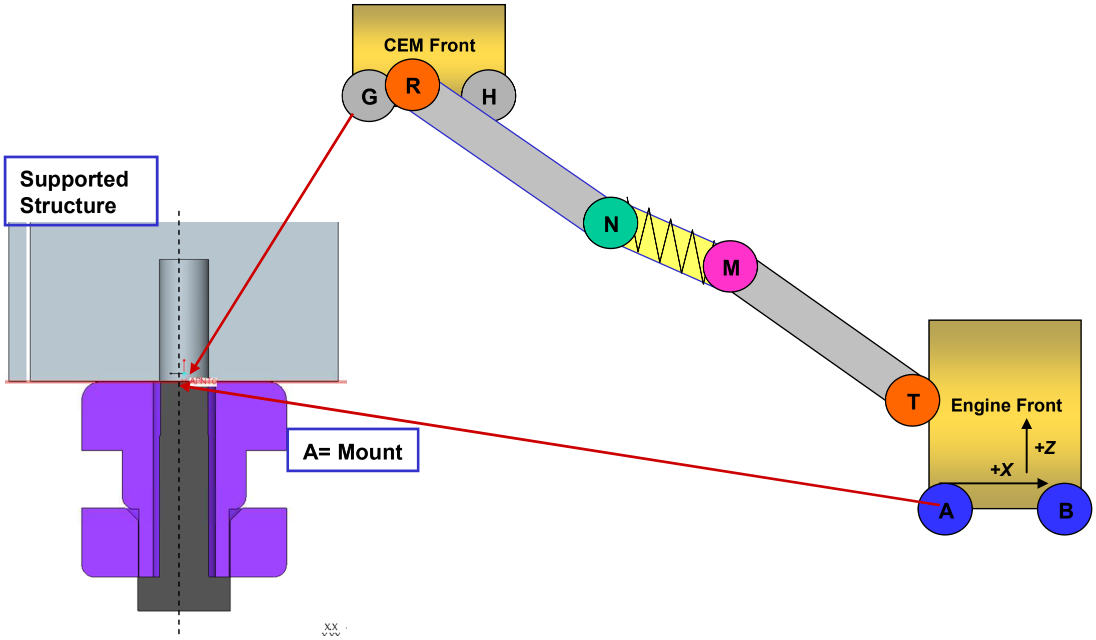
Engine setup (typical):

- Top View
  - A,B,C,D= Engine mounts
  - G,H,I,J= CEM mounts
  - R= CEM Inlet
  - T= Turbo
  - M= Bellows Inlet
  - N= Bellows Outlet
  - A= Zero Point (All points measured relative to A)

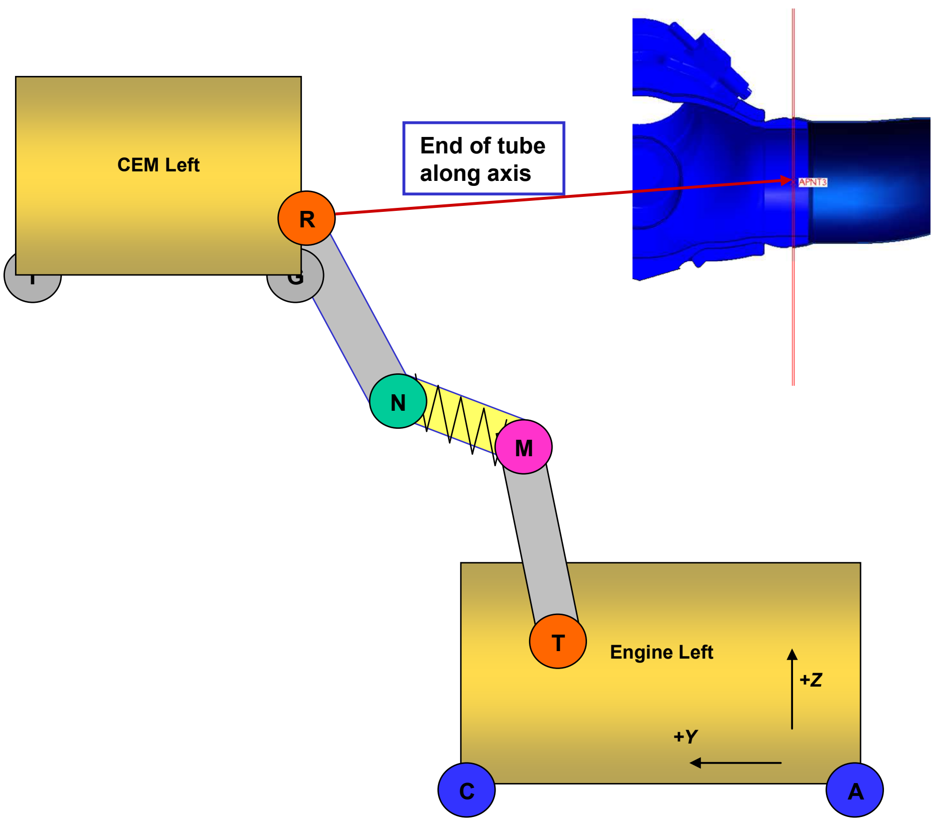



Bellows
End of convolution along axis
CEM Top
I
J
G
R
H
N
M
C
D
T
Engine Top
+Y
+X
A
B
Example
Measurements
(AM)x
(AG)x

Front View



Left View



Spreadsheet Step-by-Step Preview

Bellows Input	
Nominal Tube OD (Inches)	4

Bellows Movement Output		Acceptable
Max Bellows Capability Radial	8	M
Max Bellows Capability Axial	12	
Max Movement Radially Calculated	7.735352886	
Max Movement Axially Calculated	8.730111443	

ENGINE INPUTS	
Mount Specifications	
Engine Mass (kg)	2200
# of mounts	4
G-Load	5
Calculation (Do not edit)	
Load per mount @ G-Load (N)	26977.5
Lookup (Input)	
Mount axial displacement @ above load (mm)	2.8
Mount lateral displacement @ above load (mm)	1
Measurements (Input)	Value (mm)
(AM)x (negative if to the left of engine A mount)	-40
(AM)y (negative if to the front of the engine A mount)	350
(AM)z (negative if below the engine A mount)	560
(AT)x (negative if to the left of engine A mount)	-40
(AT)y (negative if to the front of the engine A mount)	380
(AT)z (negative if below the engine A mount)	560
Shortest distance between mounts across width of engine	600
Shortest distance between mounts across length of engine	1890
Background Calcs	

CEM INPUTS	
Mount Specifications	
Mass (kg)	300
# of mounts	4
G-Load	3
Calculation (Do not edit)	
Load per mount @ G-Load (N)	2207.25
Lookup (Input)	
Mount axial displacement @ above load (mm)	0.9
Mount lateral displacement @ above load (mm)	2.5
Measurements (Input)	Value (mm)
(AN)x (negative if to the left of engine A mount)	-40
(AN)y (negative if to the front of the engine A mount)	170
(AN)z (negative if below the engine A mount)	530
(AR)x (negative if to the left of engine A mount)	-40
(AR)y (negative if to the front of the engine A mount)	80
(AR)z (negative if below the engine A mount)	850
(AG)x (negative if to the left of engine A mount)	-40
(AG)y (negative if to the front of the engine A mount)	-140
(AG)z (negative if below the engine A mount)	800
(AH)x (negative if to the left of engine A mount)	700
(AH)y (negative if to the front of the engine A mount)	-140
(AH)z (negative if below the engine A mount)	800
(AI)x (negative if to the left of engine A mount)	-135
(AI)y (negative if to the front of the engine A mount)	1000
(AI)z (negative if below the engine A mount)	800
(AJ)x (negative if to the left of engine A mount)	700
(AJ)y (negative if to the front of the engine A mount)	1000
(AJ)z (negative if below the engine A mount)	800
Background Calcs	

Excel Sheet Directions

1. Choose tube routing nominal diameter (4" or 5")

Bellows Input	
Nominal Tube OD (Inches)	4

2. Input Engine and CEM mass
   – This is the mass supported by your mounts if they exist

ENGINE INPUTS	
Mount Specifications	
Engine Mass (kg)	2200
# of mounts	4
G-Load	3

CEM INPUTS	
Mount Specifications	
Mass (kg)	300
# of mounts	4
G-Load	3

3. Input Engine and CEM mount quantity

ENGINE INPUTS	
Mount Specifications	
Engine Mass (kg)	2200
# of mounts	4
G-Load	3

CEM INPUTS	
Mount Specifications	
Mass (kg)	300
# of mounts	4
G-Load	3

4. Input Engine and CEM expected G-loads if known (5g otherwise)

ENGINE INPUTS	
Mount Specifications	
Engine Mass (kg)	2200
# of mounts	4
G-Load	3

CEM INPUTS	
Mount Specifications	
Mass (kg)	300
# of mounts	4
G-Load	3

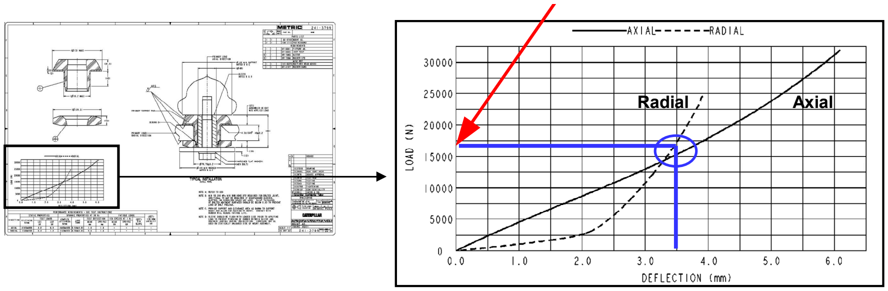
5. Based on inputs above the spreadsheet will output a load in Newton

Calculation (Do not edit)	
Load per mount @ G-Load (N)	16186.5

Calculation (Do not edit)	
Load per mount @ G-Load (N)	2207.25

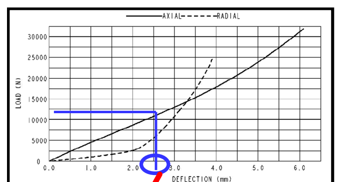
6. Use mount load to displacement chart to determine axial and lateral displacement at the output load.

Load per Mount @ G-Load (N)
(See step 5 above)



****This chart will differ by mount.**

7. Input Axial and Radial (Lateral) displacements into spreadsheet for engine and CEM respectively.



ENGINE INPUTS	
Calculation (Do not edit)	
Load per mount @ G-Load (N)	16186.5
Lookup (Input)	
Mount axial displacement @ above load (mm)	5
Mount lateral displacement @ above load (mm)	1

CEM INPUTS	
Calculation (Do not edit)	
Load per mount @ G-Load (N)	2207.25
Lookup (Input)	
Mount axial displacement @ above load (mm)	0.9
Mount lateral displacement @ above load (mm)	2.5

8. Take measurements of all points relative to point A (Front left engine mount)

Measurements (Input)	Value (mm)
(AM)x (negative if to the left of engine A mount)	-40
(AM)y (negative if to the front of the engine A mount)	350
(AM)z (negative if below the engine A mount)	560
(AT)x (negative if to the left of engine A mount)	-40
(AT)y (negative if to the front of the engine A mount)	380
(AT)z (negative if below the engine A mount)	560
Shortest distance between mounts across width of engine	600
Shortest distance between mounts across length of engine	1890

**** Avoid entering zeros here. Even if hard mounted enter hard mounting locations.**

Measurements (Input)	Value (mm)
(AN)x (negative if to the left of engine A mount)	-40
(AN)y (negative if to the front of the engine A mount)	170
(AN)z (negative if below the engine A mount)	530
(AR)x (negative if to the left of engine A mount)	-40
(AR)y (negative if to the front of the engine A mount)	80
(AR)z (negative if below the engine A mount)	850
(AG)x (negative if to the left of engine A mount)	-40
(AG)y (negative if to the front of the engine A mount)	-140
(AG)z (negative if below the engine A mount)	800
(AH)x (negative if to the left of engine A mount)	700
(AH)y (negative if to the front of the engine A mount)	-140
(AH)z (negative if below the engine A mount)	800
(AI)x (negative if to the left of engine A mount)	-135
(AI)y (negative if to the front of the engine A mount)	1000
(AI)z (negative if below the engine A mount)	800
(AJ)x (negative if to the left of engine A mount)	700
(AJ)y (negative if to the front of the engine A mount)	1000
(AJ)z (negative if below the engine A mount)	800

ENGINE INPUTS	
Measurements (Input)	**Value (mm)**
(AM)x (negative if to the left of engine mount A)	-72
(AM)y (negative if to the front of the engine mount A)	270
(AM)z (negative if below the engine mount A)	776
(AT)x (negative if to the left of engine mount A)	-66
(AT)y (negative if to the front of the engine mount A)	501
(AT)z (negative if below the engine mount A)	629
Longest distance between mounts across width of engine (eg. (AB)x)	570
Longest distance between mounts across length of engine (eg. (AC)y)	1470
9. Vertical distance of Engine CG above engine mount A	550

CEM INPUTS	
Measurements (Input)	**Value (mm)**
(AN)x (negative if to the left of engine mount A)	-72
(AN)y (negative if to the front of the engine mount A)	270
(AN)z (negative if below the engine mount A)	934
(AR)x (negative if to the left of engine mount A)	209
(AR)y (negative if to the front of the engine mount A)	1160
(AR)z (negative if below the engine mount A)	1307
(AG)x (negative if to the left of engine mount A)	-164
(AG)y (negative if to the front of the engine mount A)	323
(AG)z (negative if below the engine mount A)	1266
(AH)x (negative if to the left of engine mount A)	532
(AH)y (negative if to the front of the engine mount A)	323
(AH)z (negative if below the engine mount A)	1266
(AI)x (negative if to the left of engine mount A)	-164
(AI)y (negative if to the front of the engine mount A)	1413
(AI)z (negative if below the engine mount A)	1470
(AJ)x (negative if to the left of engine mount A)	532
(AJ)y (negative if to the front of the engine mount A)	1413
(AJ)z (negative if below the engine mount A)	1470
9. Vertical distance of CEM CG above CEM mounting plane (GHIJ)	100
Additional Input	
10. Average tube skin temp @ max gas temperatures (Celcius)	325

9. Enter CG (center of gravity distances) above mount locations for engine and CEM.
10. Enter average skin temperature of exhaust line between turbo and aftertreatment when gas temperatures are at their highest.

- Spreadsheet will output estimated movement bellows must absorb
  - Max axial and radial displacement
  - Includes dynamic and thermal displacement
  - 3 potential outputs

  - G= If all inputs are correct, design should be acceptable

Bellows Movement Output		Acceptable
Max Bellows Capability Radial	8	Y
Max Bellows Capability Axial	12	
Max Movement Radially Calculated	4.371515503	
Max Movement Axially Calculated	6.470373552	

  - Y= Contact your A&I integration engineer

Bellows Movement Output		Acceptable
Max Bellows Capability Radial	8	M
Max Bellows Capability Axial	12	
Max Movement Radially Calculated	7.735352886	
Max Movement Axially Calculated	8.730111443	

  - R= Design is not acceptable and will need some tweaking as shown on the next slide

Bellows Movement Output		Acceptable
Max Bellows Capability Radial	8	N
Max Bellows Capability Axial	12	
Max Movement Radially Calculated	11.84874136	
Max Movement Axially Calculated	12.87014782	

Options for redesign:

- Options if bellows capability is less than calculated displacements?
  - Increase mount stiffness (New Mount)
  - Increase # of mounts
  - Decrease distance between turbo outlet and CEM inlet

Recommendations/Guidelines:

- If you don’t know your G-Loads - recommendation is to use 5G’s to evaluate worst case.
- If CEM or engine is hard mounted, mount deflection values should equal 0

Appendix D: AUS / DEF Handling

Refer to Caterpillar Fluid document PELJ1160-01 for additional information on DEF fluids.

Hazards Identification
AUS / DEF (AUS32 - aqueous urea solution, 32 or 40%) is a colorless liquid with a slight ammonia (pungent) odor.

Note: Consult the Material Safety Data Sheet (MSDS) provided by your AUS32 supplier. MSDS example is:

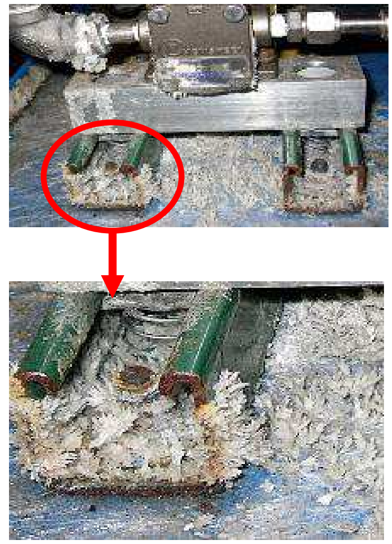
- MSDS Number 2046 (Revised October 4, 2006) for Urea Liquor supplied by Terra Industries Inc.

Warning: **AUS / DEF is a stable material, but highly reactive with strong oxidizers. Avoid contact with all oxidizers. AUS / DEF reacts violently with sodium hypochlorite (such as Clorox™) or calcium hypochlorite to form the nitrogen trichloride, which spontaneously explodes or rapidly decomposes creating toxic fumes, which may cause personal injury or death.**

When heated, AUS/DEF releases ammonia. When heated to decomposition, such as in a fire, it emits toxic fumes of nitrogen oxides (NO_X), ammonia, and cyanuric acid. Use water to control fires involving AUS/DEF liquid if water is compatible with burning material. Note that both AUS/DEF liquid and solid AUS/DEF are non-flammable.

In storage, a very small amount of the AUS/DEF in the liquid state will hydrolyze forming gaseous ammonia and carbon dioxide. The ammonia, which is soluble in the liquid, will cause the corrosiveness of AUS/DEF solution to increase as it ages due to its increasing concentration. That is, the higher ammonia concentration makes it more caustic. Note that high storage temperatures increase the rate of this decomposition.

Since AUS/DEF liquid is caustic, delivery and storage requires materials that are not susceptible to corrosion.



Recommended Materials:

- Stainless-steel
  - 300 series: OK
  - 400 series: Slow corrosion
  - Corrosion rate increases with temperatures > 60 °C
- Plastics

Materials to Avoid:

- *Unalloyed steel*
- *Aluminum*
- *Brass*
- *Galvanized steel*
- *Copper*

Eye contact may cause mild eye irritation, including stinging, watering, and redness. Wear safety glasses. Safety shield may be needed in some conditions.

Skin contact may cause mild skin irritation including redness and burning. No harmful effects from skin absorption have been reported. Use rubber gloves to prevent skin contact (All rubber types OK).

Vapor Inhalation may cause irritation leading to cough or difficulty in breathing.

Note: Contact hazards are from the caustic pH (7.5 – 10) factor of solution. AUS / DEF in solution slowly decomposes into ammonia causing the caustic reaction. “Aged” AUS / DEF solution is more caustic (high pH) than “fresh”.

Leaks and/or Spills

There is visible evidence should a leak occur:

- AUS / DEF stalactites & stalagmites
  - Formed from slow leaks and evaporation of water
  - Rate of water evaporation determines size of crystal formation
- Need to verify that joints are tight
  - Stop leaks when first noticed
    - Solid AUS / DEF will continue to accumulate
    - AUS / DEF solution is corrosive to steel and other metals
- Solid AUS / DEF is water soluble
  - ***But***… may be slow to get into solution
- Clean up spills and leaks *before* components can corrode
  - Minor spills: Use paper towels or absorbent mat
- Solid AUS / DEF is highly water soluble

  - Hot water will re-dissolve solid AUS / DEF faster
  - Small amount of soap or detergent in hot water may enhance clean up
  - Plenty of hot water is key to removing dry AUS / DEF
- AUS / DEF solution contains small amount of ammonia
  - Skin irritant
  - Wear gloves

	Marine Emission Installation Audit Questions		
	Installation Audit ID		
	Audit Description		
	Selling Dealer Name		
	Selling Dealer Code		
	Sales Model		
	Engine Serial Number		
	Aftertreatment Serial Number		
	Dosing cabinet Serial Number		
	End Customer Name		
	Vessel Name		
	Test Engineer Name		
	Emissions Audit Questions:		
1	Is the original engine emissions label clearly visibile?		Yes/No
2	If no, describe location of duplicate label.		
3	Is there an oil renewal system present (any form of system that attempts to combust used engine oil)?		Yes/No
4	Is API CJ-4,ACEA-E9 or DEO-ULS oil sticker visible at all lube fill points?		Yes/No
5	Is ULSD sticker clearly visible on all fuel filling points? Please describe all locations.		Yes/No
6	Are the flexible bellows in the exhaust system supplied by Cat?		Yes/No
7	If yes, Caterpillar flexible bellows part # (s)		
8	For third party flexible bellows in the exhaust system is there a copy of the fatigue analysis (similar to EJMA calculation)		Yes/No
9	Is the exhaust piping stainless steel from the mixing tube/urea injection nozzle to CEM? The required 300/400 Series Stainless.		Yes/No
10	Is the turbo to CEM inlet exhaust piping fully insulated?		Yes/No
11	Does the installation provide Engine and SCR system warning fault communication to the operator. Specify either Lamp or type of communication and indication		Yes/No
12	Any customer supplied aftertreatment components installed before or after the factory CEM		Yes/No
13	Is the Inlet and outlet spool on the CEM oriented and supported correctly per A&I guide instructions		Yes/No
14	Does CEM installation account for thermo growth per A&I guidelines.		Yes/No
15	Is the Dosing cabinet is located correctly to the lance/nozzle per A&I instructions.		Yes/No
16	Does urea tank meet A&I guide lines		Yes/No
17	Is their a low level DEF sensor installed in main urea tank and montored by Cat ECM correctly.		Yes/No
18	Is the factory insulation installed on CEM inlet and outlet spools correctly and no other insulation around and over the sensors.		Yes/No
19	Is the pressure sensor on inlet spool mounted in vertical orientation per A&I guidelines		
20	Is the NOx sensor box oriented correctly on the inlet and outlet spool per A&I guidelines. (NOx senors box loctated on top).		Yes/No
21	Is their a air filter/dryer installed between Air compressor and dosing cabinet.		Yes/No
22	Checked for all electrial codes to make sure all system is operating correctly		Yes/No
23	Was a complete PAR test performed and uploaded into the Cat system?		Yes/No
24	Air inlet restriction at full load rated speed with clean filter element measured at turbo compressor inlet. (If Vee, Left)		KPA
25	Air inlet restriction at full load rated speed with clean filter element measured at turbo compressor inlet (If Vee, Right)		KPA
26	Enter full load exhaust backpressure at turbo outlet. (If Vee, Left)		KPA
27	Enter full load exhaust backpressure at turbo outlet. (If Vee, Right)		KPA
28	Enter the full load backpressure at the CEM		KPA
29	CEM inlet temp at 100% load		Deg C
30	UREA Delta P between lance and dozing cabinet		kPa
31	Urea pressure to dosing cabinet		kPa
32	Air supply pressure to dosing cabinet		kPa
33	Urea concentration % (32.5% or 40%)		%
34	Vessel fuel tank capacity		Liters
35	Urea tank capacity		Liters

Revision Summary

Due to several changes required Revision 1 will be considered the first release with no Revision Summary listed. Revision Summary will begin at Draft Rev 2 release.