Power Solution Seminar

28 February 2003 - Singapore

A G E N D A

8.30am - 8.45am	Welcome Reception @ York Hotel, Carlton Hall, Level 2	All
9.00am	Welcome & Opening Message	Ringo Chow / Tan O H
9.15am	- Standards - Rating Definitions	Edwin A Kach
10.30am	B R E A K	All
10.45am	- Performance Considerations - Load Analysis - EP Design PRO - Genset Selection Considerations	Edwin A Kach
12.30pm	L U N C H	All
1.30pm	- Application & Installation Considerations	Ho Kah Huat
3.00pm	B R E A K	All
3.15pm	- Singapore Emission Regulation	Ng Buang Huat
3.45pm	- CAT Product Overview - Cogeneration	Gary Osterhout
4.15pm	- TSL Product Support Overview	Tan Oon Ho
4.30pm	Questions & Answers / Lucky Draw	All
5.00pm	Cocktail Reception	All
6.00pm	E N D	

Power Solution Seminar

presented by

TSL Power Systems
&
Caterpillar Asia Pacific Power Systems

Generator Set Guidelines overview

- Key to Success - Knowledgeable Choices
  - First Cost
    - Installation
    - Product
  - Life Cycle Cost
    - Genset Performance
    - Durability
    - Serviceability

International Standards

- Who is ISO ?
  - International Standards Organization – European based Standard writing body that is followed by many generator set manufacturers world wide.
  - Cat, Kohler, Onan, Waukesha, Stewart & Stevenson, Cummins, MTU/Detroit Diesel, Woodward gov, etc.
  -
- Why ISO ?
  - Many International Stds such as ISO 3046, SAE J1349 & BS 5514 address only the engine.
  - ISO 8528/1 : 1992: 3: 1993, ... 12:1997, address the generator set system performance, etc,etc,

ISO 8528

- True Engine + Generator System specification
  - Part 1: Application, ratings and performance
  - Part 2: Engines
  - Part 3: Alternating current Generators
  - Part 4: Control gear & Switchgear
  - Part 5: Generating Sets
  - Part 6: Test methods
  - Part 7: Technical declarations for spec. and design

ISO 8528

- True Engine + Generator System specification
  - Part 8: Requirements and tests for low-power gen sets
  - Part 9: Measurement & evaluation of mechanical vibrations
  - Part 10: Measurement of airborne noise by the enveloping surface method
  - Part 11: Dynamic, uninterrupted power supply systems
  - Part 12: Emergency power supply to safety services

International Standards

	CPP 31 (Singapore)	ISO3046-1	SAE J 1349	BS 5514	ISO 8528-1 1993
Bar Pres.	</= 300 meters	100 kPa	100 kPa	100 kPa	89.9 kPa or 1000 m
Air Temp	23 – 40 C avg 35C	25 C	25 C	27 C	Cooling Air Below 40 C
R. Humidity	84 % mean	30 %	99 kPa dry Aprox 30 %	60 %	30 %
Charge Air Temp	Not Specified	25 C	Not Specified	27 C	Not Applicable

Standards and Ratings

- Standards
  - ISO 8528 - Reciprocating Internal Combustion Engine Driven Alternating Current Generating Sets
  - ISO 3046 - Reciprocating Internal Combustion Engines Diesel and Gas. From BS5514
  - SS CP 31 - References ISO 8528 ratings,BS 7869, ISO 3046 and BS 5514
  -
  - NFPA 110 - Emergency & Standby Power Systems

Rating Definitions

Electrical kW

~~Brake~~ kW

EkW = BkW x generator efficiency for remotely cooled PGS.

EkW = (BkW – radiator fan kW) x generator efficiency for radiator cooled PGS

Rating Definitions

Ratings

- Standby
- Limited Time Running Power (LTP)
- Prime Running Power (PRP)
- Continuous Operating Power (COP)
- Load Management
  - Curtailable Rate
  - Interruptible Rate
  - Peak Shaving

Engine Rating Factors

- Fuel Burned Proportional to Power Out
  - Natural Aspirated - Limited by Air
  - Turbo Charged - Limited by Thermal & Mechanical
- Key Parameters
  - Peak Cylinder Pressure
  - Exhaust Temperature
  - Inlet Manifold Temperature
  - Turbo Charger Speed

Engine Rating Factors

Limits

- Based on Experience
- Design Factors

Standby - Traditional

- Emergency Back-up Power
- Less Than 100 hrs/yr.
- Varying Load (Load Factor 60-80%)
- Limited to 1 hr/12 at Full Rating

Standards and Ratings

- Ratings - Limited-Time Running Power (LTP) as specified in ISO 8528.
  - (Limited-time running power is the maximum power which a generating set is capable of delivering for up to 500 hour per year, of which a maximum of 300 hours is continuous running, between stated maintenance intervals and under
  - the stated ambient conditions, the maintenance being carried out as prescribed by the manufacturers).

Limited Time Running Power (LTP)

- Less Than 500 hrs/yr.
- Less Than 300 hrs/yr at one occurance
- Load Factor Up To 100%

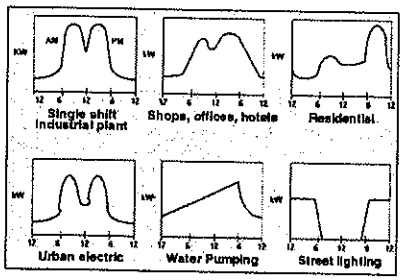
Standards and Ratings

- Prime Power (PRP) as specified in ISO 8528.
- (Prime power is the maximum power available during a variable power sequence, which may be run for an unlimited number of hours per year, between stated maintenance intervals and under the stated ambient conditions, the maintenance being carried out as prescribed by the manufacturers).

Prime Running Power (PRP)

- Unlimited hrs/yr. (8000 hrs/yr.)
- Varying Load (60-80%)
- Overload Capability Available (10%)

Prime Running Power (PRP)



Standards and Ratings

- Continuous Power (COP) as specified in ISO 8528.
- (Continuous Power is that which a generating set is capable of delivering continuously for an unlimited number of hours per year between the stated maintenance intervals and under stated ambient conditions, the maintenance being carried out as prescribed by the manufacturers.)

Continuous / Continuous Operating Power (COP)

- Continuous Application (8000 hrs/yr.)
- Steady Load (Load Factor 90-100%)
- No Overload Capability



NEW!! Load Management

- Paralleled with Utility
  - <500 hrs/yr. = Prime / PRP
  - >500 hrs/yr. = Continuous /COP
- Isolated from Utility
  - <500 hrs/yr. = Standby / LTP
  - >500 hrs/yr. = Prime / COP

Standards and Ratings

- ISO8528, is in the process of establishing four categories of power.
- Continuous operation at constant load. (COP or Continuous)
- Continuous operation at varying load. (PRP or Prime running power)
- Limited time operation at constant load. (Peak Shaving/Load Management)
- Limited time operation at varying load. (LTP or Standby)

Standards and Ratings

- ISO 8528 & CP31 - 110% overload power for governing purpose, shall not be used for the supply of electrical consumers.
- Additional power is not the same as Overload Power in ISO 3046. Gen set power limit depends upon engine fuel stop power.
- ISO /TC70/WG10 is responsible for all 12 parts of ISO 8528. The technical committee will remove all mention of "additional & overload power" in ISO 8528.

Standards and Ratings

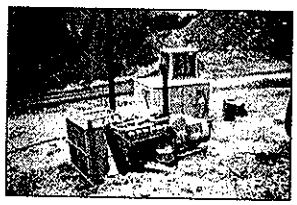
- Conclusion: 110% overload or additional power is not required. The true measure is the engine generator sets' ability to meet performance criteria under the various ISO 8528 performance classes: G1, G2, G3, G4.
- Singapore Consultants are specifying PRP when the LTP rating is sufficient.

Rating Considerations

- Site Conditions
- Generator Mapping Limits

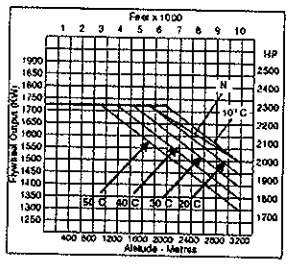
Site Conditions

- Altitude
- Temperature
- Humidity
- Dust
- Coastal



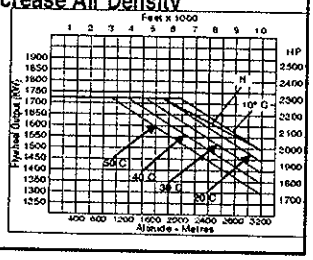
Altitude

- Lower Air Density
- Lower Air/Fuel Ratio
  - Higher Exhaust Temperature
  - Higher Turbo Speed
- Derate table in TMI



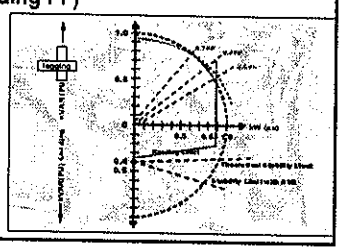
Temperature

- Higher Temperature Lowers Air Density = Altitude
- Low Temperatures - Increase Air Density
  - Higher Air/Fuel Ratio
  - Cooler Exhaust Temperatures
  - Lower Turbo Speed
  - Slight Increase in cylinder pressure



Generator Mapping Limits

- KVA Limit (Stator Temperature)
- Power Factor (Leading PF)
- KW Limit (Prime Mover)
- Excitor/Field Limit (Low Lagging PF)



Performance Considerations

Performance Considerations

- Emission
- Heat Balance
- Fuel Consumption
- Transient Response
- Starting Time
- Generator Considerations - Limits Graph

Emissions

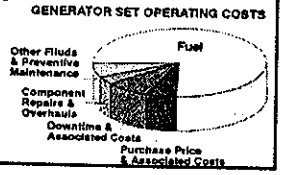
- Terms/Units in Specifications
- Measurement Techniques
- Correction Factors
  - % Oxygen
  - Wet vs. Dry Exhaust
- TMI Data
  - Nominal
  - Not to Exceed

Heat Balance

- Co-Gen Installation
  - Heat Load > Electrical Load
    - How will Heat Demands be Supplemented?
  - Heat Load < Electrical Load
    - How will Excess Heat be Dissipated?

Fuel Consumption

- Fuel Cost (up to 60-80% of O & OM Cost)
- Lower BSFC Configurations Raises NO_x Emissions
- Additional Fuel Savings
  - Electric Driven Fan Radiators
  - High Efficiency Generator



Transient Response Factors

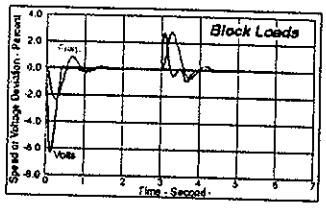
- Load Step Type
- Genset Package Configuration
- Generator Configuration
- System Interaction

Load Step Type

- Block Load
- Motor Load

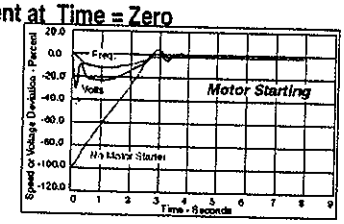
Block Load

- Instantaneous Load Acceptance/Rejection
- Typical 1.0 pf or 0.8 pf
- Intent to Demonstrate Field Conditions
- Actual Load Conditions
  Typically Do Not Represent Pure Block Loads



Motor Loads

- Dependent on Motor Starting Technique
- Typical High SKVA Requirement and Low HP Requirement at Time = Zero

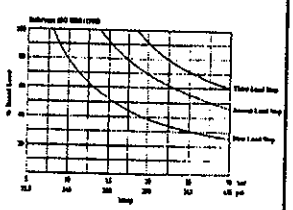


Fan Demand

- Transient Response Dependent on Acceleration bKW
- Fan Demand Reduces Acceleration bKW
- Added System Inertia

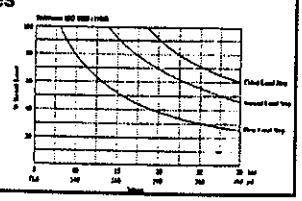
BMEP Load Steps

- Load Acceptance Capability Dependent on BMEP Load Step
  - ISO 8528-5
- Higher Ratings Reduce Transient Performance
- EDS 74.2 "Block Loading Transient Response



ISO 8528-5 Specification

- Rated BMEP determines % Block Load Requirement
- Different Transient Classes
  - Gas Engine - G1
  - Diesel Engine - G2



ISO 8528-5 Specification

diesel

	Class G1	Class G2	Class G3	Class G4
Freq. - % Acceptance	-15	-10	-7	AMC
Freq. - % Rejection	18	12	10	AMC
Voltage - % Acceptance	-25	-20	-15	AMC
Voltage - % Rejection	35	25	20	AMC
Time - Sec	5	5	3	AMC

AMC - Agreed between Manufacturer and Customer

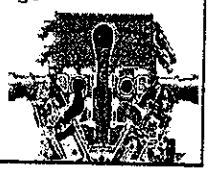
Air Systems

- Change in Boost Pressure
- Small / Low Inertia Turbochargers - Best
- Large / High Inertia Turbochargers - Worst
- System Trade - Off
  - Fuel Consumption vs. Response



Gas Engine Considerations

- Gas Engine Response Does Not Equal Diesel
- Gas Not Direct Injection
- Gas Has Significant Volume to Change
- High Pressure Gas Configurations
  - Better
  - Limited



Generator Configuration

- Low Transient Reactance (Per Unit)
  - Less Voltage Drop
  - Higher Frequency Drop - Typical
- Larger Generator
  - Higher Inertia

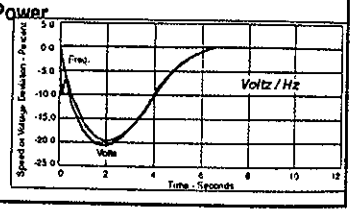
System Interaction

- Volts/Hz
- 2 Volts/Hz
- Digital Voltage Regulator

- Regulator

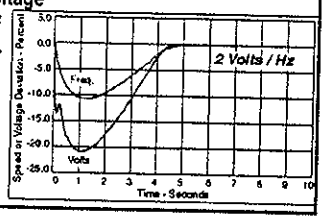
Volts / Hertz

- % Regulated Voltage Dip = Frequency Dip
- Example:
  - 10% Freq. Dip = 10% Voltage Dip
    = .90 Voltage
    = .81 Power
- Tight Voltage
- Longer Response Time

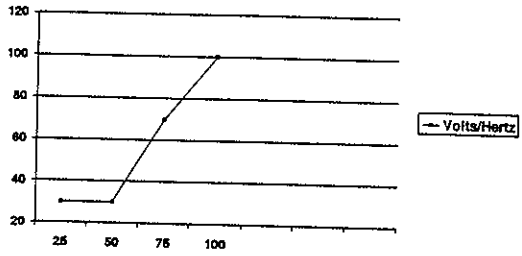


2 Volts / Hertz

- 2x% Regulated Voltage Dip = %Frequency Dip
- Example:
  - 10% Freq. Dip = 20% Voltage Dip
    = .80 Voltage
    = .64 Power
- More Voltage Dip
- Faster Response Time

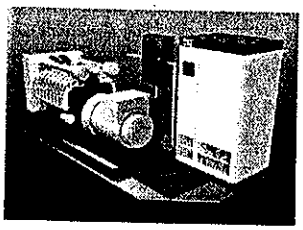


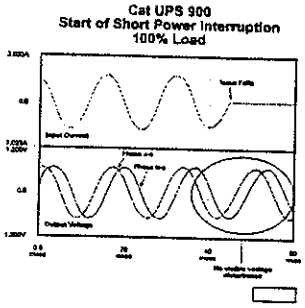
Digital Voltage Reg.

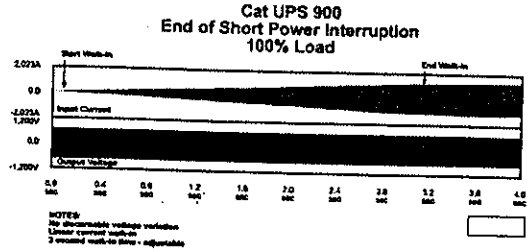


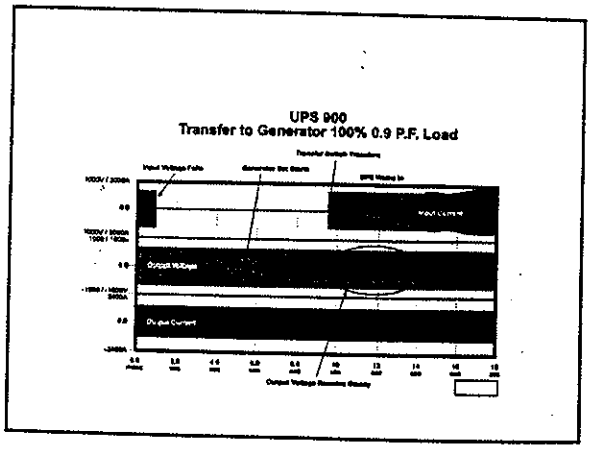
Continuous Power Solution
(Gen Set, Transfer Switch and UPS)

- Small footprint
- Front service access
- Simple installation
- Gen set friendly
  - Low input THD
  - Handles transients
  - Programmable walk-in
- No-break power solution









Ten Second Start

- NFPA 110 Requirement
  - Difficult with Gas Engine
- Design Considerations
  - When does the clock start!!! 1, 2, 3, seconds after mains failure? Or after at mains failure – important!
  - Jacket Water Heaters
  - Short Battery Cables
  - Battery Heaters
  - Warm Air Intake Until Engine is up to Rated Speed
  - Fuel Heaters

receive signal

Load Analysis

Load Analysis

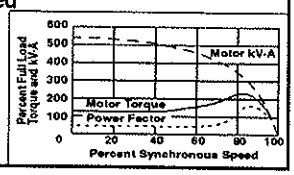
- Motors
- Lighting
- Resistive Heating
- Non - Linear Loads
- Office Equipment
- Sizing Analysis

Motor Type

- AC Motors
  - Induction
  - Synchronous
- DC Motors
- Variable Frequency Drives (VFD)

AC Motors - Induction

- Most Common
- Inductive Load (.6 -.95 Lagging PF)
- Starting Current 2-8 x Rated
- Operate at Less Than Synchronous Speed



AC Motor - Synchronous

- Few Applications (Expensive)
- Unity/Leading Power Factor
- Operate at Synchronous Speed
- "Linear" Load

DC Motor

- High Torque/Low Speed Capability
- High Speed Range
- Few Applications-Replaced with Variable Frequency Drives
- Typically Powered through:
  - AC Motor - DC Generator Set
  - DC Rectifier - Limited Application
- "Linear Load"

Variable Frequency Drive

- SCR Drive
  - Changes Frequency
  - Changes Synchronous Speed
- Replacing DC Motor Drives
  - High Torque - Low Speed
- High "Non-Linear" Load

Motor Performance

- Motor Starting (SKVA)
- Motor Torque

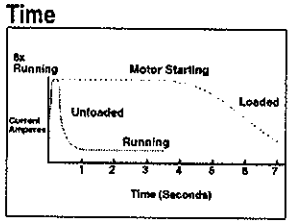
Motor Starting (SKVA)

- SKVA = $(\sqrt{3})(V_{line})$(In-Rush Current)
- Changes with Size and Design
- Typical 30% Voltage Dip Acceptable
- Generator SKVA vs Dip Curve in TMI

Voltage

Motor Torque

- Difference Between Motor and Load Torque = Acceleration Torque
- Determines Acceleration Time
- Impacts Duration of Voltage Dip



Motor Starting

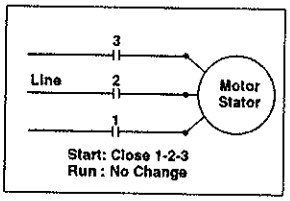
- Techniques
- Full Voltage Starting
- Reduced Voltage Starting

Motor Starting - Techniques

- Change Starting Sequence
  - Sensitive loads first
  - Build loads to approx 20%
  - Start largest load
- Use Oversized Generators - More SKVA
- Use Reduced Voltage Starters

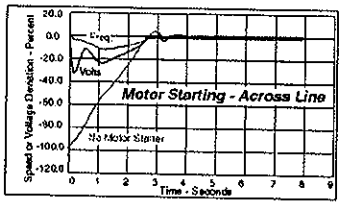
Full Voltage Starting

- Simple, Low Cost, Preferred Method
- Maximum Starting Torque
- Maximum SKVA Demand
- Fastest Starting Methods



Full Voltage Starting - Package Performance

- Full Inrush Current
- Full Load on Engine
- Example: V=1.0
  P=1.0

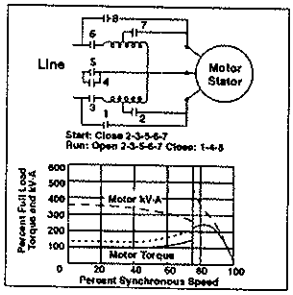


Reduce Voltage Starting

- Auto-Transformer Starter
- Reactor - Resistor Starter
- Part Winding Starter
- WYE-Delta Starter
- Solid State Starter

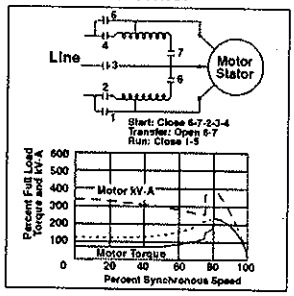
Auto-Transformer Starter

- High Starting Torque
- Low Cost Starter
- Offered in Various Taps
- Line Voltage = 80, 65 and 50%



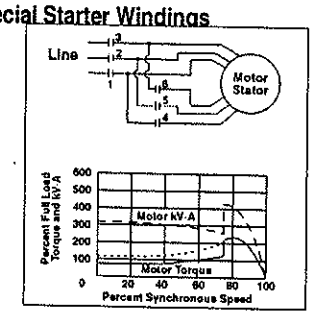
Reactor - Resistor Starter

- Reactor Starter Similar to Auto Transformer
- Fixed Tap
- Resistor Starters not Recommended
  - Add Starting KW to Engine Load



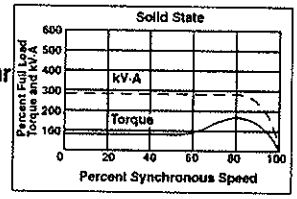
Part Winding Starter

- Special Motor with Special Starter Windings - Typical Larger Motor
- Performance Will Vary with Motor



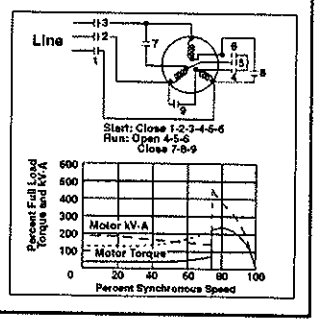
Solid State Starter

- Controls SCR Conduction
  - Controls Voltage 40-80%
  - Typically Rated as X Times Rated Current
- Becoming More Popular



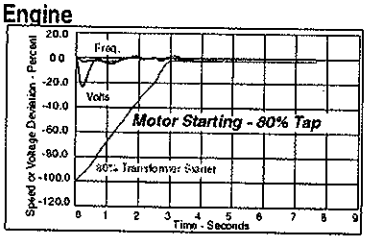
WYE-Delta Starter

- Motor Starts as WYE
- Transferred to Delta in Run
- Torque is Limited to 33% of Rated
- Requires Delta Wound Motor



Reduced Voltage Starting - Package Performance

- Reduces Inrush Current
- Reduce Load on Engine
- Example: V=.8
  P=.64



Lighting

- Incandescent
- Fluorescent
- Gas Discharge

Incandescent

- Tungsten Type
  - Inrush Current - 1.1x
- High Resistive Load (1.0 pf)
- Typical Single Phase Load (L-L / L-N)

Fluorescent

- Ballast Transformer Type
  - In Rush Current - 1.3 x
- Slightly Inductive (0.95 - 0.97 pf), at start-up
- Typical Single Phase Load (L-L / L-N)
- Possible PF correction, in extreme cases

Gas Discharge

- Halogen Type
  - In Rush Current - 1.3 x
- Slight Inductive (0.90 pf), at Start-up
- Typical Single Phase Load (L-L / L-N)
- Possible PF correction, in extreme cases

Resistive Heating

- Resistive Load
  - Inrush Current = 1.0 x
- Highly Resistive (1.0 pf)
- 3 Phase and Line to Line Loads

Non - Linear Loads

- Types
  - UPS
  - Variable Speed Drive
- SCR Controlled
  - Harmonics
  - Generator Heating - De-rate

UPS (Uninterruptible Power Supply)

- Static Type
- SCR Control
- Pulse Design Impacts Sizing
  - 6, 12, 24 Pulse Designs
  - Lower Pulse - Higher Harmonics

UPS - Continued

- EDS 70.3 - Sizing Information
- Slightly Inductive (0.94 pf)
- Typical Rated as Output KVA
  - Add Efficiency
  - Add Battery Re-charge
- Input Filtering Available

Variable Speed Drives

- Increasing Use with Power Electronics
- Displacing DC Drives / Gear Box
- Inductive Load (0.87 pf)
- Generator Impact Similar to UPS

Office Equipment

- Typical Office Profile
- Inrush = 1.0 x
- Inductive Load (0.90 pf)
- Typical Balanced Single Phase Load

Sizing Analysis

- Determine Load Steps
  - For Each Load Step
  - Add Load Step SKVA
  - Add Load Step Running kW and kVA
  - Add Impact of Previous Load Steps
  - Determine Total SKVA Voltage Dip
- Determine Size of Engine and Generator

Trans 2 Demo

Tran 2

- Intended only for use by a limited number of trained operators
- Uses an empirical engine model; models engine + governor + generator + voltage regulator interaction
- Handles only single load steps - however, it is able to handle large load steps
- Does not sum loads within a load step - you must manually do this
- Will permit modeling of many iron combinations which are not offered in our price list, including some which cannot be built
- Altitude & ambient temperature deration must be handled manually

EP Design Pro & Genset Selection Considerations

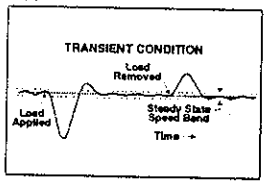
EP Design Pro

Intended for dealer/consultant use

- Uses an infinite / synchronous driver so that only generator effects are modelled
- Handles small, multiple load steps well but does not handle well large load steps
- Does a good job of summing loads within a load step
- Sizes PGS based on price list offerings
- Handles altitude & ambient temperature deratio

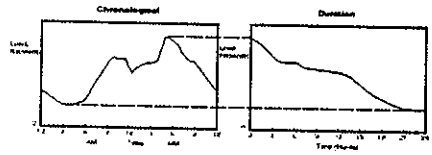
Generator vs Engine Size

- KVA vs KW Requirements
  - bKW = (eKW / Gen Eff.) + Fan Demand
- SKVA Voltage Dip - Generator
- Transient Load Changes
  - Frequency Dip - Engine
  - Voltage Dip - Generator



Load Profile

- Load List = Load Profile?
- Sized for Worst Case?
- Chronological Chart

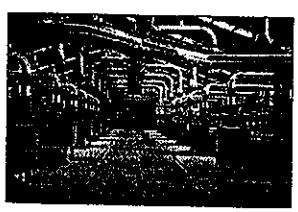


Load Type

- Linear Loads - Up to 100 % of Rating
  - Motors, Lighting
- Non-linear Loads - Up to 60% of Rating
  - Remainder 40% Linear - without De-rate
  - Harmonic Content
  - Generator Heating

Load Steps

- Load Stepping - Prioritization
  - Reduces Transients
  - Load Shedding Scheme
- Multi-Unit Timing
  - First to Rated
    - First Load Step
    - Parallel
    - Second Load Step
  - First to Rated
    - Parallel
    - One Large Load Step

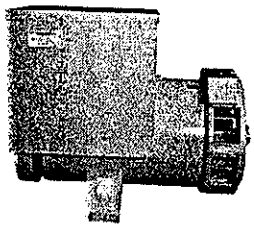


Load Balance

- 3 Phase Generator
  - 3 Phase Balance Loads
  - L - L Loads
  - L - N Loads
- Balance Phases with Similar Loads
- Size is Determined by Highest Phase Current and % Unbalance (40 % Unbalance)

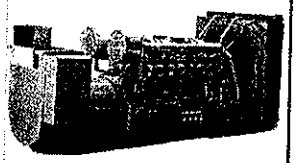
Generator Voltage Selection (600 V and Less)

- Low Voltage
  - Low Cost System Components
  - Current Limit on Multi-Units
  - 800 KVA Typical Limit for Systems Below 250V



Generator Voltage Selection (601V - 5,000V)

- Medium Voltage
  - Higher Cost System Components
  - Building Distribution - Transformers
  - Good Solution for Installations between 5 - 10 MVA



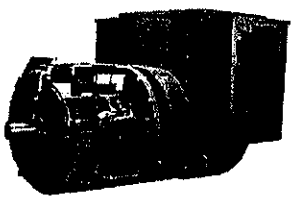
Generator Voltage Selection (6001V - 15,000V)

- High Voltage
  - High System Cost
  - Match System Input Voltage
  - Used in Large Installations (Greater than 10 MVA)



Generator Selection Considerations

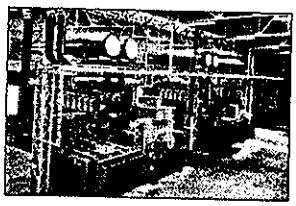
- Generator Temperature Rise
- Generator Pitch
- Insulation System
- Voltage - Number of Leads



Multi-engine Installations

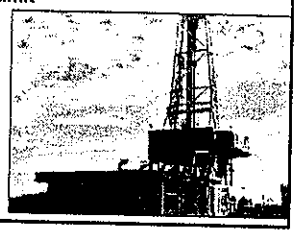
Multi-engine Installations

- When to Use Multiple Generators
- Paralleling Operation
- Synchronization
- Load Control



When to Use Multiple Engines

- N + 1 Requirements
  - Redundancy
  - Service Flexibility
- Distribution Voltage/Current Limit
- Lowest Installed Combination
- Significant Load Variation at Specific Times
- High Starting Loads
- Future Capacity
- Site Logistics/Facility Size



Paralleling Operation

- Isoc - Load Share (2301A Load Share)
  - Equal Share at Isoc Speed
  - 0-100% Operating Range
- Isoc- Droop
  - 1 Base Load at Isoc
  - 1 Swing Load w/ Droop
  - 0-100% Operating Range Possible; typically requires outside control
- Droop - Droop
  - Equal Share at Droop Speed
  - 0-100% Operating Range

Synchronization

Paralleling Unit To Bus Requires Same Frequency, Phase Rotation, and In Phase

Automatic Devices Perform Function

Manual
- Synchronizing Lights
- Synchronizing Meters

Load Control

Load Prioritization - ATS Control System

Load Acceptance Order

Load Shedding Order

Unit Starting Order

Unit Shut Down Order

Synchronization Order

Power Solution Seminar

presented by

TSL Power Systems
&
Caterpillar Asia Pacific Power Systems

Application and Installation Mechanical Issues

- Air intake and
- Exhaust system
- Cooling system
- Fuel system
- Mounting System
- Starting System
- Ventilation
- Engine Room Design Considerations

Air Intake System

- System Operation
- Combustion Air Requirements
- Air Cleaners
- Ducting
- Extreme Conditions

System Operation - Air Intake System

- Cool, Clean Air for Engine Combustion
  - Air Cleaners
  - Ducting
- Low Air Inlet Restriction Design

Combustion Air Requirements

- Engine Requires Mass Flow Not Air Flow
  - lbs / Kg of Air
- TMI (cfm, m^3/min) @ Standard Conditions
- Actual Conditions Req. Correction
  - Temp Correction
  - Altitude Correction

Air Flow vs. Mass Flow

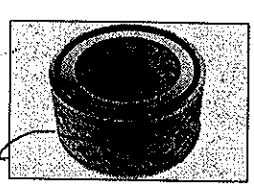
V (m^3/min) = .01486 x M (kg/hr)

or

V (cfm) = .2382 x M (lb/hr)

Air Cleaners

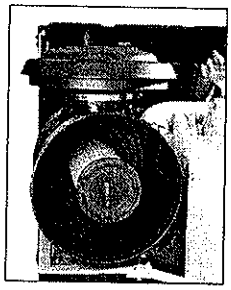
- Intake Dust = Engine Wear
  - Dust is Primary Source of Abrasive Wear
- High Efficiency, Dry Paper Elements
  - 99.5% Efficient Removing Air Cleaner Dust
- Low Restriction
- Air Service Indicators - Pressure Drop Across Filter
- Packaged in Weather Proof Housings



metal casing

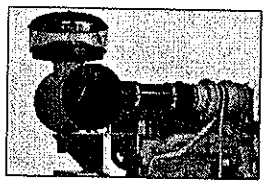
Pre-Cleaners

- Extend Service Life (3x - 7x)
- Adds Restriction (0.25 - 0.75 kPa) (1-3 inches H_2O)
- High Dust Application
  - Dirt
  - Fibers
  - Soot



Heavy Duty Air Cleaners

- Extend Service Life
- Same Protection As Standard Filter



Ducting

- Combustion Air Outside Engine Room
  - Design Target : Less Than 100° F / 38° C
- High Inlet Temperature Impacts Engine Performance
  - 1 Deg Air Inlet = 1.8 Deg Exhaust Temperature



Ducting - Design Consideration

- Filters Remain on Engine
- No Internal Fastener Hardware
- Baffles to Prevent Water Entry
- Vacuum Capability (50 in H_2O / 12.5 kPa)



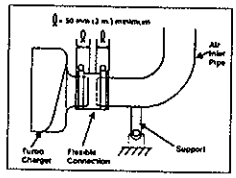
Air Intake Restriction - Ducting

- Engine Operates at Absolute Air Intake Pressure
- Ducting & Air Cleaner Restriction Additive
- Ducted System Requires more Frequent Filter Changes

Filter Change	Duct Restriction (pipe size, # bends)	Filter Life
30"	2"	= 28"*
30"	15"	= 15"

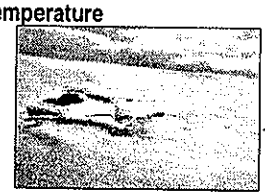
Flex Connections - Filter Housing

- Locate as Close to the Engine as Possible
- No Duct Weight on Engine Filter Housing
- Isolates Engine Vibration and Noise
- Route Rubber Flex Connections Away from Exhaust Heat



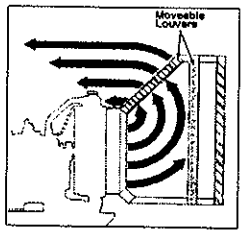
Extreme Conditions

- Extreme Cold
- Controlling Air Intake Temperature



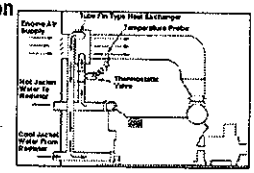
Extreme Cold - Louver Control

- Below -25° C / -13° F
- Impacts Engine Performance
  - Increased Cylinder Pressure
  - Rough Combustion @ Light Loads
- Control Intake Temperature
  - Louvers



Controlling Air Intake Temperature

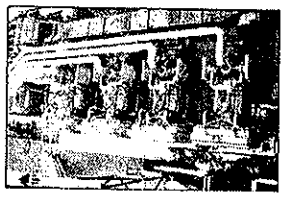
- Regulate Duct Air Temperature
  - Thermostatic Control
  - Fin Type Heat Exchanger
  - Adds System Restriction
- Does not work well under light loads



Exhaust Systems

Exhaust Systems

- System Operation
- System Elements
- Design Considerations



System Operation - Exhaust System

- Collect and Discharge Exhaust Gas
- Designed to minimize exhaust back pressure

Engine Exhaust manifold
- Dry
- Water cooled
- Airshield water cooled

Exhaust System Elements

- Engine Components
  - Exhaust Manifold
  - Turbo Charger (Turbine End)
- Manifold / Turbo Design
- Piping Design

Dry Manifolds

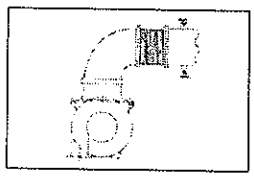
- High Surface Temperature (400-500° C / 750-950° F)
- Slip Joint (Controlled Leak)
  - Standard Configuration
- Gas Tight (No-Leak)
  - Limited Availability

Piping Design

- Flex Connection
- Turbocharger Loading
- Pipe Supports
- Piping Insulation
- Mufflers
- Exhaust Back Pressure
- Design Considerations

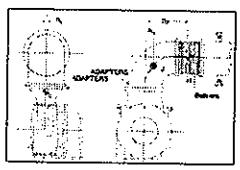
Flex Connections

- Isolates Engine From Piping
  - Vibration Isolation
  - Thermal Growth
  - Isolate Pipe Weight



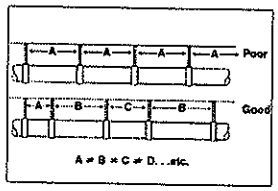
Turbocharger Loading

- Limit Force and Moment on Turbocharger
  - Not Just Weight
- A & I Manual has Limits



Pipe Supports

- Thermal Growth
- Isolation - Noise transmission through building
- Unequal Spacing (Resonance)
  of spring hangers



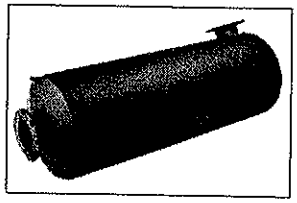
Piping Insulation

- Noise Attenuation
- Heat Rejection - Radiant
- Hot Surfaces



Mufflers

- Sizing Considerations
- Insulation

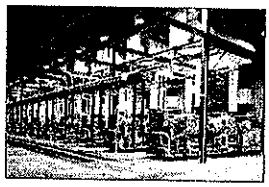


Sizing Considerations - Muffler

- Location
  - Near Engine
  - Minimizes Condensation
- Straight Inlet / Outlet Connections
  - Improved Flow through Muffler
    - 5 Pipe Diameters - Inlet
    - 2.5 Pipe Diameters - Outlet

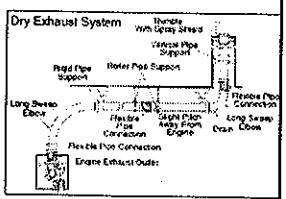
Insulation - Muffler

- Surface Noise Attenuation
- Surface Temperature



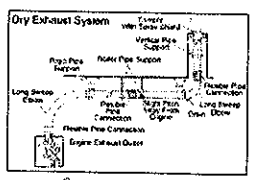
Exhaust Back Pressure

- Includes:
  - Piping
  - Muffler
  - Rain Cap
- Measurement Location
  - 3-5 Pipe Diameters of Straight Pipe After Turbocharger Outlet



Design Considerations

- Exhaust Thimbles - Mechanical / Thermal Isolation
- Long Runs Require Condensation Traps
  - Slope Toward Discharge
- Slobber - Extended Periods of Insufficient Loading
- Rain Caps
  - Flaps
  - 30º/45° Angle



• Separate exhaust pipe for each engine

Design Considerations - Multi Engine

- Never Connect Exhaust Systems
  - Condensation (Rust)
  - Turbo Free-Wheeling
- Diverter Valves — Do Not Work



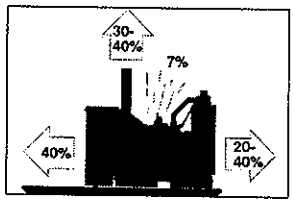
Cooling Systems

Cooling Systems

- System Operation
- Engine Considerations
- Engine Design Configurations
- Types of Cooling
- Cooling System Design Considerations
- Cooling Considerations

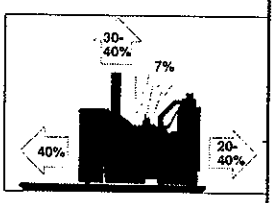
Cooling Systems - System Operation

- Engines Produce Heat as By-Product of Combustion
- Cooling System Elements
  - Jacket Water
  - After Cooler
  - Oil Cooler



Engine Considerations

- Heat Rejection - Approximate Energy Split
  - 40 % Useful Work
  - 30 - 40 % Exhaust Energy
  - 20 - 40% Cooling System Energy
  - 6-8 % Friction and Radiation
- Design Requirements
- Temperature Limits
- Pressure Limits

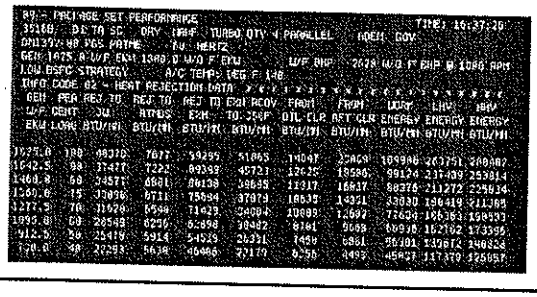


Cooling System Design Requirements

- Reject Heat
- Allow Filling Without Air Entrapment
- Provide Positive Water Inlet Pressure to Water Pump to Prevent Pump Cavitation
- Vent Air Introduced into System

Heat Rejection Data

- TMI — Safe Source



Temperature Limits - Engine Cooling

- Engine Requires Jacket Water ΔT Less Than 8.3° C (15° F)
  - Target 5.5° C (10° F) ΔT
- Must Match Flow Rate to Obtain Temperature Differential
- Excessive ΔT
  - Hot Spots in Engine
  - High Valve Temp
  - Thermal Shock

$$\text{Flow (L/min)} = \frac{\text{Heat Rejection (kW)}}{\Delta T(^\circ C) \times \text{Density (kg/L)} \times \text{Spec. Heat (kW-min/kg-}^\circ C)}$$

$$\text{Flow (gpm)} = \frac{\text{Heat Rejection (Btu/min)}}{\Delta T(^\circ F) \times \text{Density (lb/gal)} \times \text{Spec. Heat (Btu/lb-}^\circ F)}$$

	Pure Water	50/50 Water-Glycol
Density (kg/L)	.998	1.03
Density (lb/gal)	8.1	8.6
Specific Heat (kW-min/kg-°C)	0.071	0.06
Specific Heat (Btu/lb-°F)	1.0	0.85

Pressure Limits - Engine Components

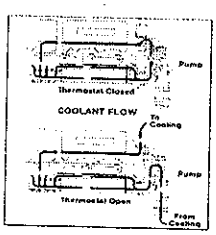
- Combined Static and Dynamic
- Component Limitations (Typical)
  - After Cooler Core
    276 kPa (40 psig)
  - Engine Block -
    276 kPa (40 psig)
  - Pump Inlet -
    173 kPa (24.7 psig)
  - Pump Outlet -
    196 kPa (28.5 psig)

Engine Design Configurations

- Temperature Control
  - Thermostat
  - Inlet Control
  - Outlet Control
- System Elements
  - Jacket Water
  - After Cooler
  - Oil Cooler

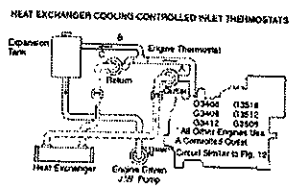
Temperature Control

- Thermostat - Controls Minimum Operating Temperature
- Two Thermostatic Control Systems
  - Inlet Regulated
  - Outlet Regulated



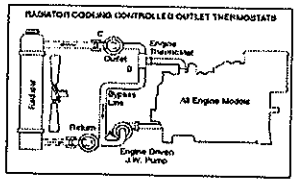
Inlet Regulated

- Provides Constant Temperature to Jacket Water Pump Inlet
- Less Thermal Shock
- Application
  - Heat Exchangers
  - High Coolant Volume Systems
  - Marine Applications



Outlet Regulated

- Provides Constant Temperature From Engine
- Simple System —
  - More Thermal Shock
  - Lower Cost
- Applications
  - Radiator
  - Low Coolant Volume Systems



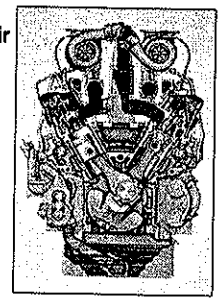
Jacket Water

- Primary Components
  - Cylinder Head
  - Wet Liner
- Secondary Component (Configuration Dependent)
  - After Cooler (JWAC)
  - Exhaust (Water Cooled)
  - Oil Cooler (Most Models)



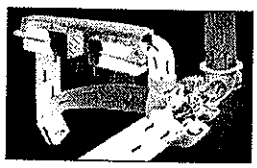
Aftercooling

- Lower Air Temperature
  - Turbocharging Increases Air Temperature
- Types
  - Jacket Water (JWAC)
  - Separate Circuit (SCAC)
  - Air to Air (ATAAC)



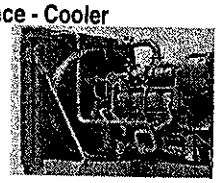
Jacket Water Aftercooling (JWAC)

- After Cooler Temp = Jacket Water Temp
- Common Water Pump with Jacket Water
- Most Common Configuration



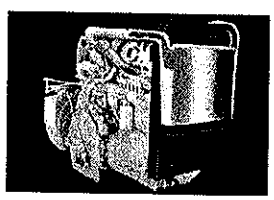
Separate Circuit Aftercooling (SCAC)

- After Cooler Temp = Water Source Temperature
- Separate Water Pump
- Improves Engine Performance - Cooler Combustion Air
  - Fuel Consumption
  - Emissions
  - Lowers Exhaust Temperature



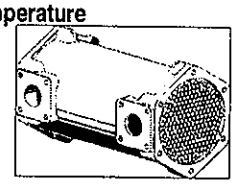
Air to Air Aftercooling (ATAAC)

- Air to Air Heat Exchanger
  - After Cooler Temp Approaches Ambient Temp
  - Best Emissions
- High Volume of Pressurized Air
  - Slower Transient Response



Oil Coolers

- Cools Engine Oil
  - Viscosity Control (Oil Film Thickness)
    - Bearing Life
- Maximum Water Inlet Temperature
  - 225° F / 110 ° C
- Not Typically Thermostatically Controlled



Types of Cooling

- Open / Closed Cooling Systems
- Engine Mounted Radiator
- Remote Mounted Radiator
- Heat Exchanger Cooling
- Submerged Pipe Cooling
- Cooling Tower

Open Cooling System – Not Recommended

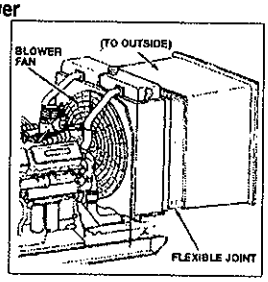
- Untreated Water Cools Engine
- Not Recommended
  - Scale Build-up
  - Corrosion
  - Erosion

Closed Cooling System

- Cooling Medium Does Not Contact Air
- Cooled By Heat Transfer
  - Coolant Water to Air (Radiator)
  - Coolant Water to Water (Co-Gen)
  - Coolant Water to Water to Air (Cooling Tower)

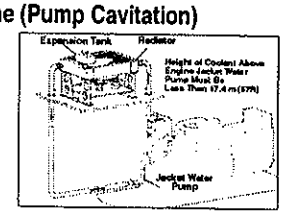
Engine Mounted Radiator

- Fan Requires Engine Power
- Mounting System
  - Fan on Engine
  - Fan on Radiator
- Fans
  - Blower Type
  - Suction Type
- Air Flow Considerations
- Radiators are a Pressurized System



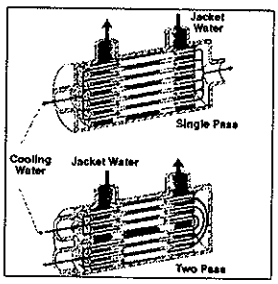
Remote Mounted Radiator

- Height Above Engine (Head Limit)
- Height Below Engine (Pump Cavitation)



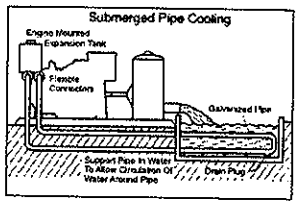
Heat Exchanger

- Shell & Tube
  - Type
    - Single Pass
    - Two Pass
  - Low Cost
- Plate Type
  - High Efficiency
  - Easy to Clean



Submerged Pipe Cooling

- Large Volume Water
- Application
  - Waste Water Treatment
  - Irrigation

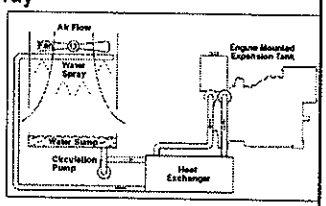


Cooling Towers

- Types
  - Open Type
  - Closed Loop Type / Evaporative
- Application
  - High Dry Bulb Temperature (37° C) (100° F)
  - Relative Humidity Below 50%
  - Sensitive to Approach Temperature
    - (Cooling Output Temperature vs. Wet Bulb Temperature)

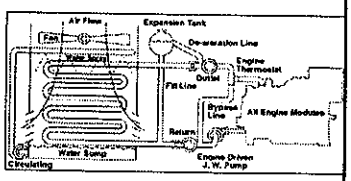
Open Type

- Requires Heat Exchanger
- Air Cools Water Spray



Closed Loop Cooling Tower

- No Heat Exchanger
- Considerations
  - Pipe Scaling
  - Water Treatment



Cooling System Design Considerations

- Heat Transfer
- Piping
- Expansion Tanks
- De-Aeration

Heat Transfer

- Closed Cooling System — Heat Transfer
  - Coolant /Air
  - Coolant / Liquid
- Considerations for Cp (Specific Heat)
  - Fowling
  - Coolant Medium

$$\text{Flow (L/min)} = \frac{\text{Heat Rejection (kW)}}{\Delta T(^\circ C) \times \text{Density (kg/L)} \times \text{Spec. Heat (kW-min.kg } ^\circ C)}$$

$$\text{Flow (gpm)} = \frac{\text{Heat Rejection (Btu/min)}}{\Delta T(^\circ F) \times \text{Density (lb/gal)} \times \text{Spec. Heat (Btu/lb } ^\circ F)}$$

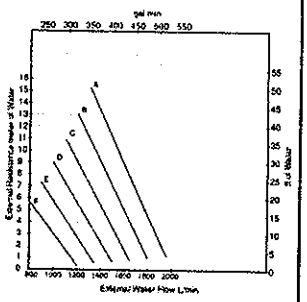
	Pure Water	50/50 Water-Glycol
Density (kg/L)	.998	1.03
Density (lb/gal)	8.1	8.6
Specific Heat (kW-min/kg-°C)	0.071	0.06
Specific Heat (Btu.lb- °F)	1.0	0.85

Piping Design

- Sizing of Pipe
- Venting
- Velocity Limits

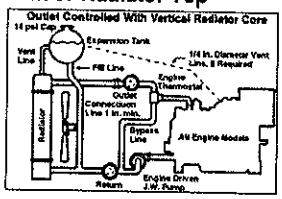
Sizing of Pipe

- Determine All System Elements
  - Auxiliaries (Heat Exchangers)
- Determine Required Flow Rate
- Iterative Process
- Pump Data in TMI
- Lines A-F = Pump Speed



Venting

- Required for All System High Points
- Join at Expansion Tank or Radiator Top Tank



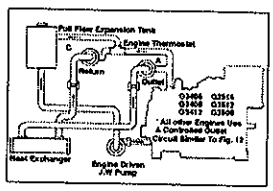
Velocity Limits

- Extends Cooling System Life
  - Minimizes Cavitation
- Performance Requirement
  - Deaeration
  - Suction

	Maximum Velocity (m/sec)	(ft/sec)
Pressurized Lines	4.5	15
Pressurized Thin-Wall Tubes	2.5	8
Suction Lines (Pump Inlet)	1.5	5
Low Velocity Deaeration Line	0.6	2

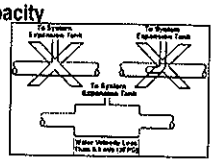
Expansion Tanks

- Multi-Purpose Function
  - Expansion Volume
  - Deaeration
  - Venting
  - Water Pump Inlet Pressure



De-Aeration

- Trapped Air in Suspension
- Effects
  - Pump Cavitation
  - Reduced Heat Transfer Capacity
- Types
  - Centrifugal
  - Low Velocity



Coolant Considerations

- Properties
- Water Treatment
- Coolant / Anti-Freeze
- Pressure & Temperature

Properties

- Minimize Corrosion
- Minimize Scale Formation
- Heat Transfer Properties
- Operational Temperature Range

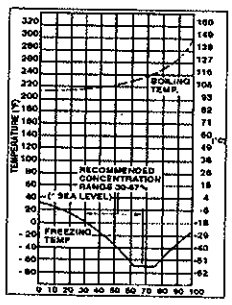
pH	5.5-9.0	
Chloride	40ppm	2.4 grains/gal
Sulfate	100ppm	5.8 grains/gal
Total Dissolved Solids	340ppm	20.0 grains/gal
Total Hardness	170ppm	10.0 grains/gal

Water Treatment

- Never Use Water Alone
- Water is Corrosive - Requires Conditioners
- Do Not Recommend Soluble Oil

Coolant / Anti-Freeze

- Increases Temperature Range
- % Concentration Impacts Performance
- Decreases Heat Rejection Capability



Operational Pressure & Temperature

- Closed Pressure Systems - 28-48 kPa (4-7 psi)
  - Increases Boiling Temp
  - Increases Heat Transfer (Higher ΔT)
- Outlet Temperature Limits
  - Continuous / Prime 210° F
  - Standby 225° F

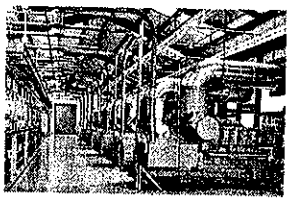
Fuel Systems

Fuel Systems

- System Operation
- Fuel Handling
- Fuel Specification

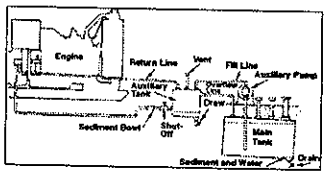
Fuel Systems - System Operation

- Clean Fuel for Engine Combustion
  - Fuel Handling
  - Filters
- Diesel
  - Combustion Fuel
  - By Pass Fuel
  - Fuel System Cooling
- Spark Ignited
  - Combustion Fuel
  - Accumulator Volume



Fuel Handling System

- Fuel Tanks
- Fuel Filters
- Design Considerations

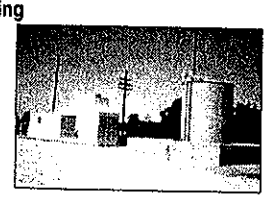


Fuel Tanks

- Bulk Tanks
  - Indoor
  - Outdoor
- Day Tanks
  - Normally Free Standing
- Package Tanks
  - Skid Tank
  - Integrated Tank
  - Sub Base Tank
  - Day Tank

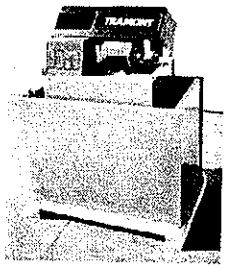
Bulk Tank

- Fuel Storage - Large Tank
  - Requires less filling
  - Provides Fuel Cooling
  - Stationary
  - May Run Several Engines



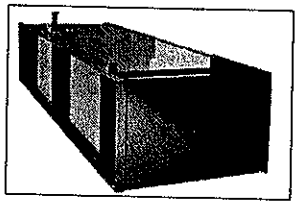
Day Tank

- Small Tank
  - May hold 8 Hours
  - Pump Fed - Optional
  - Portable - Design Dependent
  - Located Near / Under Engine
  - Free Standing - Design Dependent



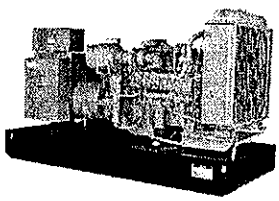
Package Tanks

- Skid Base Tank
- Sub Base Tank
- Integral Base Tank



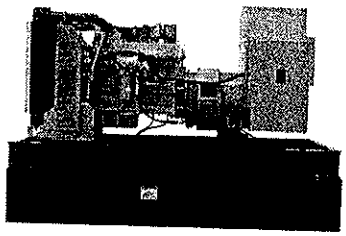
Skid Base Tank

- Heavy Duty - Single Wall
- Movable
- Main Tank



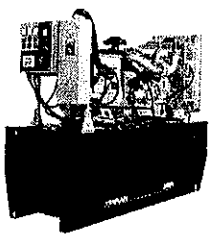
Sub Base Tank

- Main Tank
- Day Tank



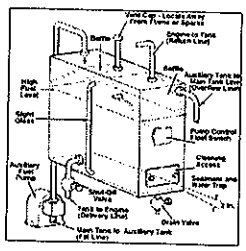
Integral Base Tank

- Portable or Stationary
- Main Tank
- Day Tank



Tank Design

- Material
  - Steel & Black Iron Preferred
  - Avoid Galvanized & Aluminum
- Allow for Draining
  - Sediment
  - Water
- Storage Temperature
- Code Dependence
- Location
  - Indoor
  - Outdoor (Tampering)
  - Above / Below Ground



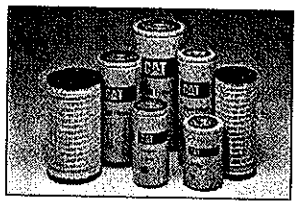
Design Considerations

- Lift Limits (3.0 m / 9 ft)
- Steel / Black Iron Pipe
- Fuel to Engine Temperature
  - Fuel Coolers
  - Fuel Heater
- Tank Size
- Leaks Provisions
- Fuel Type
  - #2 Diesel
  - Kerosene



Fuel Filters

- Fuel / Water-Sediment Separators
- Engine Mounted
  - Primary
  - Secondary
- Fuel Coolers



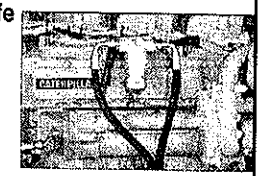
Fuel / Water Separators

- Separates Water & Sediment
- Highly Effective
- Extends Filter / Fuel System Life
- Design Considerations
  - Must Add Pressure Drop to Suction Limit
  - Location of Drain
  - Not Over Electrical Items



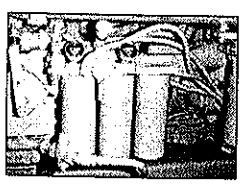
Engine Mounted - Primary

- Screens Fuel Before Transfer Pump
  - 10 - 20 micron screen
- Extends Filter & Pump Life
- Design Considerations
  - Must Add Pressure Drop to Suction Limit
  - Location of Drain
  - Not Over Electrical Items



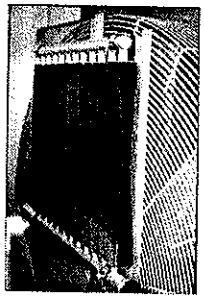
Engine Mounted - Secondary

- Filters Fuel Before Engine
  - 2 micron
  - Cat Standard
- Standard Configuration
- Duplex Configuration
  - Optional
- Design Considerations
  - Pressure Drop
  - Location - Not over electrical items



Fuel Coolers

- Fuel Temperature - Below 68° C (155° F)
- Dependent on Engine Design
- Return to Main Tank - Preferred Method
- Fuel to Air Exchanger Optional - Model Dependent



Fuel Specifications - Diesel

- Engine Designed to Operate with
  - Diesel - #2 / Furnace Oil
- Operational / Auxiliary Equipment Required
  - Kerosene
  - JET
  - Crude Oil
  - Residual
- SEBD0717 - Diesel Fuels and Your Engine

Cetane Number Precombustion Chamber Direct Injection	35 minimum 40 minimum
Viscosity	100 SUS at 38° C (100° F) max.
Pour Point	6° C (10° F) below ambient temp.
Cloud Point	not higher than ambient temp.
Sulfur	adjust oil change period for high sulfur fuel (greater) than 0.5%
Water and Sediment	0.1% maximum

Fuel Specifications - SI

- Engine Designed Per Installation
  - Energy Content
  - Methane #
  - Pressure
  - Volume
- Fuel Types
  - Natural Gas
  - Propane
  - Low BTU Fuels
    - Landfill
    - Digestor

Mounting Systems

Mounting Systems

- System Operation
- Foundations
- Bases
- Vibration



System Operation

- Support Package
- Maintains Alignment
- Isolates Vibration



Foundations

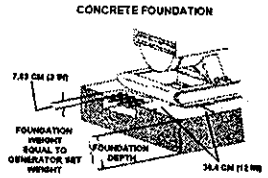
- Soil, Gravel, Rock
- Concrete
- Design Considerations

Soil, Gravel, Rock

- Acceptable
  - Firm, Dry
  - Load Distribution

Concrete

- Support Weight & Dynamic Load
- Exceed Outside Dimension by 12 in. (304mm)



Design Considerations

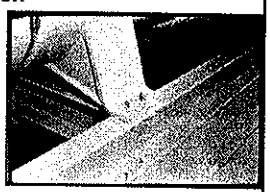
- With Vibration Isolation
  - Static Force = Weight
- Without Vibration Isolation
  - Static Force + Dynamic Force = 1.25 x Weight
- Parallel Operation
  - Static Force + Dynamic Force = 2 x Weight

$$FD = \frac{W}{D \times B \times L}$$

FD = foundation depth
W = total weight
D = density of concrete (2402.8 kg/m³, 150 lbm/ft³)
B = foundation width
L = foundation length

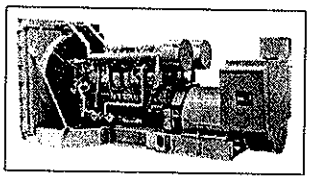
Bases - Purpose

- Maintain Alignment
- Withstand Torque Reaction
- Accommodate Thermal Growth



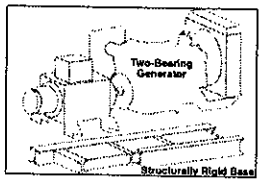
Maintain Alignment

- Shipping Ease
- Installation Time (Minimize Re-alignment)
- Portable



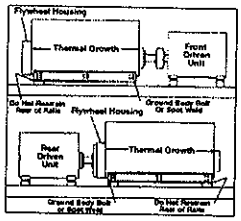
Withstand Torque Reaction

- Single Bearing & Two Bearing (Close Couple)
  - Torque Reaction - Thru Flywheel Housing
- Two Bearing
  - Torque Reaction – Thru Base



Accommodate Thermal Growth

- Cold to Operating Condition 0.1 inch (2.3mm)
- Bolt Hole Clearances
- Alignment Done At Operational Temperature

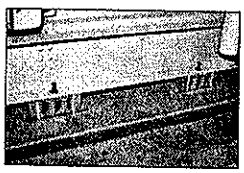


Vibration

- Linear
  - Vertical and/or Horizontal Forces
- Torsional
  - Rotating Mass Elastic System with Periodic Forces (two or more masses attached to elastic shaft)

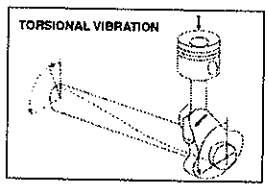
Linear Vibration

- Bulk Isolators (Uncommon)
- Vibration Isolators (Common)
  - Rubber Type
  - Spring Type
    - Seismic



Torsional Vibration

- Engine/Generator Match at Factory
-
- Torsional Vibration Analysis (TVA)
  - Engine Damper
  - Generator Rotor
  - Flywheel Inertia
- Non Price List Auxillary Equipment Requires TVA



Starting System

Starting System

- System Operation
- Basic Starter Principles
- Electric Starting System
- Air Starting System
- Other Starting Systems
- Starting Aids

System Operation - Starting System

- Match System Design to Application Requirement
  - Emergency / Fire Pump - Critical
  - Auto - Start / Remote Unmanned
  - Manual Start

Variables that Affect Starting

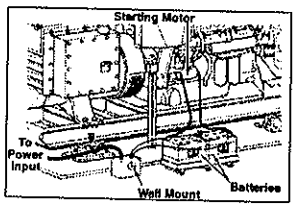
- Engine & Generator Size
- What Else Is The Starter Turning?
- Fuel Composition
  - Diesel
  - Gas
- Temperature (Ambient)
  - Jacket Water
  - Oil Temperature
  - Air Intake

Starting Requirements

- Number of Starting Attempts
- Duration of Starting Attempts
- Limits
  - Air Tank Sizing
  - Electric Starter Heating

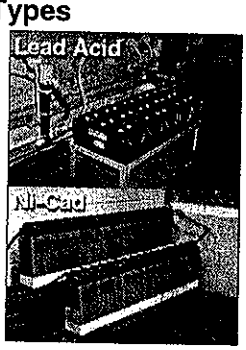
Electric Starting System

- Battery Types
- Battery Sizing
- Cable Sizing
- Charging System
- Installation Considerations



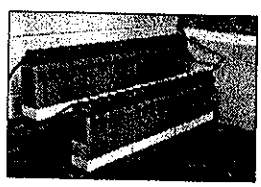
Battery Types

- Lead Acid
  - Lowest First Cost
  - High Output
- NI-CAD
  - Long Life
  - Minimum Maintenance
  - Higher Cost



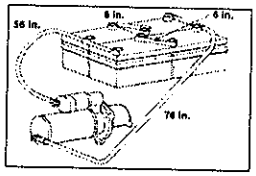
Battery Sizing

- Number of Cranks/Duration
- Battery Temperature
  - Keep Batteries Warm
  - 32°C/90°F Maximum
- Re - Charge Rate



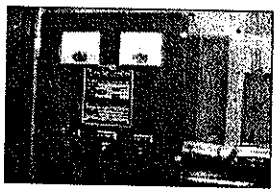
Cable Sizing

- Maximum Resistance Limits (Length & Size)
  - 12V = 0.0012 OHM
  - 24V = 0.0020 OHM
  - 32V = 0.0020 OHM
- Must Include Cable and Connection Loss (0.0001 OHM)



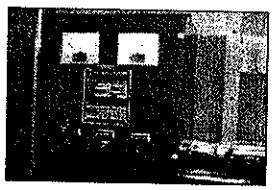
Charging System - Static

- Trickle
  - Continuous Service
  - Low Cost
- Float / Equalize
  - Line/Load Regulation
  - Maximum Battery Life
  - Higher Cost



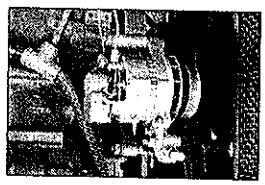
Charging System - Static

- Trickle
  - Continuous Service
  - Low Cost
- Float / Equalize
  - Line/Load Regulation
  - Maximum Battery Life
  - Higher Cost



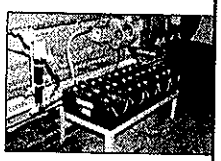
Charging System - Dynamic

- Alternator - Engine Mounted
  - Limited Function - Charge Time = Run Time
  - Disconnect Battery Charger when Operating w/Alternator



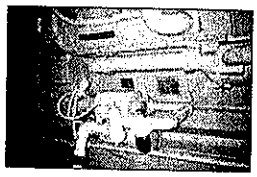
Installation Considerations

- Place Battery Near Starter
  - Minimize Voltage Drop
- Locate Batteries for Visual Inspection and Maintenance
- Isolate Batteries from Spark Sources and Vibration
- Mount Level on Non-Conducting Material



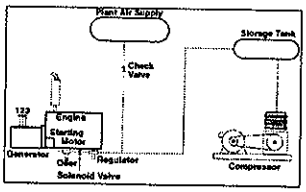
Air Starting System

- Components
- Design Considerations



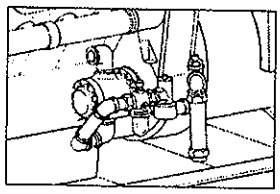
Components

- Air Starter
- Air Supply
- Regulator
- Oiler / Lubrication



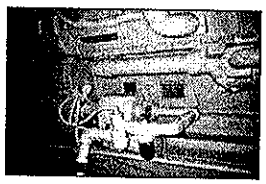
Design Considerations

- Free Air Capacity (# of Starts / Duration)
- Regulated Compressed Air (769kPa / 110psi)
- Cold Temperature
  - Condensate Freezing
- Pipe Sizing
- Cleanliness
  - Solid
  - Liquid
- Exhaust
  - Oil Laden
  - Gas



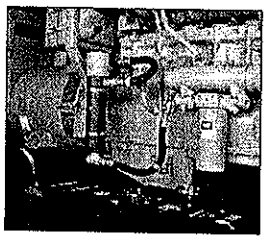
Other Starting Systems

- Electric / Air
- Auxiliary Engine
- Hydraulic



Starting Aids

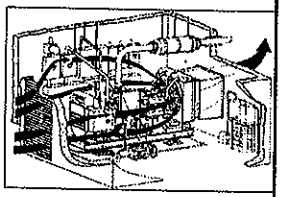
- Jacket Water Heaters
- Diesel Fired Heater
- Ether Aids
- Battery Heaters
- Oil Heaters
- Additional Starters



Ventilation

Ventilation

- System Operation
- Air Requirements
- Design Considerations

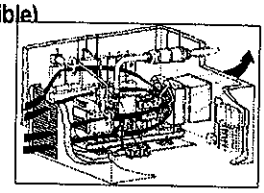


System Operation - Ventilation

- Provide Air For Engine Room
  - Most Efficient Manner
  - Most Cost Effective

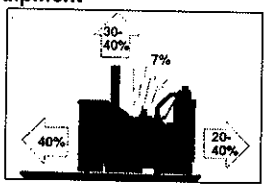
Ventilation Air Requirements

- Radiant Heat Rejection
- Combustion Air (Possible)
- Crankcase Fumes (Possible)
- Radiator Cooling (Possible)



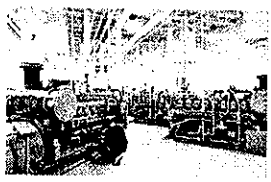
Radiant Heat Rejection

- 6-8% of Rated Energy Input
  - Size for Full Rating
- Consider Auxiliary Equipment
- Consider Exhaust System Radiant Heat Rejection



Combustion Air - Possible

- Must Include if not Ducted From Outside
- Quantity Required - Standard Conditions
  - Engine Requires Mass Flow
    - Temperature
    - Altitude
- Engine Room Temperature Rise Added to Ambient

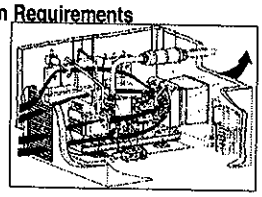


Crankcase Fumes - Possible

- Dependent on Disposal System
- Ingestive - Not Included
- Non-Ingestive
  - Included if Separate Discharge Ventilation Duct
  - Not Included if Direct Discharge

Radiator Cooling - Possible

- Ambient Temperature Rise - Engine Room
  - Radiant Heat Rejection Reduces Radiator Ambient Capability (4 Deg - C / 7 Deg - F Typical)
- Must Compare Ventilation Requirements to Radiator Requirements
- Radiator Fan Performance Dependent on System Restrictions



Design Considerations

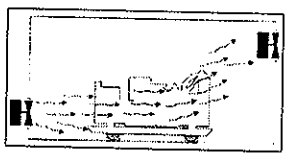
- Air Routing
  - Horizontal Air Flow
  - Air Curtains
  - Vertical Air Flow
- Engine Room Temperature
- Air Velocity

Design Considerations

- Air Routing
  - Horizontal Air Flow
  - Air Curtains
  - Vertical Air Flow
- Engine Room Temperature
- Air Velocity

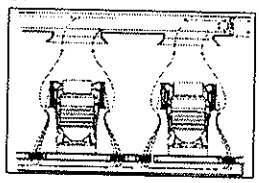
Horizontal Air Flow

- Most Common
- Across Heat Sources
- Flow Rear to Front
  - Generator Cooling
  - Air Intake - Engine



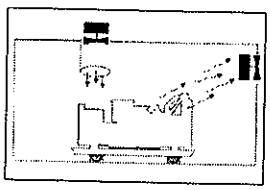
Air Curtains

- Very Effective - 1/2 Air Flow Required Compared to Horizontal
- Increased Installation Cost
- Does Not Work With Radiator Cooled Systems



Vertical Air Flow

- Least Desirable
- Not Very Effective
  - Natural Heat Rise
  - Stagnant Air Locations



Engine Room Temperature

- Operator Comfort
- Generator Cooling Air Temperature
- Auxiliary Equipment Temperature Capability
- Temperature Extremes - Ambient
  - Hot
  - Cold

Air Velocity

- Operator Comfort
- Inlet Velocity Limits
  - Water Entry
  - Louver Sizing
    - Added Restriction

(fpm)	m/min	Conditions
50	15.2	Offices, seated worker
100	30.5	Factory, standing worker
150	45.7	Capture velocity, light dust
1300	396	Capture velocity, rain
200	61.0	Maximum continuous exposure
1-2000	305-610	Maximum intermittent exposure

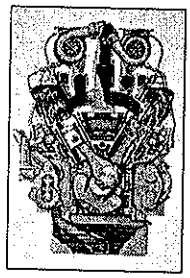
Crankcase Ventilation

Crankcase Ventilation

- System Operation
- Design Considerations

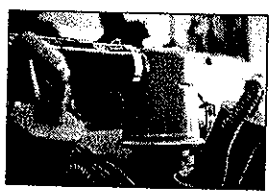
System Operation - Crankcase Ventilation

- Combustion Gas passes by Piston Rings
- Must Relieve Crankcase Pressure
  - Oil Leaks
  - Seals



Design Considerations

- Emissions
- Ingestive
- Non-Ingestive
- Blow-By Volume

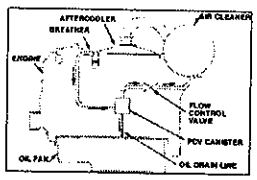


Emissions - Crankcase Fumes

- Exhaust By-Product
- Emissions Permiting
  - Typically Included Crankcase Fumes

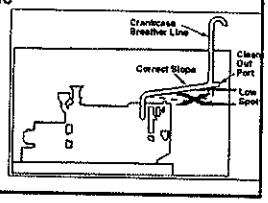
Ingestive Systems

- Engine Burns Blow-By
- Design Considerations
  - Fowling
    - Turbocharger
    - Aftercooling
  - Water in Oil (Combustion By-Product)



Non-Ingestive System

- Vent to Outside
- Design Considerations
  - Separate for Each Engine
  - Avoid Low Places — Upward Slope



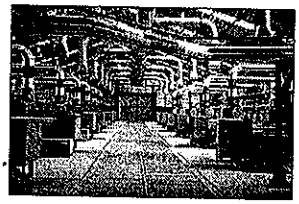
Blow-By Volume

- Data in TMI (New Engine)
- Increases with Wear (2x)
- Do Not Exceed 12 mm (0.5 in) Water Column
  - Add Breathers
  - Increase Discharge Line Size

Engine Room Design Considerations

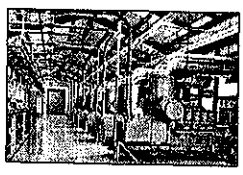
Engine Room Design Considerations

- Operational Modes
- Serviceability
- Engine Room Conditions
- Future Expansion



Operational Modes

- Single Use
  - Dedicated Genset Room
- Multi - Use
  - Share with Other Equipment
    - Operational Conditions
    - Repair/Maintenance Conditions

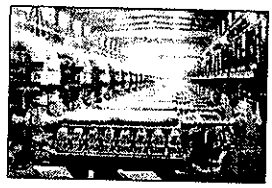


Serviceability

- Lifting - Service
- Clearance
- Access
- Service Convenience
- Load Testing
- Emergency Back-up

Lifting - Service

- Overhead Clearance
- Portable Equipment Access



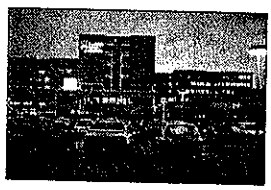
Clearance

- Side Clearance
  - Wall = Engine Width
  - Engine to Engine = Engine Width
- Front/Rear Clearance
  - Camshaft Removal
  - Generator Rotor



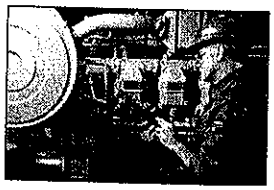
Access

- Building Access
  - Preventive Maintenance
  - Tools/Oil
- Large Repair Items
  - Weight Constraints
  - Size Constraints



Service Convenience

- Water
- Electric Power Outlets
- Air
- Lighting
- Distance to Service Truck



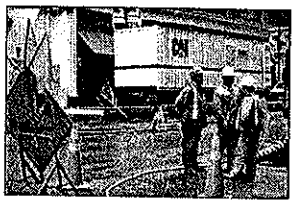
Load Testing

- Cable Routing
- Permanent Load Bank
  - Package Mounted
  - Containerized



Emergency Back-up

- System Connections for Emergency Back-up
  - Switch Gear
  - Cable Routing



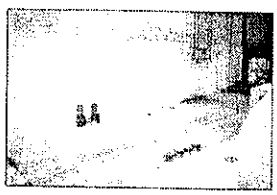
Engine Room Conditions

- Operational Mode
- Temperature
- Noise
- Air Velocity
- Air Pressure



Future Expansion

- Space for Future
- Considerations
  - Existing Installation Integrity
  - Lifting Constraints



Approximate Engine room size

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Room size (approximate)

Item	Model	Rating Kva	Heat reject to atmo (kw)	Exhaust muffler size	Combustion air flow (m3/min)	Ventilation rate (m3/min)	Discharge opening (m xm)	Air intake opening (mxm)	Estimated room size L X W X H , m
1	3406	410	93.66	6 inch	23	739	1.84	2.3	6.3 x 3.7 x 4.0
2	3456	455	103.38	6 inch	26.4	817	2.04	2.56	6.7 x 3.8 x 4.1
3	3412	810	138.96	8 inch	48.8	1111	2.77	3.46	7.0 x 4.3 x 4.0
4	3508TA	910	168.91	10 inch	63.1	1351	3.38	4.22	7.5 x 5.0 x 4.5
5	3508B	1000	116.98	12 inch	67.3	962	2.4	3.0	7.5 x 5.0 x 4.5
6	3512TA	1275	160.65	12 inch	92	1320	3.3	4.2	8.0 x 5.0 x 4.6
7	3512B	1500	154.75	14 inch	108.3	1292	3.2	4.2	8.0 x 5.0 x 4.6
8	3512B HD	1700	164.68	14 inch	126.9	1386	3.5	4.4	8.0 x 5.0 x 4.6
9	3516TA	1825	214.43	14 inch	115.7	1755	4.4	5..5	8.5 x 5.5 x 5
10	3516B	2000	178.69	16 inch	126.6	1493	3.7	4.7	8.5 x 5.5 x 5
11	3516B HD	2275	199.19	18 inch	152.7	1676	4.2	5.3	8.5 x 5.5 x 5

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Electric Power Application and Installation Guide

Air Intake System

LEBX0027-01

WHERE THE WORLD TURNS FOR POWER

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Air Intake System

A well designed air intake system provides cool, clean air while minimizing inlet air pressure drop to the turbocharger. Normally this can be accomplished by using engine-mounted air cleaners. Some circumstances require ducting combustion air from outside the engine room. There are also needs for special filtration and ducting due to fumes, dust, airborne mists, ambient temperature or even altitude. Any inlet restriction can cause an engine to be derated.

Efficient engine combustion is based on the proper mass flow ratio of fuel and air. The ratio is mass based and not volume based. It is always important to remember this fact when considering the impact of installations with elevated altitude and temperature.

Combustion Air Requirements

Depending on the engine model and rating, an engine requires approximately 0.07 m^3/min (1.84 cfm) of air per brake horsepower for combustion. Consult TMI (Technical Marketing Information) for exact data on a specific engine. A better way is to evaluate the required air mass flow, which can be as high as 32 kg (lbs) to 1 kg (lb) of fuel. Volumetric (V) and mass (M) intake air flow have the following general relationships;

V (m^3/min) = 0.01486 × M (kg/hr) @ 40°C, or
V (cfm) = 0.2382 × M (lb/hr) @ 105°F

Air Cleaners

Dirt is the major source of engine wear. Any moving engine part may be subjected to accelerated wear when dirt is contained in the inlet air. Since the air intake is one of the primary locations where dirt may enter an engine, frequent replacement of air cleaners, (and increased maintenance costs) may be needed.

Dirt may be introduced into the piping at initial assembly, enter the system during the filter change, be sucked into leaks in the piping system, or be carried by the intake air flow.

Engine wear tests have shown that dust particles under 1 micron (0.00004 in.) size have little effect on the engine. 99.5% of this dust will pass out through the engine exhaust. 1 micron to 10 micron (0.00004 to 0.0004 in.) size dust has a measurable effect on engine life. Put another way, inlet air dust particle sizes larger than bearing oil film thicknesses will seriously affect bearing and piston ring life.

Well designed air cleaners are the most efficient way of assuring that clean air enters the engine and harmful particles are not distributed through the engine systems.

Air Cleaner Efficiency

Air cleaner selection should be based upon the following air cleaner efficiency test:

A satisfactory air cleaner must meet the requirements of the SAE (Society of Automotive Engineers) Air Cleaner Test Code J726a, Section 8.1. The filter should have 99.5% minimum efficiency as calculated following test code with additions and exceptions as follows:

- Air flow corrected to m^3/min at 99.9 kPa pressure and 32.2°C (ft^3/min at 29.6 in. Hg pressure and 90°F).
- Use sonic dust feeder.
- Dust quantity determined by light-duty class.
- Filter to be dried and weighed in an oven at 93°C to 107°C (200°F to 225°F) before and after test.
- Use AC fine dust.

AC fine dust is defined as follows:

Particle Size (microns)	% Total Weight
0 – 5	39 ± 2
6 – 10	18 ± 3
11 – 20	16 ± 3
21 – 40	18 ± 3
41 – 80	9 ± 3

99.5% filtration of the AC fine dust has been determined to be a practical combination of the kind of dirt likely encountered in service, and will result in an air cleaner efficiency expected to give optimum engine wear life.

Air Cleaner Design Requirements

Following the procedure will establish sufficient control on the filter media filtering ability of the tested air cleaner, but there are other design variables needing further control which include:

- Choose filters supplied by manufacturers that can best provide quality control.
- Design filters to be resistant to damage at initial assembly or during cleaning. If end seal and filter media are subject to damage, dust leakage into the engine can result.

Precleaners

Precleaners extend filter service periods. They impose a 0.25-0.75 kPa (1-3 in. H_2O) additional restriction to the system, but can increase filter life from three to seven times. Precleaners are particularly helpful in applications where heavy amounts of dust will significantly reduce the life of a standard air filter. Precleaners, however become an added maintenance item.

Caterpillar Air Cleaners

All Caterpillar engines come standard with engine mounted air cleaners.

Most standard Caterpillar air cleaners consist of high efficiency, dry paper elements, packaged in low restriction, weather resistant housings. They remove 99.5% of AC fine dust and are designed to minimize dust entrance during filter changes.

Heavy-Duty Air Cleaners

Heavy-duty air cleaners provide the same protection as standard filters but allow extension of filter change periods. Service periods are six to seven times that of standard air cleaners.

Two-Stage Air Cleaners

For conditions where dust concentrations are higher or where increased service life is desired, air cleaners are available with a precleaning stage. This precleaner imparts a swirl to the air, centrifuging out a major percentage of the dirt particles which may be collected in a reservoir or exhausted out on either a continuous or an intermittent basis.

Exhaust Ejector

In extremely dusty environments where dust and other particles cause air cleaners to plug up quickly an improved precleaner has been designed. It is an integral part of any exhaust aspirated air cleaner system and will extend the service life of the air cleaner elements.

Using a louvered body design, the precleaner has a very high separator efficiency. It will separate and remove over 90% of the dirt and chaff from the incoming air stream.

The air comes into the precleaner where the dirt and chaff is removed from the air (see Figure 1). With a slight vacuum, the dirt is sucked directly through the muffler into the exhaust flow and does no harm to the engine.

The remaining dust in the air is then removed by the air cleaner before it enters the turbo.

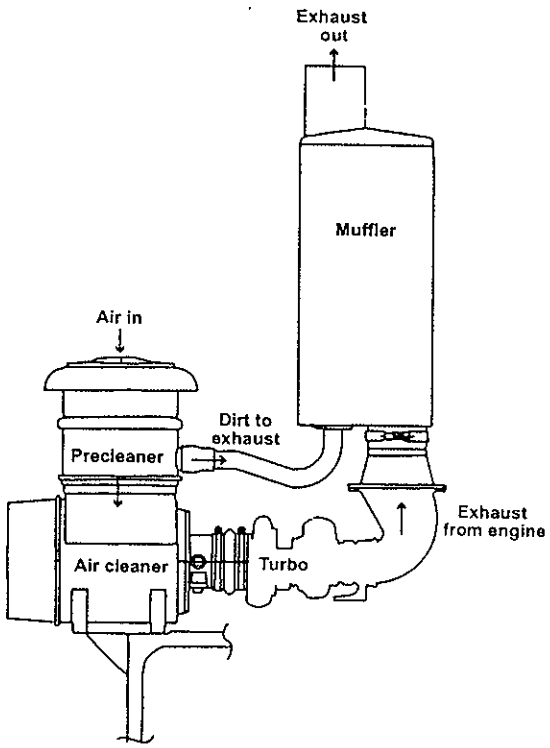


Figure 1. Exhaust aspirated air cleaning system.

With this system, consideration must be made regarding the location of exit of the exhaust and the surroundings, as there may be particles in the engine exhaust.

Oil-Bath Air Cleaners

Oil-bath air cleaners, while sometimes required to meet customer specifications, are not recommended by Caterpillar. At best their efficiency is 95% as compared to 99.5% for dry-type filters. Their relative ease of service and insensitivity to water are advantages easily outweighed by disadvantages, such as:

- Lower efficiency
- Low ambient temperatures, low oil level, high restriction @ low air flow (such as at low idle), and installed tilt angle may lessen efficiency further.
- Oil carry-over, which is the oil becoming airborne in the air intake system whether resulting from overfilling or increased air flow, can seriously affect turbocharger and engine life, and may actually become an engine fuel.

Service Indicator

Vacuum sensing devices designed to indicate the need for air cleaner servicing are commercially available and when added to the air intake system, serve a vital function. There are two types of sensing devices, both recommended for use.

The first type incorporates a trip lock device which indicates that the air cleaner condition is either satisfactory or when in need of service, it typically will have a red display. This type of mechanism uses a spring loaded diaphragm to measure the pressure differential between the clean and dirty side of the air cleaner. The trip or latching type is preferred.

The second type is a direct reading differential gauge. One end is connected to the inlet duct. The second recommended connection point would be on the straight length of pipe immediately upstream of the turbocharger.

Ducting

When ducting is necessary to obtain cooler or cleaner air, the filters should remain on the engine to prevent harmful dirt from leaking into the engine through ducting joints. When air cleaners must be remote-mounted, it is extremely important that all joints be air tight to prevent ingestion of dirt.

Design Considerations

Routing

Give careful attention to routing and support of air inlet ducting, especially on the larger engines, where overhead cranes are used to service the engines.

In addition to locating the inlet so that the coolest possible air from outside the engine compartment is used, and engine exhaust gas is not drawn in, it is best to locate the air piping away from the vicinity of the exhaust piping when possible to do so. Air temperature to the air inlet should be no more than 11°C (20°F) above ambient air temperature.

Section Before Turbocharger

When possible, the piping to the turbocharger inlet should be designed to ensure that air is flowing in a straight, uniform direction into the turbocharger compressor. A straight section of at least two or three times pipe diameter is recommended because air striking the compressor wheel at an angle can create pulsations which can cause premature compressor wheel failure.

Pressure Limit

Design inlet ducting to withstand a minimum vacuum of 12.5 kPa (50 in. H_2O) for structural integrity.

Diameter

Piping diameter should be equal to or larger than the air cleaner inlet/outlet and the engine air inlet. A rough guide for pipe size selection would be to keep maximum air velocity in the piping to 10 m/s (2,000 fpm). Higher velocities will cause high noise levels and excessive flow restrictions.

Pipe Ends and Hose Connections

Beaded pipe ends at hose joints are recommended. Sealing surfaces should be round, smooth, and free of burrs or sharp edges that could cut the hose. The tubing should have sufficient strength to withstand the hose clamping forces. Avoid the use of plastic tubing since it can lose much of its strength when subjected to temperatures of 149°C (300°F) or above. Either "T" bolt-type or SAE-type F hose clamps providing 360° seal should be used. They should be top quality clamps. Double clamps are recommended on connections downstream of the air cleaner.

Flexible Connections

Flexible connections are required to isolate engine vibration and noise from the ducting system. The flex should be as close to the engine as practical. The flex engagement with the air intake duct should be a minimum of 50 mm (2 in.) and a maximum of 200 mm (8 in.). Care must be used to prevent exhaust piping heat from deteriorating rubber flex connections and should incorporate the same clamping guidelines as "Pipe Ends and Hose Connections".

Duct Support

Provide adequate support for duct work so that its weight is not borne by the air cleaner on engine-mounted air cleaners, or by the turbocharger on remote-mounted air cleaners.

If required, all piping must be designed and supported to meet seismic requirements.

Turbocharger Loading

When remote-mounted air cleaners are used, turbocharger loading from the weight of the air inlet components becomes a concern. The turbochargers are not typically designed to support any additional weight beyond standard factory attachments. Make the flexible connection directly to the turbocharger air inlet, as in Figure 2. All duct work to that point must be supported.

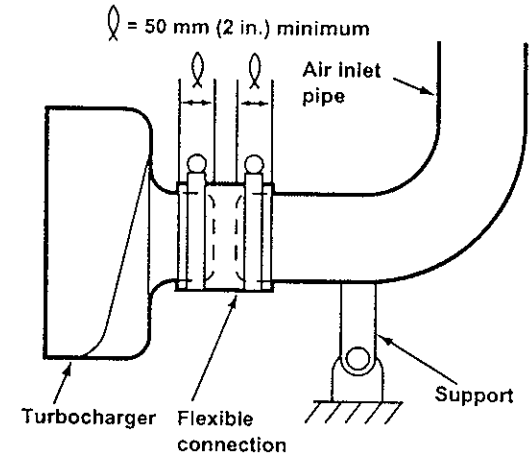


Figure 2. Flexible connection to turbocharger.

Joining Two Turbochargers

When duct work feeding two turbochargers is combined to form a single duct, a steadying zone of the length $L_S > 5 \times D$ must be provided after the dividing joint, see Figure 3.

The transitions from Sections 2-2 to 3-3 and from 1-1 to 2-2 will have many variations due to turbocharger hardware and installation site design. Regardless of the transition selected, the steadying zone must be provided.

Cleanliness

On remote-mounted air cleaners, the air intake ducting must be cleaned of all debris prior to start-up. The ducting material must be designed and constructed such that prolonged operation will not result in materials coming loose and entering the turbocharger.

Install an identifiable blanking plate ahead of the turbocharger to prevent debris from entering during initial installation of the unit. Remove the plate prior to starting the engine.

Make provisions to inspect the ducting for cleanliness just prior to initial start-up.

Inlet Air Duct Insulation

Insulation may be needed on the intake ducting for remote mounted air cleaners. Insulation reduces turbocharger noise emitted into the engine room and will minimize pre-heating of intake air.

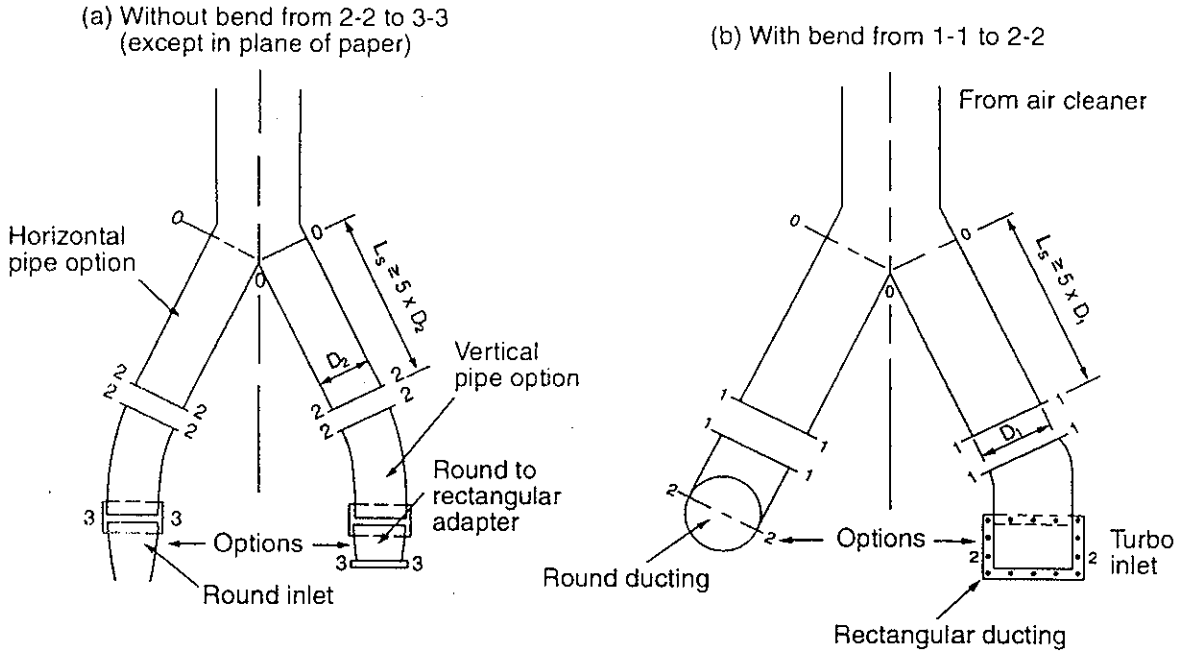


Figure 3. Pipe design when joining turbochargers.

Air Intake Restriction

Excessive vacuum on the inlet side of the turbocharger (or the air inlet on naturally aspirated engines) can result in reduced engine performance. Therefore, the air intake system's total restriction (including dirty filters, duct work, vents, etc.) is limited depending on engine model, rating and air configuration.

The gas engine total air intake restriction should not exceed 3.7 kPa (15 in. H_2O) with dirty air cleaner elements for all engine models except the G3516B. The G3516B engine can operate up to 2.5 kPa (10 in. H_2O) without derate. (See engine technical data for engine performance with an air inlet restriction above 2.5 kPa [10 in. H_2O]). The air intake restriction for all gas engine models should not exceed 1.3 kPa (5 in. H_2O) with clean elements. The air intake restriction for diesel engines can be found in TMI.

In order to maximize air filter life, it is important to keep total duct head loss (restriction) below 0.5 kPa (2 in. H_2O) for maximum filter life. Every additional restriction caused by the air inlet system subtracts from air filter life. The filter life is dependent on the absolute pressure differential between the turbocharger compressor inlet and atmosphere.

Calculate Duct Head Losses by the Following Formulas:

$$P\ (kPa) = \frac{L \times S \times Q^2 \times 3598805.2}{D^5}$$

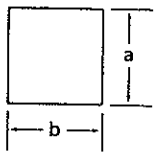
$$P\ (psi) = \frac{L \times S \times Q^2}{5184 \times D^5}$$

P = Restriction (kPa), (psi)
kPa = 0.0098 × mm H_2O
psi = 0.0361 × in. H_2O
L = Total equivalent length of pipe (m), (ft)
S = Density of air (kg/m^3), (lb/ft^3)
Q = Inlet air flow (m^3/min), (cfm)
D = Inside diameter of pipe (mm), (in.)

$$S\ (kg/m^3) = \frac{352.5}{\text{Air Temperature} + 273°C}$$

$$S\ (lb/ft^3) = \frac{39.6}{\text{Air Temperature} + 460°F}$$

If duct is rectangular



Then

$$D = \frac{(2 \times a \times b)}{a + b}$$

To obtain equivalent length of straight pipe for various elbows:

$L = \frac{33D}{X}$ Standard Elbow (Radius = Pipe Diameter)

$L = \frac{20D}{X}$ Long Elbow (Radius > 1.5 Diameter)

$L = \frac{15D}{X}$ 45° Elbow

$L = \frac{66D}{X}$ Square Elbow

Where X = 1000 mm or 12 in.

As can be seen, if 90° bends are required, a radius of two times the pipe diameter helps to lower resistance.

Example:
An example of the air intake restriction's duct head loss:

A 3412 packaged genset has an inlet flow of 36.7 m³/min (1292 cfm) (TMI) with pipe configuration consisting of 3 m (10 ft) of straight length pipe along with 2 standard elbows and a long elbow. The pipe has a diameter of 152.4 mm (6 in) and the temperature of the air is 55°C (131°F). What is the duct head loss from this air intake configuration?

Total equivalent length:

$$L = 3 + 2 \times \left(\frac{33 \times 152.4}{1000}\right) + \frac{20 \times 152.4}{1000} = 16.1 \text{ m}$$

$$L = 10 + 2 \times \left(\frac{33 \times 6}{12}\right) + \frac{20 \times 6}{12} = 53 \text{ ft.}$$

Density of air:

$$S = \frac{352.5}{55 + 273} = 1.075 \text{ kg/m}^3$$

$$S = \frac{39.6}{131 + 460} = 0.067 \text{ lb/ft}^3$$

Duct head losses:

$$P = \frac{16.1 \times 1.075 \times 36.7^2 \times 3598805.2}{152.4^5} = 1.02 \text{ kPa}$$

$$P = \frac{1.02}{0.0098} = 104 \text{ mm } H_2O$$

$$P = \frac{53 \times 0.067 \times 1292^2}{5184 \times 6^5} = 0.147 \text{ psi}$$

$$P = \frac{0.147}{0.0361} = 4.07 \text{ in. } H_2O$$

Cold Conditions

Air Cleaner Icing

Air cleaner icing can occur in saturated air environments when the dew point of the ambient air is near freezing. Small disturbances to the air such as velocity and pressure changes at the air cleaner inlet reduce the moisture-holding capacity of the air. This results in moisture condensation and ice crystal formation. The ice buildup increases the pressure differential across the air cleaner. Eventually, a stage is reached where the pressure differential remains constant even though ice buildup may continue. Power loss and increased fuel consumption can result during these periods. Severe engine damage or air filter structural failures can occur if this condition is not corrected.

Several techniques may be used to overcome air cleaner icing. One solution is to heat the intake air slightly. It is not necessary to heat the air above freezing. The air requires only enough heat to be above the dew point. Heat can be supplied to the air cleaner housing by ducting engine room air. Heated air from around the exhaust piping or muffler, or electrical heating tape may also be used.

Extreme Cold

Heated engine room air may be required (for starting purposes only) in applications at very cold ambients, -25°C (-13°F). This assumes combustion air is being drawn from outside the engine building, and the engine is preconditioned with pre-heaters for metal, water and oil temperatures of 0°C (32°F). Admitting engine room air must be done without the possibility of allowing dirt or debris into the air inlet system of the engine.

Controlling Air Temperature

One method of controlling air supply temperature is to regulate the engine room temperature. However, this approach is not recommended. It is difficult to regulate an engine room to a temperature that is both comfortable to work in and contains enough volume to provide a constant air temperature to the engine. For example, an installation expecting a 32°C (90°F) ambient temperature, will need to regulate the engine room to about 38°C (100°F) at all times. Also, engine rooms having large service doors that, at times, must be left open while the engines are running, will have a hard time maintaining air inlet temperature. Low pressure gas engines must maintain a steady air inlet temperature to maintain the proper air/fuel ratio, which will impact engine performance.

The preferred method is to use duct work to supply a temperature regulated air supply to the engine, see Figure 4. This system uses jacket water to heat the air to the temperature set by the thermostat. If one intake system is used to supply temperature controlled air to multiple engines, provisions must be made to insure that heated water is sent to the heat exchanger when engines are running. If engine jacket water is used, the engine that the water is taken from must be running when any of the other engines are operating.

Considerations for Low Pressure Gas Engines

Take special care when designing the air intake system for low pressure gas engines that do not have air-fuel ratio control. If the air and gas temperatures to the engine are not controlled, engine emissions and detonation margins can change. It is necessary to design a system that will prevent the variation in differential temperature (VΔT) between the gas and the air going to the carburetor from changing beyond the limits given in Table 1.

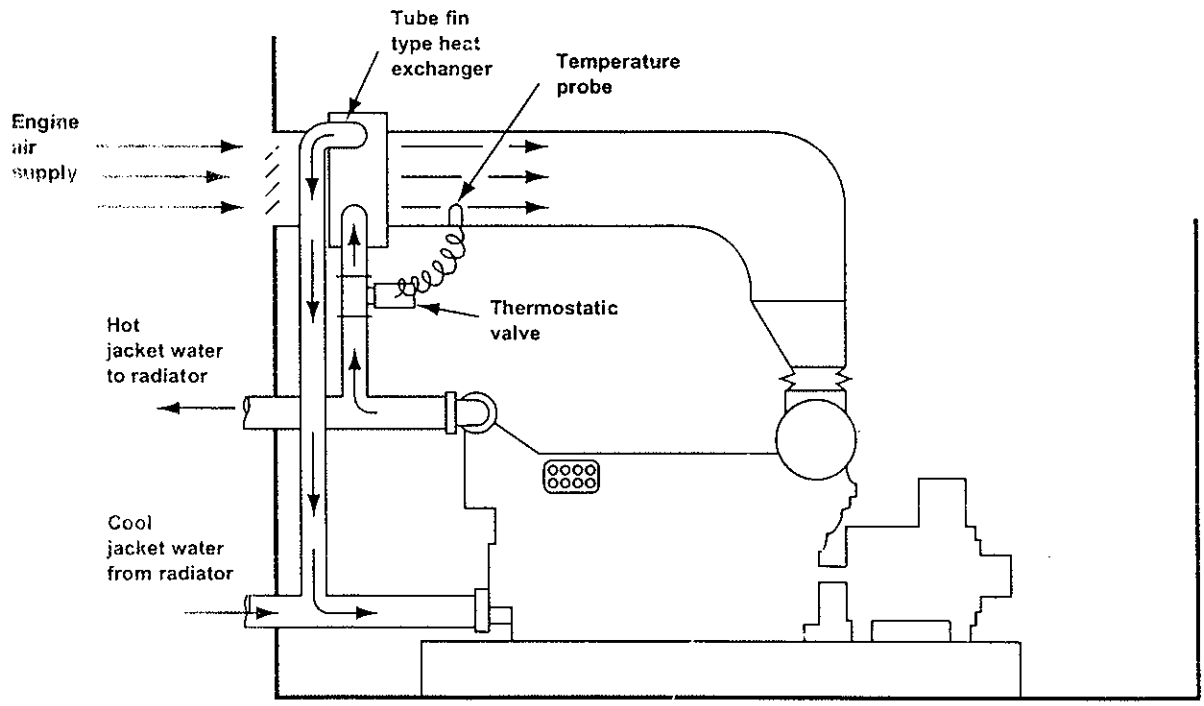


Figure 4. Ducting with temperature regulator.

Variation of VΔT	2.0 g NO_x/ hp-hr	1.5 g NO_x/ hp-hr	1.0 g NO_x/ hp-hr
Maximum Value of VΔT	± 5.5°C (±10°F)	± 5.5°C (±10°F)	± 3.3°C (±6°F)

Where: ΔT = Temperature difference of inlet air and fuel gas
VΔT = | ΔT Condition 1 - ΔT Condition 2 |
(brackets indicate absolute value of the difference)

Table 1. Emission level

Carburetors used in Caterpillar Gas Engines meter fuel into incoming air on a volume-for-volume basis. If the density of either the air or the gas changes relative to the other, the air-fuel ratio of the engine will also change.

For example, if a G3516 LE, 11:1 CR, 32°C (90°F) A/C, LE engine is adjusted to produce 2 g NO_x/bhp-hr at full load, the percent O_2 in the exhaust must be set to 8%, which results in an air-fuel ratio of 14.75 on a volume-for-volume basis.

If the engine is adjusted when the incoming air is 10°C (50°F) and the incoming gas 21°C (70°F),

$$\Delta T1 = \text{Air} - \text{Gas}$$
$$\Delta T1 = 10°C - 21°C = -11°C$$
$$(\Delta T1 = 50°F - 70°F = -20°F)$$

If the air temperature is later increased to 32°C (90°F) and the gas temperature remained constant,

$$\Delta T2 = 32°C - 21°C = 11°C$$
$$(\Delta T2 = 90°F - 70°F = 20°F)$$

Due to the absolute value the VΔT would then become:

$$V\Delta T = |-11°C - 11°C| = 22°C$$
$$(V\Delta T = |-20°F - 20°F| = 40°F)$$

The density of the air would then decrease, resulting in a lower air-fuel ratio of 13.67. The lower air-fuel ratio would result in reducing the percent O_2 in the exhaust to 6.5%. Figure 5 shows how NO_x changes as a function of percent O_2 in the exhaust. The increased air temperature in our example would increase the NO_x emissions to 8.8 g NO_x/bhp-hr, an increase of 440%.

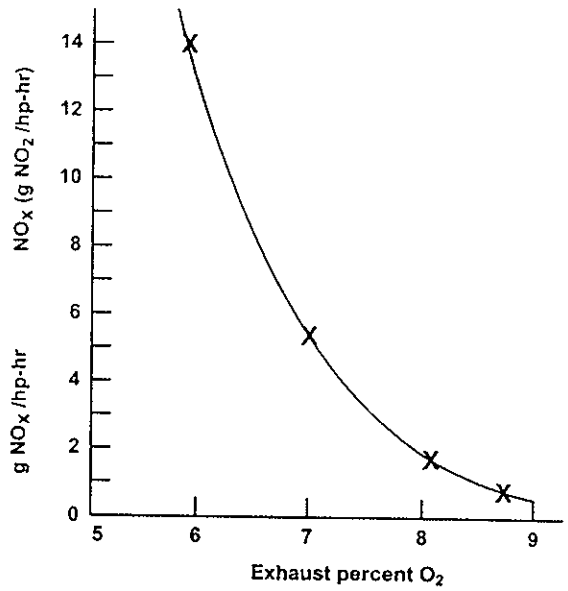


Figure 5. Nox emission vs exhaust percent O_2 for 3500 low emission engines

High pressure gas engines are not affected by these changes to the extent low pressure gas engines are. This is because the supply gas temperature remains relatively constant at most installations and the thermostatically controlled aftercooler maintains a fairly constant air temperature to the carburetor. Since these two temperatures are not subject to large changes, the air-fuel ratio remains relatively constant.

There are two primary methods of controlling VΔT:

- If the gas temperature is expected to remain relatively constant, then the air temperature to the engine can be controlled to maintain a constant temperature to the engine.
- A gas-to-air heat exchanger can be used to make the temperatures of the incoming air and gas relatively the same, or close. If either the air or gas temperature changes, the other will follow.

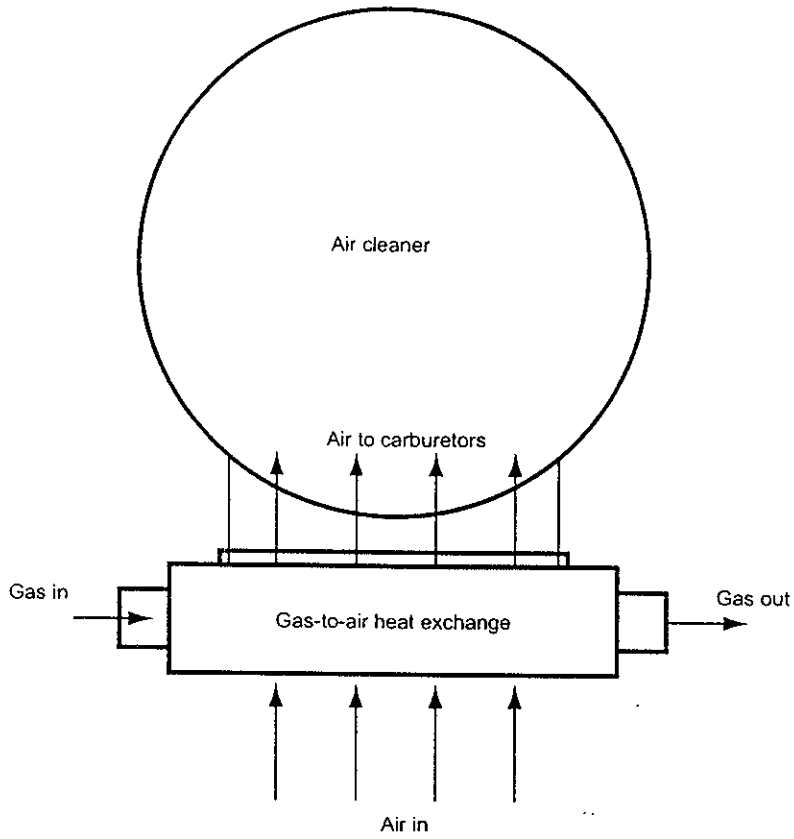


Figure 6. Gas-to-Air Heat Exchanger

Gas-to-Air Heat Exchanger

If the use of duct work is not practical for a given installation, another option is to install a gas-to-air heat exchanger, see Figure 6. If done correctly, this system will prevent temperature changes in the gas or the air from affecting the air-fuel ratio. Design the system so the gas flows through the heat exchanger before entering the gas regulator. The pressure drop across the heat exchanger at full load must be added to the minimum gas supply pressure required by the engine. Design the heat exchanger to minimize both gas and air flow pressure drop while still providing enough heat transfer so that $V\Delta T$ stays within the given limits.

CATERPILLAR®

Electric Power Application and Installation Guide

Cooling System

LEBX0028-01

WHERE THE WORLD TURNS FOR POWER

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Cooling Systems

All internal combustion engines produce heat as a by-product of combustion and friction which can create temperatures of up to 1925°C (3500°F).

The cooling system has a direct effect on the operation and service life of the engine. If the cooling system is not correctly sized, does not have good maintenance, or is not operated correctly, the engine can overheat or overcool. This can shorten the engine service life and/or result in poor engine performance.

There are many areas in an engine where it is critical that heat be removed. Cylinder walls must be cooled to maintain a film of lubrication for the piston to slide upon. Cylinder components (pistons, valves, heads) must be properly cooled to reduce the risk of detonation. The engine oil must be cooled to ensure its integrity. As a general rule, 20-40% of the energy input into an engine must be removed by the cooling system.

Cooling System Functions

Most diesel and gas engines are liquid-cooled, although a few of the small and high-speed engines are air-cooled.

Figure 1 shows the basic components of common liquid cooled engine cooling systems. These basic components are: coolant, the water pump, the engine oil cooler, coolant temperature regulators, the fan and the radiator. In operation, the water pump pushes coolant through the engine oil cooler and into the cylinder block. The coolant then flows through the cylinder block and into the cylinder head(s) where it flows to the hot areas of the cylinder head(s). Additional components that will transfer heat to the coolant are aftercoolers, water cooled exhaust manifolds, water cooled turbocharger shields and housing and oil coolers. After flowing through the cylinder head(s), the coolant goes into the coolant temperature regulator housing.

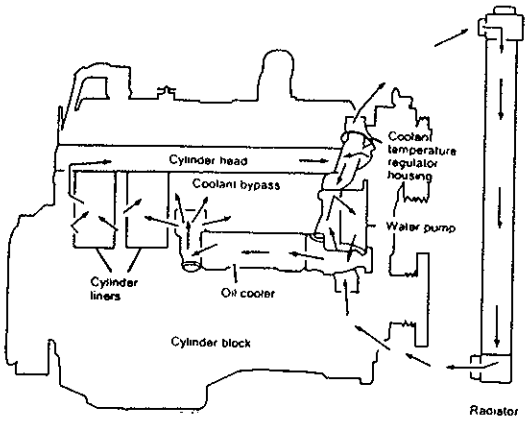


Figure 1. Cooling systems basic functions.

When the engine is cold, the temperature regulators prevent the flow of coolant to the radiator and direct the coolant back to the water pump. As the temperature of the coolant becomes warmer, the temperature regulators begin to open and permit some flow of coolant to the radiator.

The regulator opens to maintain the correct engine temperature. The amount that the regulator opens and the percent of coolant flow to the radiator depends on the load on the engine, and the outside air temperature.

The fan pushes or pulls air through the radiator and around the tubes that extend from the top to the bottom of the radiator. When the hot coolant goes through the tubes in the radiator, the flow of air around the tubes lowers the temperature of the coolant. The coolant then flows back through the water pump.

Each system has specific design criteria that must be met to ensure proper cooling of the engine.

All the pressure and temperature values in this publication are gauge values unless otherwise specified. All units are shown in the Metric convention with English units in parentheses, [e.g. meter (feet)].

Heat Rejection

Before a cooling system can be designed, the designer must understand how much heat is being rejected through each of the cooling circuits. This information is available in the Technical Marketing Information, TMI, and the Performance and Technical Information books available for each engine model. The following guide will help the designer in interpreting and applying the heat rejection data.

The heat balance: The heat input into the engine equals the sum of the heat and work outputs.

$$Q_{Total} = W + Q_{Exh} + Q_{Sur} + Q_{JW} + Q_{OC} + Q_{AC}$$

Where:

Total Heat Input (Q_{Total})
The Total Heat Input is calculated by multiplying the Brake Specific Fuel Consumption (BSFC) and the Power Output bkW(bhp).

$$Q_{Total}\ (MJ/hr) = BSFC\ (MJ/bkW\text{-}hr) \times Power\ Output\ (bkW)$$
$$Q_{Total}\ (Btu/hr) = BSFC\ (Btu/bhp\text{-}hr) \times Power\ Output\ (bhp)$$

Work Output (W)
The work output is the total power created from the energy contained in the fuel. It is expressed in kW (bhp) where one brake horsepower = 0.7457 kW.

Total Exhaust Heat (Q_{Exh})
The Total Exhaust Heat is the total heat available in the exhaust when it is cooled from the stack temperature down to standard conditions of 25°C (77°F). Values shown are low heat value and do not include the heat of vaporization. The exact exhaust temperature varies from engine to engine depending on rating and respiration. The value can be found in TMI.

Heat Loss to the Surroundings (Q_{Sur})
There is a certain amount of heat that is rejected from the engines surface to the surrounding ambient conditions. This is due to convective and radiation effects.

Jacket Water Heat (Q_{JW})
Jacket Water Heat is the total amount of heat dissipated to the engine cooling system. Caterpillar engines are designed to operate with a jacket water temperature (coolant) differential of less than 11.1°C (20°F) measured across the engine under full load.

Oil Cooler Heat (Q_{OC})
The Oil Cooler Heat rejection (Q_{OC}) is included in the jacket water heat (Q_{JW}) when not listed separately. Most of the heat in the oil comes from oil that is sprayed on the bottom side of the pistons.

Aftercooler Heat Rejection (Q_{AC})
Aftercooler heat rejection is given for standard conditions of 25°C (77°F) and 150 m (500 ft) altitude. Aftercooler heat rejection is increased for higher ambients and higher altitudes. A constant aftercooler outlet temperature is required. As the air temperature to the aftercooler goes up, so does the heat that must be removed. As the air pressure decreases, the turbocharger imparts more energy to the incoming air to increase it to the required boost pressure. The aftercooler heat rejection factor is used to adjust for ambient and altitude conditions. Failure to properly account for these factors could cause the engine to detonate and result in engine shutdown or failure.

Recoverable Heat
Recoverable heat in the exhaust is not a separate component of the heat balance equation, but is the customary number used in heat recovery calculations. It represents the heat available when cooling the exhaust from the stack temperature to 177°C (350°F).

If exhaust temperature other than 177°C (350°F) is desired, the recoverable heat can be approximated by the following formula.

$$Q = C_p \times M \times (T_1 - T_2)$$

Note: The actual formula used to calculate the TMI data is more complex and requires data not available in published sources.

Where:

Q = Heat Rejection in kW (Btu/min) where one kW = 56.86 btu/min.

C_p = Specific Heat of Exhaust Gas: [kJ/kg/°C (Btu/lb/°F)]
1.163 (0.277) – TA Standard Gas Engines
1.121 (0.267) – TA Low Gas Emission Engines
1.186 (0.280) – NA Gas Engines
See TMI – Diesel Engines

M = Exhaust Mass Flow, kg/min (lb/min)

T_1 = Exhaust From Engine, °C (°F)

T_2 =Exhaust Out of Heat Recovery Silencer, °C (°F)

Note: Exhaust gas flow is the flow at standard pressure and exhaust stack temperature.

Heat Rejection Tolerances

In every calculation using engine data, there is a tolerance band or a deviation from the norm. Heat balance tolerances must be applied when sizing cooling system components. The Caterpillar recommended tolerances vary depending on the engine model and are published in TMI.

Design Requirements

Engine Cooling Systems must:

- Reject heat from the jacket water coolant and auxiliary circuit if equipped, at greatest engine load, highest ambient temperature, and altitude.
- Allow filling without air entrapment (false fill).
- Provide sufficient suction head to prevent pump cavitation.
- Vent air introduced into the system by filling, leaks, and engine combustion.
- Maintain a required minimum operating temperature.

Coolant

Coolant must be able to transfer heat from hot engine components to a radiator or heat exchanger where the heat is dissipated.

Coolant generally consists of water combined with corrosion inhibitors or with antifreeze and corrosion inhibitors. The correct selection of coolant has a direct affect on the efficiency and/or service life of both the cooling system and the engine.

Basic Operating Parameters

All engine cooling circuits are designated by the maximum permissible inlet or outlet temperature to that circuit. Table 1 lists the temperature limits for each cooling circuit for gas engines and whether it is specified by an inlet or an outlet temperature for each engine size.

Cooling System	Cooling Circuit	G3300/G3400	G3500
Standard	AC (Inlet) AC (Inlet) JW/OC (Outlet)	32°C (90°F) 54°C (130°F) 99°C (210°F)	32°C (90°F) 54°C (130°F) 99°C (210°F) 92°C (198°F) – G3516B 60 Hz
Low Energy	AC (Inlet) JW/OC (Outlet)	NA NA	54°C (130°F) 110°C (230°F)
High Temperature	AC (Inlet) AC (Inlet) JW/OC (Outlet)	NA NA NA	32°C (90°F) 54°C (130°F) 127°C (260°F)

Table 1. Temperature limits for cooling circuits for gas engines.

Temperature Limits

Diesel

Caterpillar Diesel Engines are designed with coolant outlet temperatures listed in Table 2. An engine is considered overcooled when the coolant is below 70.4°C (160°F).

Engine Family	D3208/D3300	D3400/D3500
Application Prime/Continuous		
Alarm	102°C (215°F)	102°C (215°F)
Shutoff	107°C (225°F)	107°C (225°F)
Standby		
Alarm	107°C (225°F)	102°C (215°F)
Shutoff	113°C (235°F)	107°C (225°F)

Table 2. Temperature limits for coolant outlet temperature for diesel engines.

Gas

Caterpillar Gas Engines (except the 3600 engine family) are designed to operate with the following maximum temperature differential.

For the three different engine ratings, coolant temperatures should not exceed the following temperature limits shown in Table 3 for a properly sized cooling system.

Aftercooler Rating Inlet Temperature	Maximum Inlet Water Temperature
32°C (90°F)	32°C (90°F)
54°C (130°F)	54°C (130°F)
70°C (158°F)	70°C (158°F)

Table 3. Temperature limits, gas engines.

Note: If 70°C (158°F) aftercooler inlet temperature is used, the Engine Information System, EIS, control module will not be cooled by the aftercooler water. The EIS control module will be air cooled by the surrounding ambient conditions.

Gas

Landfill

- Pressurized 131-152 kPa (19-22 psi) capacity 110°C (230°F) Outlet

Co-gen

- Pressurized 196.5 kPa (28.5 psi) relief valve 127°C (260°F) Outlet

Diesel and Gas

Oil Cooler

- Inlet Temperature of 82°C (180°F)

Jacket Water - standard

- Pressurized 27-48.2 kPa (4-7 psi) capacity 99°C (210°F) Outlet
  [G3516B 60 Hz – 92°C (198°F) Outlet]

Failure to abide by the above limits could result in poor engine performance and/or engine failure.

Pressure Limits

Each engine cooling system component has static and dynamic pressure limitations that must be observed in order to preserve the integrity of the cooling system.

Diesel

The coolant pressure drop through the aftercooler at rated speed and load must not exceed 13.6 kPa (2 psi).

Depending on the height of the expansion tank above the jacket water pump inlet and the engine configuration, the system pressure should be between 48-96 kPa (7-14 psi). Refer to the engine data sheet for exact information.

A standard engine block should operate with pressure of 248-276 kPa (36-40 psi) but not exceed 379 kPa (55 psi).

Gas

Tables 4 and 5 contain the suggested operating and maximum pressure for Caterpillar Gas Engine cooling systems.

Component	Operating Pressure kPa (psi)	Maximum Pressure kPa (psi)
Engine Block	248-276 (36-40)	276 (40)
Aftercooler Core	248-276 (36-40)	276 (40)
Pump Inlets		196 (24.7) max. static head
Engine Outlets		196 (24.7) max. static head

Table 4. Operating pressure for the 3300 and 3400 gas engine.

Component	Operating Pressure kPa (psi)	Maximum Pressure kPa (psi)
Engine Block		
Standard	248-276 (36-40)	379 (55)*
Low Energy Fuels	248-276 (36-40)	379 (55)*
High Temp. System	310-345 (45-50	379 (55)*
Aftercooler Core	248-276 (36-40)	276 (40)
Pump Inlet		196 (24.7) max. static head

* If an operating pressure greater than 276 kPa (40 psi) is needed the customer must supply their own jacket water (coolant) pump.

Table 5. Operating pressure for the 3500 gas engine.

Coolant Flow

Calculating Required Coolant Flow

The first step in the design of a cooling system is to calculate the flow required for each circuit to transfer the heat load from the engine components to the Heat Exchangers or Radiators.

$$\text{Flow (L/min)} = \frac{\text{Heat Rejection (kW)}}{\Delta T(°C) \times \text{Density (kg/L)} \times \text{Spec. Heat (kW-min/kg°C)}}$$

$$\text{Flow (gpm)} = \frac{\text{Heat Rejection (Btu/min)}}{\Delta T(°F) \times \text{Density (lb/gal)} \times \text{Spec. Heat (Btu/lb°F)}}$$

ΔT = Outlet Temperature - Inlet Temperature (for the particular circuit)

It is important to use the correct coolant properties while figuring flow calculations.

Table 6 lists the density and specific heat capacities for pure water and water mixed with Ethylene Glycol.

	Pure Water	50/50 Water-Glycol
Density (kg/L)	0.98	1.03
Density (lb/gal)	8.1	8.6
Specific Heat (kcal/kg-°C)	1.0	0.85
Specific Heat (Btu/lb-°F)	1.0	0.85

Table 6. Density and specific heat @ 82°C (180°F). Note (kW-sec=kJ=4.19 kcal)

Example: Coolant Flow Rate Calculation

Diesel 3412C TA with engine speed @ 1800 rpm has:
Maximum top tank temperature 99°C (210°F)
Maximum bottom tank temperature 88°C (190°F)
Engine coolant heat rejection 508 kW (28,890 Btu/min)

$$\text{Flow} = \frac{508}{(99\text{-}88) \times 1.03 \times 0.06} = 747 \text{ L/min}$$

$$\text{Flow} = \frac{28{,}890}{(210\text{-}190) \times 8.6 \times 0.85} = 198 \text{ gpm}$$

Heat Transfer

Heat transfer describes the tendency of thermal energy to move from a higher temperature area to a lower temperature area. The rate of heat transfer is determined partly by the specific heat properties of a given liquid. (Specific heat is the amount of heat energy required to change the temperature of 1 g of a substance by 1°C.) The rate of heat transfer also depends on the temperature difference between the outside air and the coolant itself, plus the conductive properties of the material that surrounds the coolant.

External Restriction and Pump Flows

After determining the required coolant flow rate, pump performance establishes maximum allowable external resistance. Piping and heat transfer equipment resist water flow, causing an external pressure head which opposes the engine-driven pump. The water flow is reduced as the external resistance increases. The total system resistance must be minimized in order to ensure adequate flow. A cooling system with excessive external heads will require pumps with additional pressure capacity.

The following items will affect the flow resistance:

- Size and length of pipe
- Quantity, size and type of fittings and valves used
- Coolant flow rate
- Heat transfer devices

Table 7 lists the typical friction losses of water flowing in a pipe. Figure 2 lists the resistance of valves and fittings to flow of coolant which can be used to determine pressure drop through pipes, fittings and valves. The pressure drop (resistance) in the external cooling system can be calculated by totaling the pressure drop in each of the system's components.

Both the TMI and the Engine Performance and Technical Information books contain pump curves that show coolant flow versus external system head for the various engine-mounted pumps in Metric and English units. An example of a pump curve is shown in Figure 3. The data is shown in both tabular and graphical form.

gpm	L/s	Head Loss in ft/ 100 ft (m per 100 m)							gpm	L/s
gpm	L/s	3/4 in. (19.05 mm)	1 in. (25.4 mm)	1 1/4 in. (31.75 mm)	1 1/2 in. (38.1 mm)	2 in. (50.8 mm)	2 1/2 in. (63.5 mm)	3 in. (76.2 mm)	gpm	L/s
5	.34	10.5	3.25	0.84	0.40	0.16	0.05		5	.34
10	.63	38.0	11.7	3.05	1.43	0.50	0.17	0.07	10	.63
15	.95	80.0	25.0	6.50	3.05	1.07	0.37	0.15	15	.95
20	1.26	136.0	42.0	11.1	5.20	1.82	0.61	0.25	20	1.26
25	1.58	4 in. (101.6 mm)	64.0	16.6	7.85	2.73	0.92	0.38	25	1.58
30	1.9	0.13	89.0	23.0	11.0	3.84	1.29	0.54	30	1.9
35	2.21	0.17	119.0	31.2	14.7	5.10	1.72	0.71	35	2.21
40	2.52	0.22	152.0	40.0	18.8	6.60	2.20	0.91	40	2.52
45	2.84	0.28	5 in. (127 mm)	50.0	23.2	8.20	2.76	1.16	45	2.84
50	3.15	0.34	0.11	60.0	28.4	9.90	3.32	1.38	50	3.15
60	3.79	0.47	0.16	85.0	39.6	13.9	4.65	1.92	60	3.79
70	4.42	0.63	0.21	113.0	53.0	18.4	6.20	2.57	70	4.42
75	4.73	0.72	0.24	129.0	60.0	20.9	7.05	2.93	75	4.73
80	5.05	0.81	0.27	145.0	68.0	23.7	7.90	3.28	80	5.05
90	5.68	1.00	0.34	6 in. (152.4 mm)	84.0	29.4	9.80	4.08	90	5.68
100	6.31	1.22	0.41	0.17	102.0	35.8	12.0	4.96	100	6.31
125	7.89	1.85	0.63	0.26	7 in. (177.8 mm)	54.0	17.6	7.55	125	7.89
150	9.46	2.60	0.87	0.36	0.17	76.0	25.7	10.5	150	9.46
175	11.05	3.44	1.16	0.48	0.22	8 in. (203.2 mm)	34.0	14.1	175	11.05
200	12.62	4.40	1.48	0.61	0.28	0.15	43.1	17.8	200	12.62
225	14.20	5.45	1.85	0.77	0.35	0.19	54.3	22.3	225	14.20
250	15.77	6.70	2.25	0.94	0.43	0.24	65.5	27.1	250	15.77
275	17.35	7.95	2.70	1.10	0.51	0.27	9 in. (228.6 mm)	32.3	275	17.35
300	18.93	9.30	3.14	1.30	0.60	0.32	0.18	38.0	300	18.93
325	20.5	10.8	3.65	1.51	0.68	0.37	0.21	44.1	325	20.5
350	22.08	12.4	4.19	1.70	0.77	0.43	0.24	50.5	350	22.08
375	23.66	14.2	4.80	1.95	0.89	0.48	0.28	10 in. (254 mm)	375	23.66
400	25.24	16.0	5.40	2.20	1.01	0.55	0.31	0.19	400	25.24
425	26.81	17.9	6.10	2.47	1.14	0.61	0.35	0.21	425	26.81
450	28.39	19.8	6.70	2.74	1.26	0.68	0.38	0.23	450	28.39
475	29.97		7.40	2.82	1.46	0.75	0.42	0.26	475	29.97
500	31.55		8.10	2.90	1.54	0.82	0.46	0.28	500	31.55
750	47.32			7.09	3.23	1.76	0.98	0.59	750	47.32
1000	63.09			12.0	5.59	2.97	1.67	1.23	1000	63.09
1250	78.86				8.39	4.48	2.55	1.51	1250	78.86
1500	94.64				11.7	6.24	3.52	2.13	1500	94.64
1750	110.41					7.45	4.70	2.80	1750	110.41
2000	126.18					10.71	6.02	3.59	2000	126.18

Table 7. Typical friction losses of water in pipe (old pipe). Nominal pipe diameter.

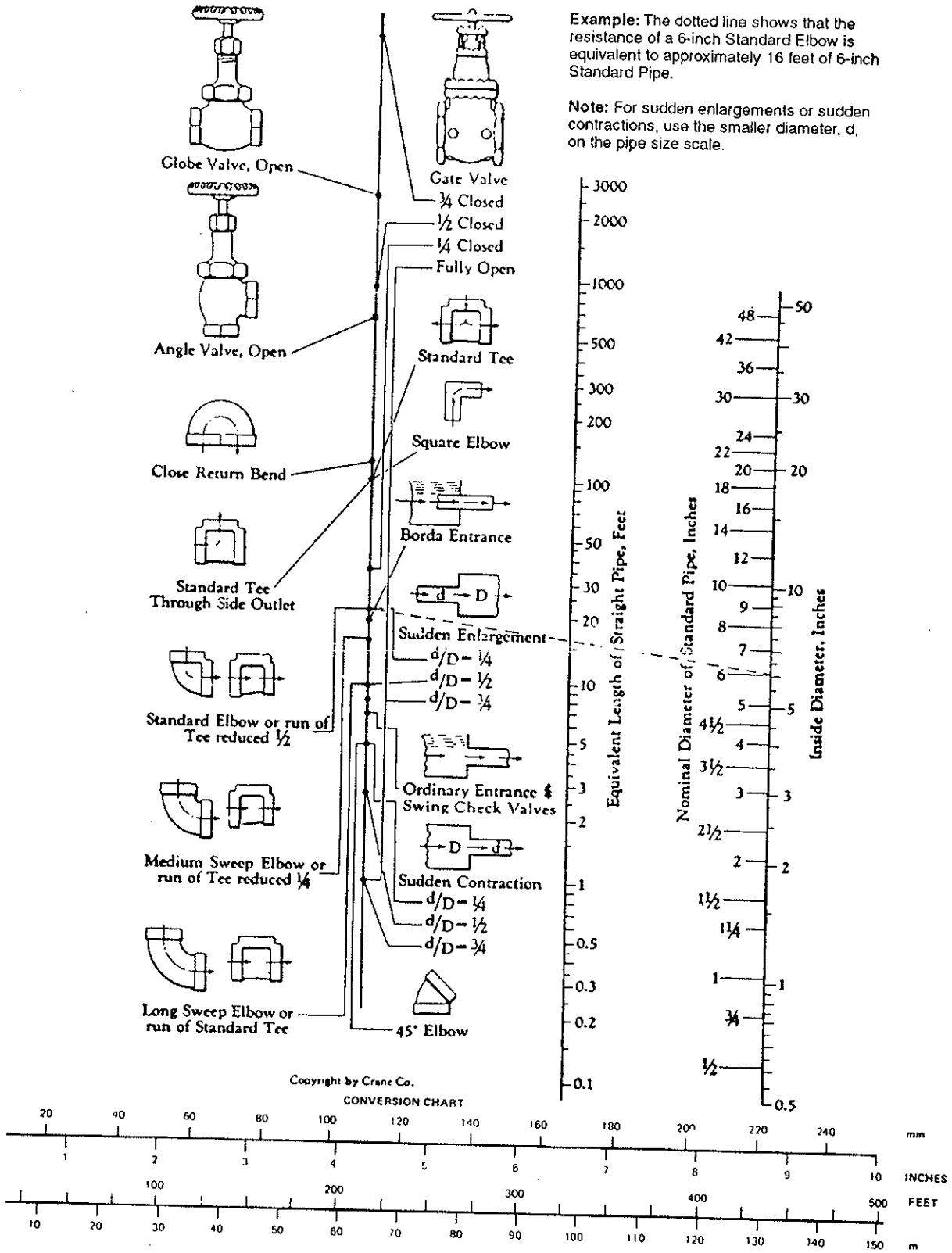
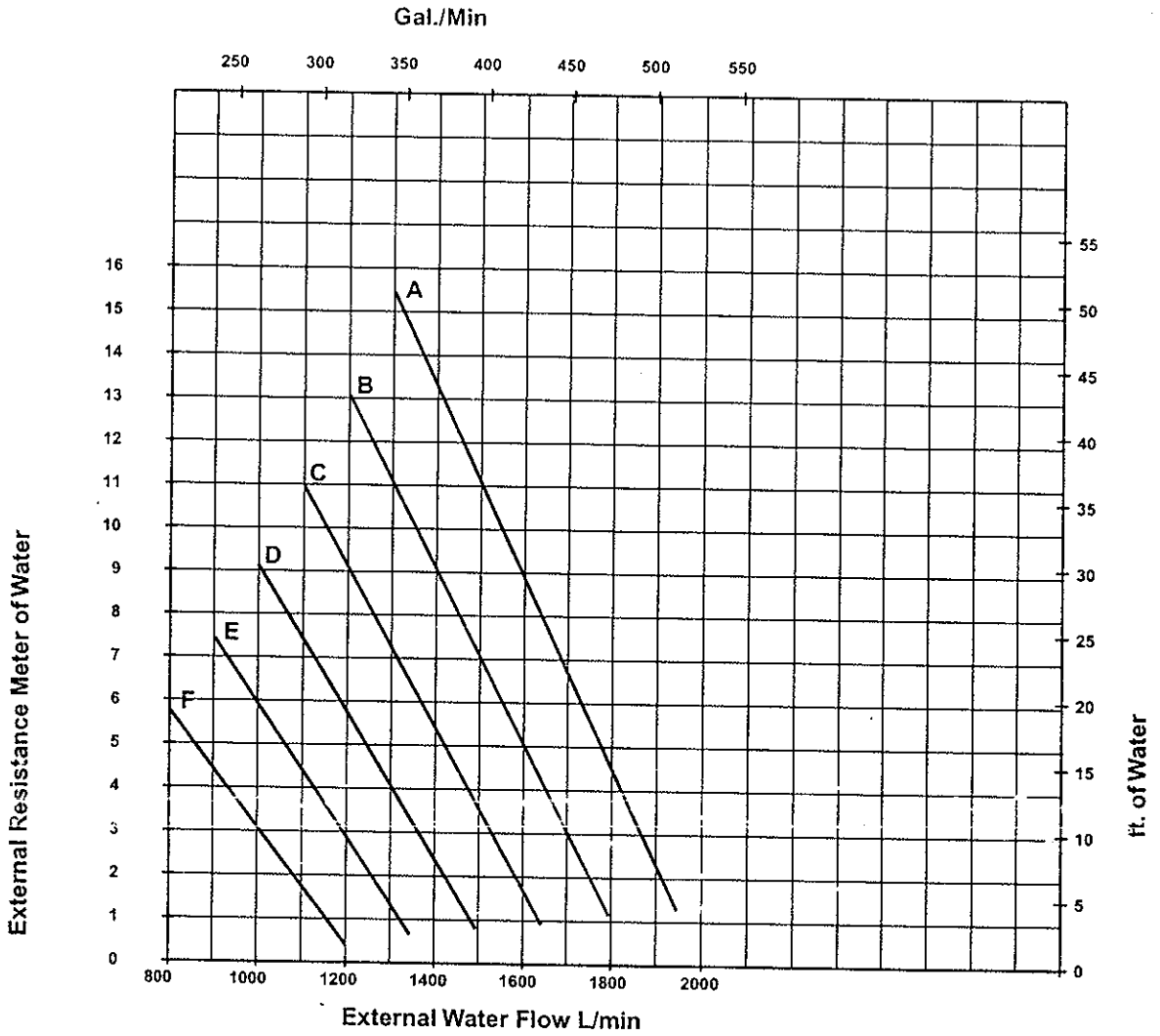


Figure 2. Resistance of valves and fittings to flow of fluids.



Jacket Water System Performance G3516 Low Speed

Curve Data

Curve Label	A	B	C	D	E	F
Engine Speed rpm	1300	1200	1100	1000	900	800
Pump Speed rpm	2600	2400	2200	2000	1800	1600
External Flow L/min	External Resistance Meter of Water					
800						5.8
900					7.4	4.4
1000				9.1	5.8	3.1
1100			11.0	7.3	4.4	1.8
1200		13.1	9.2	5.7	2.8	0.4
1400	13.2	9.0	5.4	2.4		
1600	8.8	5.0	1.7			
1800	4.4	1.0				
1900	2.3					

Curve Data

Curve Label	A	B	C	D	E	F
Engine Speed rpm	1300	1200	1100	1000	900	800
Pump Speed rpm	2600	2400	2200	2000	1800	1600
External Flow gal/min	External Resistance feet of Water					
211.4						19.0
237.8					24.3	14.6
263.2				29.9	19.1	10.2
290.6			36.1	24.1	14.3	5.7
317.0		43.0	30.0	18.8	9.2	1.3
364.9	43.2	29.5	17.8	7.8		
422.7	28.7	16.4	5.6			
475.6	14.5	3.3				
502.0	7.4					

Effective Serial No. 3RC00001

Engine equipped with water cooled exhaust manifolds or dry exhaust manifolds JW Aftercooler.

Drive ratio 2.0 tp 1

For low speed (1300 rpm and below) ratings

Curves indicate maximum allowable external resistance.

Do not project curves.

2W9729 JW Pump

Figure 3. Pump curve.

Line Velocities

It is important to observe the water velocity guidelines to help insure proper operation of the cooling system and to extend its life. Excessive velocities lead to erosive tube wear. Table 8 can be used to calculate water velocity in a pipe or tube.

	(m/sec)	(ft/sec)
Pressurized Lines	4.5	15
Pressurized Thin-Wall Tubes	2.0-2.5	6.5-8
Suction Lines (Pump Inlet)	1.5	5
Low Velocity Deaeration Line	0.6	2

Table 8. Maximum water velocity.

Connections

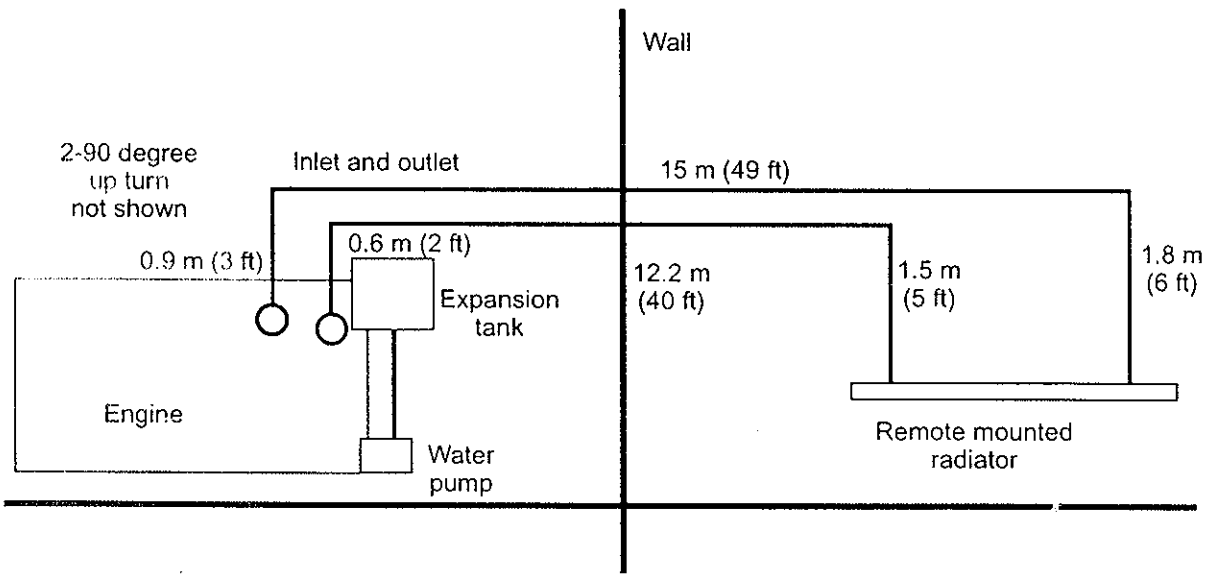
Use flexible connections for all connections to the engine (rubber hoses are not recommended). The positions of flexible connections and shut-off valves are important. Shut-off valves should be located to allow a flexible connection or engine repair without having to drain the entire cooling system. Orient the flex connector to take the maximum advantage of its flexibility. When selecting connectors, consider normal thermal expansion and maximum expected movement.

Material compatibility must also be evaluated. The internal surface must be compatible with the coolant used over the anticipated operating temperature and pressure ranges. The liner material must also be compatible with potential coolant contaminants, such as lube oil and system cleaning solutions. The outer cover must be compatible with its environment (temperature extremes, ozone, grease, oil, paint, etc.).

Example: Restriction Calculation

A G3516 Gas Engine running at 1200 rpm, requires a 1325 L/min (350 gpm) flow to provide cooling.

This could be the system design:



Components in the system:

Total straight length:	32 m (105 ft)
Standard 90° elbows:	6
Gate valve:	2

Utilizing Figure 2, Table 9a can be constructed to determine total effective straight length for various pipe diameters.

Effective straight length = straight length + 6 × Effective Elbow + 2 × Effective Value

Pipe Size (Inch)	Straight Length m (ft)	Restriction per Elbow (Equivalent Length) m (ft)	Restriction per Valve (Equivalent Length) m (ft)	Total System (Effective Straight) m (ft)
4	32 (105)	3.35 (11)	0.76 (2.5)	53.6 (176)
5	32 (105)	4.27 (14)	0.9 (3)	59.4 (195)
6	32 (105)	4.88 (16)	1.07 (3.5)	65 (214)
8	32 (105)	6.4 (21)	1.37 (4.5)	73.1 (240)

Table 9a. Example of determining total effective straight length.

Using Table 7 with the previously found equivalent length, the total restriction can be calculated as:
(Restriction/100 ft) × Equivalent Length.

Pipe Size (Inch)	Equivalent Length m (ft)	Restriction/100 ft @ 1325 L/min (350 gpm)	Total Restriction m H_2O (ft H_2O)
4	53.6 (176)	12.4	6.64 (21.8)
5	59.4 (195)	4.19	2.49 (8.17)
6	65 (214)	1.7	1.1 (3.6)
8	73.1 (240)	0.43	0.31 (1.03)

Table 9b. Example of determining total restriction.

Figure 3 gives a maximum external head allowable equal to 10.7 meters (35 ft) of water. Maximum external resistance must not be exceeded in the cooling circuit added by the customer, in order to maintain the minimum water flow for proper cooling.

Engine Design Configurations

Temperature Control

Thermostats

All internal combustion engines need to maintain a minimum operating temperature. If an engine is run continuously with an operating temperature that is too low, severe maintenance problems may arise. It is the function of the thermostat to control the minimum operating temperature of an engine. Each cooling system on an engine must have its own thermostat.

Since a thermostat controls the minimum operating temperature, the maximum temperature must be controlled by correct radiator or heat exchanger sizing. There are two basic methods for thermostatic control of minimum temperature in cooling systems: inlet regulated and outlet regulated.

Inlet Regulated

Inlet regulated cooling systems provide a constant temperature to the inlet jacket water, aftercooler, and/or oil cooler (see Figure 4). This design is used to minimize overcooling when very cold or thermally large cooling sources are involved. The sensing bulb of the thermostat is placed in the inlet flow to the expansion tank. The thermostat then balances the bypass flow (hot water directly from engine) with cool water from a heat exchanging device, i.e. radiator, heat exchanger, etc.

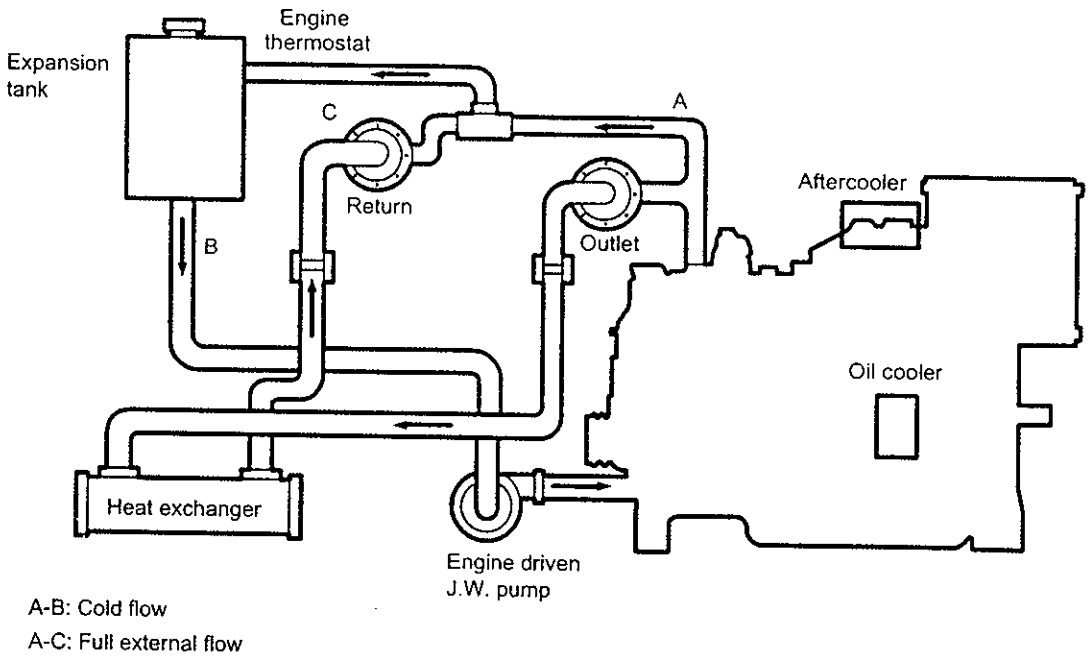


Figure 4. Inlet control.

A potential problem with inlet controlled cooling incorporating a radiator is that full pump pressure is imposed on the radiator core. This pressure usually exceeds the structural pressure of a solder tube radiator core. Therefore, inlet controlled systems are not often used with radiators. Inlet regulated cooling systems are most commonly seen in marine applications.

Outlet Regulated

Outlet regulated cooling systems provide a constant outlet temperature from the engine by regulating the flow between the bypass and cooling circuits (see Figure 5). Usually applied with radiator cooled systems, the sensing bulb of the thermostat is placed in the outlet flow from the engine. If the outlet temperature becomes too high, more water is allowed to flow to the cooling system. If the water is too cool, the water is directed through the bypass and is recirculated to the engine without being cooled. Note that all Caterpillar EPG radiator cooled systems use an outlet regulated cooling system.

Jacket Water

Water jackets in internal combustion engines consist of an outer casing surrounding the cylinders. The circulating coolant surrounds the cylinder bores and provides cooling for the cylinder heads.

Carefully sized coolant passages in the head aid in regulating the water flow and help to maintain uniform temperature throughout the block. Coolant surrounds the combustion chamber and spark plug bosses in the cylinder head.

Aftercooling

The air at the outlet of the turbocharger is at a higher temperature than the air at the inlet of the turbocharger. Some engines have an aftercooler to lower the temperature of turbocharger outlet air. Coolant is used in many aftercoolers to absorb the heat from the air. If the aftercooler core has dirt or oil in it, the coolant cannot absorb as much heat as it does normally. This can raise piston temperature and lower engine horsepower.

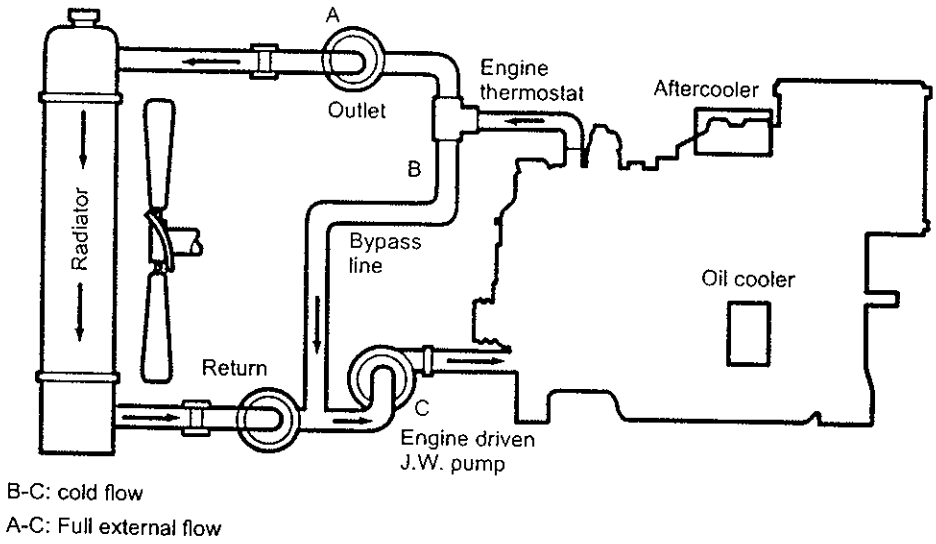
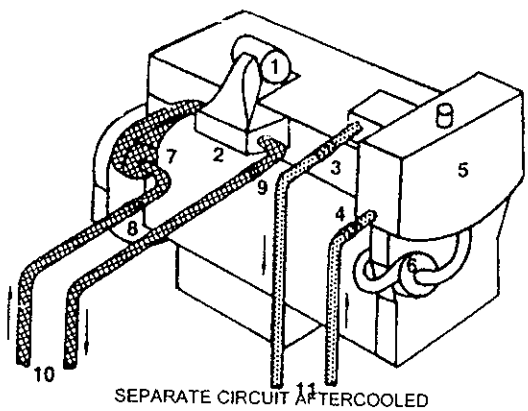


Figure 5. Outlet control.

Separate Circuit

As the name implies, the separate circuit aftercooler circuit, SCAC, provides water to the aftercooler from a source other than engine jacket water (see Figure 6). It is used to provide colder water to further reduce inlet manifold air temperatures.

The arrangement of the separate circuit aftercooled engine configuration provides a closed cooling circuit for the aftercooler coolant.



1. Turbocharger
2. Aftercooler, auxiliary water cooled
3. Jacket water outlet connection
4. Jacket water inlet connection
5. Expansion tank
6. Jacket water pump
7. Auxiliary water pump
8. Auxiliary water inlet connection
9. Auxiliary water outlet connection
10. Lines to aftercooler cooler
11. Line to jacket watercooler

Figure 6. Separate circuit aftercooled.

Aftercooler Condensation

With humid air and ambient temperatures above freezing, much of the water will be condensed in the aftercooler core. Provisions to remove the condensed water from the aftercooler core and piping must be included in the design. To address this need, a gas 3516 Low Emission Engine may produce up to 114 liters (30 gallons) of water a day.

This water can be easily drained if the intake air enters the bottom of the core on one side and exits high on the opposite side. A drain valve to automatically drain the condensed water, should be plumbed into the bottom side of the core, opposite the entrance of the intake air. The drain valve should not be allowed to freeze in cold temperatures.

Condensate traps should be installed in the intake piping close to the engine intake manifold. The design of a condensate trap is to quickly change direction of the air flow, usually by a minimum of 180°, and throw the heavier water droplets into a wall of the trap where they are collected and drained through a float valve. The condensate trap must be sized and designed so that its pressure drop is not excessive.

Air-To-Air Aftercooling (ATAAC)

Air-to-Air Aftercooling (ATAAC) can be used with turbocharged and aftercooled engines in areas where the lack of a 32°C (90°F) water source would otherwise preclude the use of full rated horsepower. This arrangement uses a dual-core radiator and fan. One section of this radiator is an air-to-air heat exchanger for the aftercooler circuit. Air piping must be fabricated to direct air from the turbocharger to the heat exchanger and return it to the engine.

Design of the aftercooler core and related piping are critical to prevent corrosion of the core, water entry into the engine, and excessive pressure drop of the intake air across the aftercooler circuit.

On low emission gas engines, a temperature control valve is required to maintain a constant air temperature of 43°C (110°F) to the engine. The control valve modulates to bypass air around the aftercooler core. Some of the air flows directly from the turbocharger into the carburetor.

ATAAC Critical Design Criteria

The piping and heat exchanger core must be sized so the total pressure drop from the compressor outlet to the carburetor inlet is less than 38 mm (1.5 in.) of Hg. Install test fittings with pipe threads (1/4 in. recommended) in the piping at the compressor outlets and carburetor inlet, so both the pressure and temperature at these points can be monitored. Measurements at these points are required to determine if the installation meets the design requirements.

Because large amounts of water can be condensed from the air, the aftercooler core must be made from a corrosion resistant material such as brass (not to be used with gas containing H_2S), aluminum, or stainless steel. The piping to and from the aftercooler core must be a corrosion resistant material.

Caution: After fabrication, the piping and cooler core must be cleaned thoroughly of weld slag, debris, etc. Anything left in the piping could break loose, pass into the engine, and cause serious engine damage.

The Air-to-Air Aftercooled engine configuration should not be used with low gas pressure arrangements. With this combination, a rather large volume of combustible air and gas mixture is flowing through the aftercooler core. If this mixture is ignited, damage may result to the aftercooler core.

Auxiliary Heat Sources

Exhaust

Heat recover mufflers economically recover about half the engine exhaust heat. Exhaust exit temperature above 177°C (350°F) helps eliminate condensation in ducting. Recoverable heat is obtained from TMI.

Lubricating Oil

When recovering heat from engines using high temperature cooling systems, it may be worthwhile to utilize heat rejected to lubricating oil. This heat can be applied to prehead boiler feed water, domestic hot water, or other low temperature requirements. Heat removed by lubricating oil from engines operating above 104°C (220°F) is always rejected to a cooling medium other than the jacket water. Heat rejection to the oil for Caterpillar Engines is approximately 0.14 kW/bkW (5.9 Btu/hp-min) for gas engines, 0.21 kW/bkW (9.1 Btu/hp-min) for diesel engines.

Types of Cooling Systems

There is a myriad of different types of cooling systems. No one system is correct for every location, size and application of Caterpillar Engine. It is important to work with our experienced engineer and/or the local dealer when designing the best cooling system for each application. The following discussion lists some of the more common types of cooling systems.

There are two basic types of cooling systems, open and closed. Examples of each are given in Table 10.

Open System not recommended	Closed System
	Radiator
Cooling Tower (without heat exchanger)	Heat Exchanger
	Cooling Tower (with heat exchanger)
Spray Pond Body of Water	Evaporative Cooler

Table 10. Types of cooling systems.

Open System

In the open system, the cooling water is exposed directly to the air and is cooled by evaporation and water-to-air heat transfer. About 75% of the total heat is removed by evaporation, and 25% by convective heat transfer. The continued process of evaporation means that any scale-forming salts present in the water will gradually be concentrated, and the water may pick up further contaminants from the air. These impurities can result in the buildup of scale on the walls of the cooling water passages in the engine, decreasing the cooling system efficiency. Overheating may occur. Open cooling systems are not recommended. The exceptions are when specific precautions have been taken to accommodate an open system. For example, some engines can be equipped with a cleanable aftercooler core and corrosion resistant piping. These aftercoolers are of a round tube/plate fin design and can be disassembled and cleaned, allowing them to be used in an open system.

Closed System

In the closed system, proper coolant treatment can virtually eliminate scale formation and corrosion. The coolant does not come into direct contact with the air but is cooled by a process of heat transfer to a cooler medium, usually air or water. The amount of coolant in the engine closed system is relatively small and confined, and can be economically treated.

Radiators

Radiator cooling is the most common type of closed cooling systems. Radiator cooling provides a closed, self-contained system that is both simple and practical for most installations.

Figure 7 shows a schematic of a typical radiator design. Cooling of the engine parts is accomplished by keeping the coolant circulating and in contact with the metal surfaces to be cooled. The pump draws the coolant from the bottom of the radiator, forces it through the jackets and passages, and ejects it into a tank on top of the radiator. The coolant passes through a set of tubes to the bottom of th e radiator and again is circulated through the engine by pump action. A fan draws air over the outside of the tubes in the radiator and cools the coolant as it flows downward. It should be noted that the coolant is pumped through the radiator from the top down. The reason for this is that when the coolant is heated in the jackets of the engine, it expands slightly and as a result becomes lighter and flows upward to the top of the radiator. As cooling then takes place in the radiator tubes, the coolant contracts, becomes heavier and sinks to the bottom. This desirable action, however, cannot take place if the coolant level is allowed to become too low.

The top tank is used for filling, expansion, and deaerating of engine coolant. Extended systems using added coolant may require enlarged expansion tanks. The top tank is fitted with a pressure cap. This cap allows coolant level to be checked and replenished as necessary. The cap also seals the cooling system and limits its pressure with a spring-loaded disc valve.

The cooling system is designed to operate under a pressure of 27.6 to 48.3 kPa (4 to 7 psi) which results in a top tank temperature of 99°C (210°F). This limit prevents steam formation in the engine water jacket.

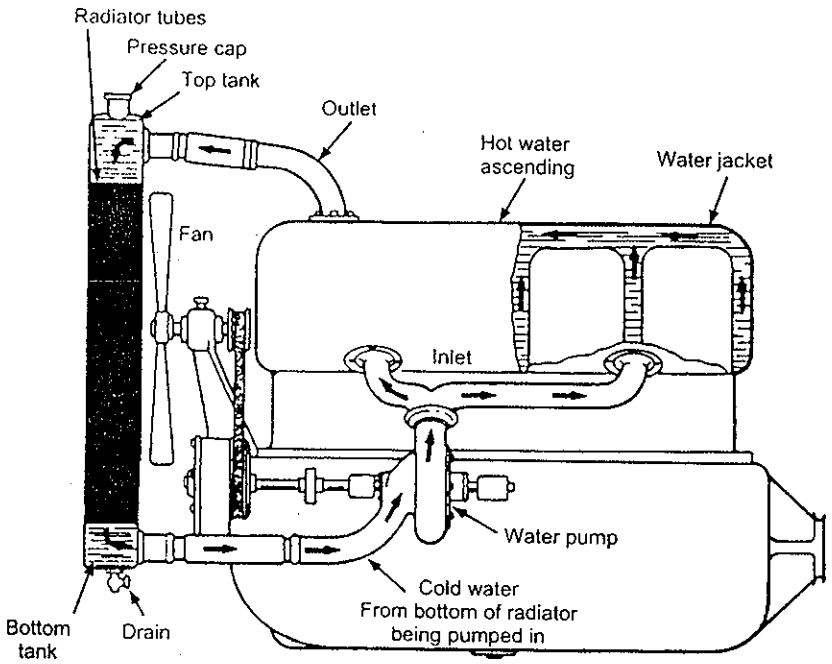


Figure 7. Schematic of typical radiator design.

Performance

Radiator Design Criteria and Considerations

The following factors must be considered when designing and installing a radiator cooling system.

- Size the radiator to accommodate a heat rejection rate approximately 10% greater than the engine's heat rejection. The additional 10% will compensate for possible variations from published or calculated heat rejection rates, overload, and system deterioration. Even if the expected load is less than the engine rated power, size the radiator to match engine rated power.

- Correction factors to the observed ambient air temperature capability for the engine must not be overlooked. Altitude above sea level reduces the density of air and its ability to cool the radiator. A good correction factor is 1.38°C (2°F) deducted from the observed ambient temperature capability for each 305 m (1000 ft) above sea level. Consult the performance book for an exact correction factor.

- Ambient air temperature may not be the same as the air temperature flowing across the radiator core. An engine equipped with an engine mounted radiator and blower fan will increase the air temperature as it flows across the engine to the radiator. The ambient temperature rise for different radiator locations is found in Table 11.

	Blower Fan	Suction Fan
Engine only, outside or in a large engine room	3°C (5.4°F)	None
Engine/generator outside or in a large engine room	4°C (7.2°F)	Not Recommended with generator
Engine/generator in enclosure with external muffler	7°C (12.6°F)	
Engine/generator in enclosure with internal muffler	9°C (16.2°F)	

Table 11. Estimated air to core rise.

- The effects of antifreeze must be considered when sizing a radiator. The ability to transfer heat diminishes when water is mixed with ethylene glycol. The loss in ambient capability due to antifreeze is about 1°C (1.8°F) for each 10% glycol, up to 50%.

- Fan noise should be considered when selecting radiator location. Fan noise transmits through the air inlet as well as the outlet. Soft flexible joints between the radiator and the ducting will prevent vibration and noise transmission.

- Position the radiator so prevailing winds do not act against the fan. One form of wind protection for radiators is a baffle located several feet from the radiator exhaust. Another method is to install an air duct outside the wall and mounting the air inlet or outlet vertically. Large radius bends and turning vanes prevent turbulence and excessive air flow restriction.

- It is important to make sure that the hot radiator air discharge is not recirculated to the air inlet. Figures 8A and B demonstrate this problem. Radiators must be arranged so that engine exhaust gases and/or crankcase ventilation gases are not drawn into the air inlet of the radiator (see Figure 8C).

- Backpressure or air flow restriction reduces radiator performance. If radiator air flow is to be ducted, consult TMI or your radiator manufacturer regarding the allowable backpressure. An engine installation in an enclosed space requires that the inlet air flow rate to the enclosed space include the combustion air requirements of the engine, unless the air for the engine is ducted directly to the engine from the outside.

Radiator/Fan Performance

Air density, flow restrictions, and speed affect fan performance, which can possibly limit radiator ambient temperature capabilities. Performance changes are estimated by the following relationships.

Air Density

$$\text{Revised Static Pressure} = \text{Original Static Pressure} \times \frac{\text{Revised Air Density}}{\text{Original Air Density}}$$

$$\text{Revised Fan Horsepower} = \text{Original Fan Horsepower} \times \frac{\text{Revised Air Density}}{\text{Original Air Density}}$$

Speed

$$\text{Revised Air Flow} = \text{Original Air Flow} \times \left(\frac{\text{Revised Fan Speed}}{\text{Original Fan Speed}}\right)$$

$$\text{Revised Static Pressure} = \text{Original Static Pressure} \times \left(\frac{\text{Revised Fan Speed}}{\text{Original Fan Speed}}\right)^2$$

$$\text{Revised Fan Horsepower} = \text{Original Fan Horsepower} \times \left(\frac{\text{Revised Fan Speed}}{\text{Original Fan Speed}}\right)^3$$

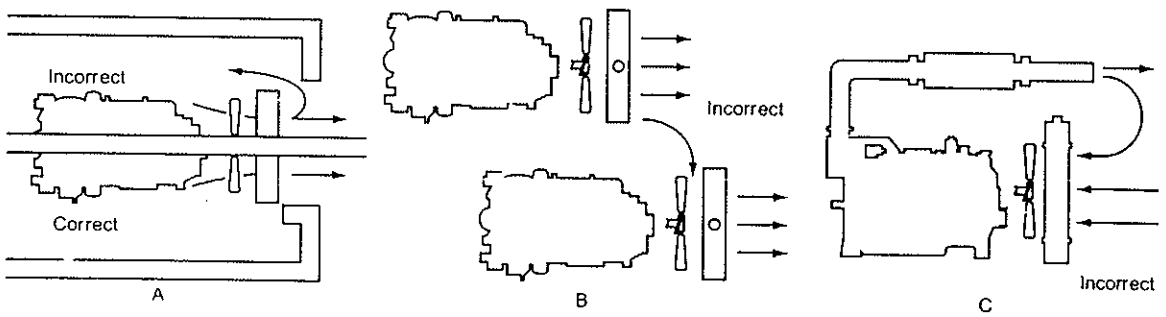


Figure 8. Radiator recirculation.

Temperature

$$\text{Revised Coolant Temp.} = \text{Original Coolant Temp.} \times \left(\frac{\text{Original Air Flow}}{\text{Revised Air Flow}}\right)^{0.7}$$

$$\text{Revised Coolant Temp.} = \text{Original Coolant Temp.} \times \left(\frac{\text{Original Fan Speed}}{\text{Revised Fan Speed}}\right)^{0.7}$$

$$\text{Radiator Ambient Capability} = \frac{99°C - \text{Revised Coolant Temp.}}{\text{Coolant Temp.}}$$

$$\text{Radiator Ambient Capability} = \frac{210°R - \text{Revised Coolant Temp.}}{\text{Coolant Temp.}}$$

Where:

Coolant Temperature Differential = Coolant top tank temperature minus air temperature to radiator.

Air Density = gm/cu•cm (lb/cu•in)
Air Flow = cu•m/min (cfm)
Coolant Temperature =

$$99°C\ (210°F) - \left(\frac{5.5}{2}\right) - \text{Original Radiator Temperature}$$

Original Radiator Temperature = the ambient air temperature that goes to the radiator
Assumptions:
Coolant Top Tank Temperature = 99°C (210°F)
Inlet to Outlet Radiator Temperature Change = 11.1°C (20°F)
Fan Horsepower = kW (hp)
Fan Speed = rpm
Static Pressure = mm (in) of H_2O

Ambient Capability
Ambient capability is a value expressing how well the cooling system cools. The value, therefore, depends on the specific cooling configuration and the ambient temperature and can be found in the price list.

Fan Speed
Fan speed affects the performance of a fan in respect to radiator ambient temperature capabilities. Revised air flow, static pressure and fan horsepower can be calculated using revised and original fan speed.

Steel bladed fans should not exceed the tip speed guidelines as the fan will produce excessive noise and could potentially fail. Recommended maximum tip speeds are 3660 m/min (12,000 ft/min) for low noise, and 4575 m/min (15,000 ft/min) for higher but acceptable noise.

Radiator System Pressure
Slight system pressure minimizes pump cavitation (voids in water) even at high altitude, and increases pump efficiency

For each 6.9 kPa (1 psi) of pressure, the boiling point is raised about 2°C (3°F).

Compared to pure water, alcohol/water mixes have a lower boiling point, while ethylene glycol mixes have a higher boiling point.

Ducting
Radiator ducting should be larger than the radiator core. A standard rule of thumb is to make the inlet air ducts 1.5 times greater than air outlet ducts.

Louvers are often used to protect the engine and engine room from rain, snow, and vandalism. Since louvers restrict air flow, the radiator ducting area must be increased a minimum of 25% when flat louvers are used. Air flow restriction due to engine room ventilation, duct work, etc. should be limited to 12.7 mm (0.5 in.) of water. Fan performance will suffer if this limit is exceeded.

If movable louvers are used, specify those which use mechanical force. Pneumatic and electric-actuated louvers are satisfactory. Use of louvers which open from the discharge pressure of the radiator fan are discouraged. Rain, ice, and snow can render them inoperative within a short period of time and cause an unwanted engine shutdown due to overheating.

Standby Ducting
Standby or emergency power units will be loaded immediately and will require full air flow upon startup. Therefore, louvers should be activated immediately on engine start-up.

Emergency units are frequently exercised at no load. The full air flow under these conditions may result in maintenance problems from overcooling, and therefore, the air flow across the radiator should be restricted to allow for the proper cooling.

Engine Mounted Radiator

If an engine mounted radiator is used and the generator set is installed in a room, a blower fan can be used and a radiator duct provided to the outside. Ducts directing radiator air to the outside prevent recirculation and high room temperatures (see Figure 9). Some generator set packages have, as standard, radiator duct flanges for installation ease. The duct length is short and direct to minimize back-pressure, with total inlet and outlet restriction on the radiator fan less than 12.7 mm (0.5 in) of water.

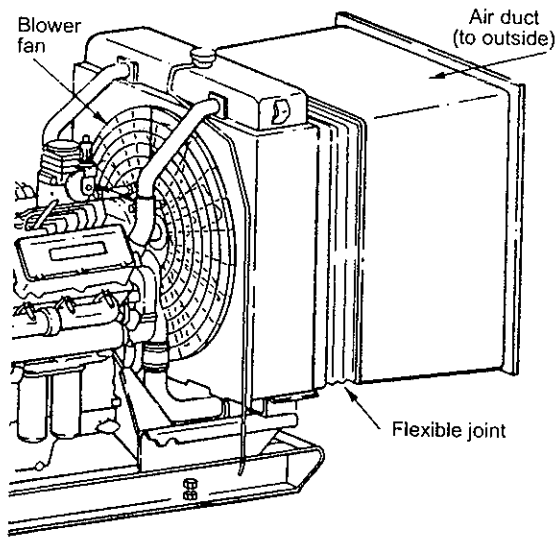


Figure 9. Ducting to the outside.

Restrictions

- If common window screening is used, the size of the opening should be increased by 40%.
- Solid walls perpendicular to fan air flow must not be closer than two fan diameters from the radiator.
- Avoid uneven loading of the fan caused by obstructions or auxiliary coolers partially obstructing air flow.
- Fatigue failure of fan blades as well as air turbulence may occur when obstructions are too close to the face of the fan. Maintain a minimum spacing equal to 8% of the fan diameter.

Remote Mounted Radiator

On installations where it is desirable to locate the radiator at some distance from the engine, a remote radiator can be used.

Remote systems impose added restriction on coolant flow by the use of additional piping and fittings. An auxiliary pump in series with the engine mounted pump should not be used to overcome this restriction. Give consideration to radiator design and larger piping. When distances separate the engine from the radiator, oversized piping may be required to minimize piping restriction.

If the empty radiator is exposed to extreme cold, initial flow of unprotected coolant can freeze and block the core. Antifreeze must be included in the coolant treatment to assure uninterrupted flow.

Never locate remote mounted radiators more than 17.4 m (57 ft) above the pump. At greater heights, the static resistance developed may cause leakage at the engine water pump seal. (Static head is the maximum height the coolant is raised.) (See Figure 10.)

The radiator inlet tank loses its air venting capability if it is located below the level of the engine regulator housing. When a radiator must be mounted lower than the engine, an expansion tank must be used.

If an engine mounted expansion tank is used, it should include a "radiator" fill cap. The radiator must be selected with consideration to the inlet controlled guidelines. The core must also withstand full pump pressure. This will usually require a round tube radiator. If the core is vertical, water flow can be reversed through the radiator. This ensures gas or air is not trapped in the radiator inlet tank.

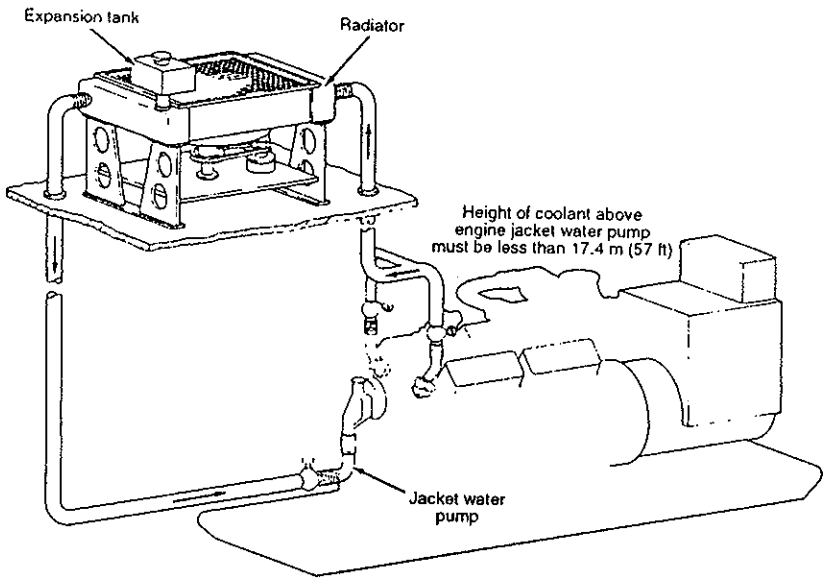


Figure 10. Remote mounted radiator.

Radiator design operating pressure must be increased by 6.9 kPa (1 psi) for every 610 mm (2 ft) the engine is above the radiator. If the radiator is mounted below the engine, do not use the radiator pressure cap. Remove the cap and seal the opening. This prevents untrained personnel from causing problems.

Vertical Remote

Vertical remote radiators are positioned so prevailing winds or structures do not impede fan air flow or cause the heated air to recirculate through the radiator core.

Horizontal Remote

Horizontal remote radiators nullify the effects of wind but may require protection from rain, snow and ice.

Booster Pumps

Booster pumps are utilized in conjunction with remote radiators which are usually applicable only for gas engines.

The function of the pump is to provide sufficient pressure for the coolant to reach the remote located radiator.

Fans

Radiator fans are belt driven from the crankshaft pulley. Fan air flow is dependent on:

- fan diameter
- number of blades
- blade shape
- blade rotation speed

Radiator and fan sizing charts should be consulted to ensure capacity and economic requirements are met.

Fan Power Demand

The fan included in Caterpillar radiator systems (typically) absorb 3-8% of the gross power output of the engine.

Fan Type

A radiator fan can be a blower or suction type. A blower fan, which forces air away from the engine, is usually a better choice for stationary engines, because it keeps the hot air from surrounding the engine. This type of fan also allows for easy disposal of hot air through a wall opening in an enclosed building installation. A suction fan, which pulls air toward the engine, is more effective in mobile equipment because of a vehicle's forward motion.

Heat Recovery

Heat recovery refers to the capture and utilization of heat energy which is normally wasted. This process, increasingly common today, improves total system efficiency and return on investment.

Reciprocating engines convert about 30-37% of their input fuel energy into mechanical power. Another 20-40% is rejected to the jacket water, 30-40% to exhaust, and 5-7% is radiated to the environment.

The heat rejected by the jacket water can be totally recovered and 50-70% of the exhaust energy is economically recoverable. Total heat recovery results in approximately 80% efficiency.

Heat recovery design best suited for any installation depends on many considerations, both technical and economic. The chief function of any design is to cool the engine. The engine must be cooled even when heat demand is low, but power is still required.

There are two heat recovery methods: standard temperature and high temperature. Standard temperature heat recovery systems recover heat from coolant at up to 99°C (210°F) outlet temperature. High temperature heat recovery systems recover heat from coolant at up to 127.1°C (260°F) outlet temperature. High temperature systems are further divided into solid water, water and steam, and ebullient steam systems.

Standard Temperature Heat Recovery

Heat recovery of a standard engine may amount to nothing more than utilizing heat transferred from the engine radiator. This air is usually 38-65°C (100-150°F). The recovered heat is quite suitable for preheating boiler combustion air, space heating, or drying grain, and lumber. The system cost is minimal and overall efficiency will increase to approximately 60%.

A more versatile method of recovering heat from a standard temperature system uses a shell and tube heat exchanger to transfer rejected engine heat to a secondary circuit, usually process water. An example system is illustrated in Figure 11. There are many advantages inherent with this design. The standard engine jacket water pump, thermostatic configuration, and water bypass line are retained. The engine system is independent from the load process loop, which allows operation with antifreeze and coolant conditioner. This relieves concern for problems associated with using process water to cool the engine.

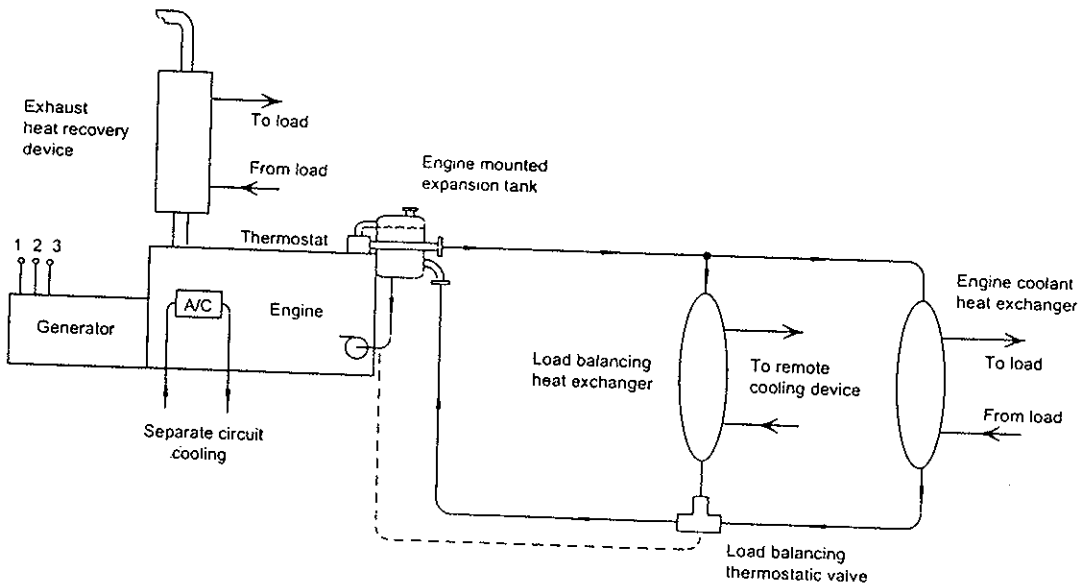


Figure 11. Standard temperature water system.

When normal process load is insufficient to absorb enough heat, load balancing thermostatic valves limit jacket water inlet temperature by directing coolant through a secondary cooling source (load balancing heat exchanger).

Note: The load balancing heat exchanger must be incorporated in the engine loop, not the load loop. The load balancing condenser may be either a heat exchanger or radiator. Heat Transfer through the load balancer is usually cyclical. If a radiator is used, it must be designed to withstand thermal shocks developed from cyclic loading.

An exhaust heat recovery device may be included in the system in series, parallel, or as a separate water or steam circuit. Consult the manufacturer for design details for the unit in question. Figure 12 shows a muffler included in series with the engine system. Note the engine loop is still separate from the load loop. The engine expansion tank may be utilized. Generally, boiler water is used as a medium in the load loop. Boiler water is pumped through the jacket water heat exchanger and exhaust heat recovery device in series where it is heated to the desired temperature. As shown, water flow through the expansion tank provides deaeration.

A third variation on the standard temperature system is to incorporate the exhaust heat recovery device into the engine cooling loop, Figure 13. To ensure coolant flow through the muffler, the engine thermostats and the bypass line must be removed and an external warm-up thermostat is added. (The added external resistance of the heat recovery device may exceed the allowable resistance available from the engine mounted pump.) An auxiliary circulation pump may be required. The advantages of this system are that the obtainable process water temperature is usually higher and there are fewer components. The disadvantages to this system are the engine cooling system is modified, and the design of the system becomes more critical to successful engine operation.

Caution: Any heat recovery system where the process water circulates in the engine is not recommended. Experience has shown that, in most cases, the user cannot economically treat the quantity of process water to the level required to avoid maintenance problems with the engine.

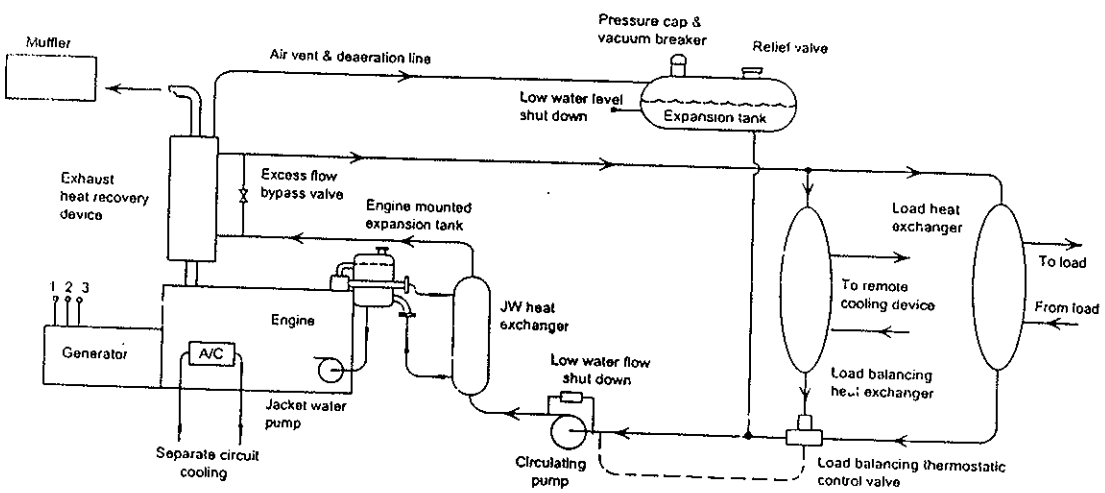


Figure 12. Standard temperature water system with muffler in series

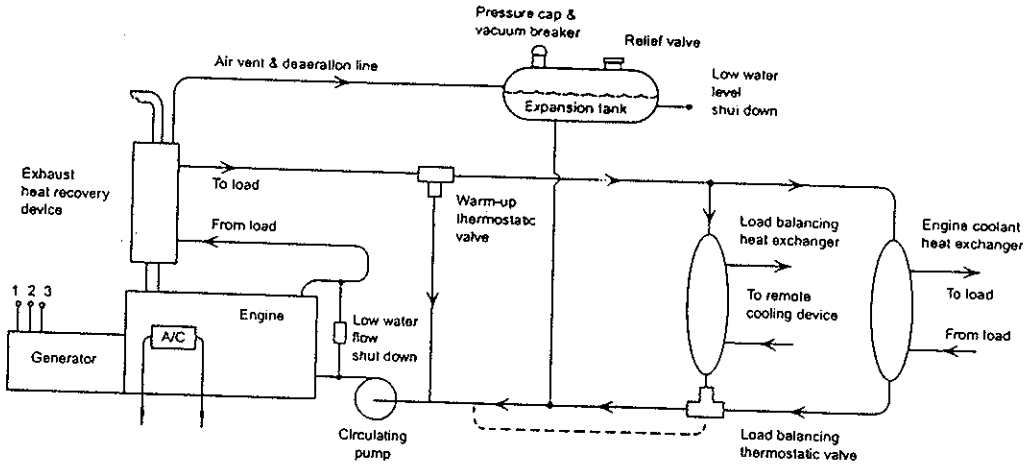


Figure 13. Standard temperature water system with the exhaust heat recovery device incorporated

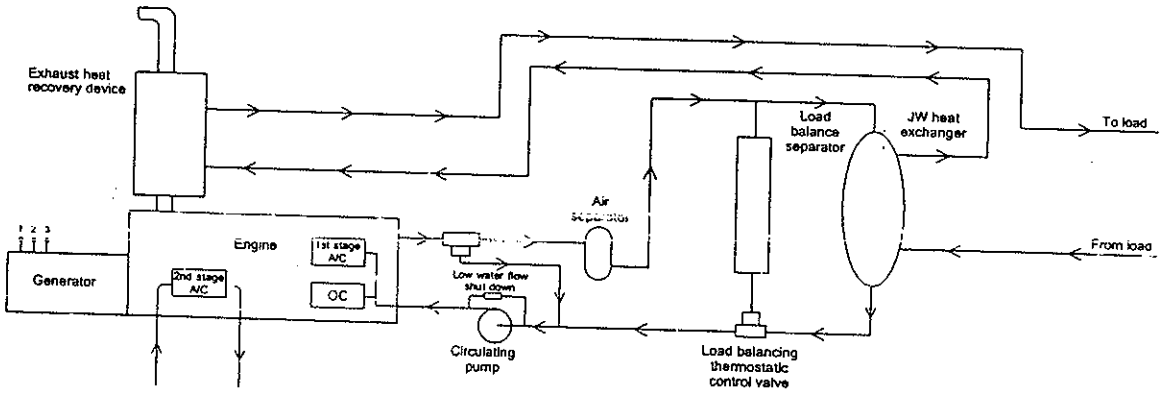


Figure 14. G3516B 50 Hz standard temperature combined heat and power system

Caterpillar G3516B 50 Hz packages with standard temperature heat recovery systems are available in the price list. This configuration is another variation of a heat recovery system. Figure 14 illustrates the design of this package. This package can be ordered with the jacket water heat recovery system only or with both the jacket water and exhaust heat recovery systems. This package is provided completely installed from the Caterpillar facility including all components and piping to recover heat from the jacket water and exhaust circuits.

Critical Design Criteria for Standard Temperature Heat Recovery

The purpose of the following discussion is to call attention to certain basic criteria necessary for proper operation of a heat recovery system. In no way should this be considered an all inclusive list. Contact a consulting engineer for specific requirements.

- The system must provide adequate coolant flow through the engine so the engine coolant temperature differential (outlet minus inlet) does not exceed 11.1°C (20°F).
- The expansion tank must be the highest point in both the engine and load loop cooling systems.

- Use only coolant or treated water in the engine cooling circuit.
- Incorporate air vents to eliminate air traps and locks.
- A load balancing thermostatic valve must be used to direct coolant through a secondary cooling source to limit jacket water inlet temperature.
- Coolant must continually flow through the exhaust heat recovery device when the engine is operating to avoid thermal shock on hot muffler surfaces. This may be accomplished using a low water flow shutdown device.
- If the engine thermostats are removed, an external warm-up thermostat is required.
- To keep external head within allowable limits for the engine mounted pump, locate heat recovery mufflers and heat exchangers as near the engine as possible. While static head on the jacket water pump is limited to 172 kPa (25 psi) static head greater than 35 kPa (5 psi) requires the expansion tank to be vented to air, i.e., no pressure cap.

High Temperature Heat Recovery Circuits
To ensure proper cooling in all types of high temperature systems, the engine oil cooler and aftercooler require a cooling water circuit separate from the engine jacket water. A thermostat in the oil system bypasses the oil cooler to control lubricating oil minimum temperatures and prevent overcooling. If the coolant in the oil cooler circuit can be below 10°C (50°F), an external control valve is recommended to allow the oil to reach operating temperature, prevent oil gelling, and ensure oil flow through the oil cooler.

High Temperature Solid Water System
This system functions similar to a standard temperature water system except elevated jacket water temperatures 99-127°C (210-260°F) are used. The standard thermostat and bypass are removed and replaced by an external control. A pressure cap or static head must be provided in the engine coolant circuit to assure a pressure of 27.6-34.5 kPa (4-5 psig) **above** the pressure at which steam forms. The source of this pressure may be a static head imposed by an elevated expansion tank or controlled air pressure in the expansion tank. For 127°C (260°F) water, the pressure at the engine should be approximately 172 kPa (25 psig). Maximum system pressure allowed on the engine water jacket is 276 kPa (40 psig). This is measured by taking the total of circulating differential pressure, system pressure, and static resistance on the system. The standard jacket water pump is removed and must be replaced by one with high temperature and pressure capabilities.

Critical Design Criteria for High Temperature Solid Water
High temperature systems include many of the same requirements as a standard temperature system, but there are some additional points which are important to take into account:

- The system must provide adequate coolant flow through the engine so the engine coolant temperature differential (outlet minus inlet) does not exceed 11.1°C (20°F).
- The expansion tank must be the highest point in the cooling system.
- Proper water treatment is essential for successful system operation.
- Incorporate deaeration circuit and air vents to eliminate air traps and locks.
- A load balancing thermostatic valve must be used to direct coolant through a secondary cooling source to limit jacket water outlet temperature.
- Coolant must continually flow through the exhaust heat recovery device when the engine is operating to avoid thermal shock on hot muffler surfaces. This may be accomplished by using a low water flow shutdown device.
- A high temperature system requires a pressure control valve for the engine coolant circuit.
- Water pumps must be suitable for use with elevated temperatures and pressures.

- The engine oil cooler requires a cooling circuit separate from the engine jacket water.
- An external warm-up thermostat is required.
- The load balancing heat exchanger must be incorporated in the engine loop, not the load loop. The load balancing condenser may be either a heat exchanger or radiator. Heat transfer through the load balancer is usually cyclical. Thus, if a radiator is used, it must be designed to withstand thermal shocks developed from cyclic loading.
- For multiple units that share a single steam separator, all circulating pumps must run when any one engine operates. This practice prevents a severe thermal shock if a unit is started later.
- High jacket water temperatures will result in after-boil if there is a hot shutdown. Add an additional 10% of system volume to the normal expansion tank sizing guidelines to provide expansion volume.

High Temperature Water-Steam System

The high temperature water-steam system provides solid water to cool the engine, but then flashes it to steam to be used for loads requiring low pressure steam, 96.5 kPa (14 psig). A circulation pump forces water through the cylinder block to the steam separator. In the steam separator, some of the water flashes to steam and the water returns to the engine.

The pressures shown in Figure 15 are representative values. The relief valve pressure 103 kPa (15 psig) is set by boiler codes qualifying low pressure steam. Pressure in the separator is controlled by the pressure control valve. Once pressure builds to 96.5 kPa (14 psig), the control valve will allow steam to flow. The actual steam pressure in the load line is a function of load requirements. If the load is not consuming steam, the pressure in the steam line will increase. Once pressure reaches 89.6 kPa (13 psig), the excess steam valve will open to transfer engine heat to the waste cooling device (load balancing condenser). The excess steam valve must be located downstream from the pressure control valve to function properly.

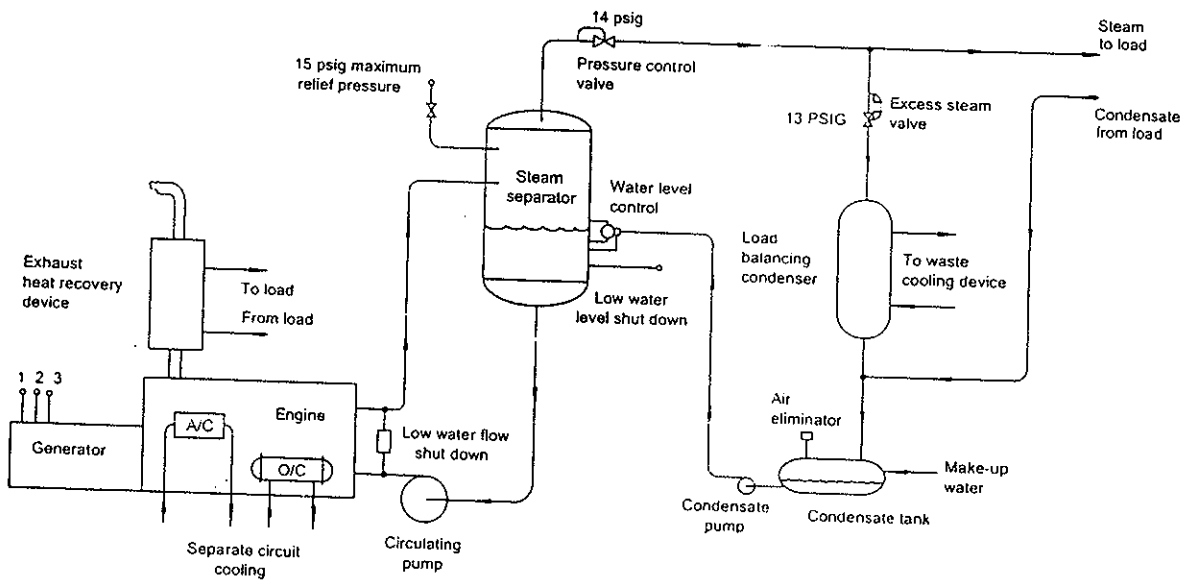


Figure 15. High temperature, water to steam system.

Critical Design Criteria for High Temperature Water-Steam

- There are no elevation or static resistance requirements for the steam separator other than what suction head is required for the circulation pump. Thus, this system may be used in locations with limited overhead clearance.
- Pressure at the engine water jacket must be maintained between a minimum 55 kPa (8 psig) to a maximum of 197 kPa (28.5 psig). Maximum temperature at engine outlet must not exceed 126.7°C (260°F).
- A low water flow shutdown device is required on high temperature cooling engines. This is accomplished by using a differential pressure gauge across the engine water jacket. When the water flow rate slows or stops the lack of a pressure drop across the engine block will shutdown the engine. Since an electric motor driven pump is used, it is important to insure the pump is operating while the engine is running. The pump should continue running approximately five minutes after the engine is stopped to cool the engine.
- Use only treated water in the cooling circuit. Continuous water chemistry monitoring with automatic boiler blow-down devices are recommended.
- A low water level shutdown on the steam separator device is required. A low water level pre-alarm is also recommended. Low water level could cause engine overheating and serious damage.
- The excess steam valve cannot be in the steam separator and must be downstream of the pressure control valve.
- A warm-up thermostat is not required since the pressure control valve does not allow any heat (steam) to exit the system until the engine has warmed up and the separator has reached system pressure.

Ebullient Cooling

The ebullient system utilizes heat of vaporization to remove heat from the engine. Steam is not collected within the engine, but moves through the water passages along with high temperature water by a change in coolant density as it gains heat. Therefore, a jacket water pump is not used. The water/steam mixture flows to a steam separator located above the engine. A temperature differential between engine-water-in and engine-water-out is usually 1.1-1.7°C (2-3°F). Correct flow requires careful design of pipes and lines. Because of critical design requirements, ebullient systems are not as popular as positive flow systems which incorporate a high temperature pump that forces steam flow through the engine.

Heat Exchanger

A heat exchanger can be used to cool the engine when ventilation air is limited, or when excessive static resistance on the engine must be avoided. Heat exchangers are typically classified according to flow arrangement and type of construction.

Advantages to using a heat exchanger are: that there is no fan noise, it reduces the air flow requirements, the parasitic load will be less, and the fuel consumption will be improved.

Some of the disadvantages are that a heat exchanger requires a separate cooling source and a separate expansion tank which means using an extra pump and plumbing. Provisions for room ventilation will also be required.

Shell and Tube Type

The most common type of heat exchanger is the shell and tube type (see Figure 16). In a shell and tube heat exchanger, the engine coolant is cooled by the transfer of heat to another liquid at a lower temperature. The design parameters available to the shell and tube heat exchanger designer include the diameter, length, number of tubes, the number of raw or treated water passes, the number and cutoff height of shell side baffles. These heat exchangers can have single-pass, or multiple-pass flows. A single pass heat exchanger has the cooling media pass through the heat exchanger only once before exiting. A multiple-pass heat exchanger allows cooling media to pass through the heat exchanger multiple times before exiting.

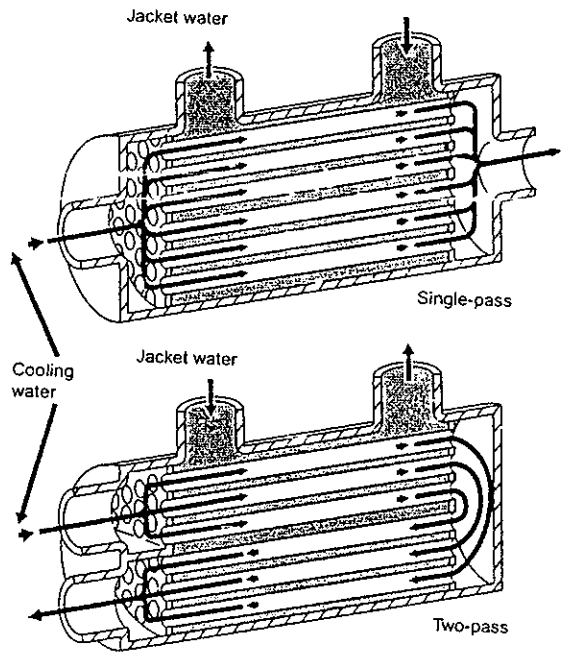


Figure 16. Heat exchanger, shell and tube type.

Plate Type

Another common type of heat exchanger is the plate type heat exchanger. The design parameters available to the plate type heat exchanger designer include the size and number of plates, the turbulator design and the number of raw or treated water passes. Tight baffling around the heat exchanger is critical to obtaining good heat transfer performance.

The remaining section about heat exchangers will refer to the heat exchanger's coolant as "Raw or Treated Water" and the engine's coolant as "coolant".

The flow of the raw water will affect the heat transfer from the engine's coolant. In a single-pass heat exchanger the raw water can flow in the same direction as the coolant (Parallel-flow) or it can flow in the opposite direction as the coolant, (Counter-flow). Counter-flow heat exchangers can transfer more heat for a given surface area than Parallel-flow heat exchangers. Therefore most single-pass, shell/tube heat exchangers use Counter-flow.

Design Criteria and Considerations

Many engine models have attachment heat exchangers in the price list. Consider the following factors when designing and installing a heat exchanger cooling system.

Size the heat exchanger to accommodate a heat rejection rate approximately 10% greater than the engine's heat rejection. The additional 10% will compensate for possible variations from published or calculated heat rejection rates and engine overload.

The cooling capacity varies for different cooling mediums, and tend to reduce heat transfer. A fouling factor is assumed during equipment sizing, which will affect the heat transfer of a heat exchanger. Factors for common types of water can be found in Table 12. The fouling factor relationship is:

$$FF = \frac{1}{U\ coolant} - \frac{1}{U\ clean\ core}$$

Where:

FF = Fouling factor, hr-m²-°C/kJ (hr-ft²-°F/Btu)

U coolant = Heat Transfer Coefficient of core with coolant, kJ/hr-m²-°C (Btu/hr-ft² °F)

U clean core = Heat Transfer Coefficient of clean core kJ/hr-m²-°C (Btu/hr-ft² °F)

Engine Coolant Temperature ≤ 116°C (240°F) Raw Water Temperature ≤ 52°C (125°F) Water Types	Raw Water Velocity ≤ 0.9 m/s (3 ft/sec)	Raw Water Velocity > 0.9 m/s (3 ft/sec)
Sea Water	0.0005	0.0005
Brackish Water	0.002	0.001
Cooling Tower and Artificial Spray Pond: Treated Makeup Untreated	0.001 0.003	0.001 0.003
City or Well Water (such as Great Lakes)	0.001	0.001
River Water	0.003	0.003
Hard (over 15 grains/gal)	0.003	0.003
Engine Jacket	0.001	0.001
Treated Boiler Feedwater	0.001	0.0005

Table 12. Fouling factor chart for water.
Units are in hr-ft²-°F/Btu
Note: 1 hr-ft²-°F/Btu= .0545 hr-m²-°C/kJ

Submerged Pipe Cooling

Submerged Pipe Cooling is a simple, but yet effective way of rejecting heat from the engine and can be used if the engine is located near a supply of relatively cool water, preferably 29°C (85°F) or less. In this system, the engine coolant water is pumped through coils (or lengths of pipe) that are submerged in the nearby cool water. Figure 17 shows an example of a typical Submerged Pipe Cooling system.

A concrete catch basin or tank should be placed in the source of the cooling water. This will help ensure a consistent volume of water around the coils and help keep mud and silt from burying the coils. The pipes must be supported up, off the bottom of the tank to ensure maximum cooling efficiency.

Engine heat rejection and the temperature of the cooling medium must be carefully considered in determining the correct amount of pipe to use. As a rule-of-thumb, 0.003 m² (0.0353 ft²) of submerged pipe surface area is required for every 1.055 kJ/min (1 Btu/min) of jacket water heat rejection that must be removed. This rule-of-thumb is for raw water temperatures up to 29°C (85°F). A trial-and-error method can be used if jacket water temperature is too high or too low: by adding or removing pipe as necessary, the engine cooling water temperature can be maximized.

The system should be connected so that jacket water flows from the engine, to the cooling coils, and to the expansion tank, before returning to the water-pump inlet.

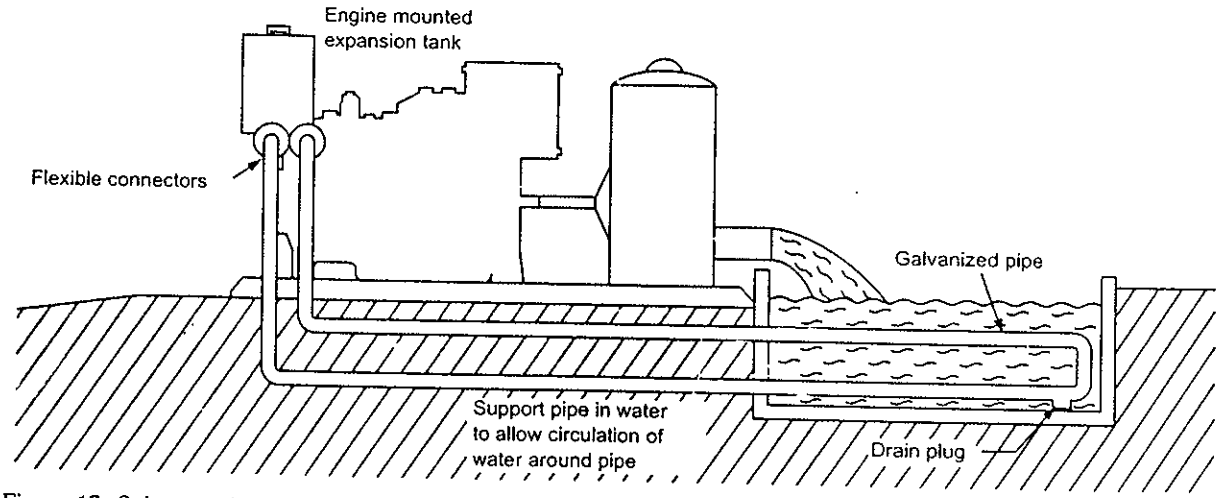


Figure 17. Submerged pipe cooling.

Cooling Towers

Since radiators are often ineffective for cooling Separate Circuit Aftercooling, SCAC, water below 54°C (130°F), an alternate source of water is needed for low temperature cooling circuits (i.e. 32°C (90°F) SCAC). In such cases, cooling towers are used when a large supply of cool water (i.e. a river, lake, cooling pond, etc.) is not available or not usable for environmental reasons.

Though there are several types of cooling towers, the basic method of heat transfer is the same: air is brought in direct contact with the cooling water. Cooling is accomplished in two ways: approximately 75% occurs by water evaporation, and about 25% by direct heat transfer from the water spray to the passing air. Since the primary mechanism for cooling the water is through evaporation, the ability of the air flow to absorb moisture is critical to the effectiveness of a cooling tower. It is for this reason that the performance of a cooling tower depends on the relative humidity of the ambient air.

Relative humidity is a measure of the air's ability to absorb moisture. When the relative humidity is 100%, the wet-bulb and dry-bulb temperatures are equal and the air cannot absorb additional moisture. Therefore, there will be no evaporation and little cooling. However, when the relative humidity is less than 100%, the wet-bulb temperature is less than the dry-bulb temperature and the air can absorb moisture by evaporation.

The prevailing wet-bulb temperature is a key factor in the design of a cooling tower. It is the theoretical limit to which a cooling tower will cool. However, in the practical application of a cooling tower, the coolant temperature can only be maintained down to about 5.6°C (10°F) above the wet-bulb temperature.

There are two types of cooling towers: the open-type and the closed-loop-type or evaporative cooler.

Open Cooling Tower

In open cooling systems using cooling towers, the engine cooling water is sprayed directly into the tower and is subjected to the inherent concentration of water contaminants of this system. Unless special provisions are made, such as a cleanable aftercooler and corrosion resistant plumbing, the use of an open cooling system is not recommended for Caterpillar Engines.

Closed Cooling Tower

Figure 18 demonstrates how a heat exchanger can be used to maintain a closed cooling system for the engine while using a cooling tower. In this system, raw water is circulated by an auxiliary water pump driven from the engine, or by an electric motor. The pump flows cool water from a basin at the bottom to the cooling tower, forces it through the heat exchanger, and to the distribution system at the top of the tower. As the heated water passes through the tower, it cools and collects in the basin.

For the closed loop cooling tower, the engine coolant can be circulated to the cooler eliminating the heat exchanger at the engine, Figure 19.

Cooling Tower Design Criteria

As a general rule, cooling towers are most effective in areas with an ambient dry-bulb temperature above 37.8°C (100°F), and an average relative humidity below 50%.

Cooling towers are very sensitive to approach temperatures (i.e. the temperature between the wet bulb temperature and the desired coolant temperature). To go from an approach temperature of 8.3°C (15°F) to an approach temperature of 5.6°C (10°F), the cooling tower size would have to be increased by as much as 50%. Any approach temperature below 2.8°C (5°F) becomes unrealistic.

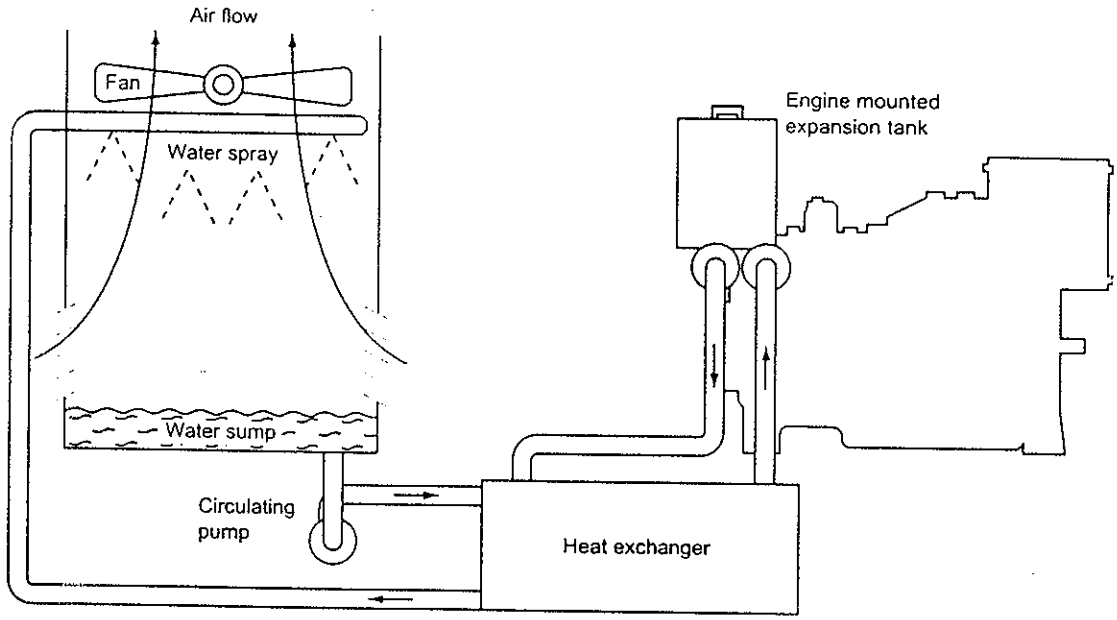


Figure 18. Closed cooling tower with externally mounted heat exchanger.

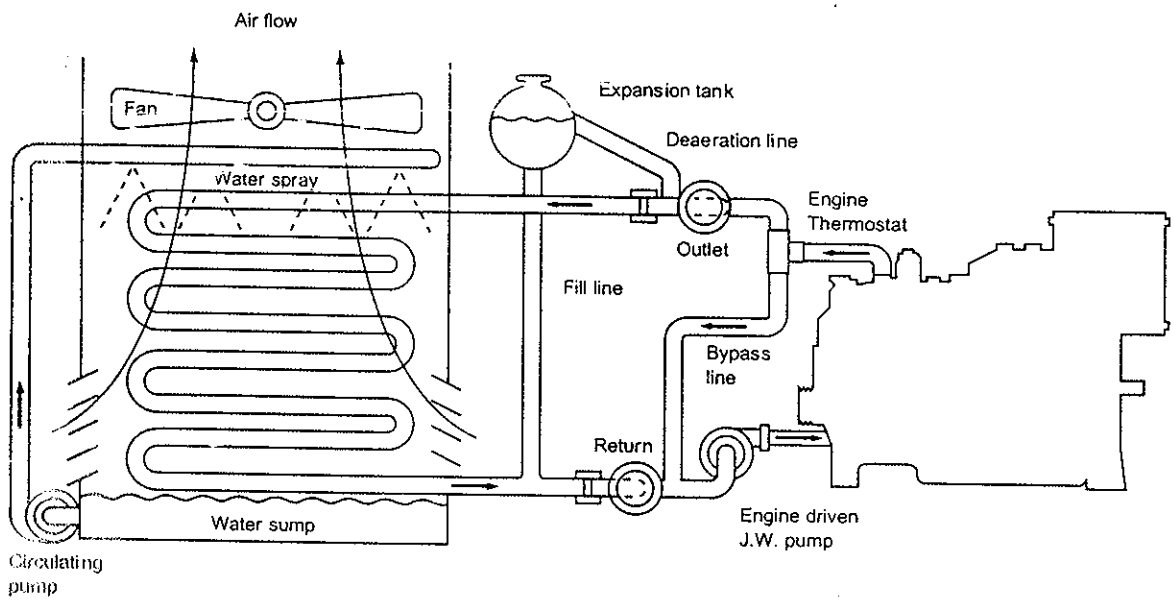


Figure 19. Closed loop cooling tower.

As with radiators, cooling towers are very sensitive to recirculation and the presence of other upwind cooling towers (see Figure 20). Any recirculation or ingestion of exhaust from another cooling tower effectively reduces the approach and wet-bulb temperature of the incoming air. As was demonstrated earlier, the approach temperature has a significant effect on cooling tower size. Therefore, factors such as location of the towers, direction of the prevailing winds, and height of the towers (a taller tower will reduce recirculation), should be taken into consideration.

The continued process of evaporation means that any scale-forming salts present in the water will gradually be concentrated; the water may pick up further contaminants from the air. These impurities can result in the build-up of scale on the cooling water passages, decreasing the cooling system efficiency. As these salts and minerals build, they must be drained and the tower water diluted with fresh water. Solids such as dust may also accumulate in the tower water. Filters or centrifugal separators can be installed to reduce these contaminants.

If the tower water is used in the engine circuits such as the aftercooler, it should be treated with corrosion inhibitors to be compatible with engine piping and components. Even with treated water, a cleanable aftercooler core is required when used with cooling tower water.

Cooling towers installed in frigid locations require additional design requirements to prevent freezing.

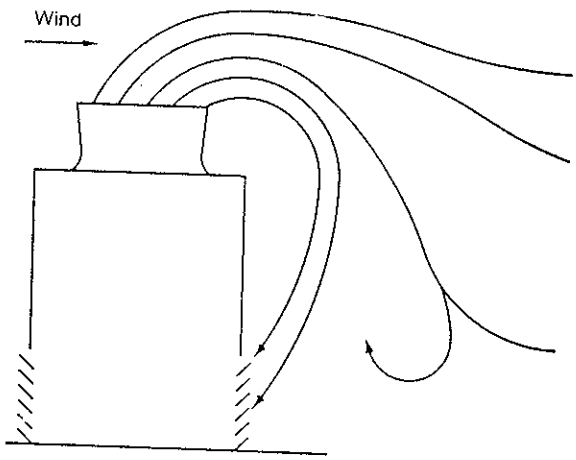


Figure 20. Tower recirculation due to wind.

Cooling System Design Considerations

Serviceability

Access to the heat exchanger is required for tube rodding (cleaning), plate scrubbing, or removal of the tube-bundle assembly. Engine water pumps must be easy to remove. Remote water temperature regulators should be accessible, and have appropriate isolation valves to allow servicing the engine without draining the entire system. Similar guidelines for radiators, heat recovery units, deaeration units, and other components requiring service or replacement apply.

Drain

Provisions must be made for adequate drainage and flushing of the cooling system.

Fill Rate

The Caterpillar engine mounted cooling circuits are designed to completely vent during the initial fill for fill rates up to 19.0 L/min (5 gpm). Vent lines are located such that the external cooling circuit will also be vented if the customer piping is installed level with, or below, the proper engine connecting points, and if no air traps are designed in the piping. Often vent valves are also part of the fill system. They provide air venting while preventing coolant from bypassing thermostat(s).

Piping Slope for Effective Venting

Piping carrying coolant from the engine to the radiator must have a continual upward slope. This is to allow any gases in the coolant to be separated from the coolant and vented in the radiator top tank.

Expansion Tanks

Heat exchangers, just like radiators, require expansion tanks. An expansion tank is an integral part of the engine cooling system and performs the following functions:

- Vent gases in the coolant
  - to reduce corrosion.
  - to prevent loss of coolant due to displacement by gases.
- Provide a positive head on the system pump
  - to prevent cavitation.
- Provide expansion volume
  - to prevent coolant loss when the coolant expands due to temperature change.
- Provide a place to fill the system and maintain its corrosion inhibiting chemical additives.
- Provide a place to monitor the system coolant level
  - an alarm switch located in the expansion tank will give early warning of coolant loss.

The expansion tank must meet the following guidelines:

- The expansion tank must be the highest point in the system. If the attachment expansion tank is not the highest point of the system, an auxiliary expansion tank will be required. The additional added static resistance provided by the auxiliary expansion tank may raise the system pressure above the limit for the attachment expansion tank. The auxiliary expansion tank is added cost and may make the attachment expansion tank redundant. Those installations may be more successfully designed with a remote expansion tank instead of the attachment expansion tank.
- The maximum pressure capability is 96 kPa (14 psi). The maximum pressure limitation will prohibit the attachment expansion tank from many high temperature applications.
- The size of the expansion tank should be at least 15% of the total system water volume. This provides for expansion plus reserve.
- Depending on location, the tank must be vented to the atmosphere or incorporate a pressure cap to assure system pressure and prevent boiling of the coolant.
- The tank must provide deaeration and is usually the means of filling a system.

Attachment engine mounted radiators and most aftermarket-supplied mounted radiators have the expansion tank functions listed above as an integral part of the top tank design. Therefore, the user has no control over the function of the expansion tank. However, many engines can have custom cooling systems and/or remote radiators that have a separate customer specified expansion tank.

Volume

An expansion tank's function, as the name implies, is to allow for thermal expansion of the coolant. Coolant expansion is a function of the coolant temperature. In addition to the thermal expansion, there should also be volume for after-boil and sufficient reserve to allow operation with small leaks until they can be repaired. Full-flow expansion tanks will require greater volume to perform the deaeration function.

Engines using high temperature cooling will need a larger volume to absorb after-boil that may occur on a hot shutdown. Closed accumulator-type tanks are not recommended since they cannot be designed to actively deaerate the coolant.

Deaeration

Air can be trapped in the cooling system at initial fill or enter through combustion leakage during operation. The cylinder head gasket design allows some continual escape of combustion gases into the cooling system. This air and gas must be vented from the system, or system deterioration and water pump cavitation will result.

Entrained combustion gases require deaeration capabilities to be built into the system. Deaeration may be accomplished with a centrifugal deaeration gas separator by venting the gases back to the expansion tank (see Figure 21). If a centrifugal deaeration gas separator is not used, separation of gas from a liquid medium requires a low coolant velocity of 9.4 cm/sec (2 ft/sec) with a diverted flow to the expansion tank, where the relatively static velocity in the tank allows the gases to be separated. The deaeration flow is regulated by a 10 mm (3/8 in.) diameter orifice placed in the line. Therefore, in the areas where deaeration must take place, the water velocity should be held below this limit by increasing the diameter of the water pipe (see Figure 22). The deaeration line is usually connected to the radiator inlet tank. Most radiator inlet tanks have sufficient cross-sectional area to meet this velocity requirement. Full-flow expansion tanks must be designed with sufficient cross-sectional area to slow the velocity of the water. They must have internal baffles designed to separate the gases from the coolant.

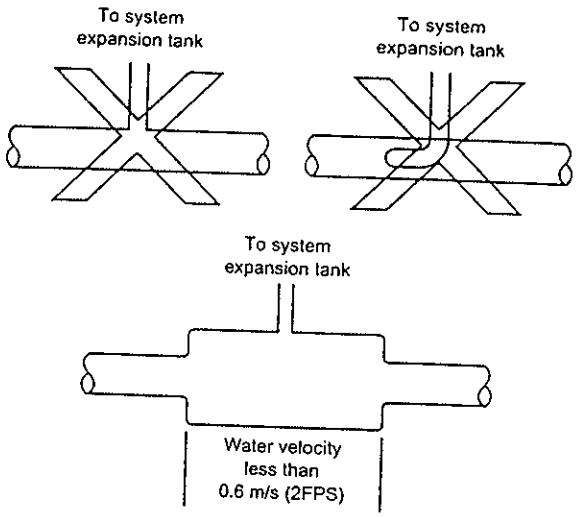


Figure 22. Diameter and water velocity.

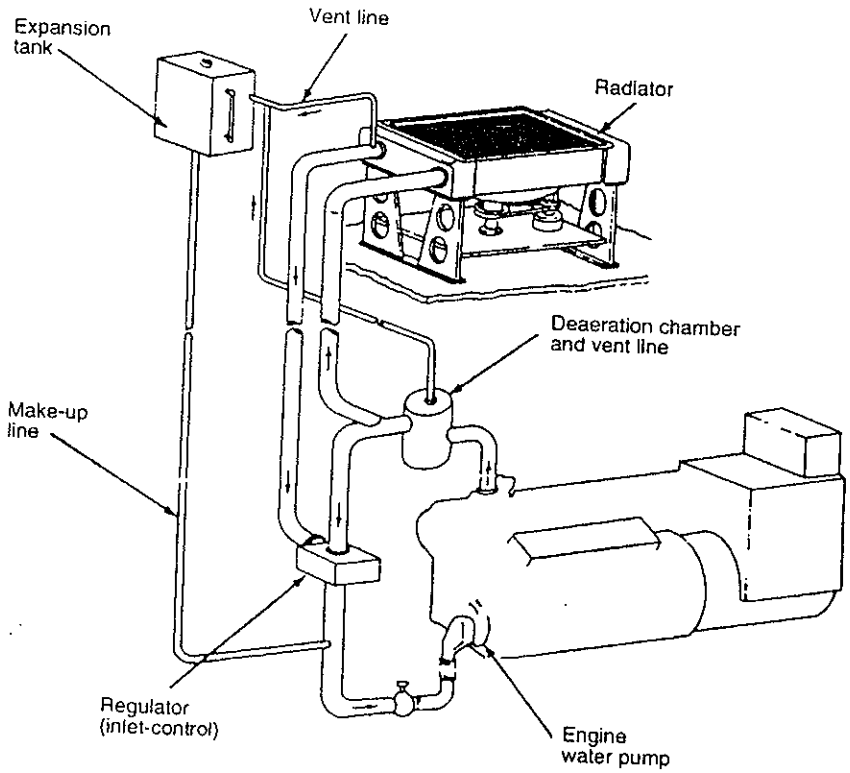


Figure 21. Deaeration.

Venting and Filling

The filler cap is usually located on the expansion tank. To accept the maximum fill rate of the system, the line connecting the expansion tank with the pump suction must be sized correctly. The minimum guidelines for filling rate are 19.0 L/min (5 gal/min). Air trapped in high points of the cooling system during the initial fill is difficult to purge and requires venting. A cooling system that will not purge itself on initial fill must have vent lines connected from the highest points of the system to the expansion tank. Vent lines must enter the expansion tank below normal water level, have a continuous upward slope, and contain no air traps. An adequate vent line would be 6.3 mm dia. (0.25 in. dia.) tubing. Use of a smaller size will clog and may not provide adequate venting ability. Too large a vent tube may introduce a circuit that could contribute either to subcooling or overheating, depending on the location.

Caution: The constant full level in the expansion tank must be above all piping. Vent high points of the engine to the expansion tank to allow a proper fill.

Maintaining Pump Suction Head with the Expansion Tank

An important function of the expansion tank is to maintain positive pressure on the suction side of the circulating pump to prevent cavitation. This function can be difficult to understand since the method depends on whether the system is inlet regulated or outlet regulated.

Inlet Regulated Systems

Inlet regulated systems have the thermostat positioned between the cooling device and the suction side of the circulating pump. The thermostat provides a restriction on the pump suction which can result in pump cavitation. To prevent the negative pressure and pump cavitation a shunt line is connected between the bottom of the expansion tank and the pump suction side (see Figure 23). The height elevation of the expansion tank provides static resistance on the pump to raise the suction pressure and prevent cavitation. The shunt line should be a minimum of 25.4 mm (1 in.) diameter. The diameter of the shunt line is important. The area of the shunt line must be at least four times the combined area of the total vent lines connected to the tank. This will minimize any reduction of the static resistance because of vent and

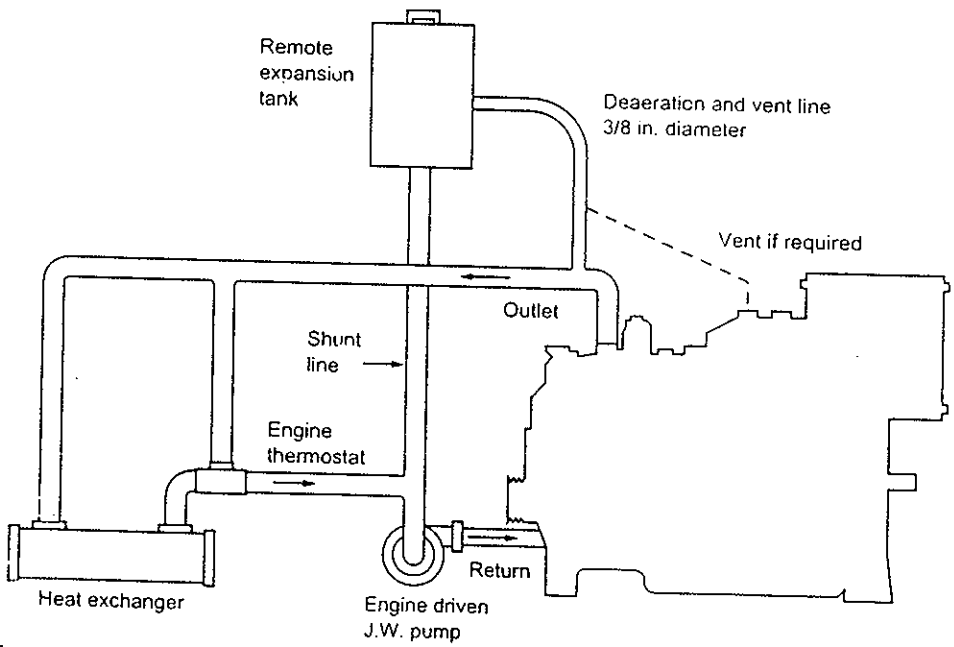


Figure 23. Inlet controlled system with non-full flow expansion tank with deaeration circuit.

deaeration flow. For a full flow or engine mounted expansion tank, the tank is located in the suction line to the pump and no shunt line is needed (see Figure 4, page 15).

Outlet Regulated Systems

Outlet regulated systems differ from inlet regulated systems in the routing of the expansion tank connection. On an outlet regulated system, the expansion tank connection is called the fill line. Since there is no thermostat located between the radiator outlet tank and the suction of the pump, the fill line does not need to be plumbed back to the inlet of the pump. The relative sizes of the return line of the radiator provides minimum pressure loss. This means the expansion tank may be connected to either the outlet tank or anywhere in the return line to the pump (see Figures 24, 25 and 26). Do not connect the fill line to the inlet tank. There will not be sufficient resistance for the deaeration circuit to function properly. Also, there will not be sufficient resistance on the pump suction which may force coolant to overflow the pressure cap.

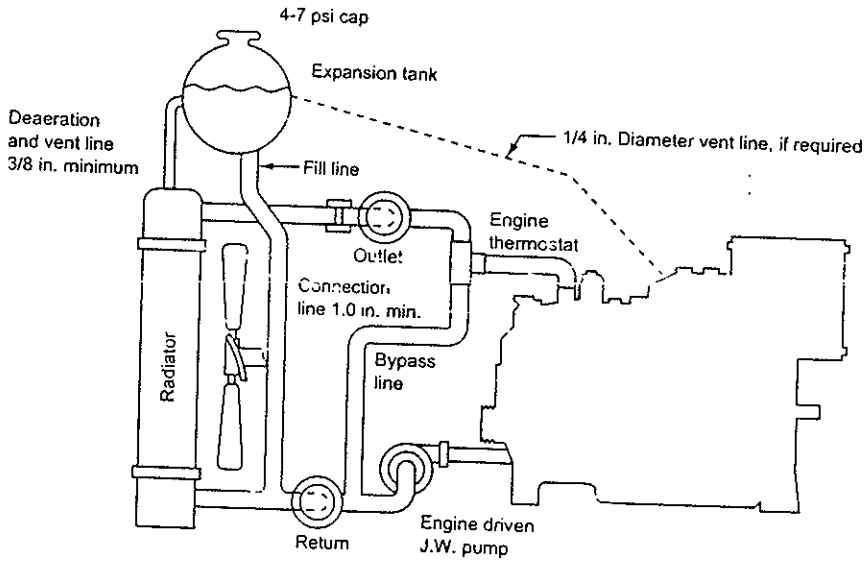


Figure 24. Outlet controlled with vertical radiator core.

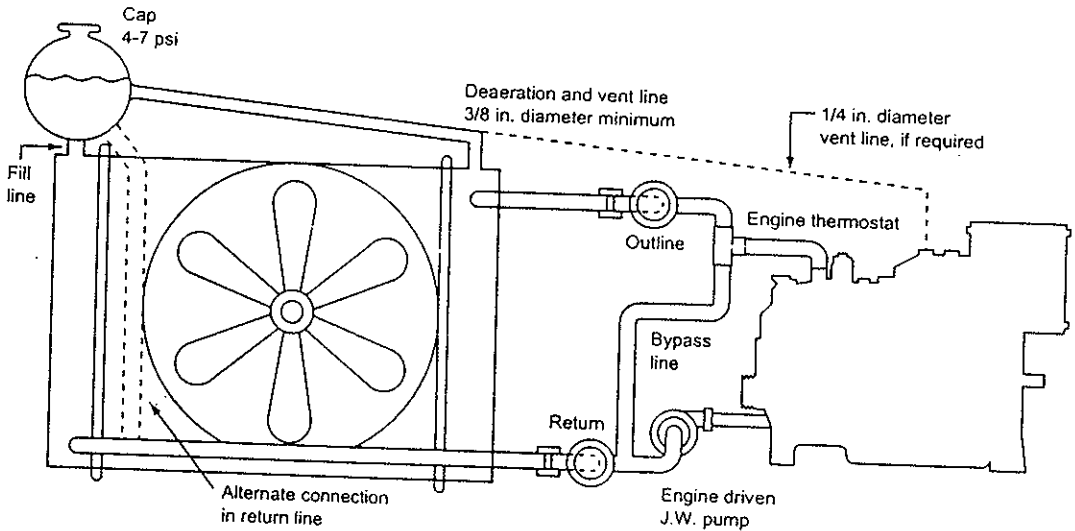


Figure 25. Outlet controlled with vertical cross flow radiator.

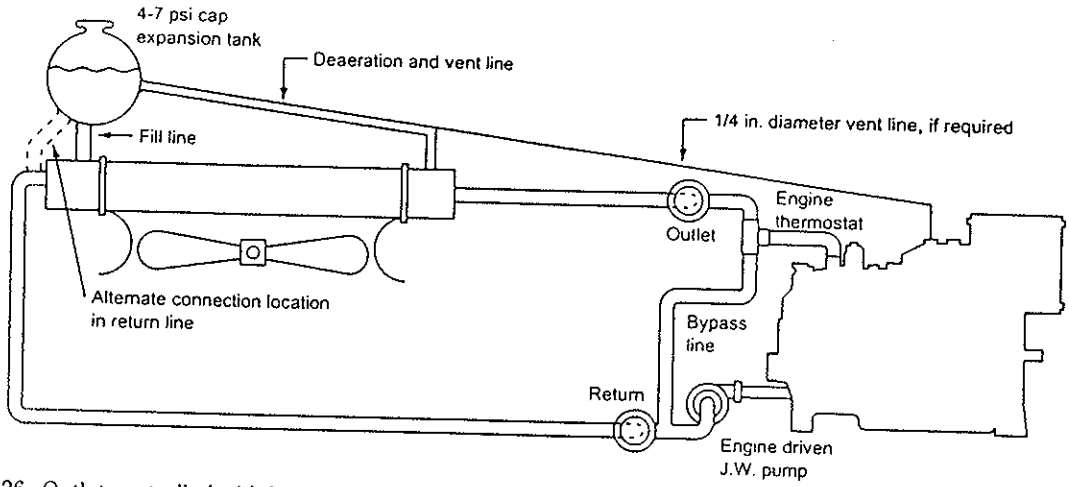


Figure 26. Outlet controlled with horizontal radiator.

Auxiliary Expansion Tank

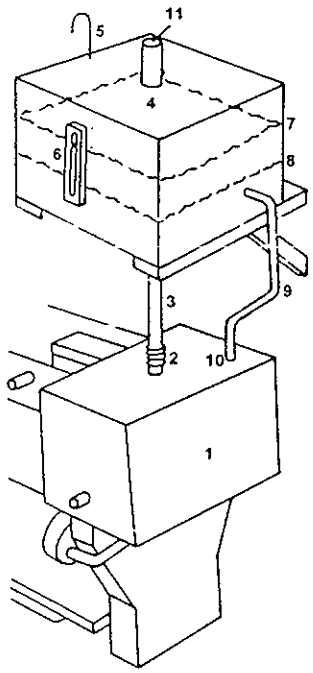
The function of the engine mounted expansion tank was covered earlier and is applicable for the engine's jacket water circuit. Caterpillar does not provide expansion tanks for the engines auxiliary water circuit (the aftercooler circuit). It can provide adequate expansion volume for only a modest amount of jacket water.

Jacket Water Circuit Auxiliary Expansion Tank

An auxiliary expansion tank is needed when additional expansion volume is required in the cooling system. This generally occurs when remote mounted heat exchangers are used.

The auxiliary tank can consist of a simple tank (see Figure 27) and is fabricated by the engine installer. Internal baffles are not required.

The engine mounted components of the cooling system will adequately separate gases from the coolant. However, the gases, once separated, must by allowed to rise by a continuous upward sloped standpipe to the auxiliary expansion tank. Additional air vent piping may be required if the auxiliary expansion tank is not located directly above the engine mounted expansion tank.



1. Engine mounted expansion tank
2. Flexible connection
3. Connecting pipe
4. Auxiliary expansion tank
5. Tank vent
6. Level gauge
7. Operating level
8. Cold fill level
9. Connecting pipe
10. Connect lower end of fill vent to vent piping entering rear side of engine mounted expansion tank
11. Tank fill

Note: Do not drill engine mounted expansion tank

Figure 27. Auxiliary expansion tank. Engine jacket water.

Aftercooler Circuit Auxiliary Expansion Tank

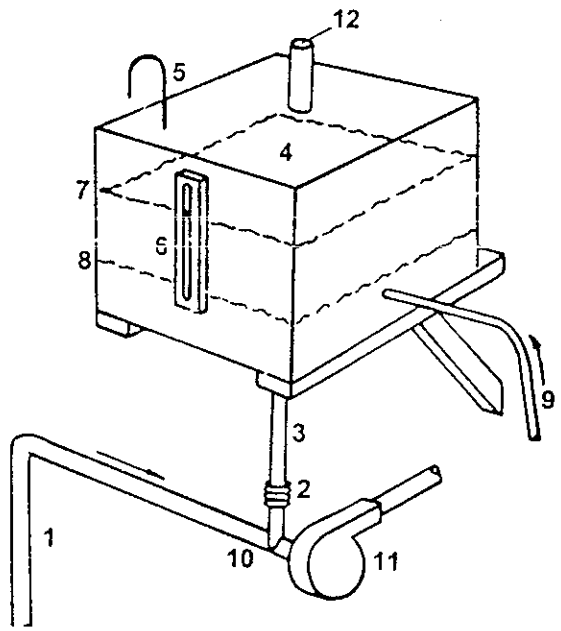
All closed fresh water aftercooler circuits require an expansion tank. The tank provides coolant expansion volume, allows system venting and provides a positive pressure on the inlet side of the circulating pump. The expansion tank must be the highest point in the aftercooler water circuit (see Figure 28).

This tank is a simple reservoir with the connecting pipe placed as close to the pump inlet as possible. The tank is fabricated by the engine installer.

Sizing the Volume of Auxiliary Expansion Tanks

The minimum volume of the auxiliary tank should include the total jacket water system expansion volume required, plus the volume for the water to the low water level in the tank. The worksheet on page 41, *Auxiliary Expansion Tank Sizing*, can be used to determine the minimum volume required.

Note: Auxiliary jacket water expansion tanks are not always required.



1. Return line from cooler
2. Flexible connection
3. Connecting pipe
4. Auxiliary expansion tank
5. Tank vent
6. Level gauge
7. Operating level
8. Cold fill level
9. Vent line from aftercooler
10. Connecting line to auxiliary pump inlet
11. Auxiliary fresh water pump
12. Tank fill

Figure 28. Auxiliary expansion tank. Separate circuit aftercooler.

Auxiliary Expansion Tank Sizing, Engine Jacket Water (see Figure 27).

Engine Model _____ Rating _____ hp at _____ rpm

1. Allowable external volume _____ L/gal, with engine mounted tank. (This value shown in Table 13, Column A, on page 42.)

2. Total volume of jacket water contained in external cooling circuit (not furnished as part of engine) _____ L/gal. See Table 14, page 42, for volume per length of standard iron pipe.

3. Line 2 minus Line 1 _____ L/gal.
   If this value is zero or less, additional tank is not required.
   If this value is greater than zero, an auxiliary tank is required.

4. If required, the *minimum* volume of the auxiliary expansion tank can be determined by:

   a. Engine volume, Table 13, Column B _____
   b. External volume Line 2 _____
   c. Multiply line a by 0.07 _____
   d. Multiply line b by 0.05 _____
   e. Total of lines c and d _____

   (This is the minimum volume of the jacket water auxiliary expansion tank.)

For Separate Circuit Aftercooler, Figure 28:

1. Total volume of aftercooler external water _____ L/gal.

2. Multiply Line 1 by 0.02 _____ L/gal.

3. Add the cold fill volume desired in auxiliary expansion tank to Line 2.
   Total of Line 2 and cold fill volume _____ L/gal.
   (This is the minimum volume of the aftercooler circuit auxiliary expansion tank.)

Engine Model	Column A Allowable External Volume With Engine Mounted Tank		Column B Engine Jacket Water System Volume With Engine Mounted Tank	
	Liters	U.S. Gal	Liters	U.S. Gal
3116	0.0	0.0	28.0	7.5
3126	0.0	0.0	28.0	7.5
3208NA	7.5	2.0	47.3	12.5
3208T&TA	7.5	2.0	56.0	14.9
3304B	8.0	2.1	55.6	14.7
3306B	8.0	2.1	55.6	14.7
3176	0.0	0.0	45.0	12.0
3406C	38.0	10.0	94.5	23.6
3408B	53.0	14.0	142.0	37.5
3412	53.0	14.0	162.0	42.8
3508	243.0	64.0	285.0	75.3
3512	182.0	48.0	323.0	85.3
3516	122.0	32.0	384.0	101.4
3606	365.0	95.0	745.0	195.0
3608	210.0	55.0	875.0	230.0
3612	550.0	145.0	1145.0	300.0
3616	260.0	65.0	1405.0	370.0
3606	4710.0	1245.0		
3608	4550.0	1200.0		
3612	4890.0	1290.0		
3616	4600.0	1210.0		

Table 13. Cooling system volumetric data.

Nominal Size		Actual I.D.		Actual O.D.					
in.	mm	in.	mm	in.	mm	ft/gal	m/L	ft/cu ft	m/cu m
.125	3.18	.270	6.86	.405	10.29	336.000	27.000	2513.000	27.049
.250	6.35	.364	9.25	.540	13.72	185.000	16.100	1383.000	14.886
.375	9.53	.494	12.55	.675	17.15	100.400	8.300	751.000	8.083
.500	12.70	.623	15.82	.840	21.34	63.100	5.000	472.000	5.080
.750	19.05	.824	20.93	1.050	26.68	36.100	2.900	271.000	2.917
1.000	25.40	1.048	26.62	1.315	33.40	22.300	1.900	166.800	1.795
1.250	31.75	1.380	35.05	1.660	42.16	12.850	1.030	96.100	1.034
1.500	38.10	1.610	40.89	1.900	48.26	9.440	.760	70.600	760.000
2.000	50.80	2.067	52.25	2.375	60.33	5.730	.460	42.900	462.000
2.500	63.50	2.468	62.69	2.875	73.02	4.020	.320	30.100	324.000
3.000	76.20	3.067	77.90	3.500	88.90	2.600	.210	19.500	210.000
3.500	88.90	3.548	90.12	4.000	101.60	1.940	.160	14.510	156.000
4.000	101.60	4.026	102.26	4.500	114.30	1.510	.120	11.300	122.000
4.500	114.30	4.508	114.50	5.000	127.00	1.205	.097	9.010	97.000
5.000	127.00	5.045	128.14	5.563	141.30	.961	.077	7.190	77.000
6.000	152.40	6.065	154.00	6.625	168.28	.666	.054	4.980	54.000
7.000	177.80	7.023	178.38	7.625	193.66	.496	.040	3.710	40.000
8.000	203.20	7.982	202.74	8.625	219.08	.384	.031	2.870	31.000
9.000	228.60	8.937	227.00	9.625	244.48	.307	.025	2.300	25.000
10.000	254.00	10.019	254.50	10.750	273.05	.244	.020	1.825	19.600
12.000	304.80	12.000	304.80	12.750	323.85	.204	.160	1.526	16.400

Table 14. Volume per length of standard iron pipe.

Installation of Auxiliary Expansion Tank

When installing an auxiliary expansion tank, separately support and isolate the auxiliary tank against vibration from the engine mounted tank with flexible tank mounting and connections.

All closed separate circuit aftercooler circuits require installation of a vent line. A tapped hole is provided at the high point in the engine mounted aftercooler circuit. Typically, this is done by installing a vent line from that point to the aftercooler circuit expansion tank. Vent line size of 6.3 mm (0.25 in.) is adequate. The vent line should enter the tank below the low water level and be sloped upwards from the engine to the tank. If possible, water lines connecting to the aftercooler circuit should be level with or below the connecting points on the engine. If the water lines must run above the connection points on the engine, it will be necessary to vent the high points in the external system. Air traps in the external system piping should be avoided.

Pressurization of Systems Containing Auxiliary Expansion Tanks — Afterboil

Generally, pressure caps are not required or desirable on auxiliary expansion tanks. This is to allow free venting and refilling, when required.

An exception exists in the situation of high performance engines, which are prone to be stopped immediately after periods of extended use. In this circumstance, a phenomenon known as *afterboil* can occur.

Afterboil is the boiling (change of liquid to vapor) of the coolant, caused by hot engine components which have lost coolant flow and pressure when the engine is hastily shut off. This can result in sudden loss of coolant out the vents and fill openings of the expansion tank. This can be dangerous to personnel in the area.

Bladder Type Expansion Tanks

Bladder type expansion tanks are commonly used in high temperature cooling applications when space restrictions and height limitations are involved. These expansion tanks eliminate the need to have the expansion tank at the highest point in the cooling circuit.

Deaeration

Air leakage into the cooling system often results in coolant foaming. Foaming promotes pitting, particularly around water pump impellers, which will affect its performance. Pitting and corrosion increase significantly when exhaust gases enter the cooling system, introducing bubbles and foam.

Low Velocity

To assure venting of gas entrained in the jacket water system, it is necessary to reduce the water flow to 0.3-0.6 m/sec (1-2 ft/sec) in the top tank of the radiator. This can be accomplished by either baffles or a dog house built into the tank. A dog house is a fabricated chamber within the radiator top tank water inlet.

Hotwell

Hotwell systems are used when static head exceeds 10 m (33 ft) or a boost pump imposes excessive dynamic head (see Figure 29).

If the Hotwell does not have sufficient volume, the pumps will draw in air during operation. The Hotwell tank must be large enough to accept the full volume of the remote radiator and the interconnecting piping, plus some reasonable amount to prevent air ingestion by the pumps. Generally, 110% of the radiator and piping volume is adequate.

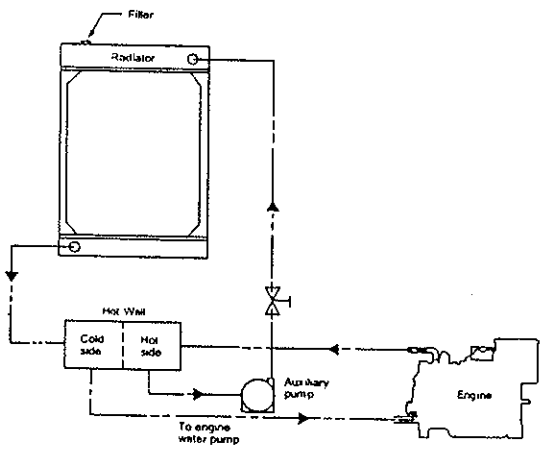


Figure 29. Hotwell system.

Mixing Tanks

A mixing tank accommodates total drainback of the remote cooling device and connecting piping. A baffle divides the tank into a hot and cold side, but is open sufficiently to assure full engine flow. Baffles are also used where water enters the tank to minimize aeration.

A tank sized for 110 percent of radiator and piping coolant ensures that pumps will not draw in air and that water levels can be checked during shutdown.

Interconnection of Engines

Central cooling systems utilize a single external circuit supplying coolant to several engines. Although separate cooling systems for each engine is preferable, use of a single radiator or heat exchanger system is possible. Practical experience has shown that only identical engines at the same loads and speeds can be successfully combined in a joint cooling system. A failure on one engine can adversely affect all engines. For this reason, interconnected engines should have isolating valves. Check valves are required on the output line of each engine to prevent recirculation through an engine that is shutdown with the thermostats opened.

The cooling system for mixed engines with mixed speeds and loads are very difficult to design and are rarely successful. They must meet the required criteria (water flow, temperatures, pressures, etc.) for each engine while operating in all possible combinations with other units.

Cleanliness

All pipe and water passages, external to the engine must be cleaned before initial engine operation. There must be flow; any foreign material must be removed.

Strainers are recommended for installation in all pipes leading to externally added equipment. They are to be installed on the site prior to startup and removed after commissioning the unit.

Similar precautions must be taken when significant modifications are made to the external cooling circuit.

Coolant Considerations

Properties

Water is used in the coolant mixture because it is the most efficient, best known, and universally available heat transfer agent. However, each water source contains contaminant levels to various degrees. At operating temperatures of diesel engines, these contaminants form acids or scale deposits that can reduce cooling system service life.

Prime consideration in closed cooling systems is to ensure no corrosion or scale forms at any point. Therefore, select the best quality water available, but never use salt water.

Water hardness is usually described in parts per million, ppm (grains/gal), of calcium carbonate content. Water containing up to 60 parts per million (3.5 grains per gallon) is considered soft and causes few deposits.

Treated Water

Never use water alone as a coolant. Supplemental coolant additives are required because water is corrosive at engine operating temperatures. Corrosion inhibitors or antifreeze solution added to water maintains cleanliness, reduces scale and foaming, and provides pH control. A 3%-6% concentration of inhibitor is recommended to maintain a pH level of 8.5 to 10. Sudden changes in coolant composition should be avoided to minimize nonmetallic components failure.

Caterpillar cooling inhibitor is compatible with ethylene glycol and propylene glycol base antifreezes but not with Dowtherm 209, or Cat Extended Life Coolant (ELC). With a 30% mixture of glycol containing corrosion inhibitors, no additional inhibitors are required. To maintain constant protection, additives should be replenished every 250 operating hours.

Caterpillar recommends the Extended Life Coolant for diesel engines, as it provides extended coolant service life, corrosion protection, extended water pump seal service life, and extended radiator service life. Caterpillar does not recommend Extended Life Coolant use in natural gas engines.

For conventional heavy duty cooling systems the antifreeze/coolant is recommended.

Note: If cooling water comes in contact with domestic water supplies, water treatment may be regulated by local codes.

Coolant/Antifreeze (Glycol)

Glycol in the coolant provides boil and feeze protection, prevents water pump cavitation, and reduces cylinder liner pitting. For optimum performance, Caterpillar recommends a 50/50 glycol/water coolant mixture.

Ethylene glycol is commonly used in heavy duty (HD) coolant/antifreezes. Propylene glycol is also common. Both ethylene glycol and propylene glycol have similar fluid properties in a 50/50 glycol/water mixture. Both ethylene glycol and propylene glycol provide similar heat transfer, freeze protection, corrosion control, and seal compatibility. The following charts define the temperature protection provided by the two types of glycol.

Ethylene Glycol		
Concentration % Glycol/% Water	Protection Against	
	Freezing	Boiling
50/50	–36°C (–33°F)	106°C (223°F)
60/40	–51°C (–60°F)	108°C (226°F)

Propylene Glycol		
Concentration % Glycol/% Water	Protection Against	
	Freezing	Boiling
50/50	–29°C (–20°F)	106°C (222°F)

Note: Do not use propylene glycol in concentrations that exceed 50 percent glycol because of propylene glycol's reduced heat transfer capability. Use ethylene glycol in conditions that require additional boil or freeze protection.

Exposing engine coolant to freezing temperatures requires addition of antifreeze. Ethylene glycol or Dowtherm 209 are recommended to protect against freezing and inhibit corrosion. Borate-nitrite solutions such as Caterpillar inhibitor are compatible only with ethylene glycol and can replenish the original corrosion inhibitors in the antifreeze.

Figure 30 defines the concentration of ethylene glycol required for system protection. It also describes the effect on coolant boiling temperature which reduces coolant afterboil. The concentration should exceed 30% to assure protection against corrosion, but above 60% will needlessly penalize heat transfer capabilities. Generally, a radiator derates 2% for each 10% of antifreeze concentration. Use of antifreeze year around decreases radiator capabilities at least 3.3°C (6°F).

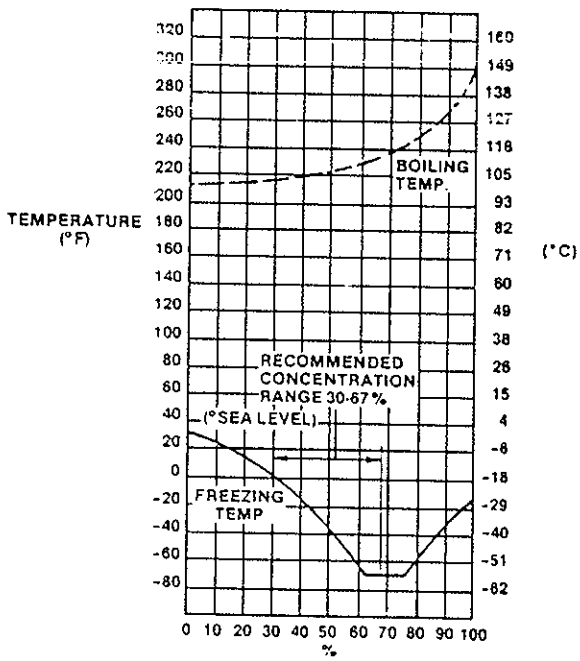


Figure 30. Ethylene Glycol concentration for protection.

Extended Life Coolant (ELC)

Caterpillar provides Extended Life Coolant (ELC) for use in heavy duty diesel engines and automotive engines. Caterpillar does not recommend Extended Life Coolant (ELC) for natural gas engines. The Caterpillar ELC anticorrosion package is totally different from conventional coolants. Caterpillar ELC is an ethylene glycol based coolant which contains organic acid corrosion inhibitors (which turn into carboxylates) and antifoaming agents. Caterpillar ELC has nitrites that serve as corrosion inhibitors that protect against cavitation corrosion. Caterpillar ELC also has TT (toly-triazole, a yellow (non ferrous) metal corrosion inhibitor). Caterpillar ELC has been formulated with the correct levels of additives to provide superior corrosion protection for all metals in diesel engine cooling systems.

Caterpillar ELC extends coolant service life to 6000 Service Hours or Four Years. Caterpillar ELC does not require frequent additions of supplemental coolant additives, SCA. A "one time only" coolant Extender is the only maintenance addition required. The Extender should be added to the cooling system at 3000 Service Hours or Two Years.

Caterpillar ELC is available Premixed with distilled water in a 50/50 concentration. The Premixed ELC provides freeze protection to -36°C (-33°F). The Premixed ELC is recommended for initial fill and for topping off the cooling system. ELC Concentrate is available to lower the freezing point to -51°C (-60°F) for Arctic conditions. ELC Concentrate should be used to adjust the coolant freeze point as required where Caterpillar ELC Premixed freeze protection is not acceptable.

Contact your Caterpillar dealer for part numbers and available container sizes.

Note: The Caterpillar EC-1. Specification is an industry standard developed by Caterpillar. The EC-1 specification defines all of the performance requirements that an engine coolant must meet in order to be sold as an extended life coolant for Caterpillar engines. Caterpillar ELC meets the industry performance requirements of ASTM D4985 and D5345 for heavy duty low silicate coolant/antifreezes. Caterpillar ELC also meets the industry performance requirements of ASTM D3306 and D4656 for automotive applications.

Note: Do not mix ordinary ethylene glycol or propylene glycol mixtures with ELC. Completely flush system before converting from one to the other coolant.

Corrosion Resistance

The coolant must prevent the formation of rust and pits in the engine and other components. Since all water can cause corrosion, water alone is not a good coolant. Both distilled water and softened water are unacceptably corrosive when corrosion inhibitors are not added.

Always add Caterpillar's corrosion inhibitor, Cooling System Conditioner, or equivalent to the water antifreeze mixture at the time of the initial fill of the cooling system if the initial fill does not include it. (This is not necessary when using Caterpillar Antifreeze. The Caterpillar formula includes all necessary inhibitors for initial fill.) If water only is used (not recommended), it is extremely important that conditioner be added. Use 3P2044, 0.118 Ltr (quart), or 6V3542, (0,24 L) (1/2 pint), Cooling System Conditioner.

Because modern antifreezes contain considerable dissolved chemical solids to accommodate aluminum components, over-concentrations can reduce heat transfer and cause water pump seal leakage or failure.

Note: Do not over inhibit your cooling system or damage will result.

Chromate Corrosion Inhibitors

Chromate is another corrosion inhibitor. In general, special testing equipment must be utilized in order to measure the coolant consist. Inappropriate amounts of corrosion inhibitor can do harm to the system. These are being phased out of usage due to toxicity and environmental concerns.

Soluble Oil

Soluble oil is used as coolant lubricant for machine tooling at the Caterpillar plants. This is not to be used in the engines as it damages hoses, gaskets, seals, does not lubricate pump bearings, or protect from damage caused by cavitation erosion. OSHA bans the use of these and are being phased out of usage due to toxicity and environmental concerns.

Water Quality and Treatment — Standard Temperature

Usable water for cooling systems must meet the following criteria:

Chloride (CL)	40 ppm (2.4 grains/gal) Maximum
Sulfate (SO_4)	100 ppm (5.9 grains/gal) Maximum
Total Hardness	170 ppm (10 grains/gal) Maximum
Total Solids	340 ppm (20 grains/gal) Maximum
pH	5.5-9.0

Water softened by removal of calcium and magnesium is acceptable.

Water Quality and Treatment — High Temperature

The engine cooling water in a low pressure steam or high temperature water system can be circulated within the engine water jacket at temperatures above 100°C (212°F). As a result, there is a potential for steam to form in both of these applications. Since several localized areas of the engine jacket water system can have very high heat flux rates and narrow water flow passages, the engine water chemistry will have the same requirements as a close tolerance steam boiler. The coolant specifications published above and in the Caterpillar operator's manual, have been written for ethylene glycol systems with temperatures less than 100°C (210°F). This is not applicable for low pressure steam and high temperature heat recovery systems.

Minerals in the water can precipitate during the heating process and form deposits within the cooling system of the engine. These deposits can restrict the heat transfer and water circulation, resulting in engine failure. To prevent these deposits from forming in the cooling system, the following engine jacket water (boiler water) quality guidelines are recommended.

Make-up Water

Make up water is added to a low pressure steam system to replace steam and blowdown losses. It should not exceed the following maximum concentrations:

Iron	0.1 ppm
Copper	0.05 ppm
Total hardness	0.3 ppm as $CaCO_3$

The make-up water can be treated to reduce, or remove, the impurities from the water. In general, the water is treated when one or more of the feed water impurities is too high to be tolerated by the system. There are many types of water treatment. Softening, Evaporation, Deaeration and Ion exchange are typically the methods used to treat makeup water for a particular system.

Feed Water

Feed water is a mixture of returning condensate and make-up water that enters the engine jacket water loop to replace steam that has left the loop. Water treatment chemicals that are added to the system are usually mixed with the feed water as it enters the engine jacket water system.

Engine Jacket Water

Engine jacket water (boiler water) is a mixture of feed water and resident water. It is the water circulated within the water jacket of the engine to cool the engine and recover heat. Engine jacket water should not exceed the following maximum concentrations:

Silica concentration	150 ppm as SiO_2
Total alkalinity	700 ppm as calcium $CaCO_3$
Specific conductance	3500 micromho per cm
Total suspended solids	10 ppm

These stringent guidelines are based on established limits of the American Boiler Manufacturer's Association (ABMA) and recommendations of the ASME Research Committee on Water in Thermal Power Systems.

In addition to the above chemistry, Caterpillar recommends the engine jacket water (boiler water) be treated with chemicals:

- An oxygen scavenger to remove oxygen from the feed water with sufficient reserve in the engine jacket water (boiler water) to remove all oxygen from the water.
- Maintain 200 to 400 ppm as $CaCO_3$ equivalent of hydroxide alkalinity in the engine jacket water (boiler water). The reserve alkalinity prevents corrosion and causes precipitation of iron and silica in a form that can be removed by blow-down.
- A blend of dispersants to adequately condition and suspend the precipitated solids in the water. The dispersants keep the solids suspended until they are removed during blow-down.
- Appropriate treatment of the steam to provide condensate returning to the engine that meets the engine jacket water (boiler water) specifications.

Total Dissolved and Suspended Solids

Depending on the make-up water source and quality of treatment, the feed water will contain some dissolved and suspended solids. On a low pressure steam system, the steam will leave the engine; however, the minerals and chemicals will remain. This results in a concentrating of the Total Dissolved Solids (TDS).

Engine water jacket scale forms when the concentration of solids reaches a critical point. This depends on the type of contaminants in the feed water, engine operating temperature, and other factors.

Measurement of TDS and Control

TDS can be measured by parts per million, ppm (grains/gal), or by conductivity (micro mhos/cm). The Caterpillar level for TDS is given in micro mhos/cm because conductivity is easier to measure with commercial continuous monitoring equipment or hand-held equipment. There is a direct relationship between ppm and conductance, 2680 ppm = 3500 micro mhos/cm.

To avoid exceeding the maximum allowable conductivity, it is necessary to drain off some of the engine jacket water (boiler water) periodically. This is referred to as *boiler blow-down*. As this occurs, new feed water is added to dilute the water in the engine water jacket, thereby reducing its conductivity. Historically, operators have performed blow-down manually by periodically opening a valve to drain the steam separator. This may be done once per hour, once per shift, or some other interval, depending on the circumstances.

Because blow-down is only performed periodically, significant dilution is needed to ensure that the engine jacket water (boiler water) conductivity does not exceed the maximum before the operator returns to blow-down the engine again. Note that the conductivity can exceed targeted maximum or even absolute maximum if the operator does not blow-down the boiler at the appointed time, or if the engine steaming rate increases between blow-down operations. If the absolute maximum is exceeded, scaling will occur. Because small amounts of scale wastes energy and can lead to engine damage, it is very important to stay below the absolute maximum.

Conversely, the steam production rate may decrease, and as a result, the operator would blow-down the engine sooner than necessary. Therefore, Caterpillar recommends continuous monitoring of TDS and automatic blow-down controls.

Conductivity runs high for ELC — carboxylated type coolants (as compared to traditional coolant inhibitors), usually 4000 micromhos/cm despite low dissolved solids.

A less common method of monitoring TDS is to measure chlorides in both the engine jacket water and the make-up water by a titration process. Since chlorides are not reduced by chemical treatment, the operator can determine the number of concentrations that have occurred in the engine jacket water by comparing the ratio of the two values. Based on known values of the make-up water, the operator can calculate the acceptable number of concentrations that can occur before blow-down is required.

Alkalinity

Alkalinity is required in a high temperature water and a low pressure steam system to prevent corrosion. Alkalinity holds silica in solution and causes iron to precipitate in a form removable by blow-down. Too much alkalinity can result in a high pH and cause caustic cracking and caustic attack to external engine compartments.

Total Alkalinity

Total alkalinity is usually measured on site by a titration with methyl orange and is frequently referred to as "M" alkalinity. Many coolant analysis companies refer to the pH of coolant water as its alkalinity. Because of the wide variation in local make-up water and commercial treatments, there is no direct correlation between total alkalinity and pH. Generally, in high temperature water and low pressure steam systems, the pH will be in a range of 10.0 to 11.5 pH.

Reserve of Hydroxide Alkalinity

To prevent corrosion and scale deposits, a reserve of hydroxide (OH) alkalinity is required. The OH alkalinity is not easily measured in the field, but can be calculated. A "P" alkalinity is measured with phenolphthalein indicator in a sulfuric acid titration. Once "P" value is determined, the following formula is used to calculate "OH" alkalinity.

"OH" Alkalinity = 2 x "P" Alkalinity - "M" Alkalinity

Low pressure steam engines will have special requirements if the unit does not run continuously. Any low pressure steam engine that is shut down, frequently can be prone to deposits even with a good water treatment program. Once the engine is shut down, the dispersants in the feed water can no longer keep the solids in suspension. They will settle to the low parts of the system, which is usually the engine. These solids will collect and harden to form scales and can result in engine failure. For turbocharged and aftercooled (TA) ebullient and all ebullient engines that do not run continuously, a circulating pump of 100 kg water/kg of steam (100 lb water/lb of steam) capacity is recommended. The circulating pump should be operated even while the engine is shutdown to keep the solids in suspension. High output TA engines can benefit from the addition of a circulating pump to prevent hot spots and reduce deposits.

The above water chemistry limits are stringent, but not overly so when considering that deposits formed within the engine are cumulative. Co-generation and heat recovery equipment is intended to last 20 years or longer.
To maintain the performance and value of equipment, it is important to eliminate scale deposits within the engine. Once a deposit is formed, it is very difficult and may be economically impractical to remove.
To emphasize again, scale formation is cumulative and the successful method of avoiding scale problems is to not permit conditions for scale to form. These guidelines are based on established limits of the American Boiler Manufacturer's Association (ABMA) and suggested guidelines by the ASME Research Committee on Water in Thermal Power Systems. We have reasonable confidence

that operators who adhere to these guidelines will have years of deposit-free and scale-free performance from their Caterpillar Engines.

Since water chemistry and water treatment are very regional items and tend to vary considerably around the world, the engine owner has the ultimate responsibility for the engine cooling water treatment.

System Pressure

Slight system pressure minimizes pump cavitation (voids in water) even at high altitude, and increases pump efficiency.

- For each 6.9 kPa (1.0 psi) of pressure, the boiling point is raised about 2°C (3°F) (see Figure 31). Elevations above 3048 m (10,000 ft) require higher rated pressure caps to avoid boiling.

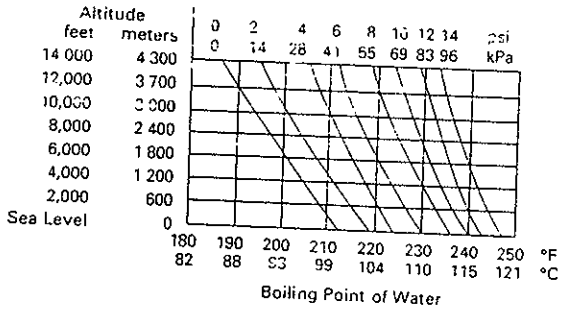


Figure 31. Cooling system pressure.

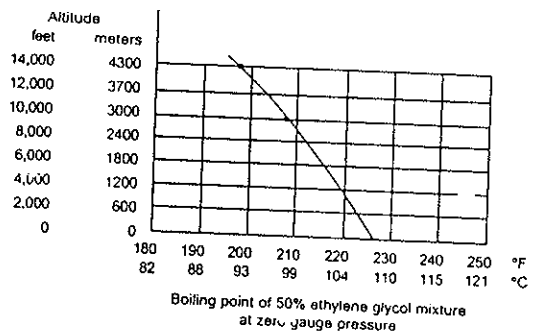


Figure 32. Cooling system pressure.

Coolant Testing

The coolant should be maintained throughout the life of the application. Dealers have available laboratory testing services which can measure not only the glycol levels but also the main corrosion inhibiting additives, as well as contaminants. Caterpillar recommends additives be kept within certain ranges depending on the type of coolant as well as the application. If regular coolant is being used, a prescribed dose of Supplemental Coolant Additive or SCA is usually added at 250 hour intervals which recharges the corrosion inhibitors in the form of nitrates, nitrites, borates, and silicates. If ELC (Extended Life Coolant) is used, Caterpillar's Cooling System Conditioner is added which contains a carboxylate or organic acid corrosion inhibitor, nitrites, and other ingredients necessary to insure the coolant remains corrosion resistant. If boiler or ebullient type coolants are used certain additives known to the system operator must be kept at corrosion arresting levels. These all should be checked at dealer recommended intervals such as every 250 hours or six months (depending on application) otherwise problems will occur. Overtreatment should also be avoided since this can cause problems as well; do not add treatment unless testing shows additive depletion. Caterpillar also has specifications covering contaminants such as chlorides, sulfates, hard water minerals, as well as dissolved gases. These must be checked by analytical methods since they can destroy a system even if corrosion inhibitor additives are in correct proportions.

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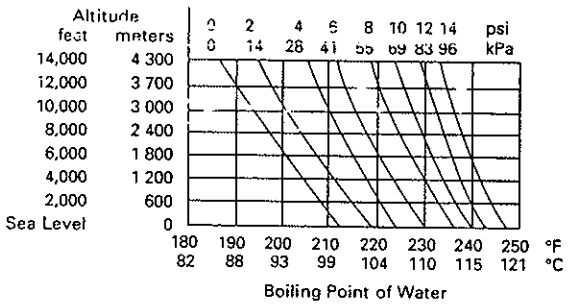

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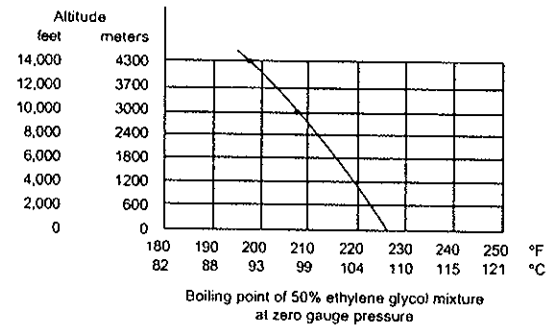

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CATERPILLAR®

Electric Power Application and Installation Guide

Engine Room Design Considerations

LEBX0034

WHERE THE WORLD TURNS FOR POWER

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Design Considerations

The engine room should be designed and sized according to the requirements of the application. The most common types of engine rooms consist of single or multiple generator set installations. Engine room design is important for ventilation, cooling and the filtering of dirt and sand from the air. Space in these rooms must also be planned for auxiliary equipment. In addition, heat and noise levels should be adequate for worker's comfort and comply with local or state codes. Considerations must be given to how the generator set is delivered to the site, i.e. by crane or other methods.

Operational Modes

As mentioned, engine room designs vary by application. In the case of prime power use, the engine room should not be located close to the actual operation room because working conditions would be inconvenient for the operator. Due to minimal usage, a standby set could remain close to the operation's area.

Single Use Facility

This room is primarily dedicated to generators.

Multiple Use Facility

The multi use facility would not only have generator sets, but also auxiliary equipment such as boiler units, compressors, etc. For this reason, it is important for the room to have ample space for maintenance and repair of the equipment.

Serviceability

Adherence to proper generator set maintenance practices is critical to generator set reliability. Caterpillar publishes guidelines and service intervals for every engine and generator model. Reference should be made to these guidelines for specific maintenance practices. However, the installation must be designed for ease of servicing to ensure adequate maintenance.

Lifting Capabilities

The room enclosures should have adequate clearance to allow lifting of the generator sets for maintenance work, etc.

Clearances

There are different types of clearances, overhead, side and front/rear.

Overhead Clearances

Overhead clearance is the clearance above the engine and generator. Special consideration should be made for clearances above the mufflers, exhaust stacks and cylinder heads to allow space for maintenance work.

Side Clearances

In a single or multiple generator set application, there should be sufficient space between engines for drain carts, tool carriages and other equipment. As a rule, the space between engines should be equal to at least the width of the largest engine installation in the room.

Front/Rear Clearances

The room should be designed to provide sufficient room in front for removing the radiator and camshaft from the block in case of major overhauls. In a similar manner, there should be sufficient space at the rear of the generator set for removal of the rotor.

Access

Accessibility is an important feature in any engine room design. Special note should be made as to whether there is a service elevator and service entrance for ease of loading and unloading service vehicles.

There will be periodic preventive maintenance on the engine, so easy access should especially be provided to:

- lube oil filters and drain plug
- fuel and air filters
- jacket water pump
- turbocharger
- heat exchanger

Routine Maintenance
Access should be available through the service entrance in the case of regular routine maintenance. The entrance should be designed to handle the removal of generator sets, parts, fluids and tools. Maintenance personnel should be able to pass through freely.

Major Repair
Rooms should be able to handle major repairs, which may involve weight and size constraints. Therefore, the design of the service elevator should be capable of shipping engine installations.

Service Convenience
Air
Air should be in sufficient supply for use with air tools as well as ventilation purposes.

Water
Water is an important resource for cooling purposes as well as for cleaning the room, engine and hands.

Cable Routing
Load Testing
There should be provisions in the building for routing cables in cases where the generator set is put on a load test with the load bank. The cable routing would provide for a quick and easy set up. For roof top installations it may be necessary to install permanent cabling to ground level.

Emergency/Rental Engine Room Conditions
The room should be designed to provide adequate space for emergency rental back up power, as well as space for switch gear installation.

Air Pressure
Doors
Air restrictions in the room can create a pressure differential between the room and the surrounding areas. A 7 kPa (1.02 psi) pressure differential can create a 1400 kg (3086 lb) force exerted on a 1 × 2 m^2 (3.28 × 6.56 ft^2) door (as pressure is equal to weight divided by area). The door design and proper ventilation should be taken into consideration when designing the room.

Louvers
Louvers come in two forms:

Natural
These are manually opened and closed depending on engine operations. Natural louvers are opened by the engine fan's airflow, and may add to restriction levels.

Mechanically Operated
In this case, the motorized louvers are hooked up to the control panel of the generator set. When the unit is in operation, the louvers are opened electronically and are closed when the generator set is shut off.

Air Velocity
While air temperatures must be controlled, air velocities affect worker comfort. The typical air motion conditions include:

Air Velocity		Conditions
m/min	(fpm)	
15.2	50	Offices, seated worker
30.5	100	Factory, standing worker
45.7	150	Capture velocity, light dust
61.0	200	Maximum continuous exposure
396.0	1300	Capture velocity, rain
306.0 – 610.0	1 – 2000	Maximum intermittent exposure

Table 1. Conditions from air velocity

Temperatures
Pre-Start
The generator set should be equipped with starting capabilities especially in cold conditions. Provisions such as jacket water heaters, battery heaters, oil heaters, ether start aids and antifreeze concentration are made to ensure proper starting. These measures are taken in cold ambient conditions.

Operational
In order to maintain temperature and prevent derating of the engine during operation, adequate air and coolant flow are necessary. The radiators provide cooling air for the room, as well as the engine. Heat exchangers and cooling towers for the cooling system remove much of the heat from the room, but ventilation will still be necessary for radiant heat.

Future Expansion

Spacing

The rooms are built for a specific capacity. The generator sets should be planned according to the needs of the application. There should be space available to provide cable lines, fuel storage, exhaust and other supplementary accessories that are needed along with additional installations.

Controls

Along with the space requirements, there should be adequate provisions for the control panels.

Installation Considerations

Handling

Lift Points

Lift points on the generator set are important as they provide support to the equipment when it is moved.

Standard

On open packages, the lift points are available on the bottom skid base for ease of lifting. Similarly, in the power module packages, lift points are provided on the edges. This makes it easier to set them up on a trailer base or on the ground.

Use a hoist in order to remove heavy components and an adjustable lifting beam in order to lift the engine. All supporting members (chains and cables) should be parallel to each other and as perpendicular as possible to the top of the object being lifted.

When it is necessary to remove a component on an angle, remember that the capacity of an eyebolt is less than the angle between the supporting members, when the object becomes less than 90 degrees. Eyebolts and brackets should never be bent and should only be loaded under tension.

To remove only the engine, use the lifting eyes on the engine itself.

Special Cases

The lifting eyes are designed for the engine arrangement as sold. If you modify the lifting eyes and/or engine arrangement weight, you are responsible for providing adequate lifting devices. Contact your Caterpillar dealer for information regarding fixtures for proper engine package lifting.

Lifting the engine and generator together requires special equipment and procedures. Contact your Caterpillar dealer for information regarding fixtures for proper lifting of your engine package.

To remove the generator only, use the lifting eyes that are on the generator.

Material

Before installation, the air at the chosen location must be analyzed to see if it contains a large amount of salt or is corrosive due to surrounding industry. These observations will have an impact on the chosen material for handles, louvers, paint etc.

Total Package Weight

Dry vs. Wet

When a generator set is shipped, it is advisable to ship it dry. It would be shipped without the lube oil and jacket water coolant. A wet package has both oil and coolant.

Component Weight

When installing a complete unit or undertaking a major overhaul, it is necessary to know the weight of the component. This will aid in designing tools such as overhead cranes and service elevators that will help in the transportation of these components.

Center of Gravity (CG) Calculations

This information is important, especially when they are hoisted by overhead cranes. Components with a lower center of gravity have less tendency to tip over when lifted.

Long Term Storage

Engine Storage

When an engine is not started for several weeks, the lubricating oil drains from the cylinder walls and piston rings. Rust can then form on the cylinder liner surface, increasing engine wear and decreasing engine life.

To prevent excessive engine wear:

- Be sure all lubrication recommendations mentioned in the Maintenance Schedule intervals chart are completed.
- If freezing temperatures are expected, check the cooling system for adequate protection against freezing. A 50/50 solution of Caterpillar (permanent-type) Antifreeze and approved water will give protection to −29°C (−20°F).

If an engine is out of operation and if use of the engine is not planned, special precautions should be made. If the engine will be stored for more than one month, a complete protection procedure is recommended. Refer to SEHS9031, Storage Procedures for Caterpillar Products, for more detailed information on engine storage.

Your Caterpillar dealer will have instructions for preparing your engine for extended storage periods.

Generator Storage

When a generator is stored, moisture may condense in the windings. Use a dry storage space and space heaters to minimize condensation.

Removing Moisture

Drying does not always produce desired results. It may be necessary for the generator to be dipped and baked by a qualified rebuild shop.

- Energize the space heaters in the generator (if equipped).
- Space heaters can be installed on generators (see the Parts Manual). They warm the windings to remove moisture. The heaters should be connected at all times in high humidity conditions, whenever the generator is not running.

Refer to SEHS9124, Special Instructions, Clean and Dry Gen Set, or contact your Caterpillar dealer.

Air Storage

Test the main stator windings with a megohmmeter:

- before the initial start-up of the generator set
- every three months* if the generator is operating in a humid environment
- if the generator has not been run under load for three months* or more

* This is a guideline only. If the environment is extremely humid or salty, it may be necessary to perform the Megger Test more frequently. Refer to one of the following publications for Megger Test information:
  - SEBU6918, SR4B Generators and Control Panels Operation and Maintenance Manual
  - SENR5359, SR4B Generator Service Manual

Ventilation Air

Air Flow

Ideally, clean, cool, dry air circulates around the switchgear, flows through the rear of the generator, across the engine and discharges through the radiator. Cool air should always be available for the engine air cleaner.

- Locate room air intakes to provide maximum cooling air to the generator set.
- Multiple generator sets require additional openings and fans.
- Units not using radiators require a forced air draft.
- Openings for intake air should be low, near the rear of the engine; position outlets high, on the opposite wall.

Air Requirements

Depending on the individual diesel engine model and the rating, the engine requires approximately 0.07 m^3/min (1.84 cfm) of air per brake kW (bhp). Consult TMI for exact data on the specific engine.

Example: A Caterpillar engine, 3412C, high rating, 648 EkW with direct injection, turbo aftercooler and jacket water cooling. The data found in TMI will be:

Engine power: 707.7 BkW (949 BHp)
Intake air flow: 48.8 m^3/min (1723 cfm)

$$\text{Air per BkW (BHp)} = \frac{48.8\ (979)}{707.7\ (1723)}$$

$$= 0.0689\ m^3/\text{min}\ (1.81\ \text{cfm})$$

Heavy fuel engines require about 40 percent greater inlet air flow than those burning distillate fuels.

Gaseous fueled engines demand twice that of diesel.

Intake Location

Although normally obtained from air surrounding the engine, some circumstances require ducting combustion air from outside the engine room. This is particularly true in high altitude operations where light air densities are further affected by engine room temperatures.

- High intake air temperatures can adversely affect engine performance and raise exhaust temperatures, which may damage pistons, exhaust valves and heads.
- Combustion air entering the engine air cleaners should ideally be less then 38°C (100°F).
- On some engine configurations, prolonged operation with extremely cold inlet air to the engine may require a boost control valve to limit intake air manifold pressure and resultant peak cylinder pressure.
- Cold air and altitudes above 2440 m (8000 ft) may cause overfueling when starting automatically, as some governors remain fully open during acceleration to rated speed.

Flooring Considerations

Ground Loading

Initial considerations include generator set weight and material supporting this weight.

The wet weight of the total package must be calculated. This includes accessory equipment and weight of all liquids (coolant, oil and fuel) supported by the foundation. Engine and attachments dry weights can be found in the price list. Liquid densities are given in Table 2.

Liquid	Density of Liquids [at 16°C (60°F)]		
	kg/m³	lb/U.S. gal	Specific Gravity
Water, Glycol	1024.4	8.55	1.03
Water, Sea	1018.3	8.5	1.02
Water, Fresh	994.6	8.3	1.00
Lube Oil	909.7	7.6	0.916
Diesel Fuel	850.7	7.1	0.855
Kerosene	802.7	6.7	0.807

Table 2. Liquid densities.

Material supporting the foundation must carry the total weight. Table 3 shows bearing load capabilities of common materials.

Material	Safe Bearing Load	
	kPa	psi
Rock, Hardpan	482	70
Hard Clay, Gravel and Coarse Sand	386	56
Loose Medium Sand and Medium Clay	193	28
Loose Fine Sand	96.5	14
Soft Clay	0-96.5	0-14

Table 3. Bearing load capability.

Firm, level soil, gravel or rock provides satisfactory support for single-bearing generator sets used in stationary or portable service. This support can be used where the weight-bearing capacity of the supporting material exceeds pressure exerted by the equipment package, and where alignment with external machinery is unimportant.

Soil, such as fine clay, loose sand or sand near the ground water level, is particularly unstable under dynamic loads and requires substantially larger foundations. Information concerning bearing capacity of soils at the site may be available from local sources and must comply with local building codes.

$$P = \frac{W}{A}$$

Where: P = pressure (kPa), (psi)
W = weight (kg), (lb)
A = area (m^2), ($in.^2$)

Pressure imposed by the generator set weight must be less than the load-carrying capacity of supporting material.

Seasonal and weather changes adversely affect mounting surfaces. Soil changes considerably while freezing and thawing. To avoid movement from seasonal change, extend foundations below the frost line.

Concrete Base

Several basic foundations are applicable for generator sets. The foundation chosen will depend on factors previously outlined as well as limitations imposed by the specific location and application.

Massive concrete foundations are unnecessary for modern multicylinder medium speed generator sets. Avoid excessively thick, heavy bases to minimize subfloor or soil loading. Bases should be only thick enough to prevent deflection and torque reaction, while retaining sufficient surface area for support. Non-parallel units require no foundation anchoring.

If a concrete foundation is required, minimum design guidelines include:

- Strength must support wet weight of units plus dynamic loads.
- Depth sufficient to attain a minimum weight equal to generator set wet weight (only if large mass, i.e. inertia block, is specified for vibration control).
- Outside dimensions exceed that of the generator set, a minimum of 304.8 mm (12 in.) on all sides.

Calculate foundation depth to equal generator set weight by:

$$FD = \frac{W}{D \times B \times L}$$

FD = Foundation depth (m), (ft)

W = Total wet weight of generator set (kg), (lb)

D = Density of concrete (kg/m^3), (lb/ft^3)

B = Foundation width (m), (ft)

L = Foundation length (m), (ft)

Considerations for Roof Top Installation

On sites where there is no ground space or basement available for installation of the generator set, the top of the roof might be considered.

Roof top installations have both advantages and disadvantages. Some of the advantages include the following: noise will no longer be a problem, there will be few space limitations, the generator set will not need long exhaust piping and the overall cost of ductwork will be lowered.

Some disadvantages are that the roof (and possibly the building) may have to be reinforced, there will be limited allowable fuel storage on the roof and a large crane will be needed for installation.

Flooring and Structure

The roof top must be carefully examined in order to decide if it is strong enough to carry the weight of the generator set. If it is not, a platform may be used, supported by the main columns of the building. These main columns must also be examined for their load capacity.

In a basement installation, the vibration from the generator set must be considered, and appropriate vibration dampers can be installed.

Fuel Storage

The allowable amount of fuel on the roof top is very limited due to fire and weight considerations. In most cases, a day tank will be installed on the roof. The size of this tank must be approved by the local fire authorities.

To supply the day tank, a bulk tank must be installed at ground level. This installation must comply with the rules of the local fire authorities.

Careful pump calculations must be made in order to size the pump properly so it can lift fuel to the roof. Additional fuel filters must also be considered.

Installation

A large crane will be needed for the installation. It might not be possible to lift the generator set in one piece due to weight restrictions. Therefore, it must be lifted in smaller units and reassembled. When using a crane and large vehicles, the street may have to be closed. Police must be informed in advance of the installation.

Exhaust

Exhaust normally does not provide problems on the roof, but the height of the roof must be considered (in comparison to surrounding buildings). The design and location of the stack should make up for any prevailing winds, neighboring buildings with open windows or fresh air intake of the building it is mounted on.

Noise

Due to weather and noise, the generator set should be installed in a sound proof enclosure. Please consult the local authorities for the allowable noise level.

CATERPILLAR®

Electric Power Application and Installation Guide

Exhaust Systems

LEBX0058-02

WHERE THE WORLD TURNS FOR POWER

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Exhaust Systems

Exhaust systems collect exhaust gases from engine cylinders and discharge them as quickly and silently as possible. A primary design consideration of the exhaust system is to minimize backpressure. Backpressure will indirectly rise the exhaust temperature which will reduce exhaust valve and turbocharger life. A well designed exhaust system will have minimum backpressure.

All internal combustion engines generate heat as a result of the full combustion. The temperatures in Caterpillar engines can reach 1927° C (3,500° F). 30% of this total heat is expelled through exhaust.

System Elements

The main components of an exhaust system are the exhaust manifold, turbocharger, wastegate, piping and the muffler. The individual components and their function will be explained below.

Exhaust Manifold

Engine exhaust manifolds collect exhaust gases from each cylinder and channels them into an exhaust outlet. The manifold encourages minimum backpressure and turbulence. Several types are available for varying installation requirements. The watercooled and watershield manifolds are mainly used in Gas and Marine applications.

Dry Manifolds

Dry manifolds are usually standard equipment as they are the most cost effective, but they are also the least effective type of manifold for heat shielding (see Figure 1, #1). During engine operation, dry manifold surface temperatures can range from 430° C to 480° C (800° F to 980° F).

Watercooled Manifolds

Watercooled manifolds' temperatures are considerably lower than those of dry manifolds. Surface temperatures reach only about 100° C (212° F) during operation. The Mining Safety and Health Agency, MSHA, requires watercooled manifolds to maintain engine surface temperatures below 200° C (400° F).

Passages within watercooled manifolds allow engine jacket coolant to flow around the manifold removing heat otherwise carried by exhaust gases (see Figure 1, #2). Heat rejection to the jacket water will increase 20-40%, which requires a larger capacity cooling system. Loss of exhaust heat energy may affect turbocharger performance, causing engine deration and/or loss of altitude capability.

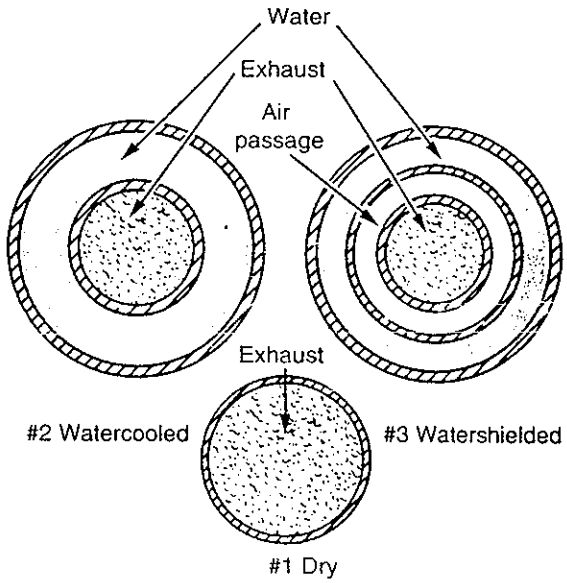


Figure 1. Three types of manifolds.

Watershielded Manifolds

Watershielded and air cooled watershielded (ACWS) manifolds incorporate an auxiliary jacket or shield. Engine water circulates through the shield but does not come into direct contact with the inner manifold (see Figure 1 #3.) Watershielding allows air to circulate between the inner and outer casings, adding little to jacket water cooling load and not affecting engine performance. ACWS manifolds trap the air sc, as with watercooled, jacket water and engine performance are affected.

Turbochargers

Turbochargers are optional components used to get more power out of an engine by utilizing some of the remaining power in the exhaust. It is done by forcing more air into the cylinder which allows more fuel to be burned resulting in a higher horsepower output.

Hot exhaust gases exit the cylinder and enter the turbine side of the turbocharger (see Figure 2). The turbine blades and the compressor blades share a common shaft.

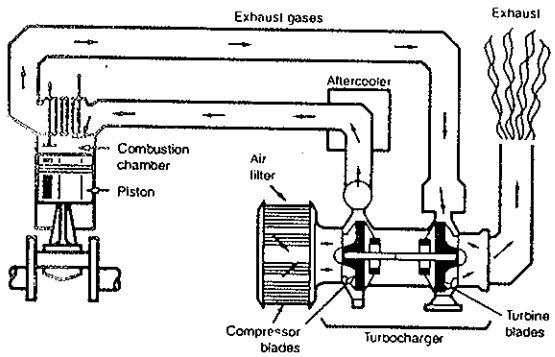


Figure 2. Schematic of a Turbocharger.

Gases drive the turbine blades which in turn drive the compressor blades on the air intake side. This high speed spinning compresses the intake air and at the same time increases its temperature.

Wastegate

For most gas engines and some diesel engines a wastegated turbocharger is being used. When the engine is running at the lower end of the rpm's the turbocharger with wastegate is maximized for improved response and performance. As the rpm's increase the boost pressure opens the wastegate. This allows the turbocharger to "bleed" excess exhaust around the turbine wheel through the wastegate so the turbocharger does not overspeed and produce excessive boost. (Tampering with the boost line to the wastegate will raise beat rejection, increase turbo speed and peak cylinder pressure. This will negatively affect engine reliability, durability and overall performance.)

Piping

The physical characteristics of the engine room will determine the exhaust system layout. Exhaust piping should be designed to minimize the exhaust backpressure while keeping engine serviceability in mind. The exhaust piping should be securely supported with rubber dampers or spring installed in the bracing to isolate vibrations.

Piping must be designed with engine service in mind. In many cases, an overhead crane will be used to service the heavier engine components.

The following recommendations should be followed when designing an exhaust piping system:

- All piping should be installed with a 229 mm (9 in) minimum clearance from combustible materials
- To prevent heat radiation, exhaust pipes should be shrouded with suitable, high temperature insulation.
- Install metal thimble guards for exhaust piping passing through wooden walls or roofs. The thimble guards should be 305 mm (12 in) greater in diameter than the exhaust pipes, see Figure 3.
- Extend exhaust stacks upward and away from engine room to avoid heat, fumes and odors.
- Locate the exhaust pipes away from the air intake system. Engine air cleaners, turbochargers, and aftercoolers clogged with exhaust products can cause premature failures.
- Pipe outlets cut at 30° to 45° angles, rather than 90° angles, will reduce gas turbulence and noise.
- Rain caps forced open by exhaust pressure will keep water from entering the exhaust system.
- Gas engines burning natural gas creates one pound of water for each 10 ft^3 of natural gas burned. For this reason long runs of exhaust piping require traps to drain moisture. Traps installed at the lowest

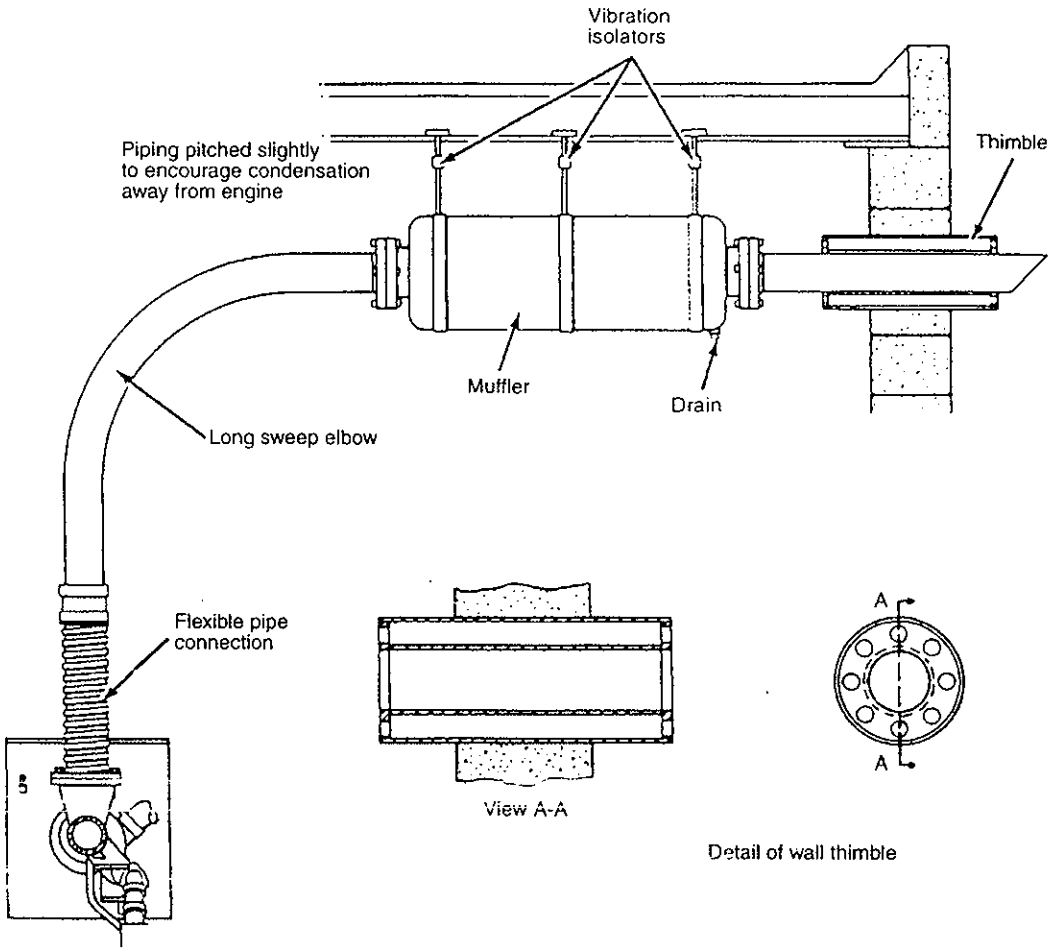


Figure 3.

point of the line near the exhaust outlet prevent rain water from reaching the engine. Slope exhaust lines from engine to the trap so condensation will drain, see Figure 3.

Although economically tempting, *a common exhaust system for multiple installations is* **not** *acceptable.* Combined exhaust systems with boilers or other engines allow operating engines to force exhaust gases into engines not operating. Water vapor created during combustion will condense in cold engines and quickly causes engine damage. Duct valves separating engine exhausts is also discouraged. High temperatures warp valve seats causing leakage.

Exhaust draft fans have been applied successfully in combined exhaust ducts, but most operate only whenever exhaust is present. To prevent turbocharger windmilling (without lubrication), the fans should not be operable when the engine is shut down. The exhaust system of non-running engines must be closed and vented.

Combining the individual vee engine exhaust outlets together on Gas and Diesel 3600 engines by using a fabrication can create problems. The fabrication may result in unequal thermal growth and backpressure from one bank to the other. This unequal growth can put unwanted loading onto the turbocharger mounting or the flex bellows. The unequal backpressure can adversely affect the operation and performance of the engine. These problems can be minimized by providing a flexible connection on each leg, and by keeping each leg equal in length.

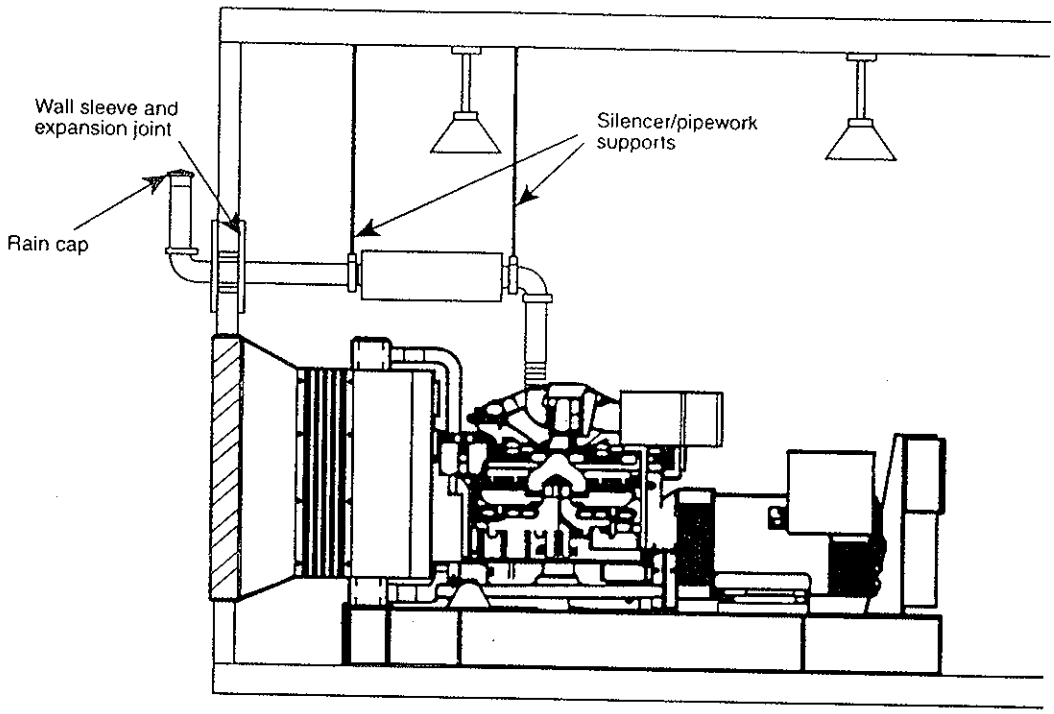


Figure 4. Exhaust arrangement.

Muffler

The purpose of the muffler, or silencer as it also is called, is to reduce the noise of the exhaust before it is released to the atmosphere.

When leaving the combustion chamber the exhaust gas is under pressure. In the muffler, the gas can expand, thereby reducing the sound pressure waves which cause the noise.

The muffler or silencer is generally the single element making the largest contribution to exhaust backpressure. The factors that influence the selection of a silencer include: available space, cost, sound attenuation required, allowable backpressure, exhaust flow, and appearance.

Silencer design is a highly specialized art. The silencer manufacturer must be given responsibility for the details of construction.

Mufflers will be discussed further later in this booklet.

Engine, Exhaust System Design

Slip Joint

Slip joints are designed to have controlled leakage when the system is cold. When the engine starts and the exhaust pipes warm up, the joints will expand and make a tight fit. The slip joints require good support on each side.

Exhaust fumes, slobber and water due to condensation can be expected from leaks.

When considering utilizing slip joints the movements of the pipe must be carefully considered. Slip joints are only flexible in one direction where the exhaust pipe requires flexibility in various directions.

Slip joints are normally not recommended by Caterpillar though they will be seen used on exhaust manifolds.

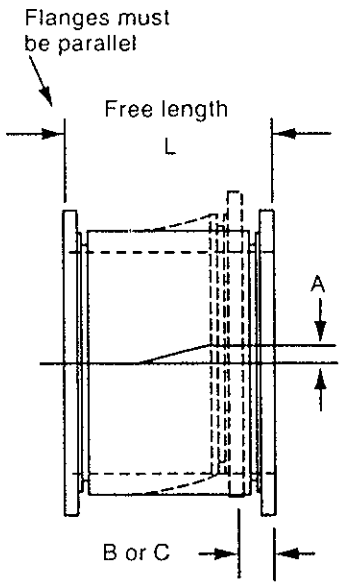
Bellows

Bellows work as flexible connections. Where the flexible connections are built out of several pieces of metal, the bellows are either solid or welded together.

Pre-stretch the exhaust bellows during installation to allow for thermal growth. Four (4) small straps can be tack-welded between the two end flanges to hold the engine exhaust bellows in a rigid position during exhaust piping installation. This will prevent the bellows from being installed in a flexed condition. Attach a warning tag to the bellows noting that the weld straps must be removed prior to starting the engine.

The installation limitations of the Caterpillar supplied flexible exhaust bellows are shown on Table 1.

For maximum durability, allow the bellows to operate as close as possible to its free state.



L = 457 (457 mm I.D.)

Installation Limits of Flexible Metal Hose-Type Exhaust Fittings						
Hose Diameter	A Maximum Offset Between Flanges		B Maximum Compression From Free Length		C Maximum Extension From Free Length	
	mm	in.	mm	in.	mm	in.
4 & 5 in.	25.4	1.0	6.25	.25	6.25	2.5
6 in.	38.1	1.5	6.25	.25	6.25	2.5

Installation Limits of Bellows-Type Flexible Exhaust Fittings						
Hose Diameter	A Maximum Offset Between Flanges		B Maximum Compression From Free Length		C Maximum Extension From Free Length	
	mm	in.	mm	in.	mm	in.
8 & 12 in.	19.05	0.75	38.1	1.50	25.40	1.00
14 in.	19.05	0.75	76.2	3.00	25.40	1.00
18 in.	22.86	0.90	76.2	3.00	44.45	1.75

Table 1. Installation limits for bellows and flexible connections.

Spring Rate for Bellows-Type Flexible Fittings		
	Spring Rate	
Diameter	kN/m	lb/in.
8 in.	29.7	170
12 in.	33.9	194
14 in.	68.5	391
18 in.	19.3	110

Table 2. Spring rates.

Heat Shielding

Heat shielding is not used much in EPG applications. If a heat shielding is necessary, guards will be used.

Blankets

Blankets are made of an insulating layer of fiberglass with a thermal outer layer. Most blankets will be held in place with a stainless steel wire which will be laced over the blankets (like on boots). Blankets will isolate both heat and noise.

Caterpillar does not recommend use of blankets on the turbo.

Hard Wrap

Hard wrap is often used on the engine itself, for example in the vee.

The hard wrap consists of three layers: A thermal sheet, a blanket of fiberglass and sheet of bendable metal. It is installed with the thermal sheet facing the hot surface but not touching as the air then will work as an insulator. Hulls for bolts can be drilled in the metal sheet and it is then very easy to mount or dismount.

Guards and Shields

Guards and shields are manufactured from a sheet of perforated iron. They are installed with an air gap between the shield and the hot surface. With proper airflow around the engine the heat transfer from iron to air will lower the temperature of the shield considerably.

Piping

Flexible Connections

The exhaust pipe must be isolated from the engine with flexible connections. They are designed to 0% leakage and they are flexible in all directions. Flexible connections are normally made out of several pieces which are being fitted together. Install the flexible connections close to the engine exhaust outlet. A flexible exhaust connection has three primary functions:

- To isolate the weight of the exhaust piping from the engine. No more than 28 kg (60 lb) of exhaust piping weight should be supported by the engine.
- To relieve exhaust components of excessive vibrational fatigue stresses.
- Allow relative shifting of exhaust components. This has numerous causes. It may result from expansion and contraction due to temperature changes, by creep processes that take place throughout the life of any structure or torque reactions when the generator set mounts on spring type isolators.

A typical piping layout with flexible connections can be seen on Figure 5.

Flexible pipe connections, when insulated, must expand and contract freely within the insulation. This generally requires a soft material or insulated sleeve to encase the connection.

The flexible connections should be pre-stretched during installation just as it is done on bellows. Please refer to the section on Bellows for instructions.

Softness or flexibility is very important to prevent excessive vibratory stresses. The flexible connector must have high fatigue life to enable it to survive for indefinite periods. Softness prevents transmission of vibration beyond the connection. Resistance to fatigue keeps it from breaking under vibratory or recycling stresses.

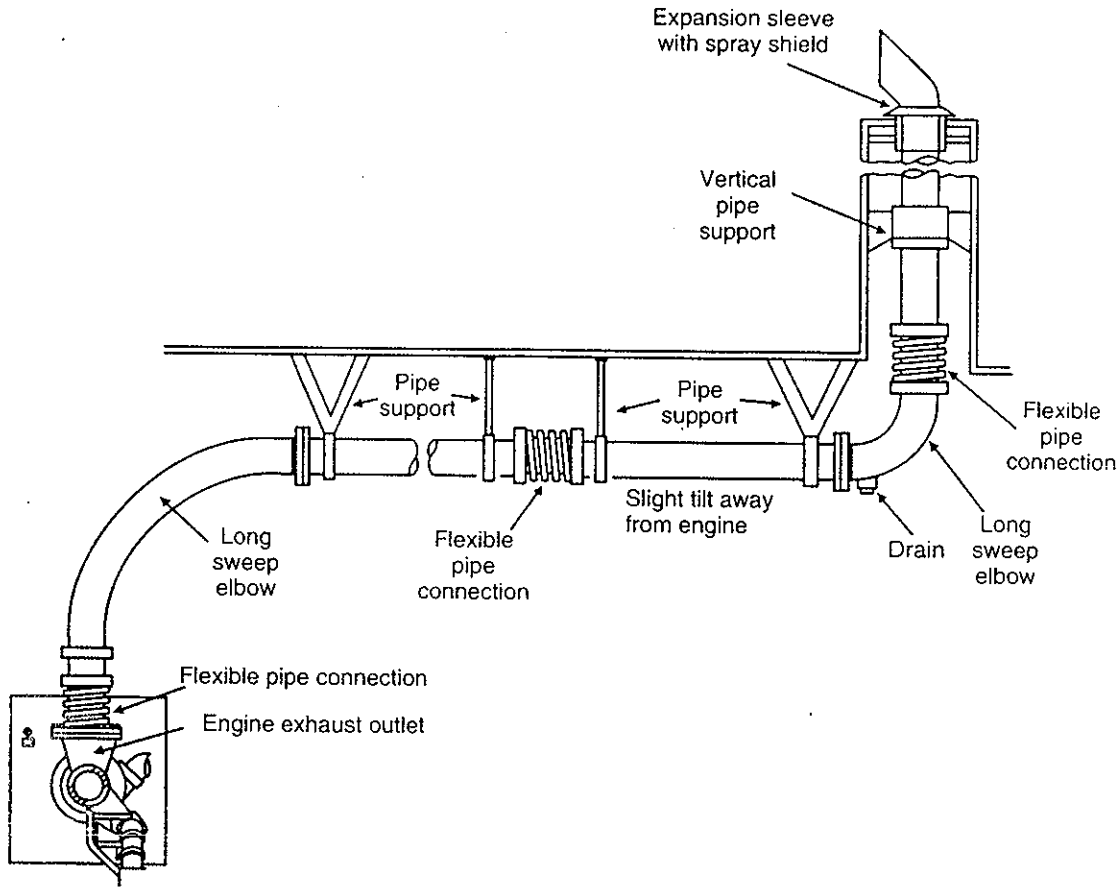


Figure 5. Typical exhaust piping with flexible connections.

Thermal Growth

Thermal growth of exhaust piping, away from the engine, must be planned to avoid excessive load on supporting structures. Steel exhaust pipe expands 1.13 mm/m (0.0076 in/ft) for each 100° C (100° F) rise of exhaust temperature. This amounts to 16.5 mm (0.65 in) expansion for each 3.05 m (10 ft) of pipe from 35° to 510° C (100° to 950° F).

Add expansion joints to long pipe runs. Each section is fixed at one end and allowed to expand at the other. Supports are located to allow expansion away from engine, avoid strains or distortions to connected equipment, and to allow equipment removal without additional support. A restraint member is often used to keep the ends of a long pipe run fixed in place, forcing all thermal growth towards the expansion joints.

Flexible pipe connection, when insulated, must expand and contract freely within the insulation. This generally requires a soft material or insulated sleeve to encase the connection.

Turbocharger Loading

Careful consideration must be given to the load external piping may induce on the turbocharger.

Figure 6 shows where to take the various distances from when calculating the forces and moments on the turbocharger.

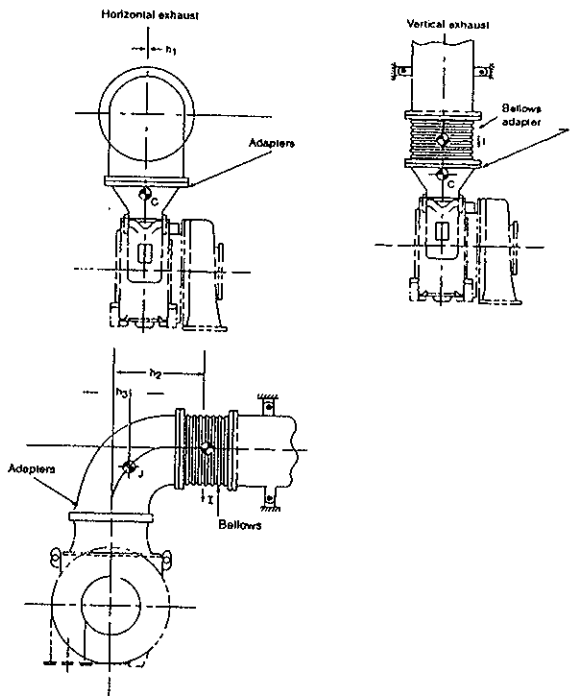


Figure 6. Vertical and horizontal exhaust.

The vertical force for the 3300 and 3400 engine family should be limited to 111 N (or 11 kg) (25 lb) and 178 N (or 18 kg) (40 lb) for the 3500 engine family.

The maximum allowable moment is 120 N•m (89.5 ft-lb) to all the engines.

For 3600 series engines the Caterpillar supplied bellows and adapter account for the maximum allowable vertical load on the turbocharger and other external piping must be self-supporting.

When horizontal piping connects to the turbocharger exhaust, the design must account for thermal growth. The maximum allowable moment for the 3600 is equal to what is applied by the Caterpillar supplied elbow and bellows.

Example:
Assume a Gas 3516 with single exhaust outlet.

Vertical Exhaust

W = Adapter Weight
I = 1/2 Bellows Weight
g = gravity = 9.82 m/s (32.2 ft)

With Caterpillar Hardware:
W = 2.9 kg (6.4 lb)
I = 0.6 kg (1.4 lb)

Forces:
$Fw = W \times g = 2.9 \times 9.82 = 28$ N (6.4 lb)
$F_I = I \times g = 0.6 \times 9.82 = 6$ N (1.4 lb)

Sum of Vertical Forces:
$F_V = F_W + F_I = 28 + 6 = 34$ N (7.8 lb)

Sum of Moments
$M = h_1 \times Fw + h_2 \times F_I = 0 \times 28 + 0 \times b =$ 0 N•m (ft-lb)
Since $F_V < 111$ N (25 lb) and $M < 120$ N•m (89.5 ft-lb) the exhaust system meets the load and moment requirements.

Horizontal Exhaust

W = Adapter Weight
J = Elbow Adapter Weight
I = 1/2 Bellows Weight

With Caterpillar Hardware:
W = 2.9 kg (6.4 lb)
I = 0.6 kg (1.4 lb)
J = 4.8 kg (10.7 lb)
$h_1 = 0$
$h_2 = 100$ mm (3.9 in)
$h_3 = 580$ mm (22.8 in)

Forces:
Fw = 28 N (6.4 lb)
F_I - 6 N (1.4 lb)
$F_J = F \times g = 4.8 \times 9.82 = 47$ N (10.7 lb)

Sum of Vertical Forces
$F_V = Fw + F_I + F_J = 28 + 6 + 47 = 81$ N (18.5 lb)

Sum of Moments

$M = h_1 \times Fw + h_2 \times F_I + h_3 \times F_J = 0 \times 28 +$ $.100 \times 6 + .580 \times 47 = 27.9$ N•m (20.8 ft-lb)

Since $F_V < 111$ N (25 lb) and $M < 120$ N•m (89.5 ft-lb) the exhaust system meets the load and moment requirements.

Pipe Supports

Slope

Long runs of exhaust piping require traps to drain moisture. Traps installed at the lowest point of the line near the exhaust outlet prevent rain water from reaching the engine. Slope exhaust lines from engine to the trap so condensation will drain (see Figure 4).

Hanger Spacing

Piping connected to generator sets requires isolation, particularly when the sets are mounted on spring isolators. These pipes could otherwise transmit vibrations long distances. Isolator pipe hangers, if used, should have springs to attenuate low frequencies, and rubber or cork to minimize high frequency transmissions. To prevent build up of resonant pipe vibrations, support long piping runs at unequal distances (see Figure 7).

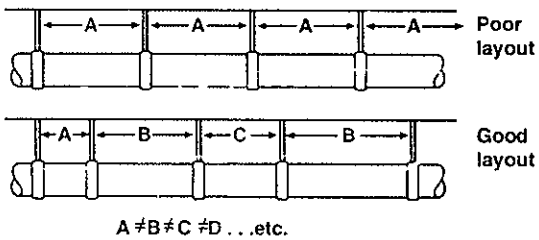


Figure 7. Layout of piping support.

Exhaust Thimbles

Exhaust thimbles separate the exhaust pipe from walls or ceiling to provide mechanical and thermal isolation. Single sleeve thimbles must have diameters at least 305 mm (12 in) larger than the exhaust pipe. Double thimbles (inner and outer sleeve) should have outside diameters at least 152 mm (6 in) larger than the exhaust pipe (see Figure 7).

Insulation

Hot Surfaces

No exposed parts of the exhaust system should be near wood or other inflammable material. Exhaust piping inside the building (and the silencer if mounted inside) should be covered with suitable insulation materials to protect personnel and to reduce room temperature. A sufficient layer of suitable insulating material surrounding the piping and silencer and retained by a stainless steel or aluminum sheath may substantially reduce heat radiation to the room from the exhaust system.

An additional benefit of the insulation is that it provides sound attenuation to reduce noise in the room. Exhaust piping passing through wooden walls or roofs require metal thimble guards 305 mm (12 in) larger than the pipe diameter (see Figure 8).

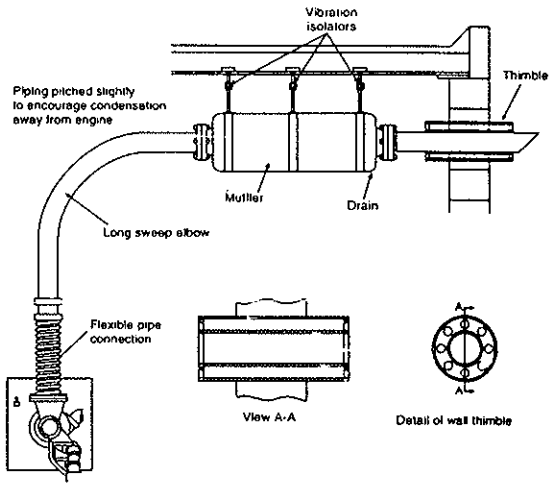


Figure 8. Exhaust layout with thimble.

Radiated Heat

The exhaust stack will remain cooler and cleaner if the engine exhaust is contained within the exhaust piping throughout its run through the stack. The discharged ventilation air will tend to cool the exhaust stack upstream of the point where it is mixed with the exhaust gases.

For further discussion of radiated heat and engine room requirements, please consult the booklets "Cooling Systems" and "Ventilation systems" guides.

Exhaust Connections

G3300, G3400 and G3500 engines use a fixed, round exhaust outlet. The outlet diameter is given as follows:

Exhaust Outlet Diameter in (mm)		
	NA	TA
G3516B 50 Hz	—	12 (304.8)
G3516B 60 Hz	—	8 (203.2)
G3500	6 (152.4)	8 (203.0)
G3400	6 (152.4)	8 (203.0)
G3300	4 (101.6)	5 (127.0)

The turbocharger exhaust outlet on G3600 Engines is rectangular with an area equivalent to a 311 mm (12.24 in) diameter pipe. An optional cast adapter mounts to the turbocharger to provide a circular connection point. For alternative outlet orientation, for alternative exhaust outlet orientation, a 90° exhaust elbow from the turbocharger is also available which be rotated in 30° increments. (see Figure 9). If other angles are required, contact the factory.

Cleanliness

Install an identifiable blanking plate to prevent debris from falling into the turbocharger during installation. The Caterpillar shipping cover can be used for this purpose. Install it directly on top of the turbine housing. Attach a warning tag to the plate indicating it must be removed prior to starting the engine.

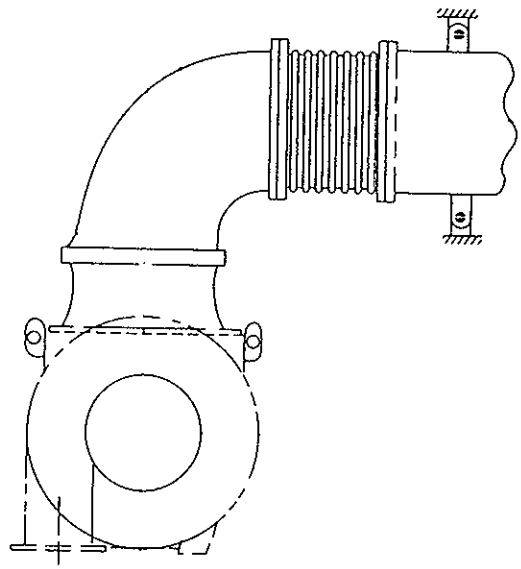


Figure 9.

Mufflers

Mufflers were introduced earlier in this booklet. The following discussion goes into more depth.

Excessive noise is objectionable in most locations. Since a large part of the generator set noise is produced in the engine's pulsating exhaust, this noise can be reduced to an acceptable level by using a muffler (or silencer). The required degree of silencing depends on the location and may be regulated by law. For example, the noise of an engine is objectionable in a hospital area but generally is not as objectionable in an isolated pumping station.

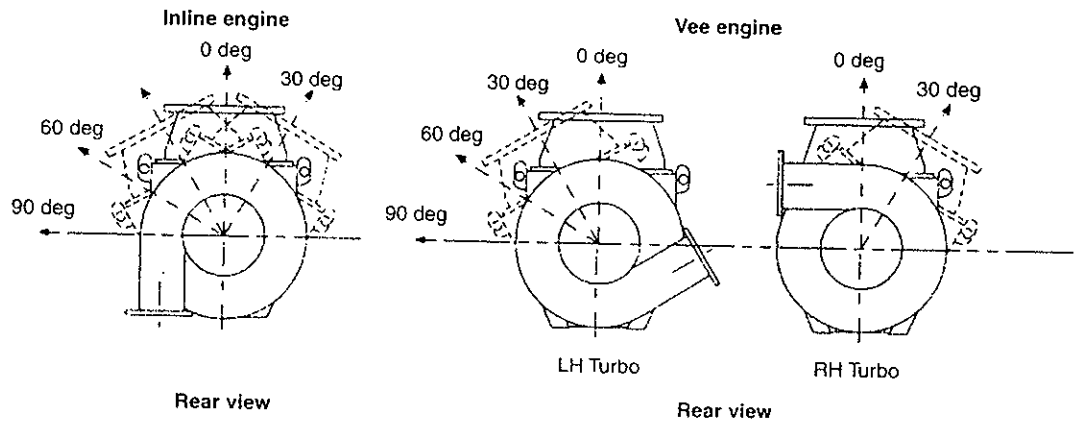


Figure 10. Exhaust stack positions possible on the turbocharger.

Muffler Rating

Mufflers are rated according to their degree of silencing and commonly referred to by such terms as "residential" or "critical" and "supercritical".

- Level 1 Silencer System "Residential" — Suitable for industrial areas where background noise level is relatively high or for remote areas where partly muffled noise is permissible.
- Level 2 Silencer System "Critical" — Reduces exhaust noise to an acceptable level in localities where moderately effective silencing is required — such as semi-residential areas where a moderate background noise is always present.
- Level 3 Silencer System "Supercritical" — Provides maximum silencing for residential, hospital, school, hotel, store, apartment building and other areas where background noise level is low and generator set noise must be kept to a minimum.

Size Considerations

Both noise reduction and backpressure considerations are necessary when selecting a silencer. Engines using heavy fuel have greater exhaust flow than those burning conventional fuels, and silencer sizing must account for this increase.

Use silencer supplier data, correct for outlet temperature and velocity. Determine silencer size and type that satisfies noise reduction criteria with 0.5 to 0.75 kPa (2 to 3 in. H_2O), maximum pressure drop.

After calculating pressure loss, it may be necessary to check a second silencer, or a different pipe size, before an optimum combination is achieved.

Noise

Exhaust noise attenuation is best performed with a quality muffler. However, the attenuation characteristics of a muffler are not the same for all frequencies. The effect of a given muffler could be quite different if the engine runs at two different speeds. The manufacturer must be contacted for any specific muffling characteristics.

The muffler may be located close to the engine, with exhaust piping leading from the silencer to the outside: or it may be located outdoors on the wall or roof. Locating the muffler close to the engine affords best overall noise attenuation because of minimum piping to the muffler. Servicing and draining of the muffler is likely to be more convenient with the muffler indoors.

Backpressure

At least 5 diameters of straight pipe upstream, and 2.5 diameters downstream are required to minimize turbulence and backpressure.

Insulation

Mufflers or exhaust piping within reach of personnel should be protected by guards or insulation. Indoors, it is preferable to insulate the muffler and piping because the insulation not only protects personnel, but it reduces heat radiation to the room and further reduces exhaust system noise. Mufflers mounted horizontally should be set at a slight angle away from the engine outlet with a drain fitting at the lowest point to allow the disposal of any accumulated moisture.

However, mounting the muffler outside has the advantage that the muffler need not be insulated (though it should be surrounded by a protective screen). The job of insulating piping within the room is simpler when the muffler is outside, and the insulation then can aid noise attenuation.

Installation

Mufflers normally are available in two configurations — (a) end inlet, end outlet, or (b) side inlet, end outlet. Having the choice of these two configurations provides flexibility of installation, such as horizontal or vertical, above engine, on outside wall, etc. The side inlet type permits 90° change of direction without using an elbow. Both muffler configurations should contain drain fittings in locations that assure draining the muffler in whatever attitude it is installed.

Since mufflers are large and heavy, consider their dimensions and weight when planning the exhaust system. The muffler must be adequately supported so its weight is not applied to the engine's exhaust manifold or turbocharger. The muffler must fit into the space available without requiring extra bends in the exhaust piping, which would cause high exhaust backpressure. A side-inlet muffler may be installed horizontally above the engine without requiring a great amount of headroom.

When practical, orient the muffler vertically and use side inlets to eliminate extra inlet and discharge elbows. If not practical, ensure the radius of all elbows is two times the pipe diameter.

Provide a minimum of 5 diameters of straight piping upstream from the silencer inlet, and 2.5 diameters downstream from the silencer outlet to minimize turbulence and backpressure.

When practical, orient the silencer vertically and use side inlets to eliminate extra inlet and discharge elbows. If not practical, insure the radius of all elbows is two times the pipe diameter.

A heat resistant material is required if lagging is used on the silencer to reduce radiated heat.

On G3600 Vee engines, consider using a dual inlet silencer instead of a "Y", "T", or 180° abrupt enlargement.

Exhaust thimbles separate the exhaust pipe from walls or ceiling to provide mechanical and thermal isolation. Single sleeve thimbles must have diameters at least 305 mm (12 in) larger than the exhaust pipe. Double thimbles (inner and outer sleeve) should have outside diameters at least 152 mm (6 in) larger than the exhaust pipe.

Exhaust Discharge

The exhaust can be directed into a special stack that also serves as the outlet for radiator discharge air and may be sound-insulated. The radiator discharge air enters below the exhaust gas inlet so that the rising radiator air mixes with the exhaust gas (see Figures 11 and 12). The muffler may be located within the stack or in the room with its tail pipe extending through the stack and then outward. Air guide vanes should be installed in the stack to turn radiator discharge air flow upward and to reduce radiator fan air flow restriction, or the sound insulation lining may have a curved contour to direct air flow upward. For a generator set enclosed in a penthouse on the roof or in a separate outdoor enclosure or trailer, the exhaust and radiator discharges can flow together above the enclosure without a stack. Sometimes for this purpose the radiator is mounted horizontally and the fan is driven by an electric motor to discharge air vertically.

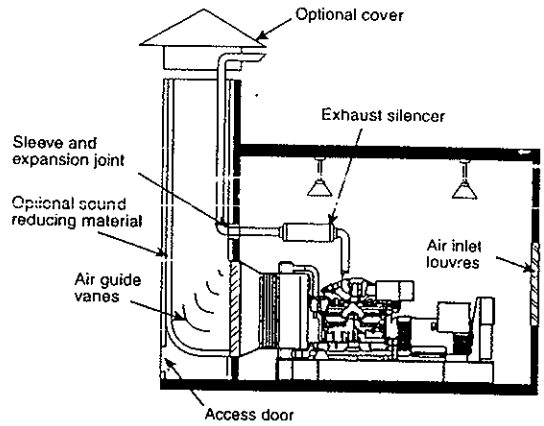


Figure 11: Horizontally mounted exhaust silencer with exhaust pipe and radiator air utilizing common stack.

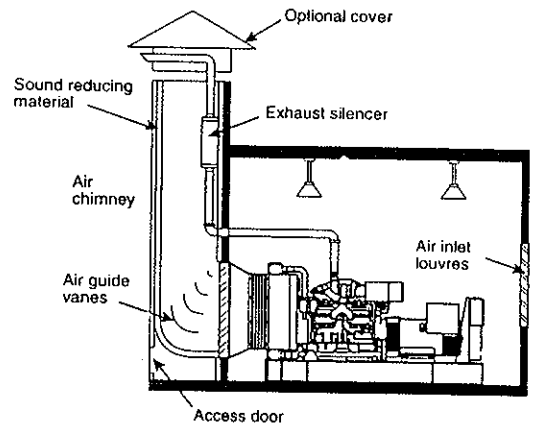


Figure 12: Radiator air discharging into sound-insulated stack containing exhaust silencer.

Rain Caps

It is the responsibility of the engine installer to provide appropriate drain connections, rain caps or other means to protect the engine from rainwater or sea spray entering the engine through the dry exhaust piping. Long runs of exhaust piping require traps to drain moisture. Traps installed at the lowest point of the line near the exhaust outlet prevent rain water from reaching the engine.

Slope exhaust lines from engine and silencer to the trap so condensation will drain.

Traps may be built by inserting a vertical pipe, with a drain petcock, down from a tee section in the line.

Slope the last few feet of the exhaust pipe discharge to prevent rain water or spray from entering the pipe. Alternatively, fit some form of rain cap to a vertical exhaust pipe section.

Saw cuts in the exhaust pipe to allow rain/spray to drain harmlessly. Deform the edges of all slots. Use a punch on engine side slot edges. Bend inward. Cut through no more than 60° of the pipe circumference.

System Design Considerations

The major difference in the exhaust system between gas and diesel engines is that the gas engines run with a higher exhaust temperature. This is because it runs with a constant air-fuel ratio at any load. The diesel engine runs with an excess amount of air at any load. Only the amount of fuel burned increases with the load. This additional air also cools the charge in diesel engines.

Common Exhaust

A common exhaust system for multiple engine installation is rarely acceptable even though it would be an economical benefit. Combined exhaust systems with boilers or other engines allow operating engines to force exhaust gases into engines not operating.

Every gallon of fuel burned provides about one gallon of water in the exhaust. This water vapor condenses in cold engines and quickly causes engine damage. Soot clogs turbochargers, aftercoolers or air cleaner elements. Duct valves separating engine exhausts is also discouraged. High temperature warp valve seats or soot deposits cause leakage.

Separate exhaust systems assure expected engine performance and life.

Exhaust Fans

Exhaust draft fans have been applied successfully in combined exhaust ducts, but most operate only whenever exhaust is present. To prevent turbocharger windmilling (without lubrication), the fans should not be operable when the engine is shut down. The exhaust system on non-running engines must be closed and vented.

Exhaust Recirculation

Exhaust stacks must be designed so engine exhaust is discharged high enough, and in a direction to keep it clear of the air turbulence created by wind swirling around the building. Engine air cleaners, turbochargers and aftercoolers clogged with exhaust products will cause engine failures.

Cleanliness

Install an identifiable blanking plate to prevent debris from falling into the turbocharger during installation. The Caterpillar shipping cover can be used for this purpose. Install it directly on top of the turbine housing. Attach a warning tag to the plate indicating it must be removed prior to starting the engine.

Slobber

Extended engine operation at no load or lightly loaded conditions (less than 15% load) may result in exhaust manifold slobber. Exhaust manifold slobber is the black oily fluid than can leak from exhaust system joints. The presence of exhaust manifold slobber does not necessarily indicate an engine problem. Engines are designed to operate at loaded conditions.

At no load or lightly loaded conditions, the sealing capability function of some integral engine components may be adversely affected. Exhaust manifold slobber is not usually harmful to the engine; the results can be unsightly and objectionable in some cases.

Exhaust manifold slobber consists of fuel and/or oil mixed with soot from the inside of the exhaust manifold. Common sources of oil slobber are worn valve guides, worn piston rings and worn turbocharger seals. Fuel slobber usually occurs with combustion problems.

A normally operating engine should be expected to run for at least one hour at light loads with significant slobber. Some engines may run for as long as three, four or more hours before slobbering. However all engines will eventually slobber if run at light loads. External signs of slobber will be evident unless the exhaust system is completely sealed.

If extended idle or slight load periods of engine operation are mandatory, the objectionable effect of the engine slobber can be avoided by loading the engine to at least 30% load for approximately ten minutes every four hours. This will remove any fluids that have accumulated in the exhaust manifold. To minimize exhaust manifold slobber, it is important that the engine is correctly sized for each application.

Backpressure

Excessive exhaust restrictions can cause performance losses, particularly in fuel consumption and exhaust temperature. Pressure drop across the exhaust system should not exceed 6.7 kPa (27 in. H_2O) of water for most Caterpillar turbocharged (TA engines). The G3516B engine is limited to 5.0 kPa (20 in. H_2O) without derate. (See engine technical data for engine performance effects when exhaust backpressure exceeds this limit.) 3600 Naturally Aspirated (NA) Gas Engines performances will be adversely affected above 3 kPa (12 in. H_2O). Exceeding this limit on 3600 engines will increase fuel consumption approximately 0.8% per each 2.5 kPa (10 in. H_2O) of backpressure above the limit. Engines burning heavy fuel have an absolute backpressure limitation of 2.5 kPa (10 in. H_2O) to avoid excessive exhaust valve temperatures and loss of horsepower.

The total D3600 exhaust back pressure drop, from the turbocharger outlet to atmosphere, has been set at 2.5 kPa (10 in. H_2O) maximum — recognizing this is lower than our limit of 6.7 kPa (27 in. H_2O), for smaller Caterpillar engines. The lower level was established with an emphasis on low BSFC, and attempts should be made to keep the back pressure below the limit. The engine will operate above the 2.5 kPa (10 in. H_2O) level limits, but with increased fuel consumption. The loss is approximately .8% per 2.5 kPa (10 in. H_2O) of exhaust back pressure increase.

Pressure drop includes losses due to piping, muffler, and rain cap, and is measured in a straight length of pipe 3 to 5 diameters from the last transition change after the turbocharger outlet. The backpressure should be measured as close to the engine as possible.

On Caterpillar G3300, G3400 and G3500 Gas Engines there is only one exhaust outlet. Either there is a single turbocharger or the two exhaust systems are merged into one outlet.

Vee engine exhaust piping for the G3600 series should be designed with equal restrictions on each bank to prevent unequal bank-to-bank backpressure.

Equivalent Length of Straight Pipe

To obtain equivalent length of straight pipe for various elbows:

$L = \frac{33D}{X}$ Standard Elbow (Radius of Elbow equals pipe diameter)

$L = \frac{20D}{X}$ Long Elbow (Radius> 1.5 Diameter)

$L = \frac{15D}{X}$ 45° Elbow

$L = \frac{66D}{X}$ Square Elbow

Where X = 1000 mm or 12 inches

As can be seen, if 90° bends are required, a radius of two times the pipe diameter helps to lower resistance.

As a general rule, the flow losses of the optional Caterpillar supplied exhaust adapters are 1 kPa (4 in. H_2O). This leaves approximately 0.75 kPa (3 in. H_2O) loss available for installation piping and 0.75 kPa (3 in. H_2O), for a muffler/silencer.

Restrictions imposed by mufflers relate to exhaust flow velocities. Figure 13 is applicable for mufflers.

$$V = \frac{Q}{A}$$

V = Velocity of exhaust gas (ft/min)
Q = Exhaust gas flow (cfm)
A = Area of muffler (Table 3)
(ft/min × 0.3048 = m/min)

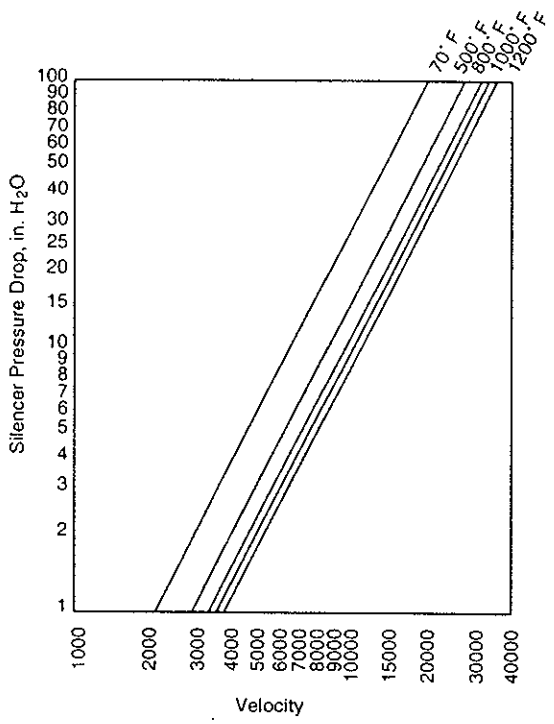


Figure 13: Restriction related to flow velocity. (kPa = 0.24908 × in. H_2O, psi = 0.0361 × in. H_2O).

Area (ft^2)	Size (in.)
0.00546	1
0.0123	1-1/2
0.0218	2
0.0341	1-1/2
0.0491	3
0.0668	3-1/2
0.0872	4
0.136	5
0.196	6
0.349	8
0.545	10
0.785	12
1.07	14
1.39	16
1.77	18
2.18	20
2.64	22
3.14	24
3.68	26
4.28	28
4.91	30

Table 3. Area vs size of muffler.

Calculating Backpressure

Backpressure is calculated by:

$$P\ (kPa) = \frac{L \times S \times Q^2 \times 3598805.2}{D^5} + Ps$$

$$P\ (psi) = \frac{L \times S \times Q^2}{5184 \times D^5} + Ps$$

P = Backpressure (kPa), (psi)
L = Length of pipe (m), (ft)
Q = Exhaust gas flow (m^3/min), (cfm)
D = Inside diameter of pipe (mm), (in)
Ps = Pressure drop of silencer/raincap (kPa), (in. H_2O)
kPa = 0.0098 × mm water column
psi = 0.0361 × inches water column
S = specific weight of gas (kg/m^3), (lb/ft^3)

$$S\ (kg/m^3) = \frac{352.5}{\text{Exhaust Temperature} + 273^\circ\ C}$$

$$S\ (lb/ft^3) = \frac{39.6}{\text{Exhaust Temperature} + 460^\circ\ F}$$

The following can be some useful conversion factors:
psi = 0.0361 × in. of water column
psi = 0.00142 × mm of water column
psi = 0.491 × in. of mercury column
kPa = 6.3246 × mm of water column
kPa = 4.0 in. of water column
kPa = 0.30 × in. of mercury column
kPa = 0.145 psi

Example:
Standby power genset 35 lb Di.TA.JW with Dry Manifold and 60H_2, rated 1750 EKW with fan @ 1800 rpm.

The stack has 5 m (16.4 ft) of straight length pipe together with two standard elbows. The pipe has a diameter of 254 mm (10 in).

Solution:
Data from TMI:
Engine power: 1307.2 Bkw (1753 Bhp) @ 70% load

Exhaust temperature: 479° C (895° F)
Exhaust gas flow: 307.7 m^3/min (10865 cfm)
From Figure 12, Ps = 3.36 kPa (0.487 psi or 13.5 in. H_2O)

Equivalent Length:

$$L = 2 \times \frac{33 \times 254}{1000} = 16.76\ m$$

$$L = 2 \times \frac{33 \times 10}{12} = 55\ ft$$

Specific Weight of Gas:

$$S = \frac{352.5}{479 + 273} = 0.468\ kg/m^3$$

$$S = \frac{39.6}{895 + 460} = 0.029\ lb/ft^3$$

Backpressure:

$$P = \frac{(5 + 16.76) \times 0.468}{\times\ 307.7^2 \times 3598805.2} + 3.36 = 6.64\ kPa$$
$$254^5$$

$$P = \frac{(16.4 + 55) \times 0.029}{\times\ 10865^2} + 0.487 = 0.96\ psi$$
$$5184 \times 10^5$$

The backpressure of 6.64 kPa (26.7 in. H_2O) is within the limit for Caterpillar engines.

Measuring Backpressure

Measure exhaust backpressure by a water manometer at the fitting provided in the engines exhaust discharge location. Use a system similar to that shown in Figure 14.

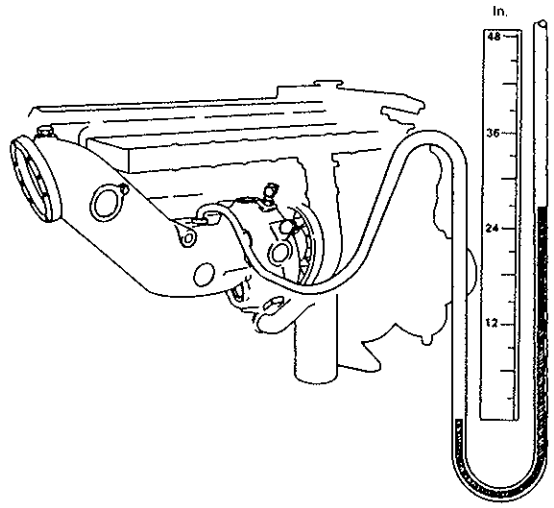


Figure 14. Measuring backpressure with a water manometer.

Exhaust backpressure is measured as the engine is operating under rated conditions. Either a water manometer or a gauge measuring inches of water can be used. If not equipped, install a pressure tap on a straight length of exhaust pipe. This tap should be located as close as possible to the turbocharger or exhaust manifold on a naturally aspirated engine, but at least 305 mm (12 in) downstream of a bend. If an uninterrupted straight length of at least 457 mm (18 in) is not available, 305 mm (12 in) preceding and 152 mm (6 in) following the tap, care should be taken to 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. The pressure tap can be made by using a 1/8 NPT "half coupling" welded or brazed to the desired location on the exhaust pipe. After the coupling is attached, drill a 3.05 mm (0.12 in) diameter hole through the exhaust pipe wall. If possible, remove burrs on the inside of the pipe so that the gas flow is not disturbed. The gauge or gauge hose can then be attached to the "half coupling."

CATERPILLAR®

Electric Power Application and Installation Guide

Starting System

LEBX0032-01

WHERE THE WORLD TURNS FOR POWER

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Starting System

An engine starting system must be able to crank the engine at sufficient speed for fuel combustion to begin normal firing and keep the engine running.

There are three common types of engine starting systems normally used for Caterpillar engines:
1) Electric
2) Air
3) Hydraulic

The choice of systems depends upon availability of the source of energy, availability of space for storage of energy, and ease of recharging the energy banks required for starting the engine.

Types of Starting Systems

Electric Starting Systems
Use chemical energy stored in batteries, automatically recharged by an engine-driven alternator or by an external source.

Air or Pneumatic Starting Systems
Use compressed air in pressure tanks, automatically recharged by an electric motor-driven air compressor.

Hydraulic Starting Systems
Use hydraulic oil stored in steel pressure vessels under high pressure automatically recharged by a small engine-driven hydraulic pump with integral pressure relief valve.

The technology of the systems are well developed. Any of the systems are easily controlled and applied either manually or automatically.

Electric and air starters can be used on both diesel and gas engines. Hydraulic starters can only be used with diesel engines.

Startability of a diesel engine is affected primarily by ambient temperature, engine jacket water temperature, and lubricating oil viscosity. Any parasitic loads (usually associated with the driven equipment) can greatly influence the startability, as well.

Function of Starting System

Terminology
Breakaway Torque
Engine breakaway torque refers to the torque required to begin rotating the crankshaft. The starter must be able to exceed the torque of the engine and auxiliary in order to begin rotating the engine. With an electric starter the voltage and amperage is important, so that the electric starter can reach its full potential which is listed in Table 1.

	Volts at Starter	Amps to Starter	Speed Starter/ Eng Cranking (rpm)	Potential Torque of Starter N·m (lb·ft)	Potential Torque on Flywheel N·m (lb·ft)
G3304, G3306 (156 flywheel teeth)	Starter Part No. — 1W5516 (12 pinion teeth)				
Breakaway*	17	1400	0/0	129 (95)	1674.4 (1235)
G3406 (113 flywheel teeth)	Starter Part No. — 2S7227 and 6V0927 (11 pinion teeth)				
Breakaway*	12.5	1400	0/0	135.6 (100)	1392.4 (1027)
G3408, G3412 (136 flywheel teeth)	Starter Part No. — 4N1062 (11 pinion teeth)				
Breakaway*	12.5	1400	0/0	135.6 (100)	1675.8 (1236)
G3508, 12, 16 (183 flywheel teeth)	Starter Part No. — 7C0527, 6V4246 (11 pinion teeth)				
Breakaway*	13	1400	0/0	124.7 (92)	2074.4 (1530)
	Starter Part No. — 6V0927 (11 pinion teeth)				
	12.5	1400	0/0	135.6/2250.7 (100/1660)	135.6/2250.7 (100/1660)

*Breakaway torque is theoretically 0 starter and engine rpm. However, the starter amperage limit is approximately 1400 amps. Thus the breakaway torque shown is reduced somewhat from actual to accommodate the amperage limit.

Table 1. Electric starter breakaway performance, gas.

Starter breakaway torque refers to the maximum torque a starter can generate at or near zero rpm. It is important to ensure that the starter breakaway torque is larger than the sum of the engine and auxiliary load breakaway torque. Since breakaway torque can vary widely, it is best to include a breakaway torque margin when handling auxiliary loads. The following equation should be used as a guideline to assure proper breakaway torque margin. The values used for $T_{eng\ brk}$ and $T_{aux\ brk}$ should be values representing worst case conditions under which an engine is expected to start.

$$T_{start\ brk} > (1.4)[T_{eng\ brk} + T_{aux\ brk}]$$

where,

$T_{start\ brk}$ = starter breakaway torque output

$T_{eng\ brk}$ = engine breakaway torque req

$T_{aux\ brk}$ = auxiliary breakaway torque req

The relationship of the starter torque to the torque applied to the engine (and auxiliary equipment if direct coupled) is:

Starter Torque = Torque to Engine & Driven Equipment
× Number of Pinion Teeth/Flywheel Teeth

This formula will work for determining either the breakaway torque needs or the cranking torque needs of the starter.

Example 1.
Starter Sizing for Breakaway Torque
An air supply source of 620.5 kPa (90 psi) is available to start a 3512 gas engine. The lowest ambient temperature will be 10°C (50°F) and 30 wt oil will be used. The engine will drive a water pump through a clutch so the breakaway torque is negligible. The customer prefers an air starter.
A) What is the breakaway torque required for this application?
B) Does a single vane starter with 620.5 kPa (90 psi) inlet air pressure have sufficient energy to rotate the 3512 engine?

Solution A:
Consulting the Engine Breakaway and Cranking Torque Chart (see Table 2). The breakaway torque for the 3512 gas engine is 1247 N•m (920 lb•ft). The auxiliary equipment has negligible breakaway torque. The starter should be able to produce 1.4 times 1247 N•m (920 lb•ft) = 1746 N•m (1288 lb•ft) for torque.

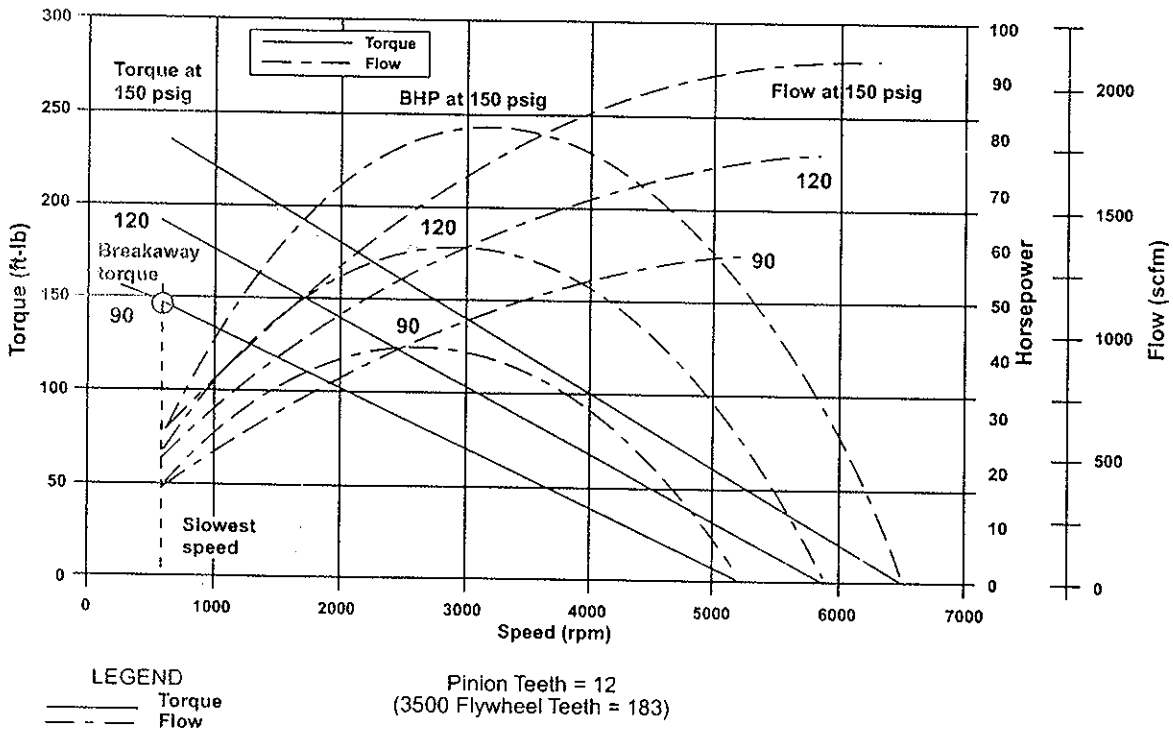


Figure 1. G3500 air starter (vane type) performance curve.

Solution B:
The starter torque = 1746 N•m (1288 lb•ft) × 12 (pinion teeth)/183 (number of flywheel teeth)

The starter torque = 115 N•m
The starter torque = 85 lb•ft

Next consult the Air Starter Torque Chart Figure 1 (can be obtained for the individual air starter from the air starter manufacturer), for the starter's capability at 620.5 kPa (90 psig). Use the torque of the slowest listed speed of the starter as the breakaway torque. The G3500 air starter (vane type) is 196.6 N•m (145 lb•ft). Thus one air starter for the 3512 engine will provide sufficient breakaway torque (145 lb•ft > 85 lb•ft).

Cranking Torque

Table 2 shows the torque requirements to crank an unloaded gas engine.

	Breakaway Torque		Cranking Torque (@ 100 or 150 rpm)			
			SAE 30 Wt Oil			
			0°C (32°F)		10°C (50°F)	
Engine Model	N-m	(ft-lbs)	N-m	(ft-lbs)	N-m	(ft-lbs)
G3304	149	110	217	160	149	110
G3306	244	180	278	205	203	150
G3406	366	270	508	375	305	225
G3408	420	310	597	440	352	260
G3412	644	475	813	600	521	385
G3508	1016	750	1085	800	854	630
G3512	1247	920	1573	1160	1037	765
G3516	1545	1140	1898	1400	1288	950

Note: Oil Temperature and Viscosity are major contributors to the actual amount of torque needed to crank the engine at the specific speed. Breakaway torque is independent of oil viscosity or temperature.

Table 2. Engine breakaway and cranking torques, gas.

Note: The temperature and oil viscosity are the largest factors that affect the cranking torque needed to start an engine. Higher oil temperatures and less viscous oil require less torque to turn the engine.

Table 3 gives the cranking performance of the electric starters used on the G3500-G3300 engines. Consult these charts to determine starter speed, volts and amps to the starter and the starters torque capability at 100 rpm and 1500 rpm engine rpm (150 rpm should be used for magneto engines and 100 rpm for Caterpillar Electronic Ignition System equipped engines). The capability of the electric starter can be compared to the total of any particular engine model's and auxiliary equipment's cranking torque needs.

Crank Terminate

Starter Overspeed

Engine overspeed can result from a governor malfunction or fuel rack sticking. With no overspeed protection, a diesel engine can rapidly accelerate to the point of destruction.

Variables that Affect Length of Engine Start and the Cranking Torque

Size the starting system for an engine to meet the most demanding conditions under which a specific engine is expected to start. To account for the variability, consider the following guidelines:

1) **Engine Size:** As the number of cylinders increases, the torque requirements to crank the engine increases. The crank torque curves for each engine must be consulted when sizing a starting system.

2) **Engine Application:** Various applications have different auxiliary loads during the start up. The auxiliary load torque curve will affect the time to accelerate the engine to the minimum recommended cranking rpm.

3) **Fuel Composition:** Fuel composition varies widely from site to site. Fuels with low energy content will lengthen the cranking time as these fuels burn slower and cylinder firing during start-up is more erratic than when using natural gas.

4) **Cold Ambient Conditions:** Cold temperature increases the viscosity of the engine oil. The torque demand of the cranking engine increases as oil temperature decreases. Start length will increase due to cold temperatures. Note: The breakaway torque is not influenced by oil temperature.

Minimum Requirements for Sizing Support Equipment

When sizing a facility's support equipment for a starting system (i.e. air tank volume, air tank location, pipe diameter, pipe length,

compressor size, battery quantity and capacity), the equipment must be capable of meeting the following minimum requirements for one start attempt:

1) The starting system must accelerate the engine and its auxiliary load to the Minimum Cranking RPM in five seconds.

2) The starter(s) must be able to sustain the Minimum Cranking RPM for a minimum of 25 seconds.

Note: Electric starter engagements longer than 30 seconds or repeat 30 second start attempts will overheat starters. Start attempts longer than 30 seconds may indicate engine problems.

Some applications may require multiple, back to-back start capability. In this case, multiply the above **one-start minimum requirements** by the total number of required start attempts. Thus, if a site must be capable of three back-to-back start attempts, the support equipment should be capable of three, five second acceleration intervals and three, twenty-five second intervals of sustained engine speed equal to or greater than the Minimum Starting RPM.

Oil Temperature

The diesel engine relies on heat of compression to ignite fuel. When the engine is cold, longer cranking periods or higher cranking speeds are necessary to develop adequate ignition temperatures. The drag due to the cold lube oil imposes a great load on the cranking motor. Oil type and temperature drastically alter viscosity. SAE 30 oil approaches the consistency of grease below 0°C (32°F).

Air Temperature

The ambient temperature is extremely important for the starter system. The colder it is the higher torque is necessary for starting the engine. Take into consideration the temperature when reading a torque graph or table.

Electric Starting

Electric starting is the most convenient to use. Storage of energy is compact, however, charging the system is slow and difficult in emergencies. Electric starting becomes less effective as the temperature drops due to loss of battery discharge capacity and an increase in an engine's resistance to cranking under those conditions. It is the least expensive system and is most adaptable to remote control and automation (see Figure 2).

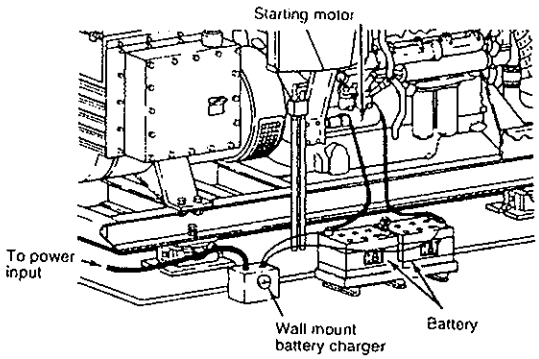


Figure 2. Battery location.

Damage can result if water enters and is retained in the starting motor solenoid. To prevent this, engines stored outside should be provided with a flywheel housing cover. If possible, the starting motor should be mounted with the solenoid in an up position which would provide drainage and prevent water from collecting in the solenoid.

Engines which are subject to heavy driven load during cold start-up should be provided with a heavy-duty starting motor.

Battery Types

Batteries provide sufficient power to crank engines long and fast enough to start (see Battery recommendations for Diesel, Table 4 and for Gas, Table 5).

Lead-acid types are common, have high output capabilities, and lowest first cost.

Nickel-cadmium batteries are costly, but have long shelf life and require minimum maintenance. Nickel-cadmium types are designed for long life and may incorporate thick plates which decrease high discharge capability. Consult the battery supplier for specific recommendations.

	Volts at Starter	Amps to Starter	Potential Torque of Starter N•m (lb•ft)	Potential Torque on Flywheel N•m (lb•ft)
G3304, G3306 (156 flywheel teeth)	Starter Part No. — 1W5516 (12 pinion teeth)			
Cranking*				
@ 100 engine rpm	19	800	70.5 (52)	916.5 (676)
@ 150 engine rpm	22	500	30 (22)	387.8 (286)
G3406 (113 flywheel teeth)	Starter Part No. — 2S7227 and 6V0927 (11 pinion teeth)			
Cranking*				
@ 100 engine rpm	17	900	73 (54)	745.7 (550)
@ 150 engine rpm	19	600	49 (36)	501.7 (370)
G3408, G3412 (136 flywheel teeth)	Starter Part No. — 4N1062 (11 pinion teeth)			
Cranking*				
@ 100 engine rpm	17	860	70.5 (52)	867.7 (640)
@ 150 engine rpm	19	580	40.7 (30)	488 (360)
G3508, 12, 16 (183 flywheel teeth)	Starter Part No. — 7C0527, 6V4246 (11 pinion teeth) [Values for 1 starter]			
Cranking* @ 100 engine rpm	19	600	40.7 (30)	678 (500)
	Starter Part No. — 6V0927 (11 pinion teeth) [Values for 1 starter]			
	18.5	600	49 (36)	813.5 (600)

*Cranking torque is at 100 engine rpm. Cranking torque is very dependent on oil viscosity and temperature. When solving a cranking issue, increasing the temperature of the engine and oil plus lowering the viscosity of the oil will dramatically improve cranking performance.

Table 3. Electric starter cranking performance, gas.

Two considerations in selecting proper battery capacity are:

- The lowest temperature at which the engine might be cranked.
- The parasitic load imposed on the engine. A good rule of thumb is to select a battery package which will provide at least four 30 second cranking periods (total of 2 minutes cranking). An engine should not be cranked continuously for more than 30 seconds or starter motors may overheat.

Ambient temperatures drastically affect battery performance and charging efficiencies. Maintain 32°C (90°F) maximum temperature to assure rated output. The impact of colder temperatures is shown in Table 6.

Minimum Battery Cold Cranking Amperes at –18°C (0°F)				
Model	Voltage	–0.5°C (31°F) and Up*	–18°C (0°F) to –1°C (30°F)**	–31.6°C (–25°F) to –18.3°C (–1°F)
3208	12 24	1140 570	1460 730	1600 800
3304	12 24/30/32	1140 570	1500 750	1740 870
3306	12 24 30/32	1140 570 570	1500 750 750	2000 1000 870
3406	12 24 30/32	1740 800 800	1800 870 870	2000 1000 870
3408/ 3412	24 30/32	870 870	1000 870	1260 1260
D348	24 30/32	870 870	1000 870	1260 1260
D349	24/30/32	1260	1260	1260
D353	24 30/32	1000 1260	1260 1260	1260 1260
D379/ 398	24/30/32	1260	1260	1260
D399	24/30/32	1260	1260	—

*Below 15.5°C (60°F) use glow plugs if available.
**Below 0°C (32°F) use ether aid for direct injection engines.

Table 4. Caterpillar diesel engine battery recommendations.

Minimum Battery Cold Cranking Amperes				
Model	Voltage	15.5°C (60°F) and Up	-1°C (30°F) to 15.5°C (60°F)	-29°C (-20°F) to -1°C (30°F)
G3304	12 24-32	725	1450 925	1225
G3306	12 24-32	725	1450 925	1225
G3406	24-32		925	1225
G3408	24-32	925	1225	1300
G3412	24-32	925	1225	1300
G3508	24-32	925	1225	1300
G3517*	30-32	725	910	1300
G3516*	30-32	725	910	1300

*Two motors.

Note: Use aids below -18°C (0°F).

Table 5. Caterpillar gas engine battery recommendations.

Battery Sizing and Temperature

Low ambient temperatures drastically affect battery performance and charging efficiencies, as well as oil viscosity (see Table 7). High temperatures should also be avoided.

- Maintain 32°C (90°F) maximum temperature to assure rated output.
- High temperatures also decrease battery life.
- Ideally, temperatures surrounding the battery should not exceed 25°C (77°F). Battery life is roughly halved by a 10°C (17°F) rise in temperature; doubled if ambients are reduced 10°C.

°C	°F	27°C (80°F) Ampere Hours Output Rating
27	80	100%
0	32	65%
-18	0	40%

Table 6. Temperature vs. output.

Specific Gravity	% Charge	Voltage per Cell	Freezes °C	Freezes °F
1.260	100	2.10	-94	-70
1.230	75	2.07	-56	-39
1.200	50	2.04	-27	-16
1.170	25	2.01	-13	-2
1.110	Discharged	1.95	-8	+17

Table 7. Battery performance.

Battery Cable Sizing (Maximum Allowable Resistance)

The start circuit between battery and starting motor, and control circuit between battery, switch, and motor solenoid must be within maximum resistance limits (see Table 8).

Magnetic Switch and Series-Parallel Circuit	Solenoid Switch Circuit	Starting Motor Circuit
12 Volt System 0.048 Ohm	0.0067 Ohm	0.0012 Ohm
24 Volt System 0.10 Ohm	0.030 Ohm	0.002 Ohm
32 Volt System 0.124 Ohm	0.070 Ohm	0.002 Ohm

Table 8. Maximum allowable resistance.

Not all this resistance is allowed for cables. Connections and contactors, except the motor solenoid contactor, are included in the total allowable resistance. Additional fixed resistance allowances are:

Contactors
Relays, Solenoid, Switches
0.0002 Ohm each

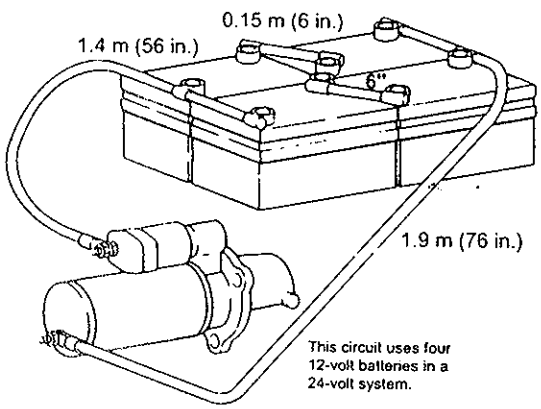
Connections
(series connector)
0.00001 Ohm each

The fixed resistance of connections and contactors is determined by the cable routing (see Table 9). Fixed resistance (Rf) subtracted from total resistance (Rt) equals allowable cable resistance (Rc): Rt - Rf = Rc.

Cable Size		12 Volt		24-32 Volt	
AWG	mm²	Feet	Meters	Feet	Meters
0	50	4.0	1.22	15.0	4.57
00	70	5.0	1.52	18.0	5.49
000	95	6.0	1.83	21.0	6.40
0000	120	7.5	2.29	27.0	8.24

Table 9. Maximum recommended total battery cable length

Example:



System	24-volt
Starting motor type	Heavy duty
Maximum allowable resistance	.00200
Minus fixed resistance —	
6 connections @ .00001	.00006 ohm
Resistance remaining for cable	.00194
Battery cable length	3.6 m (144 in.)

Figure 3. Example.

With cable length and fixed resistance determined as shown in Figure 3, the appropriate cable size can be found using Figure 4. Only full-stranded copper wire should be used. Arc welding cable is much more flexible and easier to install than full stranded copper wire cable, but welding cable is not as durable and will be damaged from corrosion in a much shorter time.

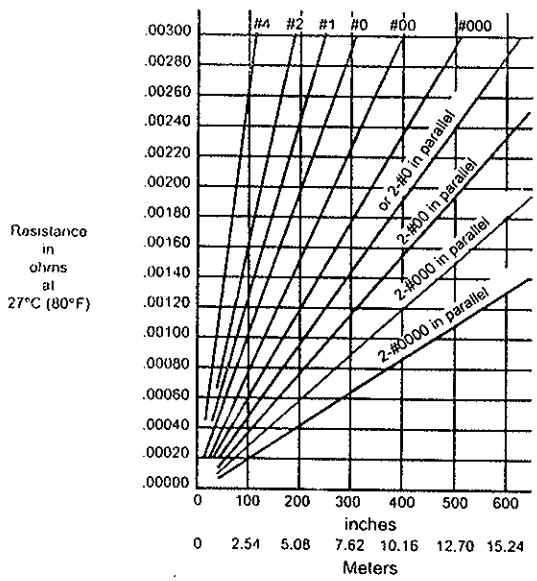


Figure 4. Cable sizing.

To meet cable length and resistance requirements, cable size must be No. 1. To determine fixed resistance in a parallel circuit, only series connections in one leg of the parallel circuit are counted.

Charging

Battery Chargers

Various chargers are available to replenish a battery.

Trickle chargers are designed for continuous service on unloaded batteries and automatically shut down to milliampere current when batteries are fully charged. Overcharging shortens battery life and is recognized by excessive water losses.

Conventional lead-acid batteries require less than 59.2 ml (2 oz) of make-up water during 30 hours of operation.

Float-equalize chargers are more expensive than trickle chargers and are used in applications demanding maximum battery life. These chargers include line and load regulation, and current limiting devices which permit continuous loads at rated output.

Both trickle chargers and float equalize chargers require a source of A/C power while the engine is not running. Chargers must be capable of limiting peak currents during cranking cycles or have a relay to disconnect during cranking cycles. Where engine-driven alternators and battery chargers are both used, the disconnect relay is usually controlled to disconnect the battery charger during engine cranking and running.

Alternators

Alternators or engine driven generators can be used as charging systems, but have the disadvantage of charging batteries only while the engine runs. Where generator sets are subject to many starts, insufficient battery capacity could threaten dependability.

Grounding

The battery must be ground before running. One battery terminal must be connected to either the engine or the frame work in order to protect against electrical shock.

Design Consideration

The cranking batteries should always be securely mounted where it is easy to visually inspect and do maintenance (see Figure 2). They must be located away from flame or spark sources and isolated from vibration. Batteries should be mount level on nonconducting material and protected from splash and dirt. By positioning batteries near the starting motor, short slack cables can be used and voltage drops minimized. All battery connections must be kept tight and coated with grease to prevent corrosion.

Disconnect the battery charger when removing or connecting battery leads. Solid-state equipment, i.e., electronic governor, speed switches, can be harmed if subjected to charger's full output.

Air Starting

Air starting, either manual or automatic, is highly reliable. It is generally applied where facilities have existing plant air, or where a combustible gas may be present in the atmosphere.

Air starting usually offers higher cranking speeds than electric starting. This will usually result in faster starts with less cranking time; however, remote controls and automation are more complex. On the other hand, the air system can be quickly recharged. Air storage tanks are prone to condensation problems and must be protected against corrosion and freezing.

The air starting system includes: air starting motor, air storage tank, starting valve, pressure regulator, and oiler (see Figure 5). A starting motor discharge air silencer/vapor arrestor is an optional accessory to the air starting system.

A check valve between plant air and receiver assures that failure of plant air will not deplete the backup supply. The air compressors are driven by gasoline engines and electric motors wired to the emergency power source.

For factory supplied electric motor driven by continuous prelube systems, power to the prelube pump is removed by a signal from the control panel when a start is initiated (see Figure 6).

Venting of the starter system must be inspected before start-up to insure that no backpressure in the vent line builds up. To prevent backpressure, a separate vent line should be provided. Another option would be to install a check valve in the starter vent line. (Check valves are not recommended in applications where freezing of the check valve can occur.)

Tandem or compound engines use two motors and solenoid valves. Valves are equal distance from their respective motors for coordinated motor engagement. When a single solenoid controls air to both motors, piping between valve and each motor must be equal length.

Air motor supply pipes are short, direct, and at least equal in size to the motor intake opening. Black iron pipe is preferable and should be supported to avoid stresses on the compressor. Flexible connections between motor and piping are required.

Deposits of an oil-water mixture accumulating in receiver and piping are removed by traps installed at intervals in the lines. The lines should slope toward these traps.

Air cranking systems may freeze at low ambients. Water vapor in compressed air freezes during expansion in temperatures below 0°C (32°F). A dryer at the compressor outlet or a small quantity of alcohol in the starter air tank prevents freezing. At temperatures below –18°C (0°F) consult the generator set supplier.

Torque available from air motors accelerate the engine to twice the cranking speed in about half the time required by electric starters. Remote controls and automation, however, are more complex. Because the exhaust from the air starter is very loud, an air silencer may be appropriate.

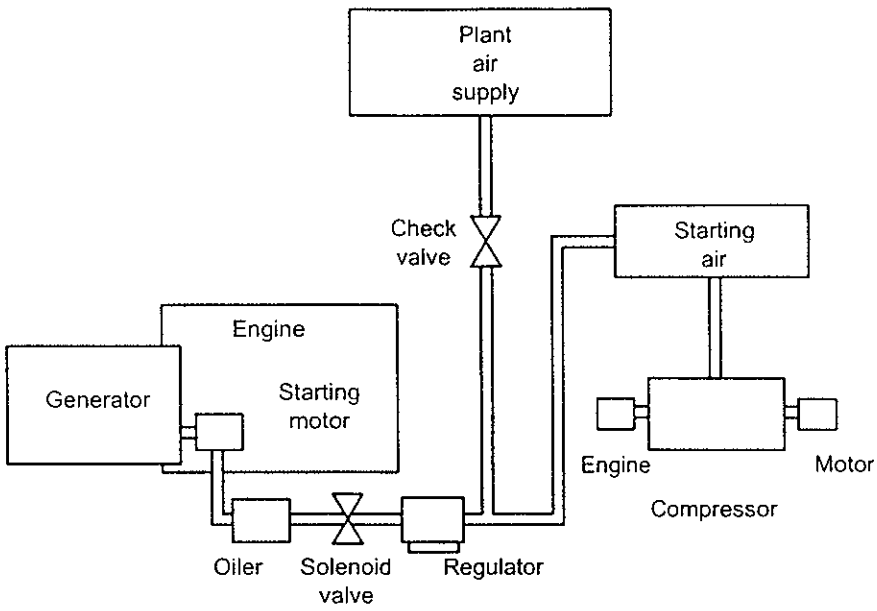


Figure 5. Air starting schematic.

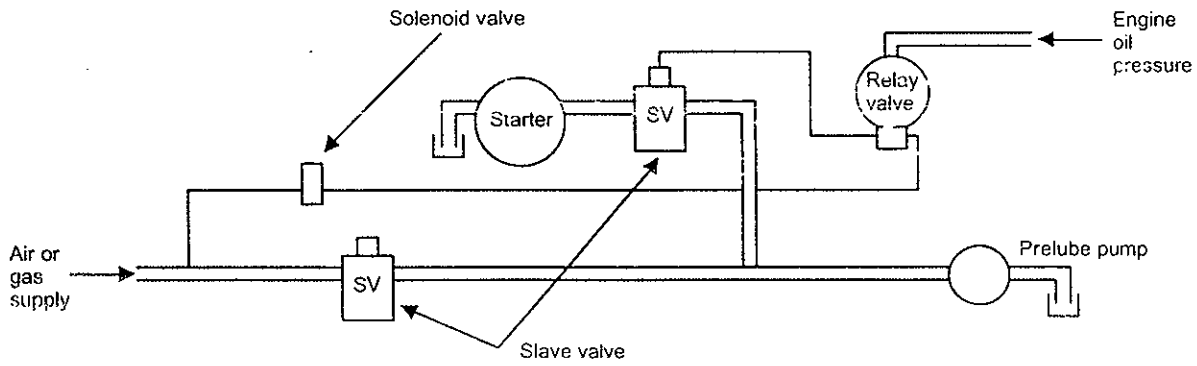


Figure 6. Air start prelube.

Free Air Consumption

Free air consumption depends to some extent on the same variables as air starting systems. In addition the pressure regulator setting must be taken into consideration.

The correct pressure regulator setting is 620 to 690 kPa (90 to 100 psi), with the higher pressure used to improve starting under adverse conditions. 0.14 to 0.42 m^3 (5 to 15 cu ft) per second is typical for engines from 37 to 1194 kW (50 to 1600 hp).

System Design Considerations

Air Pressure

Air is usually compressed between 758 and 1723 kPa (110 to 250 psi) and is stored in storage tanks. Stored air is regulated to 758 kPa (110 psi) and piped to the air motor. A check valve between the compressor and the air receiver is good practice, to protect against a failure of plant air which might deplete the air receivers supply. The air compressors are driven by external power sources.

Cranking Time

The cranking time per start depends upon the engine model, engine condition, ambient air temperature, oil viscosity, fuel type, and design cranking speed. Five to seven seconds for the first start is typical for an engine at 26.7° C (80° F). Restart of a hot engine usually takes less than two seconds.

Air Consumption of the Air Start Motor m^3/sec (ft^3/sec) -Vs-				Minimum Air Tank Pressure
	Air Pressure to Motor -Pt-			
Engine Model	793 kPaa (115 psia) 690 kPag (100 psig)	965 kPaa (140 psia) 862 kPag (125 psig)	1137 kPaa (165 psia) 1034 kPag (150 psig)	-Pmin- kPaa (psia)
3304B	.16 (5.8)	.20 (6.8)	.21 (7.7)	345 (50)
3306B	.17 (5.9)	.20 (6.8)	.22 (7.8)	352 (51)
3406B	.17 (6.2)	.21 (7.3)	.23 (8.3)	379 (55)
3406B	.18 (6.4)	.21 (7.3)	.24 (8.6)	372 (54)
3412	.25 (9.0)	.29 (10.3)	.33 (11.8)	310 (45)
D379	.26 (9.3)	.30 (10.8)	.36 (12.6)	310 (45)
D398	.28 (9.8)	.32 (11.4)	.38 (13.3)	345 (50)
D399	.30 (10.8)	.34 (12.1)	.40 (14.1)	448 (65)
3508	.26 (9.3)	.30 (10.8)	.36 (12.6)	310 (45)
3512	.28 (9.8)	.32 (11.4)	.38 (13.3)	345 (50)
3516	.30 (10.5)	.34 (12.1)	.40 (14.1)	448 (65)

Note: For engines equipped with pneumatic prelube: add 0.03 m^3/sec (1 ft^3/sec) air consumption.

Table 10. Diesel engine, air starting requirements at 10°C (50°F).

Air Consumption of the Air Start Motor m^3/sec (ft^3/sec) -Vs-				Minimum Air Tank Pressure
	Air Pressure to Motor -Pt-			
Engine Model	793 kPaa (115 psia) 690 kPag (100 psig)	965 kPaa (140 psia) 862 kPag (125 psig)	1137 kPaa (165 psia) 1034 kPag (150 psig)	-Pmin- kPaa (psia)
G3304	.16 (5.8)	.19 (6.8)	.22 (7.7)	242 (35)
G3306	.17 (5.9)	.20 (6.9)	.22 (7.8)	248 (36)
G3406	.18 (6.2)	.21 (7.3)	.23 (8.3)	276 (40)
G3408	.18 (6.4)	.21 (7.5)	.24 (8.6)	269 (39)
G3412	.25 (9.0)	.30 (10.3)	.33 (11.8)	207 (30)
G3508	.26 (9.3)	.31 (10.8)	.36 (12.6)	310 (45)
G3512	.28 (9.8)	.32 (11.4)	.38 (13.3)	344 (50)
G3516	.30 (10.5)	.34 (12.1)	.40 (14.1)	448 (65)
G353	.19 (6.6)	.22 (7.8)	.25 (8.9)	276 (40)
G379	.26 (9.3)	.31 (10.8)	.36 (12.6)	207 (30)
G398	.28 (9.8)	.32 (11.4)	.38 (13.3)	242 (35)
G399	.30 (10.5)	.34 (12.1)	.40 (14.1)	345 (50)

Note 1: Add to the G399 and G3516 0.03 m^3/sec (1 ft^3/sec) of air consumption for the air operated oil prelubrication pump. This pump will normally operate 2 to 10 seconds before the engine begins to crank.
Note 2: For start control systems with a purge cycle, include the time of the purge sequence to estimate starting time to obtain total estimated starting time.
*Minimum air storage tank pressure required to sustain cranking at 100 rpm.

Table 11. Gas engine, air starting requirements at 10°C (50°F).

Air Tank Sizing

Many applications require the sizing air storage tanks to provide a specified number of starts without recharging. The tanks must meet ASME specifications and be equipped with a safety valve and gauge. The tank size can be calculated from the following:

$$V_t = \frac{V_s \times T \times P_a}{P_t - P_{min}}$$

Where:

- V_t = Air Storage Tank Capacity, m^3 (ft^3) (Figure 7)
- V_s = Air consumption of the starter motor, m^3/sec (ft^3/sec) (see Table 10).
- T = Total Cranking time required (seconds) if six consecutive starts are required, use seven (7) seconds for first start (while engine is cold), and two (2) seconds each for the remaining five starts, a total cranking time of seventeen (17) seconds.
- P_a = Atmospheric Pressure (normally atmospheric pressure is 100 kPaa (14.5 psia).
- P_t = Air storage tank pressure kPa (psi). This is the storage tank pressure at the start of cranking.
- P_{min} = Minimum Air Storage Tank Pressure required to sustain cranking at 100 rpm.

Example:

A 3516 Diesel Engine with electric prelube has the following:

- maximum air tank pressure = 1241 kPag (180 psig)
- minimum air to starter pressure = 620.5 kPag (90 psig)
- expected air line pressure drop = 207 kPag (30 psig)
- 6 consecutive starts. First start = 7 sec. the other 5 starts = 2 sec.
- average barometric pressure at this location = 100 kPa (14.5 psi)
- preconditioned engine installation.

(cfm × 0.02832 = m^3/min)

Solution:

V_s = 0.40 m^3/sec (14.1 ft^3/sec), found by using Table 10.

T = 7 + (5 × 2) = 17 sec

P_a = 100 kPa (14.5 psi)

P_t = 1241 – 207 = 1034 kPag (180 – 30 = 150 psig)

P_{min} = 620.5 kPag (90 psig)

therefore,

$$V_t = \frac{0.4 \times 17 \times 100}{1034 - 620.5} = 1.64 \text{ m}^3$$

$$V_t = \frac{14.1 \times 17 \times 14.5}{150 - 90} = 57.93 \text{ ft}^3$$

Air Consumption of the Starter Motor

The starter motor air consumption depends on these same variables and also on pressure regulator setting. Normal pressure regulator setting is 690 kPa (100 psi) for both gas and diesel. Higher pressure can be used to improve starting under adverse conditions up to a maximum of 1034 kPa (150 psi) to the starting motor (gas and diesel). The values shown on the air starting requirements chart assume a bare engine (no parasitic load) at 10°C (50°F) (see Table 10 and 11).

Starting Aids

Starting aids are recommended when temperatures fall below certain levels, as shown in the Operation and Maintenance Guides. Glow plugs and/or ether starting aids are sufficient for most conditions, with oil and coolant heating necessary in extremely low ambients (refer to Operations and Maintenance Guides for further data on cold weather procedures).

Jacket Water Heaters

Jacket water heaters are electrical heaters which maintain the jacket water at a temperature high enough to allow for easy starting of the engine. Heaters with higher ratings may be required in areas of extremely cold temperature.

Jacket water heaters are used on both manual and automatic starting systems, but are essential for automatic starting below 21°C (70°F). Provisions should be made to maintain the jacket water temperature at a minimum of 43°C (110°F) for all G3516B applications. Heaters precondition engines for

quick starting and minimize the high wear of rough combustion, by maintaining jacket water temperature during shutdown periods.

Heaters thermostatically control jacket water temperature near 30°C (90°F) to promote fast starts. Higher temperatures accelerate aging of gaskets and rubber material.

Flame Start

In a flame start, glow plugs project into the air inlet manifold and ignite a small amount of diesel fuel during manual starting. The flame is maintained until smooth idling conditions are achieved.

Battery Heaters

Battery heaters are usually recommended in cold ambient temperatures. The heaters should be set to maintain battery temperature in the range of 32 to 52°C (90 to 125°F) for maximum effectiveness.

Ether

Ether facilitates starting because it is a highly volatile fluid which has a low ignition temperature. Many types of ether starting aids are commercially available. The high pressure metallic capsule-type is recommended. When placed in an injection device and pierced, the ether passes into the intake manifold. This has proven to be the best system since few special precautions are required for handling, shipping, or storage.

Caution: When other than fully sealed ether systems are used, ensure adequate ventilation for venting the fumes to the atmosphere to prevent accidental explosion and danger to operating personnel.

Ether must be used only as directed by the manufacturer of the starting aid device. The ether system must be such that a maximum of 3.0 cc of ether will be released, each time the button is pushed. Caterpillar ether systems are designed to release 2.25 cc of ether each time the system is activated. Excessive injection of ether can damage an engine.

Ether is a volatile and highly combustible agent. Small quantities of ether fumes added to the engines intake air during cranking reduce the compression temperature required for engine starting. Caution is required when using ether to prevent spread of fumes to atmosphere. A proper ether system will meter the rate of ether consumption. Only 1 cm^3 (0.033 oz) or less of ether should be released per 100 rated hp for each 10 seconds of cranking. Very low ambient temperatures may require increasing the ether consumption rate. *Under no circumstances should ether be released into an engine while running.*

Ether starting aids are restricted to manual starting systems and are rarely used for generator sets. Introduced into the intake air, it ignites the mixture at low cylinder temperatures. High pressure capsules are the safest and most dependable injection method. Ether injection should not be used on Cat 3600 Engines.

Oil Heaters

Heating elements in direct contact with noncirculating lubricating oil are usually not recommended due to the danger of oil coking. If specified, heater skin temperatures should not exceed 150°C (300°F) and have maximum heat densities of 0.02 W/mm^2 (13 W/in^2).

Additional Starters

Hydraulic starting provides the highest cranking speeds and fastest starts. It is relatively compact. Recharging time is fast, and the system can be recharged by a hand pump provided for this purpose. The high pressure of the system requires special pipes and fittings and extremely tight connections. Oil lost through leakage can be replaced, but recharging the pressurized gas, if lost, requires special equipment.

Air Impingement System

The air impingement system is a method of boosting the engine to get it started.

It must be noted that this system is not available for Caterpillar engines. This is due to unacceptable transient response and the fact that the turbo housing must be specially fabricated to accommodate the hose attachment.

Air impingement works by having a compressed air hose which is ported into the turbocharger turbine wheel. Once the solenoid valve is open, a blast of compressed air spins the turbine wheel. This creates more air on the compressor which then feeds more air to the cylinders which results in more combustion.

CATERPILLAR®

Electric Power Application and Installation Guide

Ventilation

LEBX0033-01

WHERE THE WORLD TURNS FOR POWER

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Ventilation

Ventilation Purpose

Six to ten percent of fuel consumed by an engine is lost as heat radiated to the surrounding air. In addition, heat from generator inefficiencies and exhaust piping can easily equal engine radiated heat. Any resulting elevated temperatures in the engine room may adversely affect maintenance personnel, switchgear, and generator set performance.

Ventilation Flow

Correct routing of ventilation air is vital. Without it, airflow will not adequately maintain comfortable engine room temperatures. Ideally, clean, cool, dry air circulates around switchgear, flows through the rear of the generator, across the engine and discharges through the radiator (see Figure 1). Cool air should always be available for the engine air cleaner.

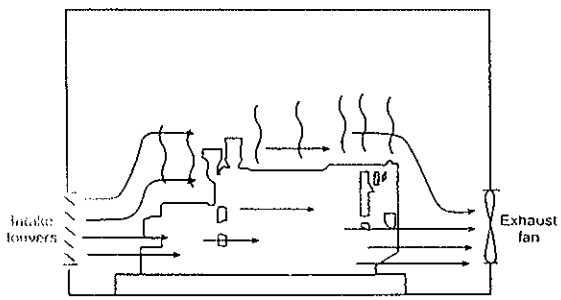


Figure 1. Ideal ventilation.

Locate room air intakes to provide maximum cooling air to the generator set, yet avoid hot, stagnant air in other areas. Multiple generator sets necessitate additional openings and fans.

Units not using radiators require a forced air draft. Openings for intake air should be low, near the rear of the generator set. Outlets should be positioned high on the opposite wall.

Another way of ventilating the engine room is the use of air curtains, although this is not so commonly utilized. The advantage of an air curtain system is that the engine room is exposed to lower air velocity than a system with radiators.

Ventilation Terms

Ventilation Air:
The flow of air required to carry away the radiated heat of the engine(s) and other engine room machinery.

Combustion Air:
The flow of air required to burn the fuel in the engine.

Crankcase Fumes Disposal:
Elimination of oil laden combustion fumes that collect in the engine crankcase (see "Crankcase Ventilation").

Radiator Cooling Air:
Air flow passing through the radiator — normally to cool the engine. Certain installations utilize radiator cooling air flow for ventilation purposes.

Ventilation Considerations

Routing

Comfortable air temperatures in the engine room are impossible without proper routing of the ventilation air.

Fresh air should enter the engine room as far from the sources of heat as practical and *as low as possible*. Since heat causes air to rise, it should be discharged from the highest point in the engine room, preferably directly over the engine. Avoid incoming ventilation air ducts which blow cool air toward hot engine components. This mixes the hottest air in the engine room with incoming cool air, raising the temperature of all the air in the engine room, and leaves areas of the room with no appreciable ventilation.

Relative Efficiency Routing

The sketches below (see Figure 2) illustrate the relative efficiency of various ventilation routing. $F_{routing}$ is a factor which relates the relative efficiency of various ventilation air routing.

Example:

If the routing in Figure A (upper left) is used as a base to which the others are compared:

- 1.4 times more air is required (duct cross-sectional area and fan capacity) to adequately ventilate the machinery space illustrated in Figure B (upper right).
- It takes twice as much air (duct cross-sectional area and fan capacity) to adequately ventilate the machinery space illustrated in Figure C (lower left).
- 3.3 times more air is required (duct cross-sectional area and fan capacity) to adequately ventilate the machinery space illustrated in Figure D (lower right).

Horizontal Air Flow

Cool, dry, clean air should enter the engine room as close to the floor as possible using fans/ducts. Allow this air to flow horizontally across the engine room from the entry point across heat sources such as the engine, exposed exhaust, generator, etc. (see Figure 3).

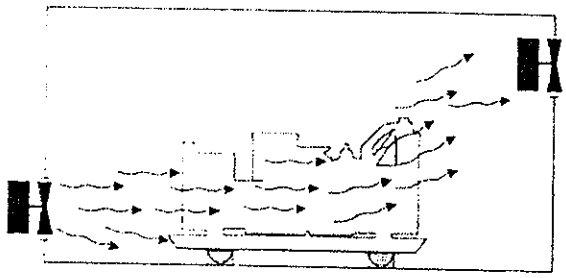


Figure 3. Horizontal air flow.

- For best results, air should flow first across the generator then to both sides of the engine.
- If engine mounted radiators are not used, air discharge fans should be mounted or ducted at the highest point directly over the heat sources.
- Inlet air must circulate between the engines in a multiple engine installation.
- Inlets located at the end of a room with multiple engines will provide adequate ventilation only to the engine nearest the inlet.

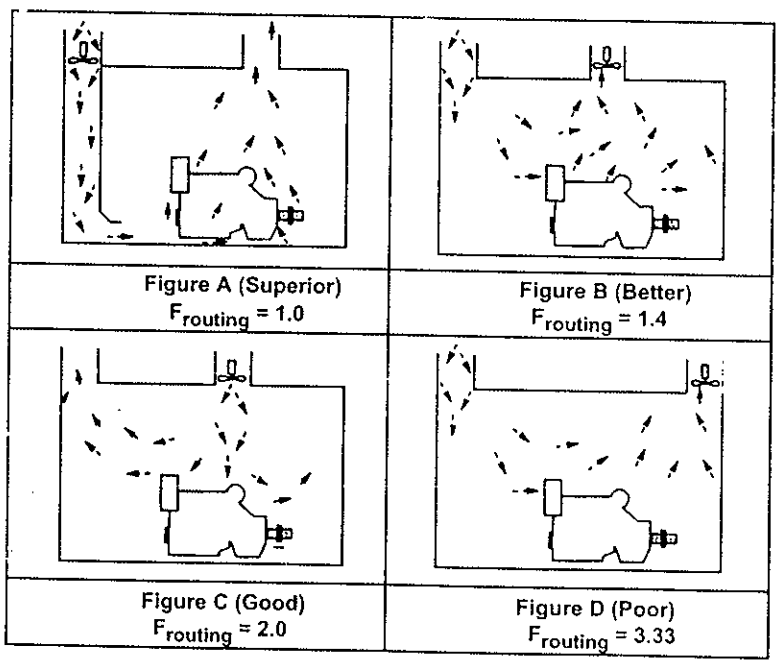


Figure 2. Efficiency of various routings.

Providing horizontal air flow will dissipate engine heat but a certain amount of heat will still radiate and heat the engine room.

Air Curtains

Air curtains, totally enveloping the generator set, provide ventilation without exposing the equipment room to high air velocities (see Figure 4). Radiated heat is removed with approximately half the air flow of a horizontal flow system.

It is important to stretch the air curtain inlet the full length of generator set.

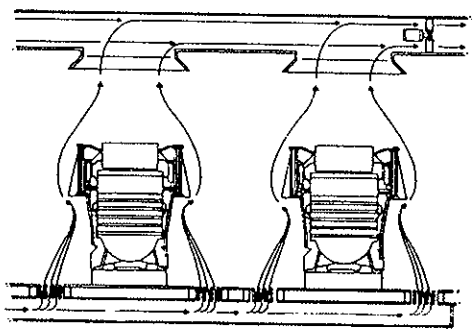


Figure 4. Air curtains.

Air curtains present ducting challenges when local fan radiators are used.

Vertical Air Flow

The least desirable ventilation system discharges outside air directly down on the engines with inlet fans (see Figure 5). Exhaust fans should be mounted in the corners of the room.

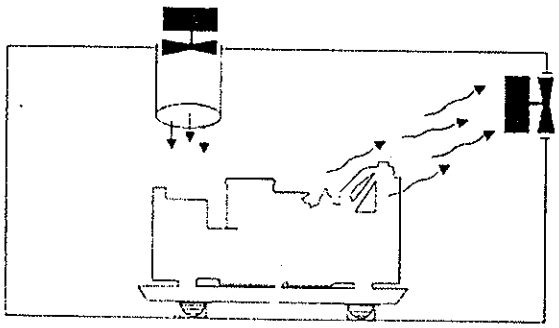


Figure 5. Vertical air flow.

Because this system interferes with the natural rising of hot air, ducting should be used to prevent air from taking the shortest path out of the engine room and bypassing the engine.

Radiator Air

Installations utilizing local free standing or engine-mounted radiators may provide sufficient air flow for cooling. Total ventilation air flow requirements must be compared to radiator fan capabilities.

Intake and exhaust ventilators may have movable or fixed louvers for weather protection. If movable louvers are used, they should be actuated by pneumatic, electric, or hydraulic motors. Do not depend on air pressure developed by the radiator fan to open the vanes. In cold climates, movable louvers can be arranged to provide circulation inside the room until jacket water temperatures reach 88°C (190°F) (see Figure 6).

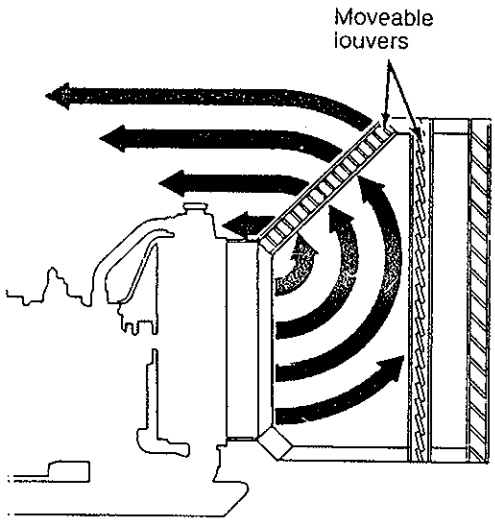


Figure 6. Moveable louvers for recirculation.

Once jacket water temperatures reach 88°C (190°F), the radiator must be furnished with sufficient cooling air. Use a number of small ventilating fans rather than a single large unit. Selective fan operation compensates for varying ambient temperatures while maintaining engine room temperatures.

Increase air flow 10 percent for every 763 m (2500 ft) above sea level to maintain original cooling capability. Final ventilation calculations must use precise heat radiation of selected engine, generator, and power output.

Engine Driven Fans

For most local radiator generator sets, a blower fan (air discharges from engine through radiator) is recommended. The blower fan will move the incoming ventilation air from the generator, past the engine block and manifolds and use that air to cool the radiator.

If a suction fan is used, special considerations must be considered to avoid recirculation of the generator cooling air. It is also much more efficient to use the engine driven blower fan as a room evacuation device than to try to force heated air from a room by pressurizing the room with preheated air from the radiator.

Air Quantity Required

In general, changing the air in the engine room every one or two minutes will be adequate, if flow routing is proper.

Combustion air would be required solely for burning the fuel in the combustion process. Hence the total air intake into the engine room would be the sum of both the combustion air and the cooling air. The quantity of air required for combustion is explained below.

Provisions should be made by the installer to provide incoming ventilation air of 0.1 – 0.2 m^3/min (4-8 cfm) per installed horsepower. This does not include combustion air for the engines.

Engine room exhaust ventilation air should be 110 to 120% of the incoming ventilation air. The excess exhaust ventilation air accomplishes two things:

- It compensates for the thermal expansion of incoming air.
- It creates an in draft to confine heat and odor to the engine room.

Operation in extreme cold weather may require reduced ventilation air flow to avoid uncomfortably cold working conditions in the engine room. This is easily done by providing ventilation fans with two speed motors (100% and 50% or 67% speeds).

Ventilating Fans

In modern installations, natural draft ventilation is too bulky for practical consideration. Adequate quantities of fresh air are best supplied by powered (fan-assisted) systems.

Fan Location

Fans are most effective when they withdraw ventilation air from the engine room and discharge the hot air to the atmosphere.

Fan Type

Ventilating air fans may be of the axial flow type (propeller fans) or the centrifugal type (squirrel cage blowers). When mounting fans in ventilating air discharge ducts (most effective location), the fan motors should be outside the direct flow of hot ventilating air for longest motor life. The design of centrifugal fans (squirrel cage blowers) is ideal.

Fan Sizing

The *name plate* ratings of fans do not necessarily reflect their *as-installed* conditions. Just because a fan's name plate says it will move 1000 cfm of air does not mean it will move 1000 cfm through an engine room which has severely restricted inlet and/or outlet openings. Fans are often rated under conditions which do not reflect as-installed flow restrictions. In general, the as-installed conditions will be more severe than the fans name plate rating conditions.

Combustion

Required Air Flow

Engine room ventilation can be estimated by the following formula. assuming 38°C (100°F) ambient air temperature:

$$V = \frac{H}{D \times C_p \times \Delta T} + \text{engine combustion air}$$

Where:

V = Ventilating Air (m^3/min), (cfm)

H = Heat Radiation i.e. engine, generator, aux (kW), (Btu/min)

D = Density of Air at 38°C (100°F) (1.099 kg/m^3), (0.071 lb/ft^3)

C_p = Specific Heat of Air (0.017 kW × min/kg × K), (0.24 Btu/°F)

ΔT = permissible temperature rise in engine room (°C), (°K)

Note: If duct work is used to bring in air for the engine's combustion air, the last term in the equation can be dropped.

Example:

A 3412 DITA genset has the following data:

Heat rejection: 659 kW (37 478 Btu/min)

Temperature rise: 11°C (20°F)

Solution:

The estimated engine room ventilation required for this arrangement:

$$V = \frac{659}{1.099 \times 0.017 \times 11} = 3206.61 \text{ m}^3\text{/min}$$

$$V = \frac{37478}{0.071 \times 0.24 \times 20} = 109970.7 \text{ cfm}$$

Combustion Air Ducts

Design combustion air ducts to have a minimum flow restriction. Note that very large amounts of air flow through the combustion air ducts.

Air Cleaners

Engines must be protected from ingesting foreign material. The engine-mounted air filter elements must never be remote-mounted, without factory approval.

If large amounts of sea spray, dust, or insects are expected, external, remote-mounted, precleaners may be installed at the inlet to a duct system to extend the life of the engine-mounted filter elements.

Location

The combustion air ducts should be located close to the engine. Usually, flexible connections are used to reduce noise from the ducting system. In addition, all duct work must be supported on the engine to avoid unnecessary loading on the turbochargers.

Duct Restriction

Total duct air flow restriction, including air cleaners, should not exceed 2.49 kPa (10 in. H_2O) measured while the engine is producing full rated power. It is good design practice to design combustion air ducts to give the lowest practical restriction to air flow, since this will result in longer times between filter element service or replacement.

Air Velocity in Combustion Air Ducts

Combustion air duct velocity should not exceed 610 m/min (2000 ft/min). Higher velocities will cause unacceptable noise levels and excessive flow restriction.

Water Traps

Traps should be included to eliminate any rain or spray from the combustion air. Rain and spray can cause very rapid plugging of the paper air filter elements on some engines. This will reduce the flow of air through the engine, raising the exhaust temperature with potentially damaging effects.

Crankcase Ventilation

Normal combustion pressures of an internal combustion engine cause a certain amount of blowby past the piston rings into the crankcase. To prevent pressure buildup within the crankcase, vent tubes are provided to allow the gas to escape. Each engine's fumes disposal should have separate discharge pipes.

Crankcase fumes must not be discharged into air ventilating ducts or exhaust pipes. They will become coated with oil deposits. Crankcase fumes must be either ingested by the engine or piped out of the engine room.

The crankcase vent pipe may be directed into the exhaust gas flow at the termination of the exhaust pipe.

Preferably, the crankcase vent pipe will vent directly to the atmosphere. The vent pipe termination should be directed to prevent rain/spray entering the engine.

Design Considerations

Heat Rejection

Engine Radiant

The heat input into the engine is the sum of the work output and the heat generated. Besides the work output, heat is rejected to the atmosphere, into the oil cooler, aftercooler, through the exhaust stack and also through the jacket water. Hence, while designing the ventilation system in a room, the engine generated heat should be taken into consideration. This information can be found in TMI.

Generator Radiant

The heat radiated by the generator can be calculated by the following formulas:

$$HRG\ (kW) = P \times \left[\frac{1}{EFF} - 1\right]$$

$$HRG\ (Btu/min) = P \times \left[\frac{1}{EFF} - 1\right] \times 56.9$$

Where:

HRG = Heat Radiated by the Generator (kW), (Btu/min)
P = Generator Output at Maximum Engine Rating (ekW)
Eff = Generator Efficiency %/100% (Example: Eff = 94%/100% = 0.94)

Example:
A 3512B, 975 ekW standby generator set has a generator efficiency of 92%. What is the generator radiant heat for this genset?

Solution:

$$P = 975\ ekW$$

$$Eff = \frac{92\%}{100\%} = 0.92$$

$$HRG = 975 \times \left(\frac{1}{0.92} - 1\right)$$

$$HRG = 84.78\ kW$$

$$HRG = 975 \times \left(\frac{1}{0.92} - 1\right) \times 56.9$$

$$HRG = 4824\ Btu/min$$

Engine Room Auxiliaries

The consultant should take all auxiliary equipment besides the generator set into consideration while designing the ventilation system. Auxiliary equipment such as switchgear, compressors, pumps, lighting, piping etc. are sources of heat. Thus the design should cover all main and auxiliary equipment so that the room temperature is maintained.

Engine Room Temperature

A 8.5°C (15°F) temperature rise above the ambient temperature is a reasonable target for engine rooms. (Ambient air temperature refers to the air temperature surrounding the engine room.) However, in cold climates this may cause discomfort from the flow of cold air. Restrict flow only if engine combustion air is available and engine jacket water is adequately cooled. In general, engine room temperature should not exceed 49°C (120°F). The primary reason for cooling an engine room is to protect various components from excessive temperatures. Items that require cooling are:

- Electrical components such as magnetos, interface box and timing control.
- Cool air to the air cleaner inlet.
- Cool air to cool the torsional damper.
- Habitable temperatures for the engine operator or service personnel.
- Cooling air for the generator or other driven equipment.

In larger multiple engine sites the normal 8.5° C (15° F) temperature rise guidelines for engine rooms require unobtainable or uncomfortable air velocities.

For larger sites, a ventilation system that gives priority to the five items listed above and provides a bottom to top air flow similar to that shown in Figure 4 can be designed for a temperature rise of 17° C (30° F).

Air Velocity for Personnel Comfort

Maintain air velocity of at least 1.5 m/s (5 ft/s) in working areas adjacent to sources of heat, or where air temperatures exceed 100°F (35°C). This does *not* mean that all the air in the engine room should be agitated so violently. High air velocity around engines and other heat sources is not good ventilation practice. High velocity air aimed at engines will hasten transfer of heat to the air, raising average engine room air temperature.

Table 1 lists typical air motions:

Air Velocity		Conditions
m/min	(fpm)	
15.2	50	Offices, seated worker
30.5	100	Factory, standing worker
45.7	150	Capture velocity, light dust
61	200	Maximum continuous worker exposure
396	1300	Capture velocity, rain
306 – 610	1000-2000	Maximum intermittent exposure

Table 1. Air velocity.

Radiators

Installations with engine-mounted radiators using engine room air for cooling (Figure 7), generally provide more air flow than is needed for adequate ventilation. The high air flow combined with low ambient temperatures, below 21°C (70°F), may cause water to condense inside exposed engine components, like valve covers. This can result in oil and maintenance problems. Therefore, special installation considerations must be made in cold climates.

There are two methods that can be used to overcome this problem.

- Remote mounted and specially ducted engine-mounted radiators do not require engine room air for cooling (see Figure 8). One advantage of such a system is that the air used to cool the radiator is not pre-heated by the engine, thus increasing the ambient capability (or reducing the size) of the unit. The disadvantage is that motor-driven fans must be installed to provide ventilation for the engine, generator and other equipment which increases the overall cost of the system. This system is suitable for continuous duty applications.

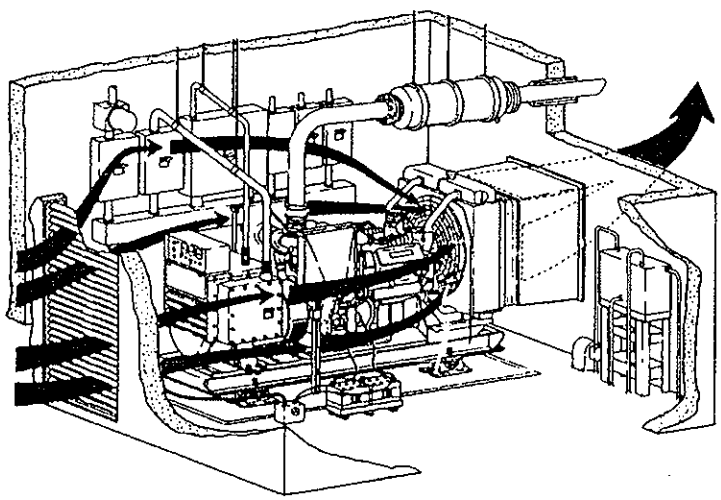


Figure 7. Engine driven fan arrangement.

- Thermostatically controlled louvers can be installed to recirculate some of the radiator exhaust in order to maintain a warm air flow across the engine (see Figure 9). This also maintains a comfortable working environment for maintenance personnel. Caution must be exercised so that the recirculated air is reintroduced upstream of the engine and is well mixed by the time it reaches the radiator.

For any arrangement where a radiator fan is used to ventilate an engine room, the vacuum created in the engine room must not exceed 0.12 kPa (0.5 in. H_2O). Any restriction above this limit could reduce air flow through the radiator and overheat the engine.

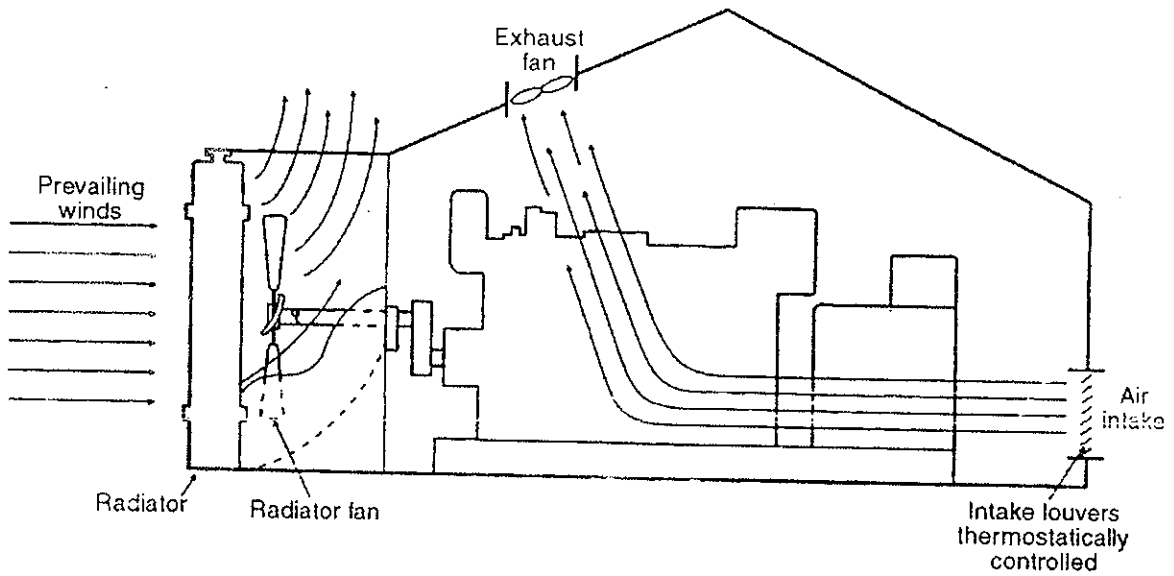


Figure 8. Engine driven fan arrangement.

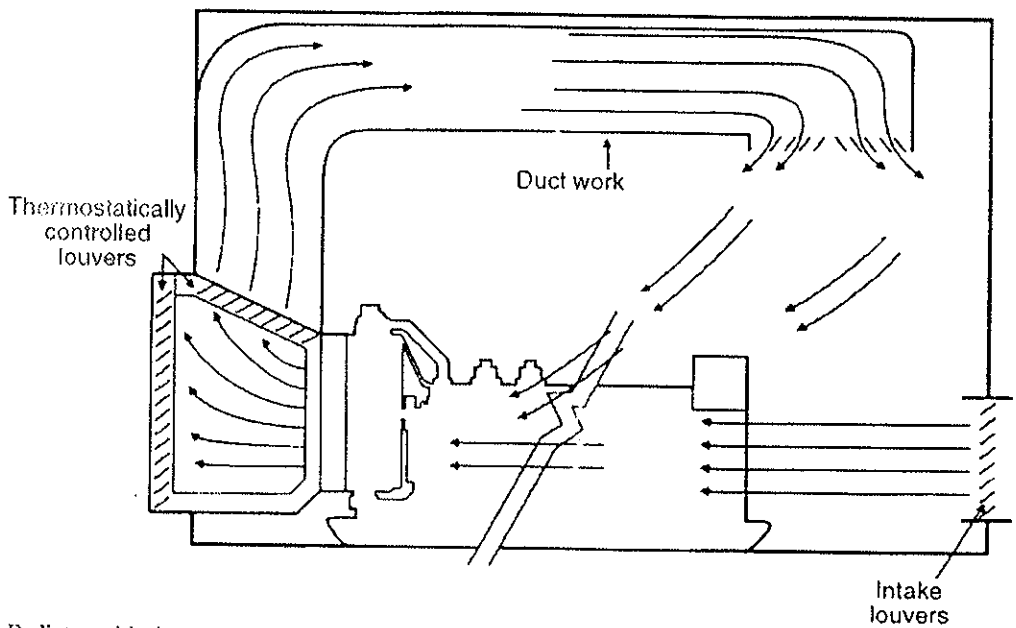


Figure 9. Radiator with thermostatically controlled louvers.

Radiator Sizing

Radiator core frontal area should be as large as possible to minimize restriction to airflow. Low radiator core restriction usually results in being able to provide a larger slower turning fan.

Radiators which are nearly square can provide the most effective fan performance. They can be installed with a minimum of unswept core area. As a general rule, keep core thickness to a minimum with a maximum of 11 fins per 2.54 cm (1.0 in.). Increasing the number of fins per cm (in.) does increase the radiator heat rejection for a given air velocity through the core but also increases the resistance to air flow.

While the most economical initial cost will be maximum core thickness and fins per cm (in.), this involves higher fan horsepower with consequent operating cost and noise penalties throughout the life of the installation. In addition, a radiator with more fins per cm (in.) is much more susceptible to plugging from insects and debris.

Fan Sizing

As a general rule, the most desirable fan is one having the largest diameter and turning at the lowest speed to deliver the required airflow. This also results in lower fan noise and lowest fan horsepower draw from the engine.

Blade tip speed, while being only one of the elements of cooling fan design, is an item easily changed by choosing an appropriate fan drive ratio. An optimum fan tip velocity of 6096 cm/s (12,000 fpm) is a good compromise for meeting noise legislation requirements and cooling system performance requirements. Maximum acceptable tip speed is 7620 cm/s (15,000 fpm) for Caterpillar fans.

Moveable Louvers

If moveable louvers are used, specify those which open in a positive manner. Pneumatic and electric-actuated louvers are satisfactory (see Figure 10).

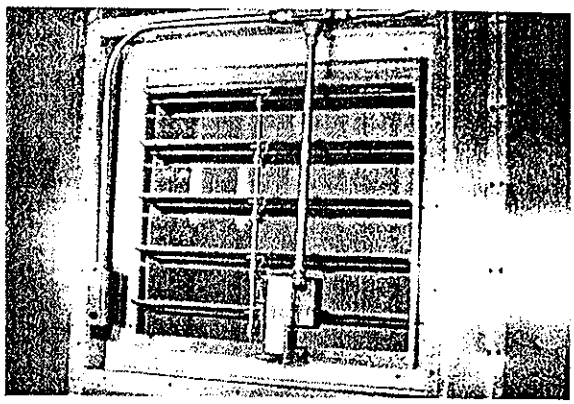


Figure 10. Moveable louvers.

Louver Operation

- Louvers which open from the discharge pressure of the radiator fan are discouraged. Rain, ice, and snow can render them inoperative within a short time and result in engine overheating and shutdown.
- Do not wait to activate the louvers until the engine warms up. In an emergency, the engine will be loaded immediately and require full air flow. Open the louvers as soon as the engine starts and install them to open fully in case of an emergency.
- Heat sensors needlessly complicate the system and their malfunction can reduce air flow to the engine which can cause shutdown.

Enclosures

Enclosures trap radiated heat and direct it through the radiator decreasing cooling capabilities 8° to 10°C (14° to 18°F). Even with doors open, radiators can derate 5° to 7°C (9° to 13°F) when enclosed.

Special Considerations

Refrigeration Equipment

Prevent refrigerant leakage into the engine's air intake system. Freon or ammonia will cause severe engine damage if drawn into the engine's combustion chambers. The chemicals in refrigerants become highly corrosive acids in the engine's combustion chambers.

If refrigeration equipment is installed within the same compartment as a diesel engine, the diesel engine must take its combustion air from a specially supplied ductwork system which carries air to the engine from an area free of refrigerant fumes.

Exhaust Pipe Insulation Recommended

Long runs of hot, uninsulated exhaust piping will dissipate more heat into the engine room than all the machinery surfaces combined. Completely insulate all exhaust piping within the engine room area. All hot surfaces within the engine room should be insulated if high air temperatures are to be avoided. Do not insulate engine turbochargers.

Test With Doors and Windows Closed

Ventilating systems must be designed to provide safe working temperatures and adequate air flow when windows, doors, and other normally closed ports are secured for bad weather conditions. Test the ventilation system fully secured for bad weather. This condition will reflect the most severe test of the ventilation system. Remember that a small room suction can exert a large pressure on an entrance door or window.

Ducting Considerations

Design all ducting to withstand extremes of vacuum or pressure and still maintain tight joints.

Provide inspection ports (or areas that are easily disassembled) to allow removal of foreign objects — especially for standby applications.

Caterpillar's Commitment to
Electric Power Generation
We've been Manufacturing, Installing and Maintaining
engine driven generator sets since
1939
(Over 60 years of experience)

Diesel Engine Development

When designing a new Diesel Engine today, the most likely objectives would be ?

- Reduced Fuel Consumption
- Reduced Exhaust Emissions (Low NOx)
- Smokeless Operation
- Improved Reliability
- Improved Serviceability

Environmental Pollution

Recognized as an issue that needs to be addressed

- Currently most developed countries have implemented emission limits for diesel engines.

  US Std - EPA, European Std EU Stage I & II, Korea KR, Japan ....
- IMO Regulation on operation of marine diesel engines effective Jan.1, 2000

  International Maritime Organization (IMO) is a UN specialized agency with responsibility for maritime safety and marine pollution prevention

Singapore Emissions Requirements

Singapore ENV/NEA announcement:

" With effect from August 1, 2000, all off-road diesel engines would be required to comply with either US or EU off-road diesel exhaust emission standards."

http://www.env.gov.sg
http://www.nea.gov.sg
http://app.nea.gov.sg

ENV's Definition of Off-Road Diesel Engines

"Any equipment or machinery that is equipped with diesel engines as a main or auxiliary prime mover and not registered with the LTA for use on public roads requires to have a permit prior to the import of such equipment"

"..... Hence , generator sets, mobile or otherwise are included and should comply with the emission limits stipulated according to their power ratings. "

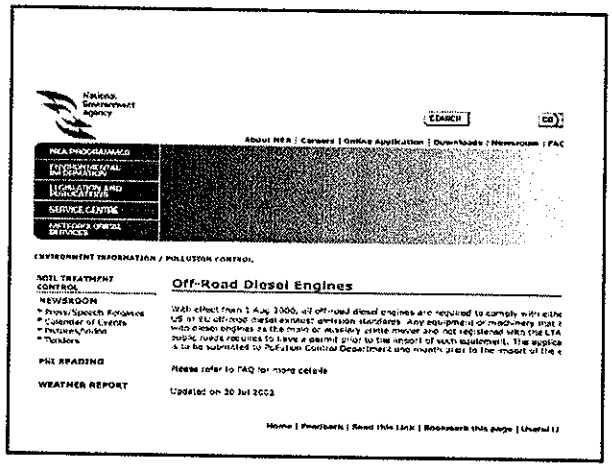
ENV Off-Road Diesel Engines Clarification

- Only applicable to engines used in Singapore not applicable to those that will be re-exported.
- Applicable to all generator sets :

  - inclusive of diesel engines driven standby (emergency) generator sets.

  - inclusive of those large stationary diesel engine driven generator sets.

http://www.nea.gov.sg



Emission Limits

Current Emission Standards for Off-Road Diesel Engines:

Net Power kW	Implementation Date	HC	CO (g/kWh)	NOx	PM
US Standard Tier I					
130 < P < 560	1996	1.3	11.4	9.2	0.54
EU Standards stage I					
130 < P < 560	Oct '98	1.3	5.0	9.2	0.54
Japan Standards (Current)					
30< P < 260	Apr '96	~~2.0~~ 1.5	6.0	9.5	--

Caterpillar Engines Cleared for Use in Singapore - Generator set Application

- 3306 (164 kW)
- 3306 (180 kW)
- 3306 (200 kW)
- 3306 (220 kW)
- 3306 (240 kW)
- 3406E (328 kW)
- 3406E (364 kW)
- 3412 (400 kW)
- 3412 (436 kW)
- 3412 (440 kW)
- 3412 (544 kW)
- 3412 (580 kW)
- 3412 (600 kW)
- 3412 (640 kW)
- 3412 (648 kW)
- 3412 (720 kW)
- 3508B (800 kW)
- 3512B (1200 kW)
- 3512B (1280 kW)
- 3512B (1360 kW)
- 3516B (1600 kW)
- 3516B (1825 kW)

New Engine Design Objectives

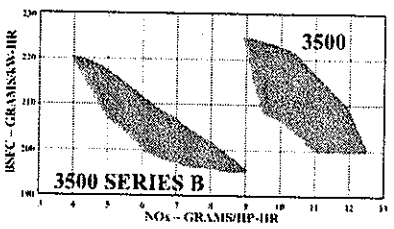
- Delivers Lower Emissions
- Provides Increased Fuel Economy
- Virtually Smokeless
- Provides Improved Responsiveness

3500 Series B Engines

- 3500B Program 1989
- 3500B Production July 1995
- Program Design Objectives
  - Lower Exhaust Emissions
  - Improve Fuel Economy
  - Reduce Smoke
  - Provide Enhanced Diagnostics and Monitoring Capabilities
- "Reliability & Engine Response"

- Delivers Lower Emissions
- Provides Increased Fuel Economy
- Virtually Smokeless
- Provides Improved Responsiveness

3500 vs. 3500 Series B
BSFC vs. NOx



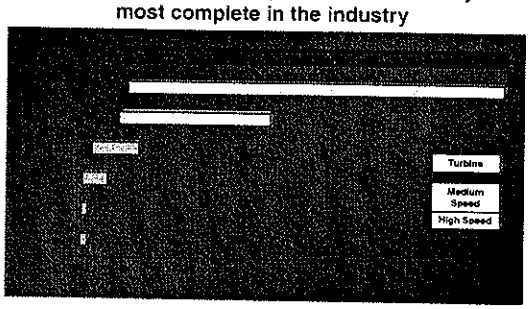
Any Questions for Discussion ?

Thank You!

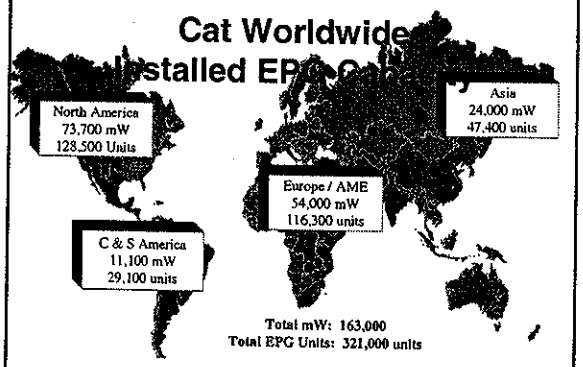
Cat Electric Power Product Overview

Product Line (5-16,000 kW)

most complete in the industry

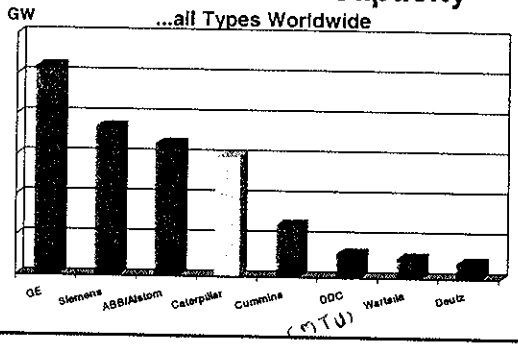


Cat Worldwide Installed EPG Units

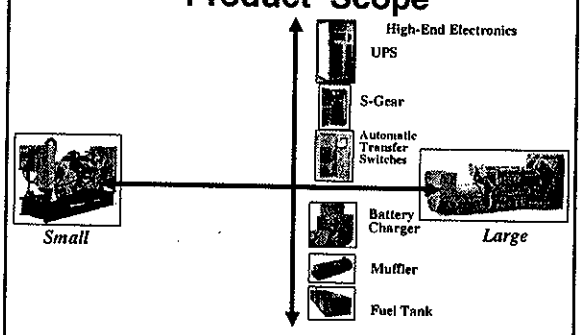


Annual Installed Capacity

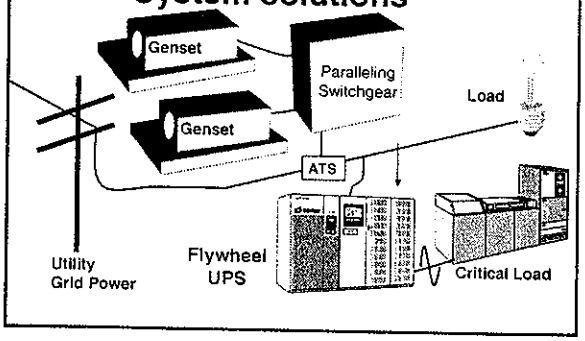
GW ...all Types Worldwide

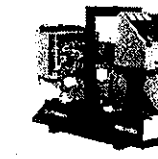


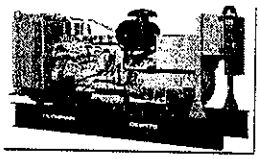
Product Scope



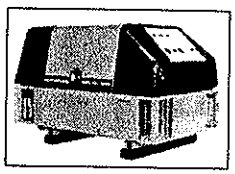
System solutions

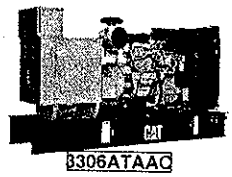




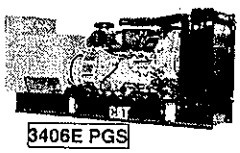


• 11.4 to 250 kV·A 50 Hz

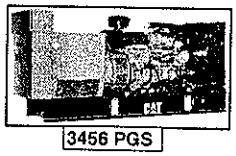




3306ATAAC



3406E PGS

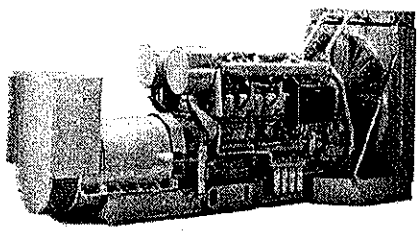


3456 PGS

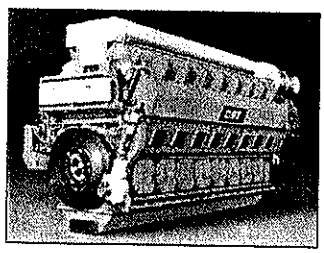


G3412 PGS

3500 MUI & B Series



Cat CM Medium Speed Product



The Caterpillar UPS Solution

- 3 years

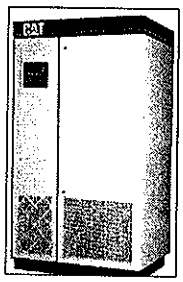
- 50/60 HZ 250 KVA available
- High efficiency flywheel energy storage
- Protects sensitive loads from:

Power Outages

Voltage Sags

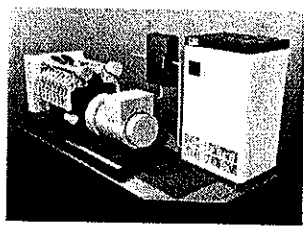
Voltage Surges
IEEE 587

- Low Maintenance



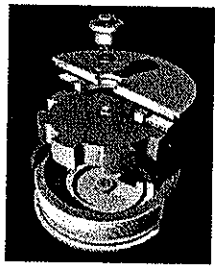
Continuous Power Solution
(Gen Set, Transfer Switch and UPS)

- Small footprint
- Front service access
- Simple installation
- Gen set friendly
  - Low input THD
  - Handles transients
  - Programmable walk-in
- No-break power solution



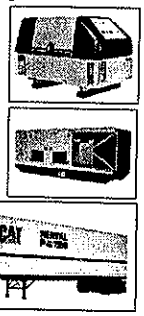
The Flywheel Advantage

- Fully integrated motor/generator energy storage device
- Simple, reliable, and compact
- Infinite life-cycle
- 3+ years of successful field operations



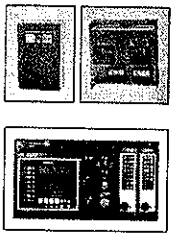
Enclosed Units

- Modular Assemblies
- Factory Assembled
- Reduced Construction Risk
- Reduced Lead Times
- Mobile & Relocatable



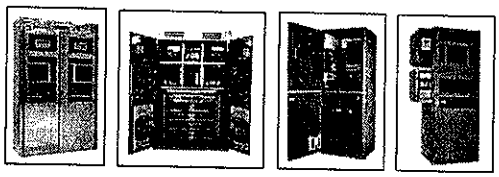
Electrical Attachments

- Digital control panels
- Starting & charging system
- Automatic Transfer Switches
- Floor standing switchgear
- Generators & AVR's
- Circuit breakers
- Battery chargers
- etc.



Custom Controls

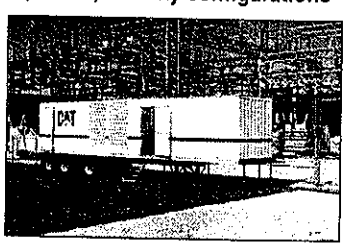
- Custom Switchgear
- Built to Specification
- Systems Integration / Value Added



Power Modules

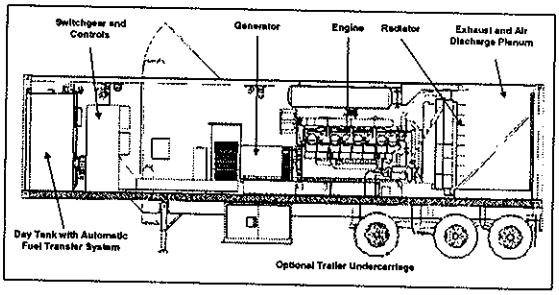
sold to Power Grid

- Standard, rental, & utility configurations



Modular Design...Side View

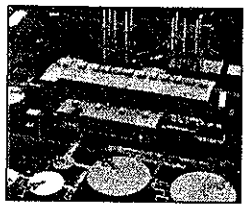
90 dBA at 3m



50 mw

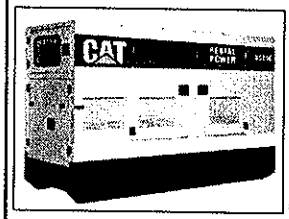
Power Plants

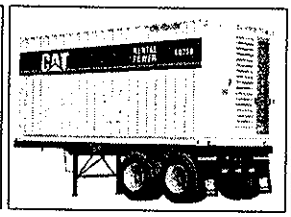
- Modular Plants
- Barges



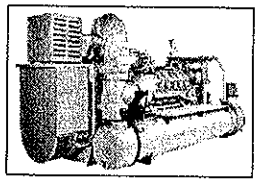


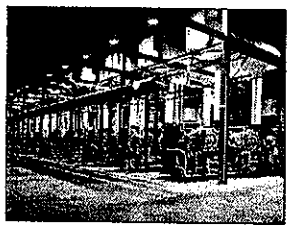
Cat Rental Power





Energy Management - CHP



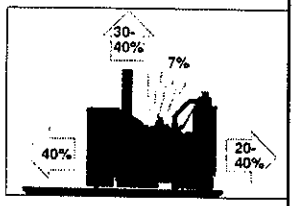


Heat Recovery

Combined Heat and Power

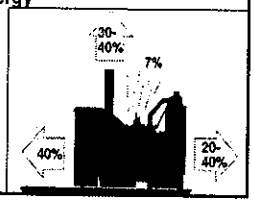
Engine Heat Balance

- Engines Produce Heat as By-Product of Combustion
- Cooling System Elements
  - Jacket Water
  - After Cooler
  - Oil Cooler



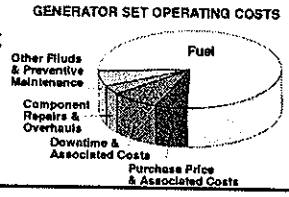
Engine Heat Balance

- Heat Rejection - Approximate Energy Split
  - 40 % Useful Work
  - 30 - 40 % Exhaust Energy
  - 20 - 40% Cooling System Energy
  - 6-8 % Friction and Radiation
- Design Requirements
- Temperature Limits
- Pressure Limits



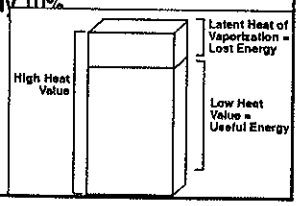
Heat Recovery

- 60-70% of Energy Input Converted to Heat
  - Exhaust Energy
  - Coolant Energy
  - Radiant Energy
- Increases Fuel Input Efficiency



Heating Value

- HHV - Higher Heating Value
- LHV - Lower Heating Value
- Difference = Latent Heat of Vaporization
  = Approximately 10%
- Useful Energy = LHV

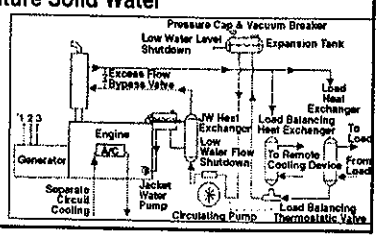


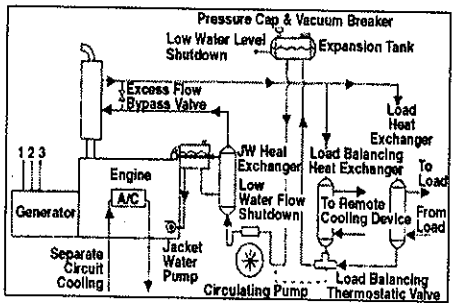
Types of Heat Available

- Solid Water - STANDARD TEMP 99°C HIGH TEMP 127°C
- Steam - ~~121°C~~ 127°C
- Hot Air - 35°C - 65°C

Cooling Systems

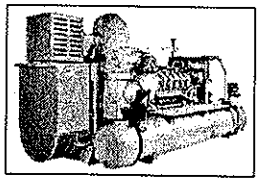
- Standard Temperature
- High Temperature Solid Water
- High Temp. Water/Steam
- Ebullient

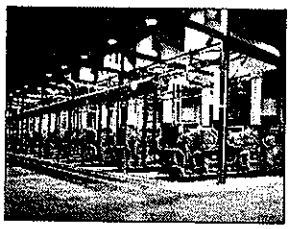




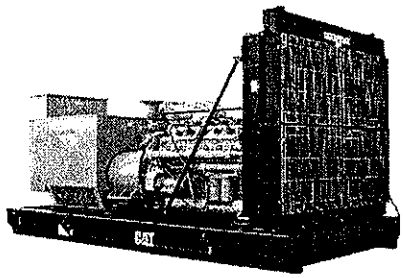
Gas Engine

Energy Management - CHP

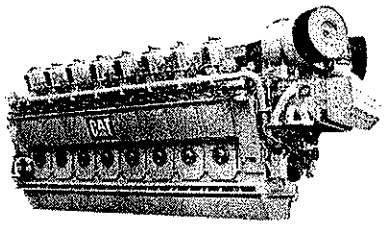




G3406 and G3412 Packages



G16CM34



5950 ekW (60 Hz)

Complete EPG System Offering

- Generator Set
- Exhaust Component
- Fuel storage / delivery
- Enclosures
- Electronic Controls
- Switchgear
- Transfer Switches

