CATERPILLAR®

LEBV0915-05

General Service Information

ENGINE INSTALLATION & SERVICE HANDBOOK

Use the bookmarks for navigation inside of the manual

Introduction

Exceptional value is built into every Caterpillar engine. Whether the application is electric power generation, marine propulsion, industrial, or petroleum; the goal of the Caterpillar factory and dealer network resources is to provide the end-user with years of dependable, economical service. One of the key factors involved in ensuring optimum service life and operating efficiency is the suitability of the installation. The engine must be properly installed in an environment where it functions as designed and is properly maintained.

This booklet is designed to be used as an on-the-job reference guide in conducting Caterpillar engine installation audits, commissionings, and performance analyses. Its use is intended only for engineers and technicians knowledgeable of the concepts and principles contained in the reference publications. The publications on the following page should be consulted if detailed information on the subject is desired. Additionally, whenever engine performance data such as heat rejection and air flow is available in the Caterpillar Technical Marketing Information (TMI), it should be used instead of the Rules of Thumb contained in this guide.

An additional pocket reference for servicemen working with electrical equipment is "Ugly's Electrical Reference", FORM #SEBD0983.

A pocket reference for Marine Applications is available. It is called "The Marine Analyst Service Handbook", FORM #LEBV4830.

Materials and specifications are subject to change without notice.

June, 1990 - First Edition

September, 1992 - Second Edition

July, 1994 - Third Edition

May, 1996 - Fourth Edition

October, 1997 - Fifth Edition

Reference Publications

Marine Engine Application and Installation Guide LEKM9213

Marine Engine Sea Trial Guide LEBM6302

Generator Set Application and Installation Guide LEBX6213

Petroleum Engines Application and Installation Guide LEBW5119

Spark Ignited Application and Installation Guide LEBH6154

3600 Application Guide LEKX1002

Generator Set Electrical Fundamentals LEHQ8054

On-Site Power Generation Handbook LEBX4457

Service Information Manual for EPG Products SEBU6126

Operation and Maintenance Management Manual by engine model [1]

Maintenance Manual for Spark Ignited Engines SEBU6127

Engine Performance Book by engine mode [2]

Truck Performance Diagnostic Guide SEBD0808

Oil and Your Engine SEBD0640

Diesel Fuels and Your Engine SEBD0717

Coolant and Your Engine SEBD0970

Cooling System Field Test LEKQ7235

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[1]Listed in Engine Publications List, SEFD3442-52

[2]Listed in Engine Division Advertising and Training Support Directory

Cooling System

Delta T-Flow Relationship

$$\Delta T\ (^\circ F) = \frac{\text{Heat Rejection (BTU/MIN.)}}{\text{Flow (GPM)} \times \text{Density (LB/GAL.)} \times \text{Spec. Heat (BTU/LB}\bullet{}^\circ\text{F)}}$$

	Pure Water	Sea Water	50/50 Water — Glycol	Diesel Fuel
Density (LB/GAL.) @ 180°F	8.1	8.5	8.6	7.1
Specific Heat (BTU/LB •°F)	1.0	0.94	0.85	0.45

$$\Delta T\ (^\circ C) = \frac{\text{Heat Rejection (kW)}}{\text{Flow (L/MIN.)} \times \text{Density (KG/L)} \times \text{Spec. Heat}\left(\frac{\text{kW}\bullet\text{MIN.}}{\text{KG}\bullet{}^\circ\text{C}}\right)}$$

	Pure Water	Sea Water	50/50 Water — Glycol	Diesel Fuel
Density (KG/L) @ 82°C	0.98	1.02	1.03	0.85
Specific Heat $\left(\frac{\text{kW}\bullet\text{MIN.}}{\text{KG}\bullet{}^\circ\text{C}}\right)$	0.071	0.066	0.06	0.032

Piping Design - Flow Relationships

Recommended Coolant Velocities

Jacket Water: 2-8 FT./SEC. (0.6-2.5 M/SEC.)

Sea Water: 2-6 FT./SEC. (0.6-1.9 M/SEC.)

Maximum Fresh Water Velocities for 3600 Engines

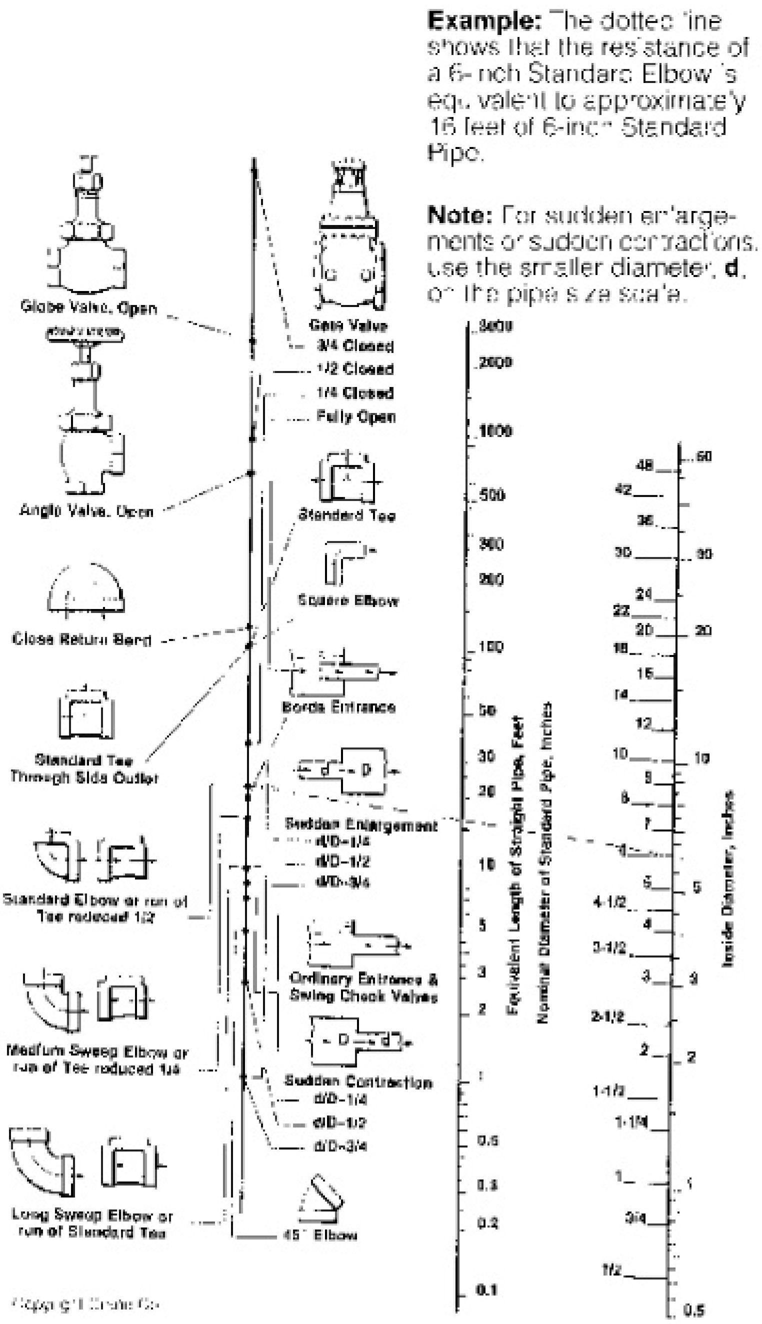
Pressurized Lines: 14.8 FT./SEC.) (4.5 M/SEC.) Max.

Suction Lines: 4.9 FT./SEC. (1.5 M/SEC.) Max.

Pipe Dimensions - Standard Iron Pipe

Nominal Size		Actual I.D.		Actual O.D.		ft. per gal.	m per Liter	ft. per cu. ft.	m per m^3
In.	(mm)	In.	(mm)	In.	(mm)				
1/8	3.18	0.270	6.86	0.405	10.29	336	27.0	2513	27,049
1/4	6.35	0.364	9.25	0.540	13.72	185	16.1	1383	14,886
3/8	9.53	0.494	12.55	0.675	17.15	100.4	8.3	751	8,083
1/2	12.7	0.623	15.82	0.840	21.34	63.1	5	472	5,080
3/4	19.05	0.824	20.93	1.050	26.68	36.1	2.9	271	2,917
1	25.4	1.048	26.62	1.315	33.4	22.3	1.9	166.8	1,795
1¼	31.75	1.380	35.05	1.660	42.16	12.85	1.03	96.1	1,034
1½	38.1	1.610	40.89	1.900	48.26	9.44	.76	70.6	760
2	50.8	2.067	52.25	2.375	60.33	5.73	.46	42.9	462
2½	63.5	2.468	62.69	2.875	73.02	4.02	.32	30.1	324
3	76.2	3.067	77.9	3.500	88.9	2.60	.21	19.5	210
3½	88.9	3.548	90.12	4.000	101.6	1.94	.16	14.51	156
4	101.6	4.026	102.26	4.500	114.3	1.51	.12	11.30	122
4½	114.3	4.508	114.5	5.000	127	1.205	.097	9.01	97
5	127	5.045	128.14	5.563	141.3	0.961	.077	7.19	77
6	152.4	6.065	154	6.625	168.28	0.666	.054	4.98	54
7	177.8	7.023	178.38	7.625	193.66	0.496	.04	3.71	40
8	203.2	7.982	202.74	8.625	219.08	0.384	.031	2.87	31
9	228.6	8.937	227	9.625	244.48	0.307	.025	2.30	25
10	254	10.019	254.5	10.750	273.05	0.244	.02	1.825	19.6
12	304.8	12.000	304.8	12.750	323.85	0.204	.016	1.526	16.4

Resistance of Valves and Fittings to Flow of Fluids



This chart is for illustrative purposes only. Do not attempt to use this for measurement. Refer to Application Installation Guides for full scale measurements.

Flow Restriction of Fittings Expressed as Equivalent Feet of Straight Pipe

Flow Restriction of Fittings Expressed as Equivalent Feet of Straight Pipe

Size of Fitting	2"	2½"	3"	4"	5"	6"	8"	10"	12"	14"	16"
90 Ell	5.5	6.5	8	11	14	16	21	26	32	37	42
46 Ell	2.5	3	3.8	5	6.3	7.5	10	13	15	17	19
Long Sweep Ell	3.5	4.2	5.2	7	9	11	14	17	20	24	27
Close Return Bend	13	15	18	24	31	37	51	61	74	85	100
Tee — Straight Run	3.5	4.2	5.2	7	9	11	14	17	20	24	27
Tee — Side Inlet or Outlet	12	14	17	22	27	33	43	53	68	78	88
Globe Valve Open	55	67	82	110	140						
Angle Valve Open	27	33	41	53	70						
Gate Valve Fully Open	1.2	1.4	1.7	2.3	2.9	3.6	4.5	5.8	6.8	8	9
Gate Valve Half Open	27	33	41	53	70	100	130	160	200	230	260
Check Valve	19	23	32	43	53						

Strainers:

As a general rule of thumb, strainers should be of adequate capacity to create no more than 1.5-2.0 psi (10-14 kPa) of pressure drop under clean strainer conditions at maximum flow.

Typical Friction Losses of Water in Pipe - (Old Pipe) (Nominal Pipe Diameter)

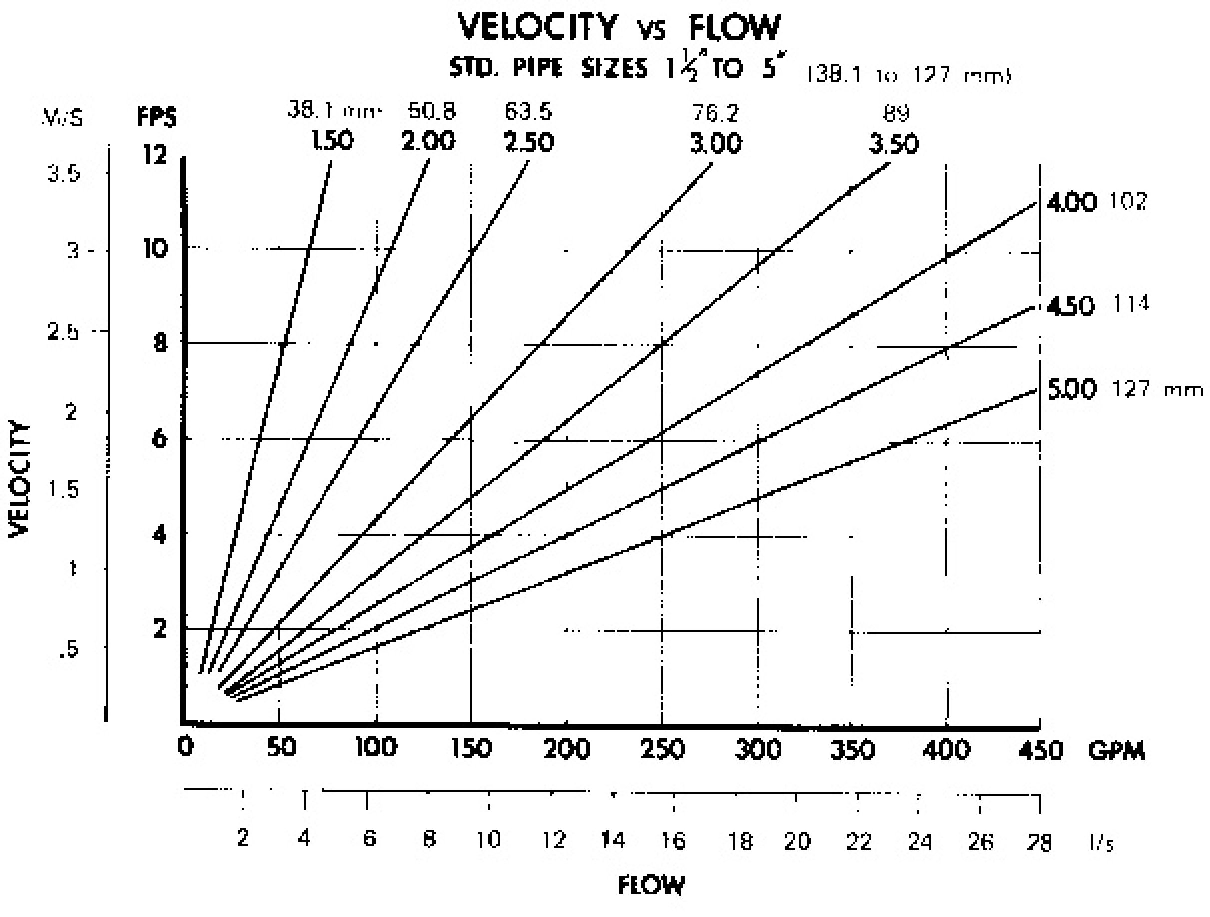
Typical Friction Losses of Water in Pipe
(Old Pipe)
(Nominal Pipe Diameter)

Gallons per Minute		Head Loss in Feet of Water per 100 ft. of Pipe (m per 100 m)							Gallons per Minute	
gpm	(l/s)	¾" (19.05 mm)	1" (25.4 mm)	1¼" (31.75 mm)	1½" (38.1 mm)	2" (50.8 mm)	2½" (63.5 mm)		gpm	(l/s)
5	.34	10.5	3.25	0.84	0.40	0.16	0.05	3" (76.2 mm)	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" (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" (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" (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" (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

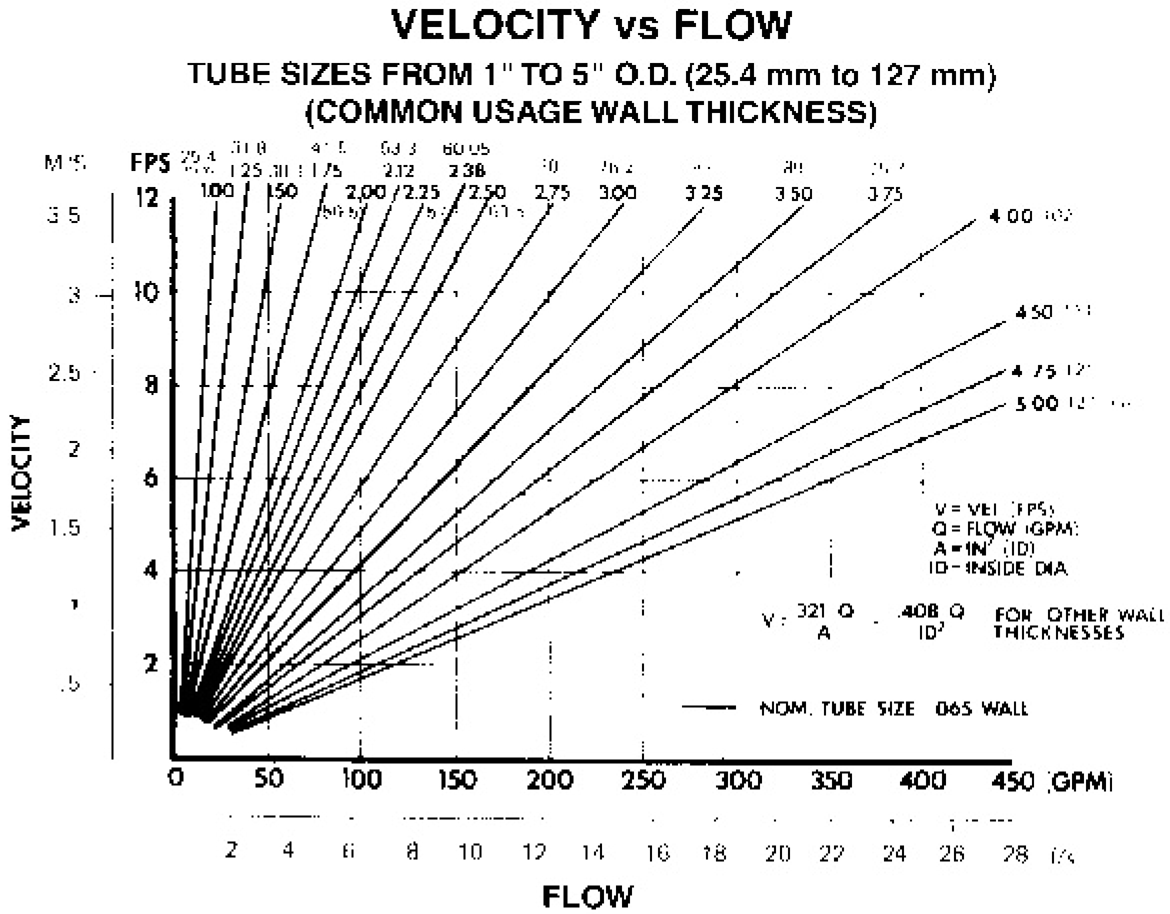
Typical Friction Losses of Water in Pipe (cont.)

gpm	(l/s)	4" (101.6 mm)	5" (127 mm)	6" (152.4 mm)	7" (177.8 mm)	8" (203.2 mm)	2½" (63.5 mm)	3" (76.2 mm)	gpm	(l/s)
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" (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" (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	0.66	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

Velocity vs Flow



STD. PIPE SIZES 11/2" TO 5" (38.1 to 127 mm)



TUBE SIZES FROM 1" TO 5" O.D. (25.4 mm to 127 mm) (COMMON USAGE WALL THICKNESS)

Coolant Chemical and Physical Properties

Minimum Acceptable Water Characteristics for Use in Engine Cooling Systems

Coolant Chemical and Physical Properties

Minimum Acceptable Water Characteristics for Use in Engine Cooling Systems

Properties	Limits	ASTM[1] Test Methods
Chloride (Cl), gr/gal (ppm)	2.4 (40) max.	D512b, D512d, D4327
Sulfate (SO4), gr/gal (ppm)	5.9 (100) max.	D516b, D516d, D4327
Total Hardness, gr/gal (ppm)	10 (170) max.	D1126b
Total Solids, gr/gal (ppm)	20 (340) max.	D1886a
pH	5.5-9.0	D1293

[1] American Society for Testing and Materials

Boiling Point of Coolant at Varying Antifreeze Concentrations

Boiling Point of Coolant at Varying Antifreeze Concentrations

% Concentration	Temperature at Which Coolant with Ethylene Glycol Will Boil[1]
20	103°C (217°F)
30	104°C (219°F)
40	106°C (222°F)
50	108°C (226°F)
60	111°C (231°F)
70	114°C (238°F)

[1] At sea level.

Protection Temperatures for Antifreeze Concentrations[1]

Protection Temperatures for Antifreeze Concentrations[1]

Protection to:	Concentration
–15°C (5°F)	30% antifreeze, 70% water
–24°C (–12°F)	40% antifreeze, 60% water
–37°C (–34°F)	50% antifreeze, 50% water
–52°C (–62°F)	60% antifreeze, 40% water

[1] Ethylene glycol-based antifreeze.

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[1]Ethylene glycol-based antifreeze.

Barometric Pressures and Boiling Points of Water at Various Altitudes

Barometric Pressure

Altitude	Inches Mercury	Lb. per Square Inch	Feet Water	Point Water Boiling
Sea Level	29.92 In.	14.69 P.S.I.	33.95 Ft.	212°F
1000 Ft.	28.86 In.	14.16 P.S.I.	32.60 Ft.	210.1°F
2000 Ft.	27.82 In.	13.66 P.S.I.	31.42 Ft.	208.3°F
3000 Ft.	26.81 In.	13.16 P.S.I.	30.28 Ft.	206.5°F
4000 Ft.	25.84 In.	12.68 P.S.I.	29.20 Ft.	204.6°F
5000 Ft.	24.89 In.	12.22 P.S.I.	28.10 Ft.	202.8°F
6000 Ft.	23.98 In.	11.77 P.S.I.	27.08 Ft.	201.0°F
7000 Ft.	23.09 In.	11.33 P.S.I.	26.08 Ft.	199.3°F
8000 Ft.	22.22 In.	10.91 P.S.I.	25.10 Ft.	197.4°F
9000 Ft.	21.38 In.	10.50 P.S.I.	24.15 Ft.	195.7°F
10000 Ft.	20.58 In.	10.10 P.S.I.	23.25 Ft.	194.0°F
11000 Ft.	19.75 In.	9.71 P.S.I.	22.30 Ft.	192.0°F
12000 Ft.	19.03 In.	9.34 P.S.I.	21.48 Ft.	190.5°F
13000 Ft.	18.29 In.	8.97 P.S.I.	20.65 Ft.	188.8°F
14000 Ft.	17.57 In.	8.62 P.S.I.	19.84 Ft.	187.1°F
15000 Ft.	16.88 In.	8.28 P.S.I.	18.07 Ft.	185.4°F

Caterpillar Diesel Engine[1] Antifreeze Protection Chart (Fahrenheit)

Caterpillar Diesel Engine[1]
Antifreeze Protection Chart
(Fahrenheit)

Gallons or Quarts Antifreeze Concentrate

Cooling System Capacity (gallons or quarts)	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
6	5	-34																
7		-18	-54															
8		-7	-34															
9		0	-20	-47														
10		5	12	34	-62													
11			-5	22	-44													
12			0	18	-34	-56												
13			3	8	-24	-44												
14				-5	-18	-34	-53											
15				0	13	-26	-42	-62										
16				3	-7	-20	-34	-50										
17					-3	-14	-26	-42	-59									
18					0	-10	-20	-34	-47									
19					3	-7	-16	-26	-39	-56								
20					5	-3	-12	-22	-34	-47	-62							
21						0	-8	-18	-26	-39	-53							
22						2	-5	-14	-22	-34	-44	-59						
23						5	-3	10	-18	-28	-39	-50						
24							0	-17	-16	-24	34	-44	-56					
25							2	-5	-12	-20	-28	39	-50	-62				
26							3	-1	-8	-16	-24	-34	-44	-56				
27								0	-7	-14	-20	-28	-39	-47	-59			
28								2	5	-10	-18	-24	-34	-42	-53			
29								3	-1	-6	-14	-22	-28	-39	-47	-59		
30								5	0	7	-12	-18	-26	-34	-42	-53	-62	
31									2	-3	10	-16	-22	-28	-39	-47	-56	
32									3	-1	-7	-14	-20	-26	-34	-42	-50	-59

[1]Also for use in natural gas engines

Caterpillar Diesel Engine[1] Antifreeze Protection Chart (Celsius)

Caterpillar Diesel Engine[1]
Antifreeze Protection Chart
(Celsius)

Gallons or Quarts Antifreeze Concentrate

Cooling System Capacity (gallons or quarts)	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
6	-15	-37																
7		-28	-48															
8		-22	-37															
9		-18	-29	-44														
10		-15	-24	-37	-52													
11			-21	-30	-42													
12			-18	-27	-37	-49												
13			-16	-22	-31	-42												
14				-21	-28	-37	-47											
15				-18	-25	-32	-41	-52										
16				-16	-22	-29	-37	-46										
17					-19	-26	-32	-41	-51									
18					-18	-23	-29	-37	-44									
19					-16	-22	-27	-32	-39	-49								
20					-15	-19	-24	-30	-37	-44	-52							
21						-18	-22	-28	-32	-39	-47							
22						-17	-21	-26	-30	-37	-42	-5[illegible]						
23						-15	-19	-23	-28	-33	-39	-46						
24							-18	-22	-27	-31	-37	-42	-49					
25							-17	-21	-24	-29	-33	-39	-46	-52				
26							-16	-18	-22	-27	-31	-37	-42	-49				
27								-18	-22	-26	-29	-33	-39	-44	-51			
28								-17	-21	-23	-28	-31	-37	-41	-47			
29								-16	-18	-22	-26	-30	-33	-39	-44	-51		
30								-15	-18	-22	-24	-28	-32	-37	-41	-47	-52	
31									-17	-19	-23	-27	-30	-33	-39	-44	-49	
32									-16	-18	-22	-26	-29	-32	-37	-41	-46	-51

[1]Also for use in natural gas engines

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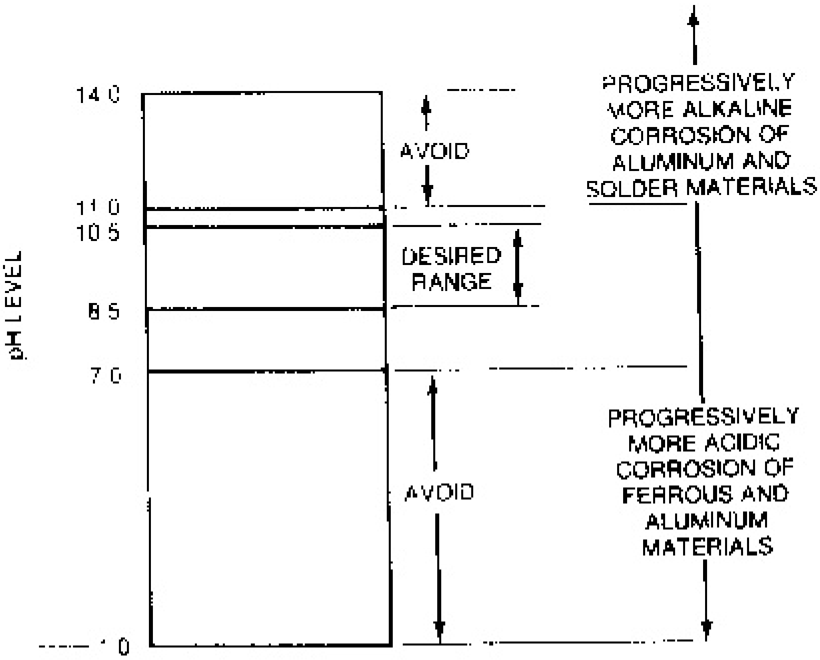
pH Scale for Coolant Mixture



Temperature Regulators

Temperature Regulators

CAT Part No.	Opening Temperature*	Fully Open Temperature
4W0018	27°C (81°F)	37°C (99°F)
7C0311	45°C (113°F)	55°C (131°F)
7E1237	68°C (154°F)	81°C (178°F)
4P0301	68°C (154°F)	81°C (178°F)
4W4011	77°C (170°F)	89°C (192°F)
7E6210	77°C (171°F)	89°C (192°F)
7N0208	79°C (175°F)	91°C (196°F)
9N2894	79°C (175°F)	92°C (197°F)
7E7933	83°C (181°F)	92°C (198°F)
4W4794	84°C (183°F)	92°C (198°F)
7N8469	88°C (190°F)	96°C (205°F)
7C3095	88°C (190°F)	98°C (208°F)
4W4842	88°C (190°F)	98°C (208°F)
7W0371	95°C (203°F)	104°C (219°F)
9Y7022	100°C (212°F)	110°C (230°F)
9Y8966	110°C (230°F)	129°C (265°F)

* Normally stamped on regulator

New Temperature Regulators - 1330, 1355; 3606 (8RB), 3608 (6MC), 3612 (9RC), 3616

(1PD) Industrial Engines

The 3600 Family of Engines has three sets of temperature regulators. The regulators are the jacket water (JW) inlet control, the oil cooler and aftercooler (O/C and A/C) inlet control, and the oil cooler oil temperature control. The chart identifies the new and former regulators. The recommended service hours of temperature regulators is every **6000 service meter hours** or annually, whichever occurs first.

Application	New Regulator Part No.	Former Regulator Part No.	Nominal Temperature°C (°F)	Temperature Range°C (°F)
JW Inlet Control Distillate Fuel	6I4957[2]	4W4794	90 (194)[1]	85-95 (185-203)
JW Inlet Control Distillate Fuel	6I4950[3]	4W4794	87.5 (189.5)[1]	82-92 (179.8-197.6)
JW Inlet Control Residual Fuel	6I4956	7C3095	93 (199.4)[1]	88-98 (190.4-208.4)
O/C-A/C Inlet Control Distillate Fuel	6I4952	7C0311	46 (118)	48-50 (114.8-122)
O/C-A/C Inlet Control Residual Fuel (Two Step)	6I4963[2] 6I4951	4W0018 7E1237	32 (89.6) 75 (167)	27-37 (80.6-98.6) 68-81 (154.4-177.8)
Oil Cooler	6I4954[2]	7E6210	83 (181.4)	76-89 (168.8-192.2)
Oil Cooler	6I4955	4P0301	75 (167)	68-81 (154.4-177.8)

NOTES:
1. Jacket water thermostats control jacket water inlet temperature, while water temperature gauge reads **outlet** temperature.
   If the external cooling system has the proper restriction and the engine is operating at full load, the **outlet** temperature will be approx. 9°F above inlet temperature.
2. These part numbers are recommended for inland tow boat applications.
3. Alternate thermostats used if application has an outlet temperature of 210°F.

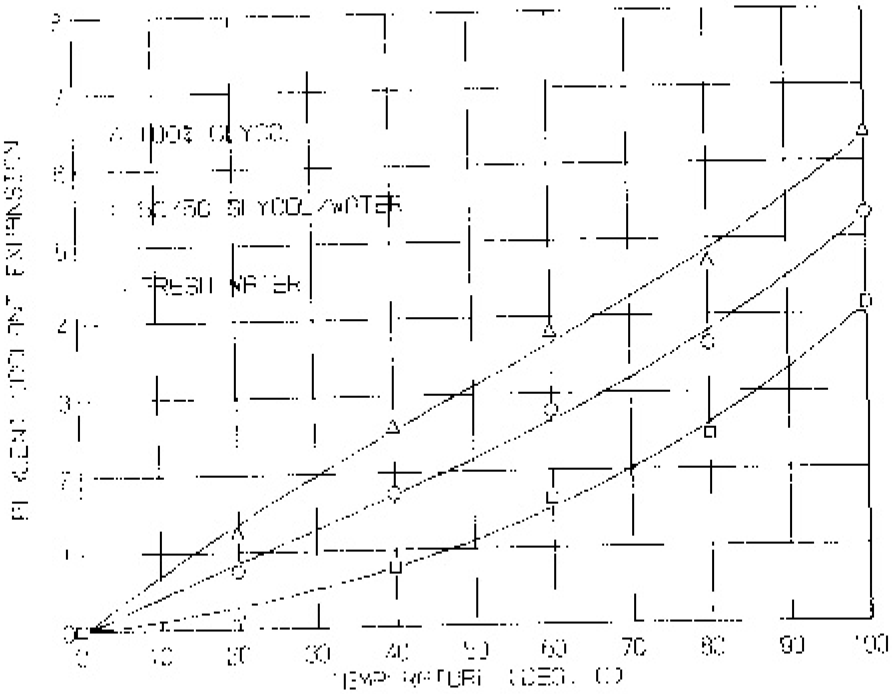
Diagnostic Tooling

Self-Sealing Probe Adapters:

Diagnostic Tooling
Self-Sealing Probe Adapters:

Size	CAT Part No.
1/8" NPT	5P2720
1/4" NPT	5P2725
1/2" O-ring	4C4547
9/16" O-ring	5P3591
3/4" O-ring	4C4545
Pressure Probe	5P2718

Coolant Expansion Rates



As a rule of thumb, expansion tanks should have a capacity of 16% of the total system coolant volume for expansion plus reserve.

Densities of Liquids [at 60°F (16°C)]

Densities of Liquids [at 60°F (16°C)]

Liquid	lb/U.S. gal	lb/cu ft	kg/cu meter	Specific Gravity
Water, Fresh	8.3	62.1	994.6	1.00
Water, Sea	8.5	63.6	1018.3	1.02
Water/Glycol	8.55	64.0	1024.4	1.03
Diesel Fuel	7.1	53.1	850.7	0.855
Lube Oil	7.6	56.8	909.7	0.916
Kerosene	6.7	50.1	802.7	0.807

Supplemental Coolant Additive (Conditioner or Inhibitor)

SCA %

30% - 60% Antifreeze solution . . . . 3% to 6%

Water only coolant . . . . 6% to 8%

Caterpillar recommends using antifreeze in the coolant mixture to get maximum life from cooling system components. 30% is minimum recommendation.

Exhaust System Formulas

Water Cooled Exhaust

There are two basic types of exhaust systems used. The two systems are "wet" (water cooled) and dry exhaust systems. The main consideration is to design the system to remove the exhaust gases from the engine room and limit the backpressure to a minimum.

The limits for a given engines' exhaust backpressure can be located in the TMI system. In general terms the backpressure limit is 27 inches of water for all Caterpillar turbocharged/turbocharged aftercooled engines. 34 inches of water is the limit for naturally aspirated engines. The 3600 series of engines have a limit of 10 inches of water. Some special rating, such as the 435 Hp 3208 E rating have a limit of 40 inches of water. You need to determine the limit of your engine, rating and then size the exhaust system to be below the limit. Remember that the closer you get to the limit the more affect the exhaust backpressure will have on the performance of the engine.

Many "wet" exhaust systems utilize an exhaust riser to help prevent sea water from entering the engine through the exhaust system when the engine is not operating or when the boat is "backed down" quickly. As a general rule of thumb the riser should be at least 22 inches above the level of the sea water to the lowest portion of the riser.

The minimum water flow requirements to a wet exhaust system can be calculated by using the following formula.

$$\text{Flow} = \frac{Vd \times Ne}{66000} \qquad \text{Flow} = \frac{Vd \times Ne}{285.785} = \text{Metric}$$

Flow = Gallons per minute (L/min)

Vd = Engine displacement [cubic inches (liters)]

Ne = Rated speed (rpm)

66,000 = constant for gallons

285.785 = constant for liters

A water lift muffler is also common in some of the smaller pleasure craft. If a water lift muffler is to be used the following are some points to pay close attention to.

1. Size the muffler outlet for a minimum exhaust velocity (gas only) of 5000 ft/min at rated engine power and speed. The following formula will give the maximum pipe diameter, "De" that can be used to insure the 5000 ft/min velocity.

$$De = 0.19\sqrt{Qe} \qquad De = 28.67\sqrt{Qe} = \text{Metric}$$

De = The maximum water lift exhaust outlet pipe diameter [inches (mm)]

Qe = Exhaust flow rate from the muffler [cfm (m^3/min)]

2. The tank itself should be of sufficient size. A rule of thumb would be at least 8 cubic inches per rated horsepower.
3. The inlet pipe to the tank should be truncated near the top of the tank.
4. The outlet pipe should extend to near the bottom of the tank (about 1 inch from the bottom) and should be angle cut (mitered) to increase exit gas velocity at lower loads and flow rates.
5. A siphon break should be installed between the exhaust elbow and the high point of the outlet pipe from the muffler.

Dry Exhaust

The dry exhaust system has some typical points that need to be considered as well.

1. A flexible connection at the engine exhaust outlet. No more than 60 pounds of exhaust piping weight should be supported on the flexible connection.
2. Flexible connection(s) are installed on the horizontal portion and on the vertical stack of the exhaust system.
3. Horizontal portions of the exhaust system are sloped away from the engine.
4. A spray shield/rain trap is used on the exhaust outlet.

The exhaust gas flow rate for a given engine and rating can be obtained from the TMI system. It can be closely estimated by using the following formula.

$$Qe = \frac{(Te + 460) \times Hp}{214} \qquad Qe = \frac{(Te + 273) \times kW}{3126.52} = \text{Metric}$$

Qe = Exhaust gas flow rate [cfm (m^3/min)]

Te = Exhaust gas temperature [°F (°C)]

Hp = Engine rated horsepower (kW)

After you have determined the exhaust gas flow rate the exhaust system backpressure can be calculated using the following formula.

$$dP = \frac{Lte \times Se \times Qe^2}{187 \times d^5} \qquad P = \frac{Lte \times S \times Qe^2 \times 3600000}{d^5} = \text{Metric}$$

P = Exhaust system backpressure [inches of water] or kPa

Lte = Total length of piping for diameter "d" [ft (m)]

d = Duct diameter [inches (mm)]

Lte is the sum of all the straight lengths of pipe for a given diameter "d", plus, the sum of equivalent lengths, "Le", of elbows and bends of diameter "d". Straight flexible joints should be counted as their actual length if their inner diameter is not less than "d".

Le = equivalent length of elbows in feet of straight pipe

Standard elbow - Le (ft) = 2.75 × d (inches)

Long elbow - Le (ft) = 1.67 × d (inches)

45° elbow - Le (ft) = 1.25 × d (inches)

NOTE: "Le" results are in feet but "d" must be in inches

Le = equivalent length of elbows in meters of straight pipe

Standard elbow - Le = 0.033 × d = (metric)

Long elbow - Le = 0.020 × d = (metric)

45° elbow - Le = 0.015 × d = (metric)

NOTE: "Le" results are in meters but "d" must be in mm

Qe = Exhaust gas flow [cfm (m^3/min)]

Se = Specific weight (density) of exhaust gas [lbs/cu. ft. (kg/m^3)]

The specific weight of the exhaust gas is calculated using the following formula.

$$Se = \frac{39.6}{(Te + 460)\ °F} \qquad Se = \frac{352}{(Te + 273)\ °C} = \text{Metric}$$

Se = Specific weight [lbs/cu. ft./kg/m^3)]

Te = Exhaust gas temperature [°F (°C)]

d = pipe diameter [inches (mm)]

The values of Lte, Se, Qe, and d must be entered in the units specified above if the formula is to yield valid results for backpressure.

To get the total exhaust pressure you must add to the answer from the above formula the pressure drop of the muffler. The pressure drop for Caterpillar mufflers is available in the TMI system.

Exhaust gas velocity should also be checked. If the velocity is too high, excessive noise or whistle may occur and inner pipe and wall surfaces may erode at an unacceptable rate. As a rule of thumb, the velocity is best kept to 18,000 ft/min or less. The velocity can be calculated using the following formula:

$$Ve = \frac{183 \times Qe}{d^2} \qquad Ve = \frac{1,270,691.83 \times Qe}{d^2} = \text{Metric}$$

Ve = Exhaust gas velocity [ft/min (m/min)]

Qe = Exhaust gas flow rate [cfm (m^3/min)]

d = Pipe diameter [inches (mm)]

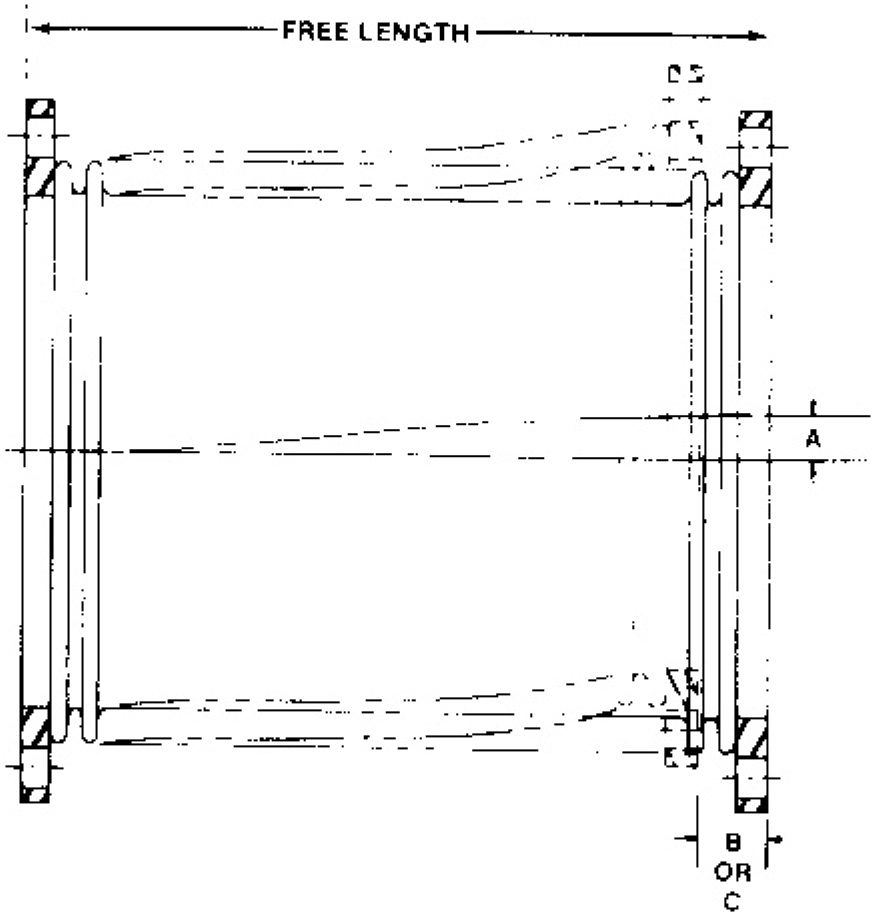
Exhaust System

Thermal Growth Allowance

Thermal growth of exhaust piping must be planned to avoid excessive load on supporting structures. Steel exhaust pipe expands 0.0076 inches per foot of pipe for each 100°F rise of exhaust temperature (1.13 mm per meter for each 100°C). This amounts to 0.65 in (16.5 mm) expansion for each 10 ft (3.05 m) of pipe from 100° to 950°F (35° to 510°C).

Exhaust Bellows Installation Limitations

Exhaust Bellows
Installation Limitations



If bellows-type exhaust fittings are distorted beyond limits in table while engine is operating at full throttle, service life will be greatly reduced. Flanges must be parallel.

Exhaust Bellows Installation Limitations

Exhaust Bellows Installation Limitations

	A = Max Offset Between Flanges in.	(mm)	B = Max Compression From Free Length in.	(mm)	C = Max Extension From Free Length in.	(mm)
8 in. (200 mm) and 10 in. (254 mm)	0	0	1.50	38.1	1.00	25.4
	0.12	3.05	0.90	22.9	0.50	12.7
	0.25	6.35	0.60	15.2	0.28	7.11
	0.38	9.65	0.40	10.2	0.20	5.08
170 lb/in Spring Rate	0.50	12.7	0.23	5.8	0	0
	0.75	19.1	0	0	0	0
12 in. (305 mm)	0	0	1.50	38.1	1.00	25.4
	0.12	3.05	0.90	22.9	0.50	12.7
	0.25	6.35	0.60	15.2	0.28	7.11
194 lb/in Spring Rate	0.38	9.65	0.40	10.2	0.10	5.08
	0.50	12.7	0.23	5.8	0	0
	0.75	19.1	0	0	0	0

Exhaust Bellows Installation Limitations (cont.)

	A = Max Offset Between Flanges in.	(mm)	B = Max Compression From Free Length in.	(mm)	C = Max Extension From Free Length in.	(mm)
	0	0	3.90	99.06	2.06	52.32
14 in. (356 mm)	0.12	3.05	2.85	72.39	2.06	52.32
	0.25	6.35	1.70	43.18	2.06	52.32
100 lb/in Spring Rate	0.38	9.65	0.55	13.97	2.06	52.32
	0.44	11.2	0	0	2.06	52.32
	0.50	12.7	0	0	2.06	52.32
	0.75	19.1	0	0	2.06	52.32
	0	0	6.30	160.0	3.28	83.31
18 in. (457 mm)	0.12	3.05	5.46	138.7	3.28	83.31
	0.25	6.35	4.55	115.6	3.28	83.31
110 lb/in Spring Rate	0.38	9.65	3.64	92.46	3.28	83.31
	0.44	11.2	2.80	71.12	3.28	83.31
	0.50	19.05	1.05	26.67	3.28	83.31
	0.75	22.86	0	0	3.28	83.31

Piping - Back Pressure

Pressure drop includes losses due to piping, muffler, and rain cap.

Calculate backpressure by:

$$P\ (\text{psi}) = \frac{L \times S \times Q^2}{5{,}184 \times D^5}$$

$$P\ (\text{kPa}) = \frac{L \times S \times Q^2 \times 10\,000}{0.0027787 \times D^5}$$

P = Backpressure (psi) (kPa).

psi = 0.0361 × inches water column.

kPa = 6.3246 × mm water column.

L = Total equivalent length of pipe (feet) (meters).

Q = Exhaust gas flow (cfm) (m^3/min).

D = Inside diameter of pipe (inches) (mm).

S = Specific weight of gas (lb/ft^3) (kg/m^3).

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

$$S\ (kg/m^3) = \frac{352.05}{\text{Exhaust Temperature} + 273.16°C}$$

To obtain equivalent length of straight pipe for each bend:

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

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

$$L = 15 \times \frac{D}{X}$$ 45° Elbow

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

Where x = 12 in. or 1000 mm.

Exhaust Pipe Diameter to Meet Back Pressure Limits (English Units System)

$$D = \sqrt[5]{\frac{L S Q^2}{187 P}}$$

P = Backpressure Limit (inches of water column)

D = Inside diameter of pipe (inches)

Q = Exhaust Gas Flow (ft^3/min.) See engine performance curve

L = Length of pipe (feet) Includes all of the straight pipe and the straight pipe equivalents of all elbows

S = Specific weight of gas (lb/ft^3)

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

Exhaust Pipe Diameter to Meet Back Pressure Limits (Metric Units System)

$$D = \sqrt[5]{3600000\ \frac{LSQ^2}{P}}$$

P = Backpressure Limit (kPa)

D = Inside diameter of pipe (mm)

Q = Exhaust gas flow (m^3/min.) See engine performance curve

L = Length of pipe (meters) Includes all of the straight pipe and the straight pipe equivalents of all elbows

S = Specific weight of gas (kg/m^3)

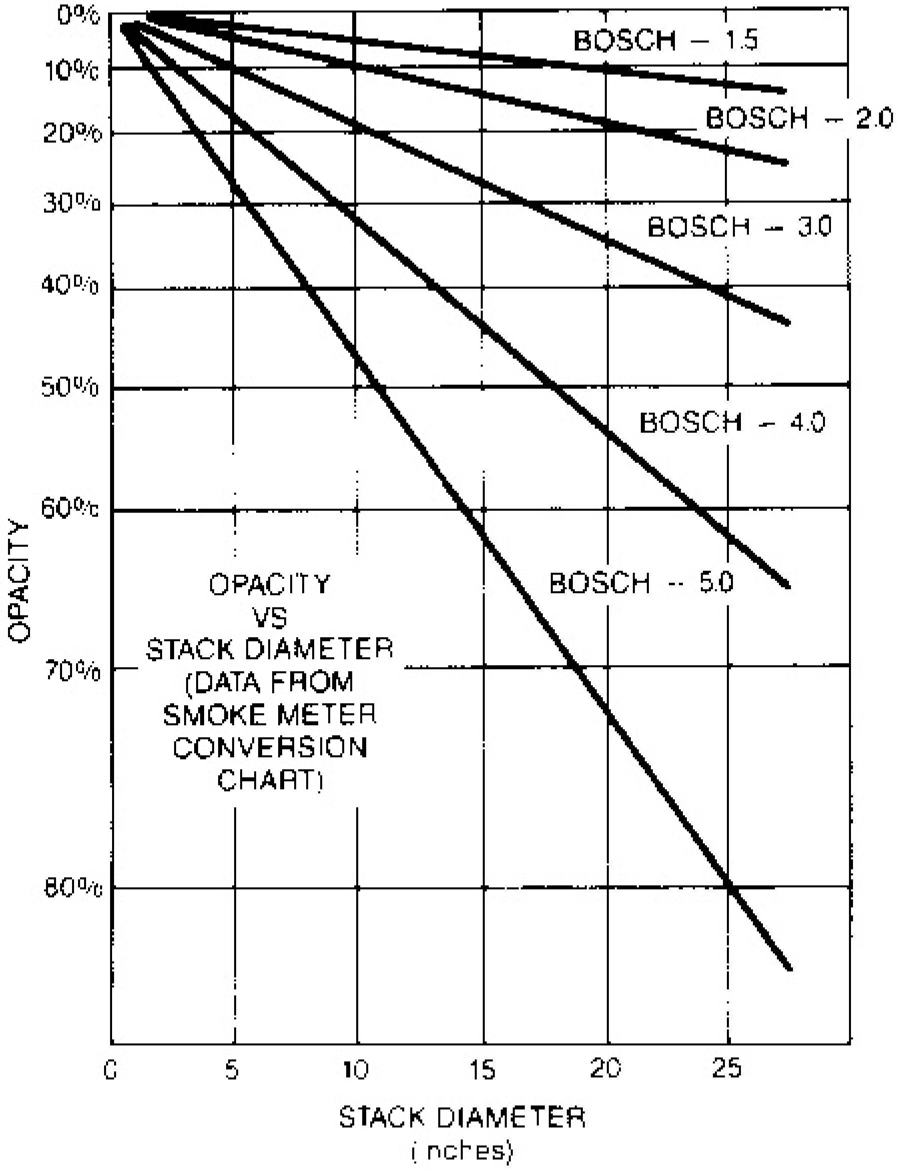
$$S\ (kg/m^3) = \frac{352}{\text{Exh. Temp.} + 273°C}$$

Smoke Measurement

Typical Smoke Guidelines* — % Opacity		
Test Conditions	Standard Engine Ratings	Standby Generator Sets and Other High Performance Engines
High Idle	15%	20%
Full Load	10%	20%

* General guidelines only. Do not consider as rigid specifications.
See Special Instruction SEHS8731 for more information.
Smoke Meter Group: 8T5100

Smoke Meter Conversion Chart (Sample)



BOSCH – 1.5
BOSCH – 2.0
BOSCH – 3.0
BOSCH – 4.0
BOSCH – 5.0
OPACITY
VS
STACK DIAMETER
(DATA FROM
SMOKE METER
CONVERSION
CHART)
0%
10%
20%
30%
40%
50%
60%
70%
80%
OPACITY
0
5
10
15
20
25
STACK DIAMETER
(inches)

Heat Recovery Systems

NOTE: Use only TIF heat rejection data for heat recovery calculations, DO NOT USE RULES OF THUMB.

Conversions:

One Boiler HP = 558 BTU/min = 33,475 BTU/hr = 9.8 kW

One Refrigeration Ton = 200 BTU/min = 12,000 BTU/hr = 3.5 kW

Recoverable Exhaust Heat:

Heat recovery mufflers economically recover about half the engine exhaust heat. Exhaust exit temperature above 300°F (149°C) discourages condensation in ducting.

Recoverable heat is obtained from the engine manufacturers but can be estimated by:

$Q = CpM (T_1 - T_2)$

Where:

Q = Recoverable Heat (Btu/h)

Cp = Specific Heat (Btu/lb per °F)

Diesel Engines - 0.258

Gas Engines - 0.279

T_1 = Exhaust Gas Stack Temperature °F

T_2 = Exhaust Gas Exit Temperature °F (300°F Minimum)

M = Exhaust Mass Flow (lb/h)

$$M = \frac{\text{Exhaust Flow (cfm)} \times 60 \times 39.6}{T \cdot (^\circ F) + 460^\circ F}$$

or

$Q = CpM (T_1 - T_2)$

Where:

Q = KJ/h

Cp = Diesel Engines - 1.081 KJ/kg per °C

Gas Engines - 1,169 KJ/kg per °C

M = Exhaust Mass Flow (kg/h)

$$M = \frac{m^3/min \times 60 \times 353.0}{T_1 (°C) + 273°C}$$

Enthalpy Table:

Enthalpy of Steam

Psia	kPa	Temp. °F	Temp. °C	Enthalpy of Vaporization, Btu/lb.	Enthalpy of Vaporization, kJ/kg
14.696	101	212	100	970.3	2257
15	103	213.03	100.65	969.7	2255
16	110	216.32	102.48	967.6	2250
17	117	219.44	104.22	965.5	2245
18	124	222.41	105.87	963.6	2241
19	131	225.24	107.44	961.9	2237
20	138	227.96	108.95	960.1	2233
21	144.8	230.37	110.29	958.4	2229
22	151.7	233.07	111.79	956.8	2225
23	158.6	235.49	113.14	955.2	2221
24	165.4	237.82	114.43	953.7	2218
25	172.4	240.07	115.69	952.1	2214
26	179.3	242.25	116.90	950.7	2211
27	186.2	244.36	118.07	949.3	2207
28	193	246.41	119.21	947.9	2204
29	200	248.40	120.32	946.5	2201
30	206.9	250.33	121.39	945.3	2198

Ebullient and Solid Water Cooled Engines:

Make-up Water Characteristics (max concentrations):

Iron 0.1 ppm

Copper 0.05 ppm

Total hardness 0.3 ppm as $CaCO_3$

Feed Water Characteristics (max concentrations):

Silica concentration 150 ppm as Si02

Total Alkalinity 700 ppm as calcium $CaCO_3$

Specific Conductance 3500 micro ohm per centimeter

Total Suspended Solids 10 ppm

Feed Water Chemical Treatment Program:

1. Maintain oxygen scavenger to remove oxygen from the feed water with sufficient reserve to remove all oxygen from the water.

2. Maintain 200 to 400 ppm as $CaCO_3$ equivalent of hydroxide alkalinity in the feed water. The reserve alkalinity prevents corrosion and causes precipitates of iron and silica in a form that can be removed by blow down.

3. 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.

4. Appropriate treatment of the stream to provide condensate returning to the boiler that meets the feed water specifications.

Ventilation System Formulas

As a rule of thumb, the installer should provide ventilation air flow of about 8 cfm (.22656 m^3/min) per installed horsepower. If combustion air is to be drawn from the engine room increase that figure to 91/4cfm (.26196 m^3/min).

If you wish to compute more exact engine room air requirements it is necessary to determine the following factors:

H = Heat radiated to the engine room

This data is available from the TMI system for Caterpillar engines. Add in 4 Btu/min per generated 0.07032 kW for the normal maximum auxiliary generator load. Miscellaneous heat loads from other sources (pumps, motors, etc.) can be ignored if they are not exceptional.

Ta = Maximum ambient air temperature the vessel is expected to operate in during its whole life. [Usually assume 110°F (43.3°C).]

Sa = Density of the air at the maximum ambient air temperature.

Density of Air at Various Temperatures

Density of Air at Various Temperatures

°F/°C	lbs/cu. ft./kg/m³	°F/°C	lbs/cu. ft./kg/m³
0/–18	0.086/1.38	70/21	0.075/1.20
10/–12	0.084/1.35	80/27	0.074/1.18
20/–7	0.083/1.33	90/32	0.072/1.15
30/–1	0.081/1.30	100/38	0.071/1.14
40/4	0.079/1.27	110/43	0.070/1.12
50/10	0.078/1.25	120/49	0.068/1.09
60/16	0.076/1.22	130/54	0.067/1.07

dT = Maximum desired air temperature in the engine room. (Usually assume 10°F (5.6°C) rise above ambient)

When these factors have been determined, the ventilation air requirements in cubic feet per minute (cfm) can be calculated by the following formula:

$$Qa = \frac{H}{Sa \times 0.24 \times dT}$$

$$Qa = \frac{H}{Sa \times 0.017 \times dT} \text{ – Metric}$$

Qa = Volume of inlet air required in cfm (m^3/min)

H = Radiated heat [btu/min (kW)]

Sa = Inlet air density [lbs/cu. ft. (kg/m^3)]

0.24 = Specific heat of air (btu/lbs/°F)

0.017 = Specific heat of air (kW·min/kg·°C)

dT = Temperature rise from ambient air to engine air [°F(°C)]

Ventilation Air Duct Sizing

Before the duct cross-sectional area can be calculated you must determine two elements.

Qcfm = Amount of Ventilation air and Combustion air (combine system) in cfm.

Va = Desired inlet air velocity [Not to exceed 2,000 feet per minute (609.6 m/min)]

Once these two elements have been determined then the following formula can be used to determine the minimum cross-sectional for both intake and exhaust ducts or openings.

$$Av = \frac{144 \times Q_a}{V_a} \qquad Av = \frac{39{,}365.7 \times Q_a}{V_a} = \text{Metric}$$

Av = Duct cross sectional area in square inches (mm)

Q_a = Quantity of air flow in cubic feet per minute (m^3/min)

V_a = Velocity of air in the duct in feet per minute (m/min)

Combustion Air Formulas

If combustion air is to be drawn from the engine room, a slight modification is in order. Since the air used for combustion takes some engine room heat with it, it can be counted partially as ventilation air. This can be added into the calculation by adding about half of the combustion air required (1/2 Qc) resulting in the following equation:

$$Qa = \frac{H}{Sa \times 0.24 \times dT} + \frac{1}{2} Qc$$

$$Qa = \frac{H}{Sa \times 0.017 \times dT} + \frac{1}{2} Qc = \text{Metric}$$

Qa = Volume of inlet air required in cfm (m^3/min)

H = Radiated heat [btu/min (kW)]

Sa = Inlet air density [lbs/cu. ft. (kg/m^3)]

0.24 = Specific heat of air (btu/lbs/°F)

0.017 = Specific heat of air (kW·min/kg·°C)

dT = Temperature rise from ambient air to engine air [°F (°C)]

Qc = Combustion air required in cfm (m^3/min)

For combustion air requirement a good rule of thumb is to multiply the horsepower in the engine room by 2.5. Remember to include all engines in the engine room space for this calculation. If you need more exact combustion air figures then you can get that information from the TMI system. However, the 2.5 times rule is usually adequate for sizing purposes.

If the rule of thumb of 8 cfm/.22656 m^3/min of air per installed horsepower is applied, the minimum duct cross sectional area (Av) per installed horsepower would be:

Av = 0.6 in^2/Hp (3.87 cm^2/kW) @

Va = 2000 fpm (609.6 m/min)

Av = 0.9 in^2/Hp (5.81 cm^2/kW) @

Va = 1200 fpm (365.8 m/min)

If you included combustion air into the ventilation system [used 9.25 cfm (.262 m^3/min)]:

Av = 0.7 in^2/Hp (4.52 cm^2/kW) @

Va = 2000 fpm (609.6 m/min)

Av = 1.0 in^2/Hp (6.45 cm^2/kW) @

Va = 1200 fpm (365.8 m/min)

Remember air should enter the engine room freely. It is far better to have extra air than not enough. This installation parameter is second only to sufficient liquid cooling capacity in importance. If the rules of thumb are adhered to they will normally be sufficient, however, they are not overly conservative ... Don't Cheat!

Sizing Combustion Air Ducts

Obtain the actual air requirement from the TMI system or use the rule of thumb (2.5 × Hp) to calculate the air required. The formula used to calculate the ventilation cross-sectional area can then be applied by using the appropriate combustion air volume and a velocity. (8000 fpm maximum)

This will most likely yield a cross-sectional area smaller than that of the factory connection to the air cleaner, however, be sure to keep the duct size equal to, or greater than, that of the factory connection.

If the straight length of duct is long, (over 25 × the diameter or diagonal of the factory connection) or includes more than two right angle bends, it would be wise to calculate the pressure drop at full air flow. This can be done using the following formula:

$$dP = \frac{Le \times S \times Q^2}{187 \times d^5} \qquad dP = \frac{Le \times S \times Q^2 \times 3600000}{d^5} = \text{Metric}$$

dP = Pressure loss [inches (kPa) of water]

Q = Air flow [cfm (m^3/min)]

d = Duct diameter [inches (mm)]

Le = Equivalent duct length [ft (m)]

S = Density of combustion air [lbs/cu.ft. (kg/m^3)]

Use the following method to determine Le:

Standard elbow = 2.75 × d

Long Sweep elbow = 1.7 × d

45° elbow = 1.25 × d

d = value must be in inches

Standard elbow = 0.033 × d = meter

Long Sweep elbow = 0.020 × d = meter

45° elbow = 0.015 × d = meter

d = value must be in mm

General Service Information
ENGINE INSTALLATION & SERVICE HANDBOOK
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LEBV09150010

Formula for Calculating Horsepower

$$\text{Horsepower} = \frac{2\pi \times \text{TORQUE} \times \text{RPM}}{33000}$$

This formula was established by James Watt in the 1800's and requires some known values:

Average horse walks at 21/2 MPH

Average horse pulls with a force of 150 pounds

1 mile = 5,280 feet

With this background, we will be able to establish the Horsepower formulas used today.

5,280 feet × 21/2 MPH = 13,200 FEET per HOUR

$$\frac{13200 \text{ FT/HR}}{60 \text{ Minutes}} = 220 \text{ FEET per MINUTE}$$

220 FT/MIN × 150 POUNDS = 33,000 FT LBS per MINUTE

2π = 6.2831853

$$2\pi = 6.2831853$$

$$\frac{33000}{6.2831853} = 5252$$

Thus we get the familiar formula used today in calculating Hp.

$$Hp = \frac{Torque \times RPM}{5252}$$ or expressed another way as

$$Torque = \frac{Hp \times 5252}{RPM}$$

Γ
= Radius from centerline of rotating shaft. Usually measured at a distance of one foot out from centerline.

Fuel System

Day Tank Sizing

$$\text{Tank Size (gal)} = \frac{\text{Rated BSFC (lb/hp}\bullet\text{hr)}}{7.076\ \text{(lb/gal)}} \times \text{Rated HP} \times \text{Load Factor} \times \text{Hours Between Refilling} + \text{Reserve Requirement}$$

OR

Rule of Thumb for tank size with 25% reserve

0.056 × Ave. BHP demand × Hours between refills × 1.25 = _____ gal.

0.27 × Ave. BKW demand × Hours between refills × 1.25 = _____ liters

NOTE: Additional tank capacity required for cooling of recirculated fuel in unit injected engines. Tank should be located below level of injectors or nozzles.

Piping

Fuel Supply Line Maximum Restriction*:

3600 ... -38.8 kPa (11.6 in Hg)(Vacuum)

3400, 3500 ... -30 kPa (9 in. Hg) (Vacuum)

3300 ... -20 kPa (6 in. Hg) (Vacuum)

3208 ... -27 kPa (8 in. Hg) (Vacuum)

Fuel Return Line Maximum Restriction:*

3600 ... 350 kPa (51 psi)

3300 ... 20 kPa (3 psi)

3208, 3400, 3500 ... 27 kPa (4 psi)

---

*Locate day tank and design piping to meet these requirements.

Fuel Properties

Fuel Properties

Distillate Fuel Chart

		Caterpillar Preferred Fuel Requirements (As Delivered To Fuel System)
Aromatics, % (ASTM D1319)	Max.	35%
Ash, % Weight (ASTM D482)	Max.	.02%
Carbon Residue on 10% Bottoms, % (ASTM D524)	Max.	1.05
Cetane Number (ASTM D613)	Min.	35 PC/40 DI
Cloud Point, °C (°F) (ASTM D97)	Max.	Not Above Ambient
Copper Strip Corrosion (ASTM D130)	Max.	No. 3
Distillation — 10% °C (°F)	Max.	282°C (540°F)
— 90% °C (°F) (ASTM D86, D158 or D285)	Max.	360°C (680°F)
Flash Point, °C (°F) (ASTM D93)	Min.	Legal
Gravity API (ASTM D287)	Min.	30
	Max.	45
Pour Point, °C (°F) (ASTM D97)	Min.	6 (10) Below Ambient
Sulfur, Total % Weight (ASTM D2788 or D3605 or D1552)	Max.	0.05% max over the road 0.5% max commercial
Viscosity, Kinematic, cSt (ASTM D445)	Max.	20.0
	Min.	1.4
Water and Sediment, % Volume (ASTM D1796)	Max.	0.1
Water, % Volume	Max.	0.1
Sediment, % Weight	Max.	0.05

Fuel Properties

Blended Fuel Chart

Fuel Properties and Characteristics		Permissible Fuels As Delivered To The Fuel System	
		3500	3600
Water and Sediment % volume (ASTM D1796)	Max.	0.5	0.5
Sulfur (ASTM D2788 or D3605 or D1552)	Max.	4%	5%
Viscosity	Min.	1.4 cSt	1.4 cSt
(Viscosity to the Unit Injector) (ASTM D445)	Max. cSt/50°	180	20
Carbon Residue (CCR) ASTM D189	Max.	15	22
Vanadium PPM	Max.	250 PPM	600 PPM
Aluminum PPM (ASTM D2788 or D3605)	Max.	1 PPM	80 PPM
Silicon (ASTM D2788 or D3605)	Max.	1 PPM	80 PPM

PPM = parts per million

Blended (Heavy) fuels are usually described by their viscosity, expressed either in "centistokes" (cSt) or "Seconds Redwood". The Redwood scale at 100°F is being phased out and replaced by the centistokes scale at 50°C. The centistoke viscosity may be preceded by the letters IF for "intermediate fuel" or IBF for "intermediate bunker fuel". For example, IF 180 fuel has a viscosity of 180 cSt at 50°C. The following table gives the **approximate** relationship between the two scales.

cSt at 50°C	Seconds Redwood at 100°F
30	200
40	278
60	439
80	610
100	780
120	950
150	1250
180	1500
240	2400
280	2500
380	3500

Fuel Properties

Crude Oil Chart		
Fuel Properties and Characteristics		**Permissible Fuels as Delivered to the Fuel System**
Cetane Number or Cetane Index (ASTM D613 or calculated index) (PC Engines)	Min.	35
(DI Engines)	Min.	40
Water and Sediment % volume (ASTM D1796)	Max.	0.5%
Pour Point (ASTM D97)	Min.	6°C (10°F) Below Ambient Temperature
Cloud Point (ASTM D97)	Min.	Not Higher than Ambient Temperature
Sulfur (ASTM D2788 or D3605 or D1552)	Max.	0.5%
Viscosity at 38°C (100°F) (ASTM D445)	Min. Max.	1.4 cSt 20 cSt
API Gravity (ASTM D287)	Min. Max.	45 30
Specific Gravity (ASTM D287)	Min. Max.	0.8017 0.875
Gasoline and Naphtha Fraction (Fractions Boiled off below 200°C)	Max.	35%
Kerosene and Distillate Fraction (Fractions boiled off between 200°C and cracking point)	Min.	30%

Fuel Properties

Crude Oil Chart (cont.)

Fuel Properties and Characteristics		Permissible Fuels as Delivered to the Fuel System
Carbon Residue (Ramsbottom) (ASTM D524)	Max.	3.5%
Distillation · 10%	Max.	282°C (540°F)
— 90%	Max.	380°C (716°F)
— Cracking %	Min.	60%
— Residue (ASTM D86, D158 or D285)	Max.	10%
Reid Vapor Pressure (ASTM D323)	Max.	20 psi (kPa)
Salt (ASTM D3230)	Max.	100 lb per 1000 Barrels
Gums and Resins (ASTM D381)	Max.	10 mg per 100 ml
Copper Strip Corrosion 3 Hrs @ 100°C (ASTM D130)	Max.	No. 3
Flashpoint °C/°F (ASTM D93)		Must be legal limit
Ash % Wt. (ASTM D482)	Max.	0.1%
Aromatics % (ASTM D1319)	Max.	35%
Vanadium PPM (ASTM D2788 or D3605)	Max.	4 PPM
Sodium PPM (ASTM D2788 or D3605)	Max.	10 PPM
Nickel PPM (ASTM D2788 or D3605)	Max.	1 PPM
Aluminum PPM (ASTM D2788 or D3605)	Max.	1 PPM
Silicon (ASTM D2788 or D3605)	Max.	1 PPM

Density and Specific Gravity

Density and Specific Gravity

Specific Gravities and Densities of Fuel		
Gravity		Density
Degrees API at 15°C (60°F)	Specific Gravity at 15°C (60°F)	Pounds per gallon
25	.9042	7.529
26	.8984	7.481
27	.8927	7.434
28	.8871	7.387
29	.8816	7.341
30	.8762	7.296
31	.8708	7.251
32	.8654	7.206
33	.8602	7.163
34	.8550	7.119
35	.8498	7.076
36	.8448	7.034
37	.8398	6.993
38	.8348	6.951
39	.8299	6.910
40	.8251	6.870
41	.8203	6.830
42	.8155	6.790
43	.8109	6.752
44	.8063	6.713
45	.8017	6.675
46	.7972	6.637
47	.7927	6.600
48	.7883	6.563
49	.7839	6.526

Fuel API Correction Chart - API Gravity Corrected to 60°F

Fuel API Correction Chart

API Gravity Corrected to 60°F

(Measured Fuel Temperature °F)

Measured °API Gravity	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°	110°	120°	130°	140°	150°
	°API Gravity At 60°F															
29°	33	32.5	32	31	30	30	29	28	28	27	26.5	26	25	24.5	24	23.5
30°	34	33.5	33	32	31.5	31	30	29	29	28	27.5	27	26	25.5	25	24.5
31°	35	34.5	34	33	32.5	32	31	30	30	29	28.5	28	27	26.5	26	25
32°	36	35.5	35	34	33.5	33	32	31	30.5	30	29	29	28	27.5	27	26
33°	37	36.5	36	35	34.5	34	33	32	31.5	31	30	29.5	29	28.5	28	27
34°	38.5	38	37	36	35.5	35	34	33	32.5	32	31	30.5	30	29	29	28
35°	39.5	39	38	37	36.5	36	35	34	33.5	33	32	31.5	31	30	29.5	29
36°	41	40	39	38	37.5	37	36	35	34.5	34	33	32.5	32	31	30.5	30
37°	42	41	40	39	38.5	38	37	36	35.5	35	34	33.5	33	32	31.5	31
38°	43	42	41	40.5	39.5	39	38	37	36.5	36	35	34.5	34	33	32	32
39°	44	43	42	41.5	40.5	40	39	38	37.5	37	36	35	34.5	34	33	32.5
40°	45	44	43	42.5	41.5	41	40	39	38.5	38	37	36	35.5	35	34	33.5
41°	46	45	44.5	43.5	42.5	42	41	40	39.5	39	38	37	36.5	36	35	34.5
42°	47	46	45.5	44.5	44	43	42	41	40.5	39.5	39	38	37.5	37	36	35
43°	48.5	47.5	46.5	45.5	45	44	43	42	41.5	40.5	40	39	38	37.5	37	36
44°	49.5	48.5	47.5	46.5	46	45	44	43	42	41.5	41	40	39	38.5	38	37

Fuel API Correction Chart (cont.)

Measured °API Gravity	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°	110°	120°	130°	140°	150°
	°API Gravity At 60°F															
45°	50.5	49.5	49	48	47	46	45	44	43	42.5	42	41	40	39.5	38.5	38
46°	52	51	50	49	48	47	46	45	44	43.5	42.5	42	41	40	39.5	39
47°	53	52	51	50	49	48	47	46	45	44.5	43.5	43	42	41	40.5	40
48°	54	53	52	51	50	49	48	47	46	45	44.5	44	43	42	41	40.5
49°	55	54	53	52	51	50	49	48	47	46	45.5	45	44	43	42	41.5
50°	56	55	54	53	52	51	50	49	48	47	46.5	45.5	45	44	43	42
51°	57.5	56	55	54	53	52	51	50	49	48	47	46.5	45.5	45	44	43
52°	58.5	57.5	56	55	54	53	52	51	50	49	48	47	46.5	45.5	45	44
53°	60	58.5	57	56	55	54	53	52	51	50	49	48	47.5	46.5	46	45

Tooling: Fuel Thermo-hydrometer 1P7408 Test Breaker 1P7438

Distillate Fuel Temperature

Maximum Fuel Supply Temperature:
Without Power Reduction: 85°F (29°C)
Power is reduced 1% for each 10°F (5.6°C) above 100°F (38°C) if engine is running against fuel stop.
— Without Injector Damage: 150°F (65°C)

Tooling: Fuel Thermo-hydrometer 1P7408

Test Breaker 1P7438

Distillate Fuel Temperature

Maximum Fuel Supply Temperature:

- Without Power Reduction: 85°F (29°C)

Power is reduced 1% for each 10°F (5.6°C) above 100°F (38°C) if engine is running against fuel stop.

- Without Injector Damage: 150°F (65°C)

Performance Analysis Rules of Thumb

Correction Factors:

Correction Factors:

Fuel Temperature Correction Factors

Fuel Temp °F	Correction Factor
10	.905
–5	.910
0	.915
5	.920
10	.925
15	.930
20	.935
25	.940
30	.945
35	.950
40	.955
45	.960
50	.965
55	.970
60	.975
65	.980
70	.985
75	.990
80	.995
85*	1.000
90	1.005
95	1.010
100	1.015
105	1.020
110	1.025
115	1.030
120	1.035
125	1.040
130	1.045
135	1.050
140	1.055
145	1.060
150	1.065
155	1.070
160	1.075

*Standard value.

Fuel Density (API)[1]
Correction Factors

API at 60°F	Correction Factor
32.0	.987
32.5	.989
33.0	.991
33.5	.993
34.0	.995
34.5	.998
35.0[2]	1.000
35.5	1.003
36.0	1.005
36.5	1.008
37.0	1.011
37.5	1.014
38.0	1.017
38.5	1.020
39.0	1.024
39.5	1.027
40.0	1.031
40.5	1.035
41.0	1.039
41.5	1.043
42.0	1.047
42.5	1.052
43.0	1.056
43.5	1.061
44.0	1.066
44.5	1.072
45.0	1.077
45.5	1.083
46.0	1.089
46.5	1.096
47.0	1.102
47.5	1.109
48.0	1.116
48.5	1.124
49.0	1.131
49.5	1.139
50.0	1.148

[1]The measured fuel API and corresponding temperature must be corrected to 60°F before selecting an API correction factor. Use the Fuel API Correction Chart on pages 87 and 88 to determine the API at 60°F.

[2]Standard value.

Air Pressure Correction Factors	
Air Pressure " Hg	Correction Factor
31.0	.996
30.5*	1.000
30.0	1.004
29.5	1.007
29.0	1.011
28.5	1.015
28.0	1.019
27.5	1.023
27.0	1.027
26.5	1.031
26.0	1.036
25.5	1.040
25.0	1.045
24.5	1.049
24.0	1.054
23.5	1.059
23.0	1.064
22.5	1.069
22.0	1.075
21.5	1.080
21.0	1.086
20.5	1.092
20.0	1.098

*30.5 " Hg is used as the standard value to account for the air cleaner restriction and vapor pressure (humidity).

Power Calculation:

Power Calculation:

$$HP = \frac{\text{Fuel Rate (GPH)} \times \text{Fuel Density}\left(\frac{LB}{GAL}\right)}{\text{BSFC}\left(\frac{LB}{HP \bullet HR}\right)}$$

$$kW = \frac{\text{Fuel Rate (L/HR)} \times \text{Fuel Density}\left(\frac{GRAM}{LITER}\right)}{\text{BSFC}\left(\frac{GRAM}{kW \bullet HR}\right)}$$

BSFC

$$\frac{\text{CSFC (GRAMS/kW HR)}}{454} = \text{LBS/kW HR}$$

$$\frac{\text{LBS/kW HR}}{1.34} = \text{BSFC (LBS/HP HR)}$$

Tolerances

Performance curves represent typical values obtained under normal operating conditions. Ambient air conditions and fuel used will affect these values. Each of the values may vary in accordance with the following tolerances:

Exhaust Stack Temperature ±42 DEG C

±75 DEG F

Intake Manifold Pressure-Gage ±10 kPa

±3 in Hg

Power ±3 Percent

Fuel Consumption ±6 g/kW-hr

±.010 lb/hp-hr

Fuel Rate ±5 Percent

Conditions

Ratings are based on SAE J1349 standard conditions of 100 kPa (29.61 in Hg) and 25°C (77°F). These ratings also apply at ISO 3046/1, DIN 6271 and BS 5514 standard conditions of 100 kPa (29.61 in Hg), 27°C (81°F) and 60% relative humidity.

Fuel Rates are based on fuel oil of 35° API [16°C (60°F)] gravity having an LHV of 42 780 kJ/kg (18,390 Btu/lb) when used at 29°C (85°F) and weighing 838.9 g/liter (7.001 lbs/U.S. gal).

Additional Formulas Used to Develop Marine Par Curves

For Torque Check GPH proceed as follows:

Torque Check GPH = TQ COR. Fuel Rate (G/MIN) ÷ 454 × 60 = LBS/HR

LBS/HR ÷ 7.076 = GPH

For BSFC proceed as follows:

BSFC = Adjusted CSFC (G/kW HR) ÷ 454 = LBS/kW HR

LBS/kW HR ÷ 1.34 = BSFC (LBS/HP HR)

Recommended "Guide Line" Gas Supply Pressures for Caterpillar Gas Engines - All Values in PSIG (kPag) Natural Gas

Recommended "Guide Line" Gas Supply Pressures for Caterpillar Gas Engines
All Values in PSIG (kPag) Natural Gas

Model	TA Low Emission High Pressure		TA Low Emission Low Pressure		TA STD High Pressure		TA STD Low Pressure		NA STD	
	Min Psig (kPa)	Max Psig (kPa)	Min Psig (kPa)	Max Psig (kPa)	Min Psig (kPa)	Max Psig (kPa)	Min Psig (kPa)	Max Psig (kPa)	Min Psig (kPa)	Max Psig (kPa)
3300					12 (83)	25 (172)	1.5 (10)	10 (69)	2 (14)	20 (138)
3400					20 (138)	25 (172)	1.5 (10)	5 (35)	2 (14)	20 (138)
3500 9:1 & 8:1	35 (241)	40 (276)	1.5 (10)	6 (41)						
3500 11:1	35 (241)	40 (276)	1.5 (10)	6 (41)						
3500 9:1 EIC					25 (172)	25 (172)	2 (14)	10 (69)	2 (14)	10 (69)
3500 Deltec			1.5 (10)	7 (48)						
3600	48 (330)	150 (1030)								
6.25 BORE	28 (193)	30 (207)			12 (83)	25 (172)			2 (14)	20 (138)
G342					12 (83)	25 (172)			2 (14)	20 (138)

If the regulator supply pressure is inadequate, poor response and low power levels may result. To determine the minimum regulator supply pressure required to obtain rated power, use the following formula for both NA and TA engines.

Min Gas Supply Pressure (psig) = {[(Boost Pressure)[1] + (ΔP3)[2] + (Transient Factor)[3]] – (Corrected Site Atmospheric P)[4]} × 0.4912 psi/in Hg.

1 – Boost Pressure = For NA engines = Full Load Carb air inlet pressure (Absolute inches of Hg Abs) at operating altitude.
For TA engines = (Full Load boost pressure in inches of Hg Abs + 5% tolerance) at operating altitude.

2 – ΔP3 = "Net Eff Supply Pressure" converted to inches of Hg. This establishes fuel flow across a given regulator and orifice and can be found on pp. 62-63 of form LEBV0915-01, p. 25 of form LEKQ2461, or in gas engine class handout – Gas Regulator Capacity Chart, form PSHO-042.

3 – Transient factor – for Soft loads = 0, for Transient loads = 4.07 in Hg.

4 – Corrected Site Atmospheric Pressure – [Standard barometer (29.92 in Hg) – Altitude (ft) × 0.001 in Hg/ft].

Gas Regulator Capacity Chart

Gas Regulator Capacity Chart

Regulator Model	Body Size NPT	Orifice Size In. (mm)	Cat Part Number	Engine	ΔP1 Delivery Pressure Range (Inches of H_2O)	ΔP3 — Flow in SCFH for Varying Net Effective Supply Pressures — PSI (In H_2O) [mbar] 0.125 (3.45) [8.6]	0.25 (6.89) [17]	0.5 (13.78) [34]	0.75 (20.67) [51]	1.0 (27.56) [69]	2.0 (55.12) [137]	5.0 (137.8) [343]
Y600	1	1/2	7L6766	G3300	3.5-6			510		1120		1425
Y600	1 1/4	9/16	2W6022	G3300	3.5-6			750	950	1160	1500	1800
S301	1 1/2	3/4 × 7/8	7C9735	G3406 LO SP	3.5-6.5			700	1050	1410	2000	2800
Y610	1 1/2	3/4	3N4630	G3408/12 LP	1-3 Neg			1400	1750	2100	2800	4500
Y610	1 1/2	3/4	5Z4017	G3306 LP	3-8 Neg			1400	1750	2100	2800	4500
Y610	1 1/2	3/4	4P2866	G3406 LP	1-3 Neg			1400	1750	2100	2800	4500
S201	1 1/2	3/4	6L4104	G300 Series	3.5-6.5			1400	1750	2100	2800	4500
S201	1 1/2	1	7W2363	G3408/12	3.5-6.5			1600	2050	2500	3500	5300
S201	1 1/2	1 3/16			3.5-6.5			1800	2250	2700	3800	6000
S201	2	1	2W7978	G3500	3.5-6.5			2200	2700	3200	5500	9500
S201	2	1 3/16	9Z5301	G3306 LO PR	3.5-6.5			2400	3100	3800	6400	10000
L34CSE-40	2	7/8 × 1	7E3407	G3500 LE	3.5-6.5			2100	3000	3700	5800	9000
133L	2	2	7C5001	G3516 LNDFL-US	3.5-6.5			7000	10000	13000	20000	30000
4.11.0040	Flange	1.57 (40)		G3500 LO PR-COSA Propane	0-1	2754	3885	5474	6710	7416	10594	N/A
4.11.0065	Flange	2.56 (65)	7E8190	G3500 LO PR-COSA	0-1	7789	10595	14126	17658	19777	27546	N/A
4.11.0080	Flange	3.15 (80)	124-9023	G3500 LO PR-COSA	0-1	11654	16245	22601	26839	31077	42378	N/A

Gas Regulator Capacity Chart (cont.)

Regulator Model	Body Size NPT	Orifice Size In. (mm)	Cat Part Number	Engine	ΔP1 Delivery Pressure Range (Inches of H_2O)	ΔP3 — Flow in SCFH for Varying Net Effective Supply Pressures — PSI (In H_2O) [mbar] 0.125 (3.45) [8.6]	0.25 (6.89) [17]	0.5 (13.78) [34]	0.75 (20.67) [51]	1.0 (27.56) [69]	2.0 (55.12) [137]	5.0 (137.8) [343]
4.30.0100	Flange	3.94 (100)	110-7872	G3500 LNDFL-COSA	0-1	21190	28253	37091	45910	49442	67100	N/A
99-903	2	1 1/8	6I1946	G3600	45-65 psi							7200
99-901	2	1 1/8	4P2124	G3600	45-65 psi							12000

Model	Manufacturer	Max Gas Supply Pressure	Comments Note 35.314 cu foot = cu meter
Y600	Fisher	25 psi	
Y610	Fisher	25 psi	
S301	Fishor	25 psi	
S201	Fisher	varies with orifice	12 psi with 1 3/16" orifice, 25 psi with 1" orifice, and 40 psi with 3/4" orifice
133L	Fisher	35 psi	
99-903	Fisher	150 psi	
99-901	Fishor	150 psi	
L34CSE-40	Sprague	150 psi	
4.11.0040	Dungs	3.0 psi	
4.11.0065	Dungs	3.0 psi	
4.11.0080	Dungs	3.0 psi	
4.30.0100	Crom Schroeder	3.0 psi	

Fuel Gas Methane Numbers

Fuel Gas Methane Numbers

Gas or Representative Gas Mix	Methane Number
Methane	100
Ethane	44
Propane	34
Butane (Commercial)	15
n-Butane	10
Hydrogen	0
Pipeline Gas	65-90
Field Gas (dry)	30-85
HD95 Propane*	33
Digester or Landfill	120

* Propane of 95% purity, HD-5 specification, should be used in low compression ratio engines. High compression ratio (HCR), naturally aspirated (NA) engines are limited to non-lug applications and many HCR turbocharged-aftercooled (TA) engines cannot burn propane or need to be derated. Consult factory for advice.

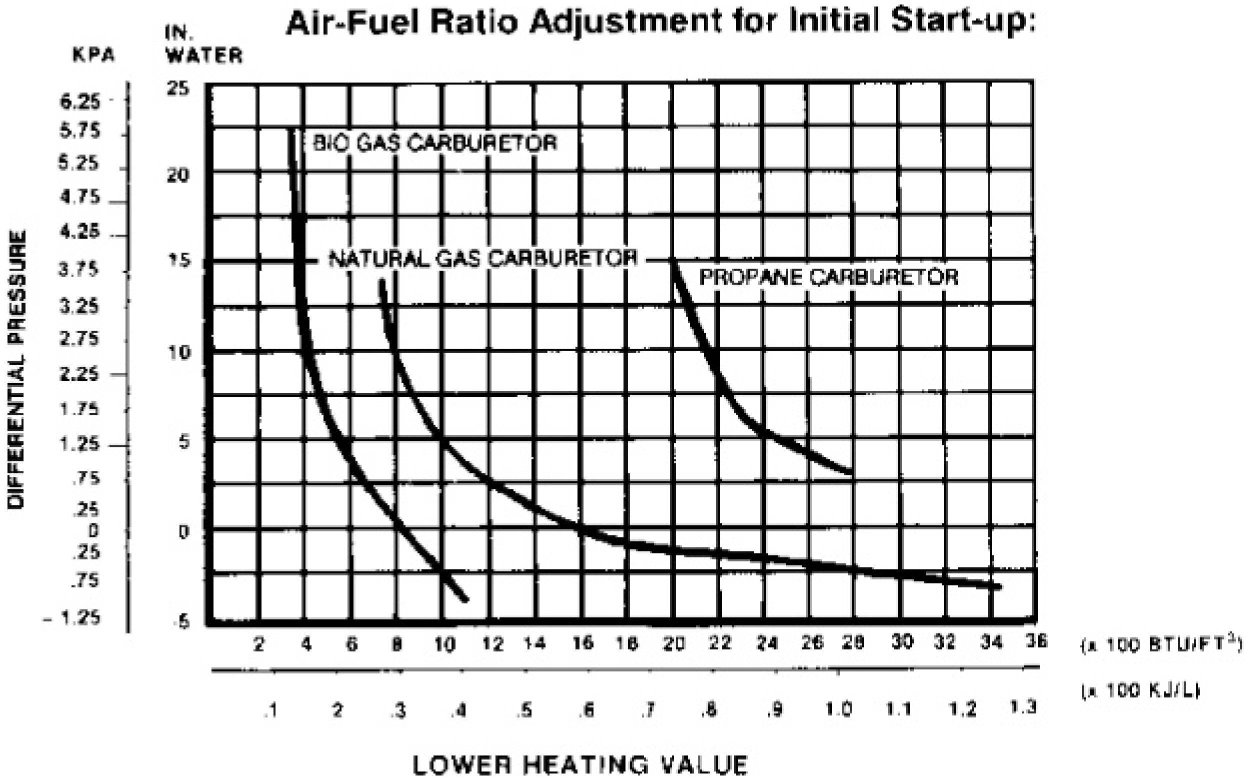
Physical Constants of Gases:

Physical Constants of Gases:

Gas	Formule	Gas Density, 60°F. 14.695 psia: Boiling Point at 14.696 psi	Specific Gravity (Air = 1)	cu ft Gas/lb	cu ft Gas/gal Liquid	lb/gal Liquid	Heat Value: At 60°F: Btu/cu ft Vapor at 14.696 psia (LHV)	Btu/cu ft Vapor at 14.696 psia (HHV)	Btu/lb Liquid (LHV)	Btu/gal Liquid (LHV)	Air Required for Combustion (cu ft/cu ft)	Flammability Limits Volume Percent in Air Mixture: Lower	Higher
Methane	CH_4	−258.68	0.5550	23.6100	—	—	911	1012	—	—	9.53	5.00	15.00
Ethane	C_2H_6	−127.53	1.046	12.5200		—	1,631	1.763		—	16.67	3.22	12.45
Propane	C_3H_8	−43.73	1.5470	8.4710	35.780	4.2240	2,353	2.557	19.932	84.194	23.82	2.37	9.50
Butane	C_4H_{10}	−31.10	2.0710	6.3270	30.770	4.8630	3.101	3.369	19.670	95.412	30.97	1.86	8.41
Pentane	C_5H_{12}	+96.93	2.4906	5.2601	27.680	5.2528	3.709*	4.009*	19.510	102,481	38.11	1.40	7.80
Hexane	C_6H_{14}	−155.73	2.9749	4.4403	24.361	5.5273	4.404*	4.756*	19.555	108.092	45.26	1.25	6.90
Heptane	C_7H_{16}	+209.17	3.4501	3.7875	21.73*	5.7284	5.101*	5.503*	19.320	110.673	52.41	1.00	6.00
Octane	C_8H_{18}	+258.19	3.9432	3.3724	19.577	5.8833	5.797*	6.250*	19.280	113.312	59.55	0.84	3.20
Carbon Monoxide	CO	−313.60	0.9670	13.5500	—	—	320.86	320.86	—	—	2.39	12.50	74.20
Carbon Dioxide	CO_2	−109.30	1.5194	8.5690	—	—		-	—	—		—	
Hydrogen	H_2	−422.90	0.0696	188.6790	—	-	273.00	324.00	—	—	2.39	4.00	74.20
Hydrogen Sulphide	H_2S	76.50	1.1764	11.0500	—		621.00	672.00	—		7.20	4.30	45.50
Oxygen	O_2	297.40	1.1047	11.8480	—	-	—	—	—	—	—	—	—
Nitrogen	N_2	−320.40	0.9672	13.5320	—	—	—	-	—	—	—		—
Air		−317.70	1.1000	13.0890	—	—		-	—	—		—	

* Approximate Value

Air-Fuel Ratio Adjustment for Initial Start-up:



Fuel Consumption Calculation

Published fuel consumption values are for 905 BTU/FT3 LHV. To calculate fuel consumption for other fuel gas, the following equation can be used:

$$\text{cu. ft. per hr.} = \frac{\text{Specific fuel consumption in Btu (LHV)} \times \text{Hp load}}{\text{LHV of fuel to be used}}$$

$$m^3 = \frac{\text{Specific fuel consumption in kJ (LHV)} \times \text{kW load}}{\text{LHV of fuel to be used}}$$

Special Lube Oil Information for Gas Engines:

Condemning limits

Alternate Oil Analysis (additional test procedures for more data)

Viscosity (ASTM D445)	3 cSt increase from new oil
Total Base Number (TBN) (ASTM D2896)	50% of original TBN
Oil pH. (ASTM 667)	4.0 minimum
Total Acid Number (TAN), (ASTM 664)	3.0 increase of new oil number
Solids or insolvables ASTM D893 or equivalent	1.0% maximum

-1

Differential infrared analysis of used oil must not exceed the following absorbance/CM:

Scheduled Oil Sampling

Parameter	Limit
Oxidation	20 Absorbance/cm at Wave Number of 1710 or 100% as defined by S•O•S
Nitration	20 Absorbance/cm at Wave Number of 1630 or 100% as defined by S•O•S
Water	0.5% Maximum
Glycol	0%
Wear Metals	Trend Analysis

If analysis of the used oil at the recommended oil change interval exceeds the condemning limits, the following courses of action can be taken:

1. Modify the jacket water temperature and/or adjust the air-to-fuel to minimize the oil degradation rate.

2. Shorten the oil change interval.

3. Work with your oil supplier to arrive at an oil that will not exceed the limits.

Maximum PPM (Parts Per Million) of Wear Metals Detected at 750 Hours to Achieve Projected Overhaul Interval

Oil Failure

Causes and Avoidance

Symptoms of oil failure are stuck piston rings, heavy piston deposits, sludged oil, plugged oil filters, rapid ring and liner wear, and high copper concentrations in oil analysis.

It is important that oil analysis measure oxidation and nitration since they result in corrosive wear and accelerate oil degradation. Oxidation and nitration cause oil to thicken and form lacquer and maroon-colored deposits.

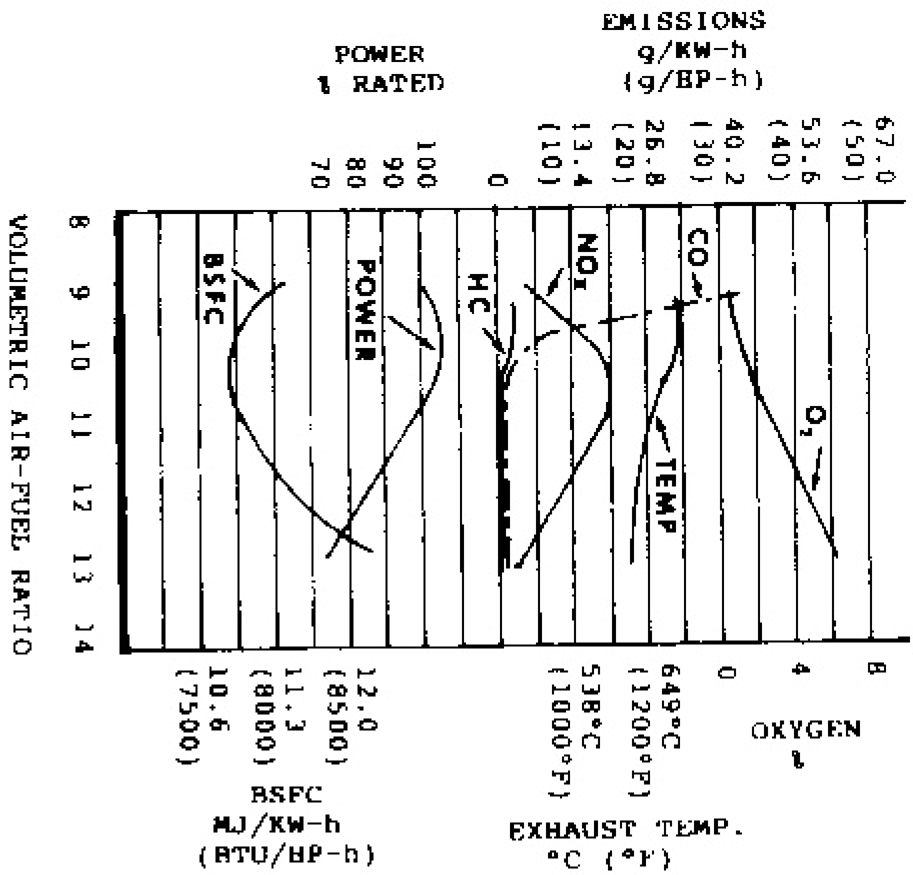
The nitration rate of an oil is associated with the air-to-fuel ratio for the engine. There is evidence that suggests operating the engine with an air-to-fuel ratio between 10:1 and 11:1 promotes rapid nitration of the oil. This is the normal air-to-fuel ratio range for most Caterpillar Natural Gas Engines and permits the optimum fuel consumption at rated power. In this range, nitrous oxide (NO_X) as measured in the exhaust stream is at its highest level. This range may cause the oil to degrade at an unacceptable rate.

If nitration is determined to be the principal reason for oil degradation, it may be necessary to adjust the air-to-fuel ratio either higher or lower to minimize the nitration rate.

If the air-to-fuel ratio is changed, it must be done with care because it may have a negative effect on the power of the engine or result in excessive exhaust temperature which could affect the service life of the engine.

Engine Data Sheet 195.0 Form LEKQ2364, of the Caterpillar Technical Manual shows the effects of different air-to-fuel ratio settings on various engine functions. The graphs included in that publication are for 6.25 inch bore natural gas engines, but the general shapes of the curves are similar for all natural gas engines.

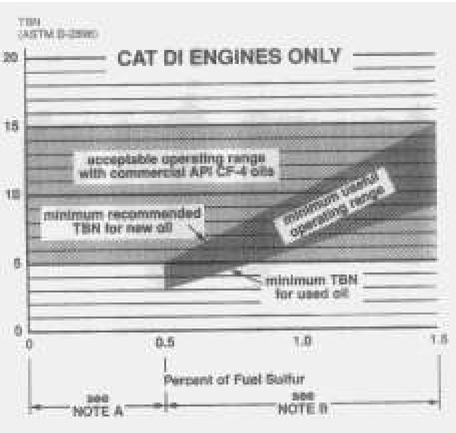
The chart on page 52 illustrates how fuel consumption, exhaust temperature, exhaust emissions, and engine power vary with air-fuel ratio. The air-fuel ratio which produces the lowest fuel consumption generally produces the maximum oxides of nitrogen (NO_X). This level of NO_X can cause rapid deterioration of lube oil through nitration.



At air-fuel ratios within the nitration range, engine jacket water temperature becomes very important. Cooler temperature allows moisture to condense within the crankcase creating acids which result in corrosive wear to piston rings and liners. The jacket water temperature must be kept as warm as possible to improve oil life and reduce wear. Radiator-cooled systems should be maintained between 93°C to 99°C (200°F to 210°F). Ebullient-cooled engines have high jacket water temperatures and usually deteriorate the oil at a slower rate.

Lubrication System

Oil TBN vs. Fuel Sulfur Content



Graph for determination of necessary TBN. Find the fuel sulfur percentage on bottom of the graph. Find point where the new oil TBN line intersects the sulfur content line, and read the required TBN at the left side of the chart.

Rule of Thumb: New oil TBN should be 10 times fuel sulfur content. Change oil when TBN drops to 1/2 its original value when using API CF-4 oil and you are using a DI engine.

Additives

There are chemical substances added to a petroleum product to impart or improve certain properties.

Additives strengthen or modify certain characteristics of the base oil. Ultimately, they enable the oil to meet requirements quite beyond the abilities of the base oil.

The most common additives are: detergents, oxidation inhibitors, dispersants, alkalinity agents, anti-wear agents, pour-point depressants and viscosity improvers.

Here is a brief description of what each additive does and how.

Detergents help keep the engine clean by chemically reacting with oxidation products to stop the formation and deposit of insoluble compounds.

Oxidation inhibitors help prevent increases in viscosity, the development of organic acids and the formation of carbonaceous matter.

Dispersants help prevent sludge formation by dispersing contaminants and keeping them in suspension.

Alkalinity agents help neutralize acids.

Anti-wear agents reduce friction by forming a film on metal surfaces.

A pour-point depressant keeps the oil fluid at low temperatures by preventing the growth and agglomeration (the gathering together into a mass) of wax crystals.

Viscosity improvers help prevent the oil from becoming too thin at high temperatures.

Anti-Wear Additive

This is an additive in a lubricant that reduces friction and excessive wear.

API (American Petroleum Institute)

This is a trade association of petroleum producers, refiners, marketers, and transporters, organized for the advancement of the petroleum industry by conducting research, gathering and disseminating information, and maintaining cooperation between government and the industry on all matters of mutual interest. One API technical activity has been the establishment of API Engine Service Categories for lubricating oils.

API Engine Service Categories

Gasoline and diesel engine oil performance levels are established jointly by API, SAE, and ASTM called API Engine Service Classifications. API Service Categories are as follows:

Diesel Engine Oils

Diesel Engine Oils

API Letter Designation		**API Engine Service Description**
		Key: X Obsolete Test Techniques O Active Test Techniques
CA	X	Diesel Engine Service (Obsolete)
CB	X	Diesel Engine Service (Obsolete)
CC	X	Diesel Engine Service

CD	O	Diesel Engine Service The category CD denotes service typical of certain naturally aspirated, turbocharged, or supercharged diesel engines where highly effective control of wear and deposits is vital or when using fuels of a wide quality range, including high sulfur fuels. Oils designed for this service were introduced in 1955 and provide protection from bearing corrosion and from high-temperature deposits in these diesel engines.
CD-II	O	Severe Duty Two-Stroke Cycle Diesel Engine Service typical of two-stroke cycle diesel engines requiring highly effective control over wear and deposits. Oils designed for this service also meet all performance requirements of API Service Category CD.
CE	X	1983 Diesel Engine Service Service typical of certain turbocharged or supercharged heavy-duty diesel engines manufactured since 1983 and operated under both low-speed, high-load and high-speed, high-load conditions. Oils designed for this service may also be used when API Engine Service Category CD is recommended for diesel engines.
CF-4	O	1990 Diesel Engine Service Service typical of certain turbocharged or supercharged heavy-duty diesel engines manufactured and operated under both low-speed, high-load and high-speed, high-load conditions. Oils designed for this service may also be used when API Engine Service Category CD and CE are recommended for diesel engines.
CG-4		1995 Diesel Engine Service Service for engine wear and deposits issues linked to fuel specifications and engine designs that are required to accommodate 1994 EPA emission regulations for low sulfur fuel (0.05%).

Gasoline Engine Oils

API Letter Designation		API Engine Service Description
SA	(No test required)	Formerly for Utility Gasoline and Diesel Engine Service (Obsolete)
SB	X	Minimum Duty Gasoline Engine Service (Obsolete)
SC	X	1964 Gasoline Engine Warranty Maintenance Service (Obsolete)
SD	X	1968 Gasoline Engine Warranty Maintenance Service (Obsolete)
SE	X	1972 Gasoline Engine Warranty Maintenance Service (Obsolete Starting in 1989)
SF	X	1980 Gasoline Engine Warranty Maintenance Service
SG	O	1989 Gasoline Engine Warranty Maintenance Service The category SG denotes service typical of present gasoline engines in passenger cars, vans, and light-duty trucks operating under manufacturers' recommended maintenance procedures. Category SG quality oils include the performance properties of API Service Category CC. (Certain manufacturers of gasoline engines require oils also meeting the higher diesel engine Category CD). Oils developed for this service provide improved control of engine deposits, oil oxidation, and engine wear relative to oils developed for previous categories. These oils also provide protection against rust and corrosion. Oils meeting API Service Category SG may be used when API Service Categories SF, SE, SF/CC, or SE/CC are recommended.
SH	O	API category for use in service typical of gasoline engines in present and earlier vehicles. These oils have been tested according to the CMA product approval code of practice and may be used where API category SG and earlier categories have been recommended. They must meet all API SG requirements and use Multiple Test Acceptance Criteria (MTAC).

Anti-Wear Additive

This is an additive in a lubricant that reduces friction and excessive wear.

Ash Content

This is the noncombustible residue of a lubricating oil or fuel. Lubricating oil detergent additives contain metallic derivatives, such as barium, calcium, and magnesium sulfonates, that are common sources of ash. Ash deposits can impair engine efficiency and power. See detergent.

ASTM (American Society for Testing and Materials)

This organization is devoted to "the promotion of knowledge of the materials of engineering and the standardization of specifications and methods of testing." A preponderance of the data used to describe, identify, or specify petroleum products is determined in accordance with ASTM test methods.

Base Stock

Base stock is a primary refined petroleum fraction, usually a lube oil, into which additives and other oils are blended to produce finished products.

Bid Oil

This is oil produced by an oil company which just meets the minimum of the diesel engine oil performance specifications. These oils are usually the least expensive because they have only the minimum amount of additives to just get by. These oils might be acceptable for lightly loaded applications but could cause problems in more severe machine application.

Blow-By

This comes from an internal combustion engine where seepage of fuel and gases past the piston rings and cylinder wall into the crankcase, results in crankcase oil dilution and sludge formation.

BMEP

Brake mean effective pressure is the theoretical average pressure that would have to be imposed on the pistons of a frictionless engine (of the same dimensions and speed) to produce the same power output as the engine under consideration; a measure of how effectively an engine utilizes its piston displacement to do work.

Borderline Pumping Temperature °C (ASTDM D3829)

This is the temperature at which the oil becomes too viscous (thick) and cannot be moved when force is applied. The oil, however, is not yet a solid (pour point).

Bulk Delivery

This is a large quantity of unpackaged petroleum product delivered directly from a tank truck, tank car, or barge into a consumer's storage tank.

Colloid

A colloid is a suspension of finely divided particles 5 to 5000 angstroms in size in a gas or liquid, that do not settle and are not easily filtered. An Angstrom is a unit of wave length of light equal to one ten billionth of a meter which carries a positive or negative charge.

Colloids are usually ionically stabilized by some form of surface charge on the particles to reduce the tendency to aggolomerate (gather into a ball or mass). A lubricating grease is a colloidal system, in which metallic soaps or other thickening agents are dispersed in, and give structure to, the liquid lubricant.

Color Scale

These scales serve primarily as indicators of product uniformity and freedom from contamination. The scale is a standardized range of colors against which the colors of petroleum products may be compared. There are a number of widely used systems of color scales, including: ASTM scale (test method ASTM D

1500), the most common scale, used extensively for industrial and process oils.

Crude Oil

Crude oil is a complex, naturally occurring fluid mixture of petroleum hydrocarbons, yellow to black in color, and also containing small amounts of oxygen, nitrogen, and sulfur derivatives and other impurities. Crude oil was formed by the action of bacteria, heat, and pressure on ancient plant and animal remains, and is usually found in layers of porous rock such as limestone or sandstone, capped by an impervious layer of shale or clay that traps the oil. Crude oil varies in appearance and hydrocarbon composition depending on the locality where it occurs. Crude is refined to yield petroleum products.

Demerit Rating

This is an arbitrary graduated numerical rating sometimes used in evaluating engine deposit levels following testing of an engine oil's detergent-dispersant characteristics. On a scale of 0-10, the higher the number, the heavier the deposits. A more commonly used method of evaluating engine cleanliness is merit rating. See Engine Deposits.

Detergent

This is an important component of engine oils that helps control varnish, ring zone deposits, and rust by keeping insoluble particles in suspension and in some cases, by neutralizing acids. A detergent is usually a metallic compound. Because of its metallic composition, a detergent leaves a slight ash when the oil is burned. A detergent is normally used in conjunction with a dispersant.

Dispersant

A dispersant is an engine oil additive that helps prevent sludge, varnish, and other engine deposits by keeping soot particles suspended in a colloidal state (prevents these particles from gathering into a ball or mass).

Engine Deposits

These are hard or persistent accumulations of sludge, varnish, and carbonaceous residues due to blow-by of unburned and partially burned (partially oxidized) fuel, or from partial breakdown of the crankcase lubricant. Water from condensation of combustion products, carbon, residues from fuel or lubricating oil additives, dust, and metal particles also contribute. Engine deposits can impair engine performance and damage engine components by causing valve and ring sticking, clogging of the oil screen and oil passages, and excessive wear of pistons and cylinders. Hot, glowing deposits in the combustion chamber can also cause pre-ignition of the air-fuel mix. Engine deposits are increased by short trips in cold weather, high temperature operation, heavy loads (such as pulling a trailer), and over-extended oil drain intervals.

EPA (Environmental Protection Agency)

The EPA is an agency of the federal executive branch, established in 1970 to abate and control pollution through monitoring, regulation, and enforcement, and to coordinate and support environmental research.

Fighting Grade Oil

See Bid Oil.

Flashpoint

This is the lowest temperature at which the vapor of a combustible liquid can be made to ignite momentarily in air. Flash point is an important indicator of the fire and explosion hazards associated with a petroleum product.

Lubrication

Lubrication is the control of friction and wear by the introduction of a friction-reducing film between moving surfaces in contact. The lubricant used may be a fluid, solid, or plastic substance.

Merit Rating

This is an arbitrary graduated numerical rating commonly used in evaluating engine deposit levels when testing the detergent-dispersant characteristics of an engine oil. On a scale of 10-0, the lower the number, the heavier the deposits. A less common method of evaluating engine cleanliness is demerit rating. See Engine Deposits.

Mineral Oil

This is any petroleum oil, as contrasted to animal or vegetable oils. Also, a highly refined petroleum distillate, or white oil, used medicinally as a laxative.

OSHA (Occupational Safety and Health Administration); Oxidation

Oxidation is the chemical combination of a substance with oxygen. All petroleum products are subject to oxidation. This degrades their composition and lowers their performance. The oxidation process is accelerated by heat, light, metal catalysts (agents which bring about a chemical reaction) and the presence of water, acids or solid contaminants.

These substances react with each other to form sludges, vanishes and gums that can impair equipment operation.

To minimize oxidation and its effects, carefully select a good base stock oil, insure an oxidation inhibitor is added to the base stock and maintain equipment and change oil to prevent contamination and excessive heat.

Oxidation Inhibitor

This is any substance added in small quantities to a petroleum product to increase its oxidation resistance, thereby lengthening its service or storage life; also called anti-oxidant. An oxidation inhibitor may work in one of three ways (1) by combining with and modifying peroxides (compounds high in oxygen) to render them harmless, (2) by decomposing the peroxides, or (3) by rendering an oxidation catalyst (metal or metal-ions) inert; that is, lacking in a chemical reaction. See Oxidation.

Oxidation Stability

This is the resistance of a petroleum product to oxidation; hence, a measure of its potential service or storage life. There are a number of ASTM tests to determine the oxidation stability of a lubricant or fuel, all of which are intended to simulate service conditions on an accelerated basis. In general, the test sample is exposed to oxygen or air at an elevated temperature, and sometimes to water or catalysts (usually iron or copper). Depending on the test, results are expressed in terms of the time required to produce a specified effect (such as pressure drop), the amount of sludge or gum produced, or the amount of oxygen consumed during a specified period.

Pass-Oil

See Bid Oil.

Pour Point

Pour point is the lowest temperature at which an oil or distillate fuel is observed to flow, when cooled under conditions prescribed by test method ASTM D97. The pour point is 3°C (5°F) above the temperature at which the oil in a test vessel shows no movement when the container is held horizontally for five seconds. Pour point is lower than wax appearance point or cloud point. It is an indicator of the ability of an oil or distillate fuel to flow at cold operating temperatures.

Ring Land

This is the area on the surface of the piston that is between either the top of the piston and first ring groove or between two adjacent ring grooves.

Ring Sticking

Ring sticking is freezing of a piston ring in its groove, in a piston engine or reciprocating compressor, due to heavy deposits in the piston ring zone. This prevents proper action of the ring and tends to increase blow-by into the crankcase and to increase oil consumption by permitting oil to flow past the ring zone into the combustion chamber. See Engine Deposits.

SAE (Society of Automotive Engineers)

The Society of Automotive Engineers reviews the total automotive engine and lubricant situation and defines the requirement for new oil specifications.

SAE Oil Viscosity Classification

Because of the important effects of oil viscosity the Society of Automotive Engineers (SAE) has developed a system for classifying lubricating oils in terms of viscosity only; no other physical or performance characteristics are considered.

The viscosity numbers without the letter W are based upon 210°F viscosities. Viscosity at that temperature correlates with oil consumption and other oil performance characteristics influenced by viscosity at normal engine operating temperatures. The viscosity numbers with the letter W are based on 0°F viscosities.

The 0°F viscosities for W-numbered oils were selected because they correlate with the cranking characteristics of motor oils in the average automobile engine under low-temperature starting conditions.

Viscosity Grades for Engine Oils

Viscosity Grades for Engine Oils

SAE Viscosity grade	Viscosity (cP)[a] at temp. (°C) max	Boderline[b] pumping temp. (°C) max	Viscosity[c] at 100°C (cSt) min	max
0W	3250 at −30	−35	3.8	—
5W	3500 at 25	−30	3.8	—
10W	3500 at −20	−25	4.1	—
15W	3500 at −15	−20	5.6	—
20W	4500 at −10	−15	5.6	—
25W	6000 at −5	−10	9.3	—
20	—	—	5.6	< 9.3
30	—	—	9.3	<12.5
40	—	—	12.5	<16.3
50	—	—	16.3	<21.9
60	—	—	21.9	<26.1

Note: 1cP = 1mPa s, 1cSt = 1 mm^2/s

[a] ASTM D 2602 (cold cranking simulator)

[b] ASTM D 4684 (MRV TP-1)

[c] ASTM D 445 (capillary viscometer)

Single-Grade Oil

This is the engine oil that meets the requirements of a single SAE viscosity grade classification. i.e., SAE 10W, 30 and 40.

Scote

Scote stands for single cylinder oil test engine. Cat developed, tested and supports the single cylinder oil test engine for the CF-4 engine oil service category. This test is known as the Cat 1K Scote.

Shear Stability

Shear stability is the ability of a multiviscosity oil to resist shear forces (sudden and abrupt changes in movement) on the oil that would cause it to revert to the base oil and become too thin to provide adequate lubrication.

Sludge

In diesel engines, sludge is a soft, black, mayonnaise-like emulsion of water, other combustion by-products, and oil formed during low-temperature engine operation. Sludge plugs oil lines and screens, and accelerates wear of engine parts. Sludge deposits can be controlled with a dispersant additive that keeps the sludge constituents finely suspended in the oil. See Engine Deposits.

Soot

This is unburned fuel. Black smoke and a dirty air filter indicate its presence. It causes oil to turn black.

Synthetic Lubricant

A synthetic lubricant is a lubricating fluid made by chemically reacting materials of a specific chemical composition to produce a compound with planned and predictable properties. The resulting base stock may be supplemented with additives to improve specific properties. Many synthetic lubricants - also called synlubes - are derived wholly or primarily from petrochemicals; other synlube raw materials are derived from coal and oil shale, or are lipochemicals (from animal and vegetable oils). Synthetic lubricants may be superior to petroleum oils in specific performance areas. Many exhibit higher viscosity index (V.I.) better thermal stability (heat resistance) and oxidation stability, and low volatility (which reduces oil consumption). Because synthetic lubricants are higher in cost than petroleum oils, they are used selectively where performance or safety requirements may exceed the capabilities of a conventional oil.

Total Base Number (TBN)

Understanding TBN requires some knowledge of fuel sulfur content. Most diesel fuel contains some degree of sulfur. How much depends on the amount of sulfur in the crude oil from which it was produced and/or the refiner's ability to remove it. One of the functions of lubricanting oil is to neutralize sulfur by-products, namely sulfurous and sulfuric acids and thus retard corrosive damage to the engine. Additives in the oil contain alkaline compounds which are formulated to neutralize these acids. The measure of this reserve alkalinity in an oil is known as its TBN. Generally, the higher the TBN value, the more reserve alkalinity or acid-neutralizing capacity the oil contains.

Toxicology

This is a science that deals with poisons and their affect and with the problems involved (as clinical, industrial or legal).

Viscosity

Viscosity is one of the more critical properties of oil. It refers to an oil's thickness or its resistance to flow. Viscosity is directly related to how well an oil will lubricate and protect surfaces that contact one another. Regardless of the ambient temperature or engine temperature, an oil must flow sufficiently to ensure an adequate supply to all moving parts.

The more viscous (or thicker) an oil is, the thicker the oil film it will provide. The thicker the oil film, the more resistant it will be to being wiped or rubbed from lubricated surfaces. Conversely, oil that is too thick will have excessive resistance to flow at low temperatures and so may not flow quickly enough to those parts requiring lubrication. It is therefore vital that the oil has the correct viscosity at both the highest and the lowest temperatures at which the engine is expected to operate.

Viscosity Index (VI)

Oil thins out as temperature increases. The measurement of the rate at which it thins out is called the oil's viscosity "index" (or VI). New refining techniques and the development of special additives which improve the oil's viscosity index help retard the thinning process.

The Society of Automotive Engineers (SAE) standard oil classification system categorizes oils according to their quality (via an alphabetical designation, like CD) and viscosity (via a number).

Zinc

This is widely used as an anti-wear agent in motor oils to protect heavily loaded parts, particularly the valve-train mechanisms (such as the camshaft and cam followers) from excessive wear. It is also used as an anti-wear agent in hydraulic fluids and certain other products.

General Service Information
ENGINE INSTALLATION & SERVICE HANDBOOK
Media Number -LEBV0915-05 Publication Date -01/01/1997 Date Updated -26/04/2006

LEBV09150013

Starting System

Electric Starters

Cable Size

The start circuit between battery and starting motor, and control circuit between battery, switch, and motor solenoid must be within maximum resistance limits shown.

Maximum Allowable Resistance		
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

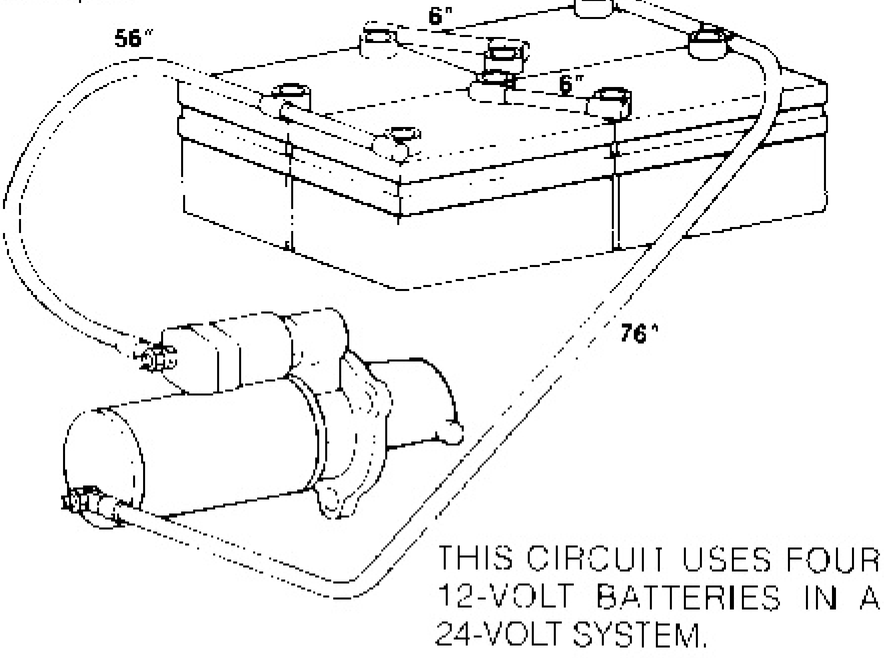
Not all this resistance is allowed for cables. Connections and contactors, except the motor solenoid contactor, are included in the total allowable resistance. Additional fixed resistance allowances are:

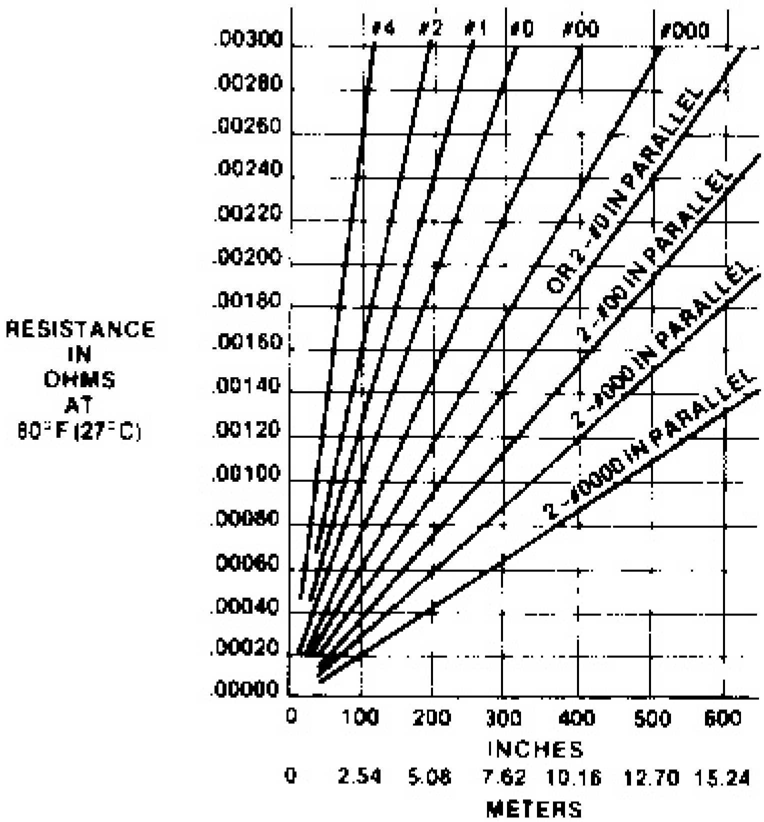
-Contactors (Relays, Solenoid, Switches)-0.0002 ohm

-Connections (Each Series Connectors)-0.00001 ohm

The fixed resistance of connections and contactors is determined by the cable routing. Fixed resistance (R_f) subtracted from total resistance (R_f) equals allowable cable resistance (R_c): $R_t - R_f = R_c$.

Lxamp'e:





Battery Performance

Battery Performance

Specific Gravity vs. Voltage			Freezes	
Sp. Gravity	% Charge	V per Cell	°F	°C
1.260	100	2.10	–70	–94
1.230	75	2.07	–39	–56
1.200	50	2.04	–16	–27
1.170	25	2.01	– 2	–29
1.110	Discharged	1.95	+17	– 8

Temperature vs. Output Rating		
°F	°C	% 80°F Ampere Hours Output Rating
80	27	100
32	0	65
0	–18	40

Battery Performance (cont.)

Battery Voltage	Suggested Minimum Battery Cold Cranking Amps								
	12			24-32 1-motor			30-32 2-motor		
Minimum °F	–20	30	60	–20	0	60	–20	0	60
3304		1450		1225	925	725			
3306		1450		1225	925	725			
3406				1225	925				
3408				1300	1225	925			
3412				1300	1225	925			
3508				1300	1225	925			
3512							1300	910	725
3516							1300	910	725
D379				1300	910	725			
D398							1300	910	725
D399							1300	910	725

NOTE: Use aids below 0°F (–18°C)

Air Starters

Air Storage Tank Sizing

Many applications require sizing air storage tanks to provide a specified number of starts without recharging. This is accomplished as follows:

$$V_T = \frac{V_S \times T \times P_a}{P - P_{min}}$$

Where:

V_T = Air storage tank capacity (ft^3 or m^3)

V_S = Air consumption of the starter motor (ft^3/sec or m^3/sec) - see air starting requirements chart on next page.

T = Total cranking time required (sec). If 6 consecutive starts are required, use 7 sec for 1st start, (while engine is cold), and 2 sec each for remaining 5 starts, or a total cranking time of 17 sec.

Pa = Atmospheric pressure (psia or kPaa) - normally, atmospheric pressure is 14.7 psia or 101 kPaa.

P_T = Air storage tank pressure (psia or kPaa) - this is the storage tank pressure at the start of cranking.

Pmin = Minimum air storage tank pressure required to sustain cranking at 100 rpm (psia or kPaa) - see air starting requirements chart on next page.

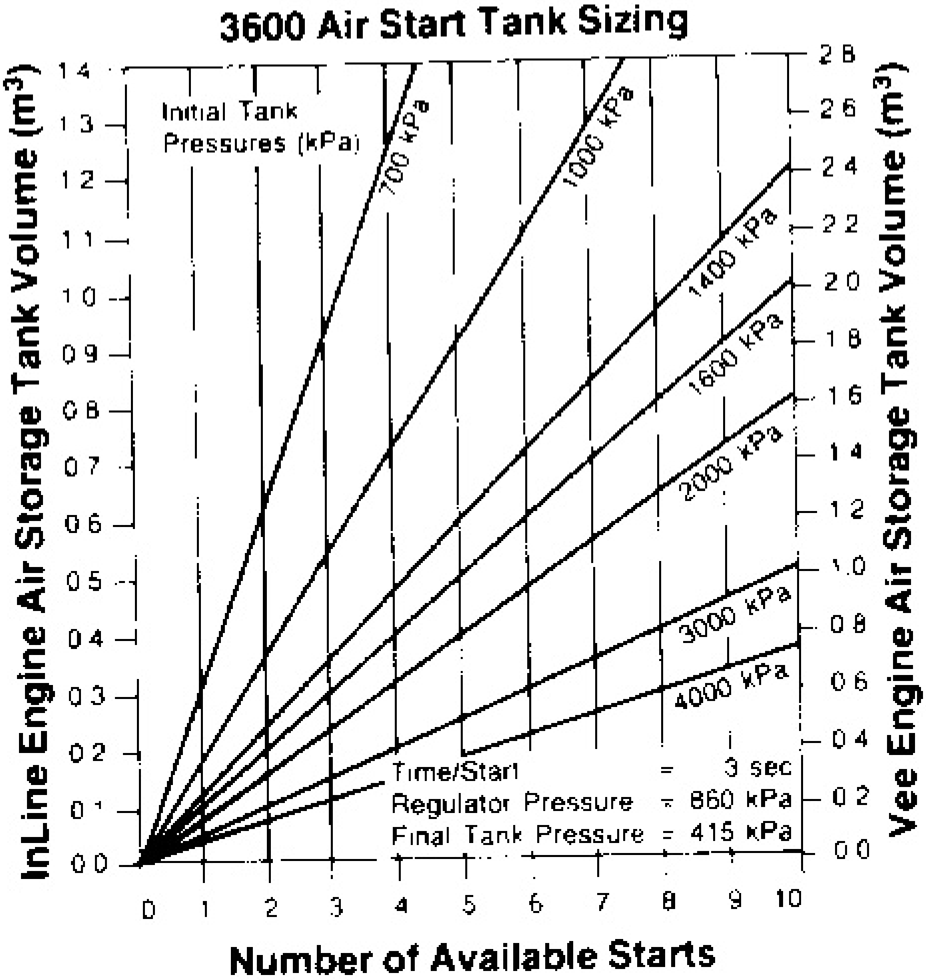
Air Starting Requirements

Air Starting Requirements

Engine Model	Air Consumption of the Air Start Motor — Vs — ft^3/sec (m^3/sec) of Free Air; Air Storage Tank Pressure — P_T —			Minimum Tank Pressure — Pmin — psia (kPaa)
	115 psia (793 kPaa) 100 psig (690 kPag)	140 psia (965 kPaa) 125 psig (862 kPag)	165 psia (1137 kPaa) 150 psig (1034 kPag)	
3304	5.8 (0.16)	6.8 (0.20)	7.7 (0.21)	50 (345)
3306	5.9 (0.17)	6.9 (0.20)	7.8 (0.22)	51 (352)
3406	6.2 (0.17)	7.3 (0.21)	8.3 (0.23)	55 (379)
3408	6.4 (0.18)	7.5 (0.21)	8.6 (0.24)	54 (372)
3412	9.0 (0.25)	10.3 (0.29)	11.8 (0.33)	45 (310)
D348	8.3 (0.23)	9.8 (0.28)	10.8 (0.30)	51 (351)
D349	9.2 (0.26)	10.5 (0.30)	11.8 (0.33)	66 (455)
D353	6.6 (0.19)	7.8 (0.22)	8.9 (0.25)	55 (379)
D379	9.3 (0.26)	10.8 (0.30)	12.6 (0.36)	45 (310)
D398	9.8 (0.28)	11.4 (0.32)	13.3 (0.38)	50 (344)
D399	10.5 (0.30)	12.1 (0.34)	14.1 (0.40)	65 (448)
3508	9.3 (0.26)	10.8 (0.30)	12.6 (0.36)	45 (310)
3512	9.8 (0.28)	11.4 (0.32)	13.3 (0.38)	50 (344)
3516	10.5 (0.30)	12.1 (0.34)	14.1 (0.40)	65 (448)

NOTE: For engines equipped with air prelube: add 1 ft^3/sec (0.03 m^3/sec) air consumption

3600 Air Start Tank Sizing


3600 Air Start Tank Sizing
InLine Engine Air Storage Tank Volume (m³)
Vee Engine Air Storage Tank Volume (m³)
Initial Tank Pressures (kPa)
700 kPa
1000 kPa
1400 kPa
1600 kPa
2000 kPa
3000 kPa
4000 kPa
Time/Start = 3 sec
Regulator Pressure = 860 kPa
Final Tank Pressure = 415 kPa
Number of Available Starts

Mounting and alignment

Available Installation and Alignment Instructions

Engine Data Sheet 102.2	Installation/Alignment Instructions for Caterpillar Engines with Reintjes Free Standing Marine Gears and Vulcan Rato Flexible Couplings
Special Instruction SEHS9070	Installation and Alignment of 3606 and 3608 Marine Engines on Resilient Mounts
A&I Guide 3600 LEKX1002	Procedure for Aligning Single Bearing Generators to 3600 Engines
A&I Guide 3600 LEKX1002	Procedure for Aligning Two Bearing Generators to 3600 Engines
Special Instruction SEHS7654	Alignment — General Instructions
Special Instruction SEHS7456-01	Alignment of Caterpillar Marine Transmissions and Marine Engines
Special Instruction SEHS7956	Alignment of Caterpillar Diesel Engines to Caterpillar Marine Transmission (7271-36W)
Special Instruction SEHS7073	Alignment of Two Bearing Generators

Allowance for Expansion due to Thermal Growth

Cast iron has a thermal expansion coefficient of 0.0000066 in. per in. per Degree F (0.000012 mm per mm per Degree C). Steel has an average thermal expansion coefficient of 0.0000063 in. per in. per Degree F (0.000011 mm per mm per Degree C).

The engine mounting system must allow for this expansion through the proper use and placement of clearance bolts, fitted bolts, and dowels. Failure to allow for thermal expansion will result in driven equipment misalignment and engine block distortion.

Compensation offsets must be incorporated into alignment procedures to accommodate this growth when alignment is performed cold.

Thermal expansion = Expansion Coefficient × Linear Distance* × Delta T

---

*Linear distance is the length or width of engine for horizontal growth and the distance between the mounting surface and the crankshaft centerline for vertical growth.

Examples: 3606 - Cast Iron Block, Length of block between rear fitted bolt and front clearance bolt in 87.6 in. (2226 mm). Delta T = 130°F (72°C). Expansion allowance required is:

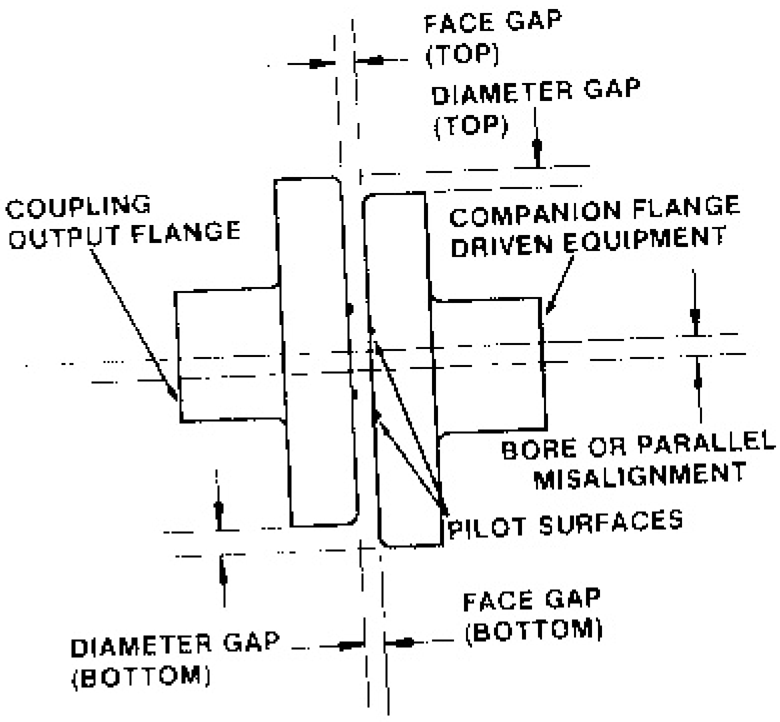
0.0000066 (0.000012) × 87.6 in. (2226 mm) × 130°F (72°C) = 0.075 in. (1.9 mm)

Collision Blocks for Marine Engines

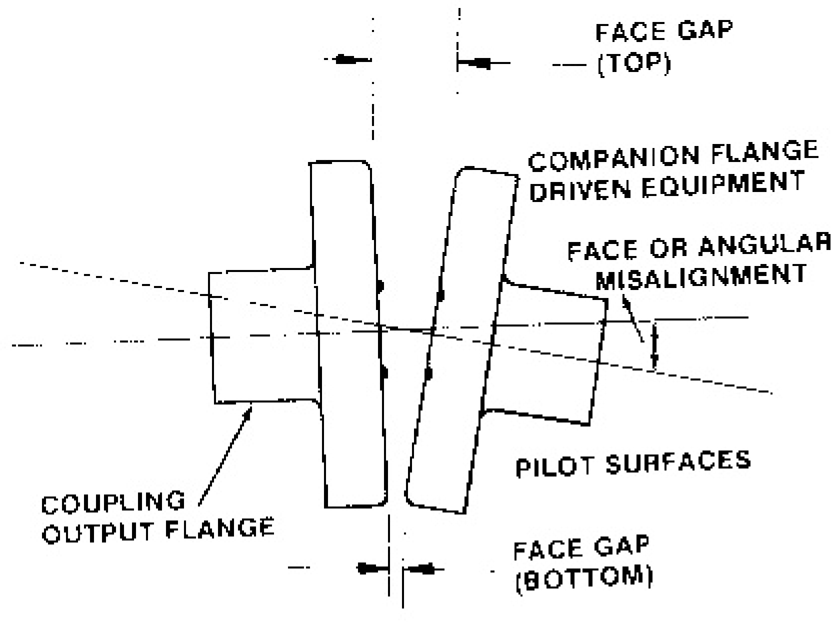
When marine classification societies or local marine practice requires the use of collision blocks, they should be located with sufficient clearance to allow for thermal growth of the engine. Prefabricate the collision blocks and install them while the engine is at operating temperature with approximately 0.005 in (0.12 mm) *hot* clearance. Collision blocks are recommended to resist the shock loads encountered in hard docking collisions and groundings.

Types of Misalignment

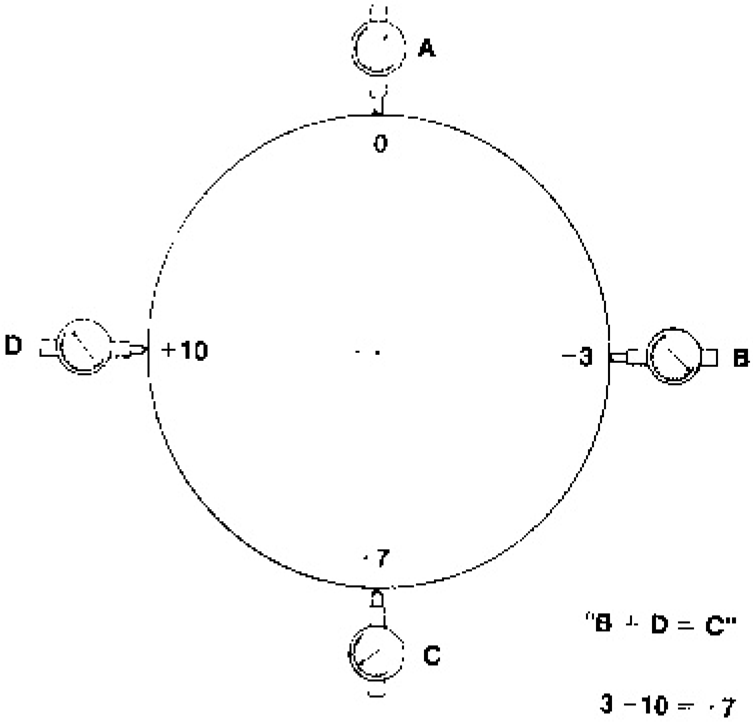
Parallel or bore misalignment occurs when centerlines of driven equipment and engine are parallel but not in the same plane.



Angular or face misalignment occurs when centerlines of driven equipment and engines are not parallel.



Dial Indicator Quick Check



When both shafts are rotated together, the algebraic sum of the readings at D and B should equal the reading at C. This check is useful for identifying improper indicator setup or procedure. The example shown is out of alignment.

Required Foundation Depth for Stationary Installations

Calculate foundation depth to equal generator set weight by:

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

FD = foundation depth in feet (meter)

W = total wet weight of generator set in pounds (kg) Use 125% of actual weight if vibration isolators are not used.

D = density of concrete in pounds per cubic foot (kg/m^3)

NOTE: Use 150 for English unit and 2402.8 for metric unit.

B = foundation width in feet (meter)

L = foundation length in feet (meter)

Pressure on Supporting Material

$$P\ (psi) = \frac{W\ (Pounds)}{A\ (inches)^2} \qquad kPa = \frac{kg}{m^2}$$

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

Where: P = Pressure in psi (kpa)

W = Weight in pounds (kg)

A = Area in square inches (m^2)

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

General Torque Specifications

The following charts give general torque values for fasteners of SAE Grade 5 or better and Metric ISO Grade 8.8.

Torques for Bolts and Nuts with Standard Threads

Torques for Bolts and Nuts with Standard Threads

Thread Size	Standard Torque	
Inch	N•m*	lb ft
1/4	12±4	9±3
5/16	25±7	18±5
3/8	45±7	32±5
7/16	70±15	50±10
1/2	100±15	75±10
9/16	150±20	110±15
5/8	200±25	150±20
3/4	360±50	265±35
7/8	570±80	420±60
1	875±100	640±80
1 1/8	1100±150	800±100
1 1/4	1350±175	1000±120
1 3/8	1600±200	1200±150
1 1/2	2000±275	1480±200

*1 Newton meter (N•m) is approximately the same as 0.1 mkg.

Torques for Taperlock Studs

Torques for Taperlock Studs

Thread Size Inch	Standard Torque N•m*	Standard Torque lb ft
1/4	8±3	6±2
5/16	17±5	13±4
3/8	35±5	26±4
7/16	45±10	33±7
1/2	65±10	48±7
9/16	90±15	65±11
5/8	110±15	80±11
3/4	170±20	125±15
7/8	260±30	190±22
1	400±40	300±30
1 1/8	500±40	370±30
1 1/4	650±50	480±37
1 3/8	750±50	550±37
1 1/2	870±50	640±37

*1 Newton meter (N•m) is approximately the same as 0.1 mkg.

Metric ISO Thread

Metric ISO Thread

Thread Size	Standard Torque N•m*	Standard Torque lb ft
M6	12±4	9±3
M8	25±7	18±5
M10	55±10	40±7
M12	95±15	70±10
M14	150±20	110±15
M16	220±30	160±20
M18	325±50	240±35
M20	450±70	330±50
M22	600±90	440±65
M24	775±100	570±75
M27	1150±150	840±110
M30	1600±200	1175±150
M33	2000±275	1480±200
M36	2700±400	2000±300

Vibration

Vibration Summary

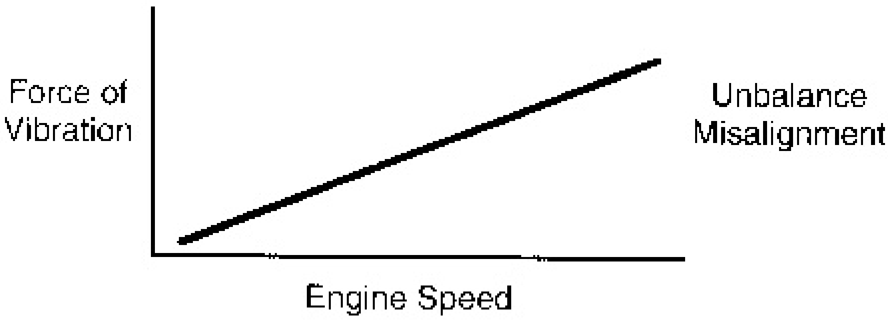
Vibrations can have many causes such as those listed in A through F:

A. Unbalance of rotating or reciprocating parts.
B. Combustion forces.
C. Misalignment of engine and driven equipment.
D. Inadequate anchoring of equipment.
E. Torque reaction.
F. Resonance with the mounting structure.

Causes of vibrations can usually be identified by determining if:

1. Vibration forces increase with speed. These are caused by centrifugal forces bending components of the drive train.

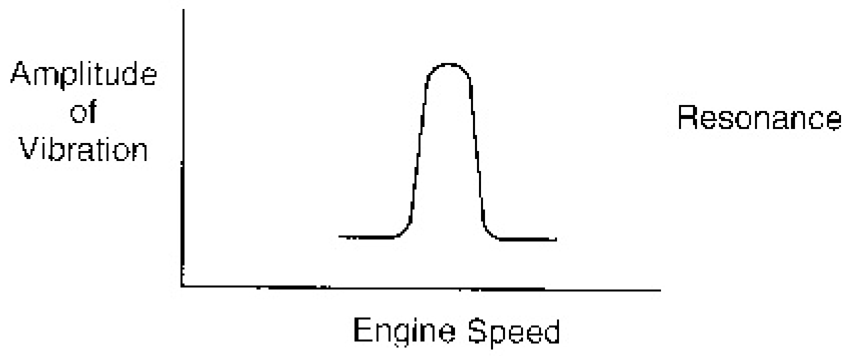
These are normally caused by A, B, or C.



2. Vibrations occur within a narrow speed range. This normally occurs on equipment attached to the engine-pipes, air cleaners, etc. When vibrations "peak out" in a narrow speed range, the vibrating component is in resonance.

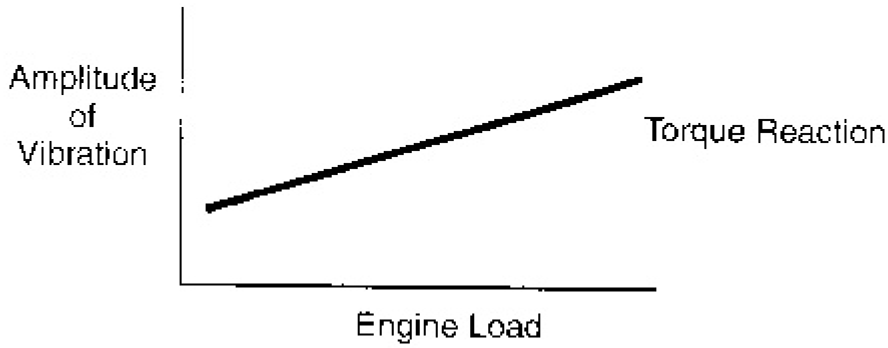
These vibrations can be modified by changing the natural frequency of the part by stiffening or softening its mounting. A defective viscous vibration dampener can also cause this.

These are normally caused by A, C, or F.



3. Vibrations increase as load is applied. This is torque reaction and can be caused by insecure mounting of engine or driven equipment, or by a base or foundation which is not sufficiently rigid to withstand the driving torque of the engine or defective worn couplings.

These are normally caused by D or E.



Order of Vibration

$$\text{Order} = \frac{\text{Vibration Frequency (Hz)}}{\text{Engine RPM/60}}$$

Order of Firing Frequency

$$\begin{array}{c}\text{Firing Frequency}\\ \text{(4 Cycle Engines)}\end{array} = \frac{\text{Number of Cylinders}}{2}$$

Data Interpretation

Order of Vibration:	Possible Cause:
0.5 Order	Misfire of one or more cylinders
1.0 Order	Out of balance component rotating at crankshaft speed
2.0 Order	Out of time balancer gears rotating at twice engine speed. Misaligned U-Joint. Piston or upper end of connecting rod is too light or too heavy.
Order = Firing Frequency	Normal, may also occur at 0.5 orders adjacent to firing frequency

First Order Vibration Frequencies for Standard Rated Speeds

$$\text{Frequency (Hz)} = \frac{\text{RPM}}{60}$$

Engine RPM	First Order Frequency (Hz)
700	11.7
720	12
800	13.3
900	15
1000	16.7
1200	20
1225	20.4
1300	21.7
1350	22.5
1500	25
1600	26.7
1800	30
2000	33.3
2100	35
2200	36.7
2400	40
2600	43.3
2800	46.7
2900	48.3

<u>Relationships of Sinusoidal Velocity, Acceleration, Displacement</u>

English		Metric	
$V = \pi f D$		$V = \pi f D$	
$V = 61.44\ g/f$	D = inches pk-to-pk	$V = 1.56\ g/f$	D = meters pk-to-pk
$g = 0.0511\ f^2 D$	V = inches/second	$g = 2.013\ f^2 D$	V = meters/second
$g = 0.0162\ Vf$	f = Hz (cps) or RPM/60	$g = 0.641\ Vf$	f = Hz (cps) or RPM/60
$D = 0.3183\ V/f$	g = 386.1 in/sec^2	$D = 0.3183\ V/f$	g = 9.806 65 m/sec^2
$D = 19.57\ g/f^2$		$D = 0.4968\ g/f^2$	

Electrical Fundamentals*

Ohm's Law

$E = IR$

where E = voltage in volts

I = current in amperes

R = resistance in ohms

By simple algebra this equation may be written:

$$I = \frac{E}{R}$$

or

$$R = \frac{E}{I}$$

Power

$P = IE$

where P = power in watts

I = current in amperes

E = voltage in volts

This equation for power may also be transposed to:

$$I = \frac{P}{E}$$

or

$$E = \frac{P}{I}$$

From Ohm's law it is known that E = IR. If this expression for voltage is substituted in the power law, we can derive the additional equation: $P = I^2R$

If we use the equation for current from Ohm's law, I = E/R, the equation for power becomes:

$$P = \frac{E^2}{R}$$

---

*See "Ugly's Electrical Reference" (SEBD0983) for additional information.

Resistance

Series Circuits $R_T = R_1 + R_2 + R_3 + \ldots R_N$

$$\text{Parallel Circuits } R_T = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots \frac{1}{R_N}}$$

where R_N = resistance in the individual resistors

R_T = total resistance in circuit

Reactance

$X_L = 2 \pi f L$

where X_L = inductive reactance in ohms

f = frequency in hertz

L = inductance in henries

$\pi = 3.1416$

$$X_C = \frac{1}{2\pi f C}$$

where X_C = capacitive reactance in ohms

f = frequency in hertz

C = capacitance in farads

π = 3.1416

Impedance

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

where Z = impedance in ohms

R = resistance in ohms

X_L = inductive reactance in ohms

X_C = capacitive reactance in ohms

Note that the impendance will vary with frequency, since both X_C and X_L are frequency dependent. In practical AC power circuits, X_C is often small and can be neglected. In that case, the formula above simplifies to:

$$Z = \sqrt{R^2 + X_L^2}$$

Transformer Voltage Conversion

$$V_S = V_P \cdot \frac{N_S}{N_P}$$

where V_S = secondary voltage

V_P = primary voltage

N_S = number of secondary turns

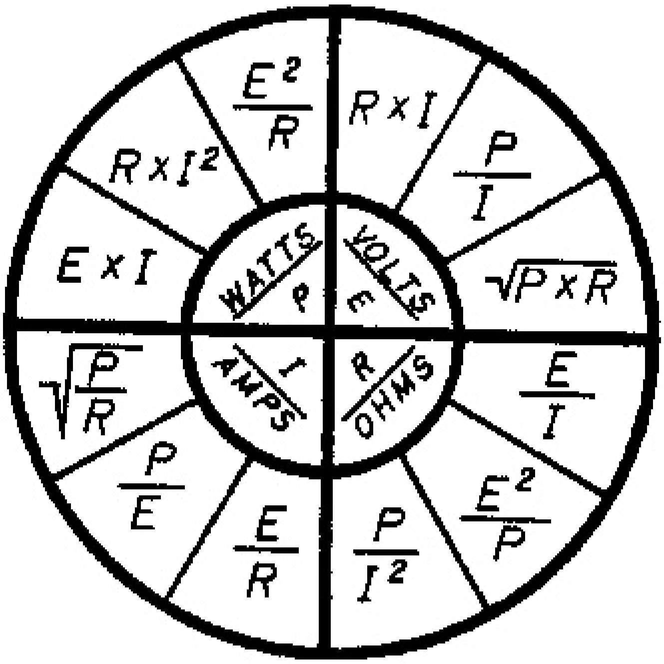
N_P = number of primary turns

Power Factor

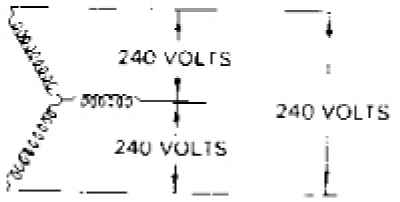
$$\text{Power Factor} = \frac{\text{Actual Power (watts)}}{\text{Apparent Power (V•A)}}$$

In mathematical terms, the power factor is equal to the cosine of the angle by which the current leads or lags the voltage. If the current lags the voltage in an inductive circuit by 60 degrees, the power factor will be 0.5, the value of the cosine function at 60 degrees. If the phase of the current in a load leads the phase of the voltage, the load is said to have a **leading power factor**; if it lags, **a lagging power** factor. If the voltage and current are in phase, the circuit has a **unity power factor**.

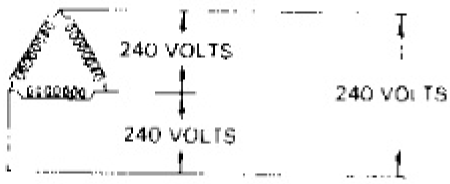
Equation Summary Diagram



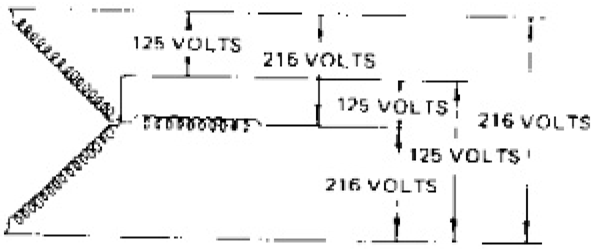
Three Phase Connection Systems:



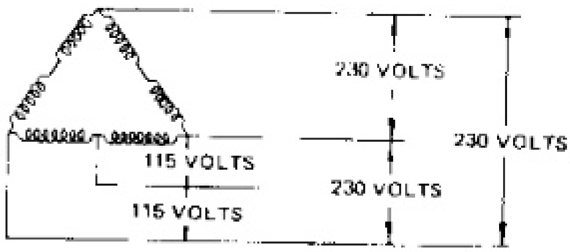
THREE PHASE, THREE WIRE (WYE)
A



THREE-PHASE, THREE-WIRE (DELTA)
B



THREE PHASE, FOUR WIRE (WYE)
C



THREE PHASE FOUR WIRE (DELTA)
D

Electrical Enclosure Protection = IEC

The degrees of protection provided within an electrical enclosure is expressed in terms of the letters IP followed by two numerals. Mechanical protection against impact damage is defined by an optional third numeral.

	First Numeral		Second Numeral		Third Numeral		
	Protection against:		Protection against:		Weight kg	Drop m	Impact J
0	Non-protected	0	Non-protected	0		Non-protected	
1	Object > 50 mm Dia.	1	Dripping Water	1	0.15	0.15	0.225
2	Object > 12 mm Dia.	2	Dripping Water (tilt up to 15°)	2	0.15	0.25	0.375
3	Object > 2.5 mm Dia.	3	Rain (tilt up to 60°)	3	0.25	0.20	0.50
4	Object > 1.0 mm Dia.	4	Splashing Water				
5	Dust-protected	5	Water Jets	5	0.50	0.40	2
6	Dust Tight	6	Heavy Seas				
		7	Immersion Effects	7	1.5	0.40	6
		8	Submersion Effects				
				9	5.0	0.40	20

Example: An IP55 enclosure protects its contents against dust and spray from water jets.

Reference: DIN 40050 of July 1980, IEC 144 of 1963, IEC 529 of 1976, NF C 20-010 of April 1977

Electrical Enclosure Protection - NEMA

Type	Use	Protection against
1	Indoor	Contact with enclosed equipment.
2	Interior	Limited amounts of falling water and dirt.
3	Outdoor	Windblown dust, rain, sleet, and external ice formation.
3R	Outdoor	Falling rain, sleet, and external ice formation.
3S	Outdoor	Windblown dust, rain, sleet, and external ice formation. (Provision for external mechanism operation when ice laden).
4	Indoor or Outdoor	Windblown dust and rain, splashing and hose-directed water.
4X	Indoor or Outdoor	Corrosion, windblown dust and rain, splashing and hose-directed water.
5	Interior	Dust and falling dirt.
6	Indoor or Outdoor	Occasional temporary submersion at a limited depth.
6P	Indoor or Outdoor	Occasional prolonged submersion at a limited depth.
11	Indoor	Corrosive liquids and gases (protection accomplished by oil immersion).
12	Indoor	Dust, falling dirt, and dripping non-corrosive liquids.
12K	Indoor	Dust, falling dirt, and dripping non-corrosive liquids except at knockouts. (knockouts permitted)
13	Indoor	Lint, dust, seepage, external condensation and spraying water, oil, and non-corrosive liquids.

Electrical Tables

Table 1 Electrical Formulae

	Alternating Current		
To Obtain	Single-Phase	Three-Phase	Direct Current
Kilowatts	$\frac{V \times I \times P.F.}{1000}$	$\frac{1.732 \times V \times I \times P.F.}{1000}$	$\frac{V \times I}{1000}$
KV•A	$\frac{V \times I}{1000}$	$\frac{1.732 \times V \times I}{1000}$	
Horsepower required when KW known (Generator)	$\frac{KW}{.746 \times EFF. (Gen.)}$	$\frac{KW}{.746 \times EFF. (Gen.)}$	$\frac{KW}{.746 \times EFF. (Gen.)}$
KW input when HP known (Motor)	$\frac{HP \times .746}{EFF. (Mot.)}$	$\frac{HP \times .746}{EFF. (Mot.)}$	$\frac{HP \times .746}{EFF. (Mot.)}$
Amperes when HP known	$\frac{HP \times 746}{V \times P.F. \times EFF.}$	$\frac{HP \times 746}{1.732 \times V \times EFF. \times P.F.}$	$\frac{HP \times 746}{V \times EFF.}$
Amperes when KW known	$\frac{KW \times 1000}{V \times P.F.}$	$\frac{KW \times 1000}{1.732 \times V \times P.F.}$	$\frac{KW \times 1000}{V}$
Amperes when KV•A known	$\frac{KV•A \times 1000}{V}$	$\frac{KV•A \times 1000}{1.732 \times V}$	

Table 1 — Electrical Formulae (cont.)

Frequency (c.p.s.)	$\frac{\text{Poles} \times \text{RPM}}{120}$	$\frac{\text{Poles} \times \text{RPM}}{120}$	
Reactive KV•A (KVAR)	$\frac{V \times I \times \sqrt{1 - (PF)^2}}{1000}$	$\frac{1.732 \times V \times I \times \sqrt{1 - (PF)^2}}{1000}$	
% Voltage Regulation	$\frac{100\,(V_{NL} - V_{FL})}{V_{FL}}$	$\frac{100\,(V_{NL} - V_{FL})}{V_{FL}}$	$\frac{100\,(V_{NL} - V_{FL})}{V_{FL}}$

The following abbreviations are used in the table:

- V = voltage in volts
- I = current in amperes
- KW = power in kilowatts (actual power)
- KV•A = kilovolt-amperes (apparent power)
- HP = horsepower
- RPM = revolutions per minute
- KVAR = reactive kilovolt-amperes
- EFF. = efficiency as a decimal factor
- NL = no load
- FL = full load

Because the basic units of electrical quantities are often inconveniently large or small, prefixes are often added to the terms which denote those units. The prefixes have the effect of multiplying or dividing the quantity by some factor, usually one thousand or one million. "kilo—" is used, for instance, to express a multiplication of one thousand. A kilovolt (kV) is therefore 1000 volts. A milliampere (mA) is one thousandth of an ampere. The commonly-used prefixes, their multiplying factors and their abbreviations are tabulated below:

Prefix	Factor	Symbol
kilo—	× 1000	k
mega—	× 1,000,000	M
milli—	÷ 1000	m
micro—	÷ 1,000,000	μ

Table 2 KV·A of AC Circuits

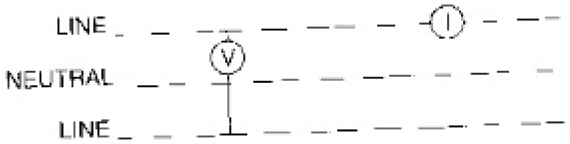
Table 2
KV•A of AC Circuits

Single-Phase, Two-Wire

$$KV{\bullet}A = \frac{V \times I}{1000}$$

Single-Phase, Three-Wire — Balanced

$$KV{\bullet}A = \frac{V \times I}{1000}$$



Single-Phase, Three-Wire — Unbalanced

$$KV{\bullet}A = \frac{(V_1 \times I_1) + (V_2 \times I_2)}{1000}$$

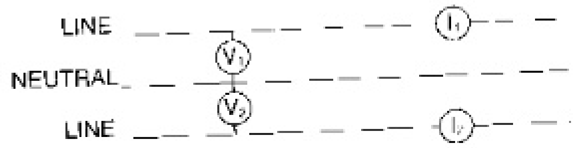
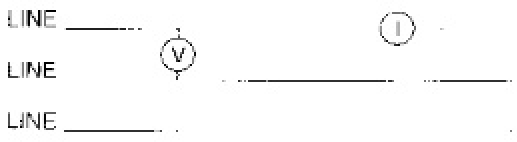


Table 2 — KV•A of AC Circuits (cont.)

Three-Phase, Three-Wire — Balanced

$$KV{\bullet}A = \frac{1.732 \times V \times I}{1000}$$



Three-Phase, Three-Wire — Unbalanced

$$KV{\bullet}A = \frac{1.732 \times V \times \left(\frac{I_1 + I_2 + I_3}{3}\right)}{1000}$$

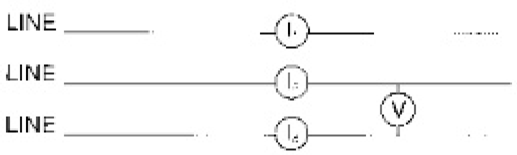
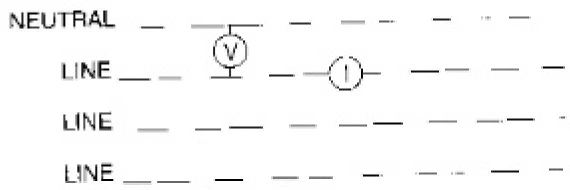


Table 2 — KV•A of AC Circuits (cont.)

Three-Phase, Four-Wire — Balanced

$$KV{\bullet}A = \frac{1.73 \times V \times I}{1000}$$



Three-Phase, Four-Wire — Unbalanced

$$KV{\bullet}A = \frac{1.73 \times V \times \left(\frac{I_1 + I_2 + I_3}{3}\right)}{1000}$$

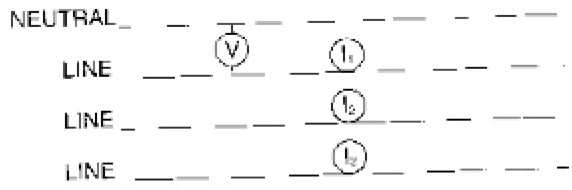


Table 3 Copper Wire Characteristics

Table 3
Copper Wire Characteristics

Wire Size AWG (B & S)	Diam. in Mils	Circular mil Area	Ohms per 1000 ft. 25°C (77°F)	Diam. in mm	Nearest British SWG No.
1	289.3	83690	.1264	7.348	1
2	257.6	66370	.1593	6.544	3
3	229.4	52640	.2009	5.827	4
4	204.3	41740	.2533	5.189	5
5	181.9	33100	.3195	4.621	7
6	162.0	26250	.4028	4.115	8
7	144.3	20820	.5080	3.665	9
8	128.5	16510	.6405	3.264	10
9	114.4	13090	.8077	2.906	11
10	101.9	10380	1.018	2.588	12
11	90.7	8234	1.284	2.305	13
12	80.8	6530	1.619	2.053	14
13	72.0	5178	2.042	1.828	15
14	64.1	4107	2.575	1.628	16
15	57.1	3257	3.247	1.450	17
16	50.8	2583	4.094	1.291	18
17	45.3	2048	5.163	1.150	18
18	40.3	1624	6.510	1.024	19
19	35.9	1288	8.210	.912	20
20	32.0	1022	10.35	.812	21

Table 4 Single-Phase AC Motors Full Load Currents in Amperes

Table 4
Single-Phase AC Motors
Full Load Currents in Amperes

HP	115 V	208 V	230 V	440 V
¼	5.8	3.2	2.9	
⅓	7.2	4.0	3.6	
½	9.8	5.4	4.9	
¾	13.8	7.6	6.9	
1	16	8.8	8	
1½	20	11	10	
2	24	13.2	12	
3	34	19	17	
5	56	31	28	
7½	80	44	40	21
10	100	55	50	26

Table 5 Three-Phase AC Motors - 80% Power Factor Full Load Current in Amperes - Induction-Type, Squirrel Cage and Wound Rotor

Table 5
Three-Phase AC Motors — 80% Power Factor
Full Load Current in Amperes — Induction-Type, Squirrel Cage and Wound Rotor

HP	110 V	208 V	220 V	440 V	550 V	2300 V
½	4	2.1	2	1	.8	
¾	5.6	3.0	2.8	1.4	1.1	
1	7	3.7	3.5	1.8	1.4	
1½	10	5.3	5	2.5	2.0	
2	13	6.9	6.5	3.3	2.6	
3		9.5	9	4.5	4	
5		16	15	7.5	6	
7½		23	22	11	9	
10		29	27	14	11	
15		43	40	20	16	
20		55	52	26	21	
25		68	64	32	26	7
30		83	78	39	31	8.5
40		110	104	52	41	10.5
50		133	125	63	50	13
60		159	150	75	60	16

Table 5 — Three-Phase AC Motors (cont.)

HP	110 V	208 V	220 V	440 V	550 V	2300 V
75		198	185	93	74	19
100		262	246	123	98	25
125		330	310	155	124	31
150		360	360	180	144	37
200		510	480	240	192	48
250		697	657	328	262	65.7
300		837	790	394.5	315	78.8
350		976	922	461	368	92.2
400		1114	1051	526	421	105.2
450		1254	1192	592	473	118.3
500		1393	1317	657	526	130
600		1672	1578	789	632	157
700		1950	1842	921	737	184
800		2220	2103	1051	842	210
900		2504	2365	1194	947	233
1000		2789	2639	1316	1050	265

Table 6 Direct Current Motors Full Load Current in Amperes

Table 6
Direct Current Motors
Full Load Current in Amperes

HP	115 V	230 V	550 V
1/4	3	1.5	
1/3	3.8	1.9	
1/2	5.4	2.7	
3/4	7.4	3.7	1.6
1	9.6	4.8	2.0
1 1/2	13.2	6.6	2.7
2	17	8.5	3.6
3	25	12.5	5.2
5	40	20	8.3
7 1/2	58	29	12
10	76	38	16
15	112	56	23
20	148	74	31
25	184	92	38
30	220	110	46
40	292	146	61
50	360	180	75
60	430	215	90
75	536	268	111
100		355	148
125		443	184
150		534	220
200		712	295

Table 7 Conduit Sizes for Conductors

Table 7
Conduit Sizes for Conductors

Size AWG or MCM	Number of Conductors in One Conduit or Tubing* 1	2	3	4	5	6	7	8	9
18	½	½	½	½	½	½	½	¾	¾
16	½	½	½	½	½	½	¾	¾	¾
14	½	½	½	½	¾	¾	1	1	1
12	½	½	½	¾	¾	1	1	1	1¼
10	½	¾	¾	¾	1	1	1	1¼	1¼
8	½	¾	¾	1	1¼	1¼	1¼	1½	1½
6	½	1	1	1¼	1½	1½	2	2	2
4	½	1¼	†1¼	1½	1½	2	2	2	2½
3	¾	1¼	1¼	1½	2	2	2	2½	2½
2	¾	1¼	1¼	2	2	2	2½	2½	2½
1	¾	1¼	1½	2	2½	2½	2½	3	3
0	¾	1½	2	2	2½	2½	3	3	3
00	1	2	2	2½	2½	3	3	3	3½
000	1	2	2	2½	3	3	3	3½	3½
0000	1¼	2	2½	3	3	3	3½	3½	4
250	1¼	2½	2½	3	3	3½	4	4	5
300	1¼	2½	2½	3	3½	4	4	5	5
350	1½	3	3	3½	3½	4	5	5	5
400	1½	3	3	3½	4	4	5	5	5
500	1½	3	3	3½	4	5	5	5	6
600	2	3½	3½	4	5	5	6	6	6
700	2	3½	3½	5	5	5	6	6	
750	2	3½	3½	5	5	6	6	6	
800	2	3½	4	5	5	6	6		
900	2	4	4	5	6	6	6		
1000	2	4	4	5	6	6			
1250	2½	5	5	6	6				
1500	3	5	5	6					
1750	3	5	6	6					
2000	3	6	6						

Table 7 — Conduit Sizes for Conductors (cont.)

† Where a service run of conduit or metallic tubing does not exceed 50 feet (15.3 m) in length and does not contain more than the equivalent of two quarter bends from end to end, two No. 4 insulated and one No. 4 bare conductors may be installed in 1-inch (25.4 mm) conduit or tubing.

Table 8 Allowable Current-Carrying Capacities of Insulated Copper Conductors

Table 8
Allowable Current-Carrying Capacities of Insulated Copper Conductors*

	60°C	75°C	85°C	110°C	125°C	200°C
	Types of Insulation					
	Rubber		Paper	Asbestos		
Size AWG or MCM	R, RW, RU, RUW 14-2 Thermoplastic T, TW	Type RH, RHW	Var-Cam-Type V 90°C Thermoplastic Asbestos-TA Asbestos-Var-Cam-AVB	Var-Cam Type AVA Type AVL	Impregnated Type A1 14-8 A1A	Type A 14-8 AA
14	15	15	25	30	30	30
12	20	20	30	35	40	40
10	30	30	40	45	50	55
8	40	45	50	60	65	70
6	55	65	70	80	85	95
4	70	85	90	105	115	120
3	80	100	105	120	130	145
2	95	115	120	135	145	165
1	110	130	140	160	170	190
0	125	150	155	190	200	225
00	145	175	185	215	230	250
000	165	200	210	245	265	285
0000	195	230	235	275	310	340

* With not more than three conductors in a raceway or cable and a room temperature of 30°C (86°F).

Table 8 -- Allowable Current-Carrying Capacities of Insulated Copper Conductors* (cont.)

250	215	255	270	315	335	
300	240	285	300	345	380	
350	260	310	325	390	420	
400	280	335	360	420	450	
500	320	380	405	470	500	
600	355	420	455	525	545	
700	385	460	490	560	600	
750	400	475	500	580	620	
800	410	490	515	600	640	
900	435	520	555			
1000	455	545	585			
1250	495	590	645	680	730	

Correction Factors for Room Temperatures Over 30°C

C	F					
40	104	0.82	0.88	0.90	0.94	0.95
45	113	0.71	0.82	0.85	0.90	0.92
50	122	0.58	0.75	0.80	0.87	0.89

* With not more than three conductors in a raceway or cable and a room temperature of 30°C (86°F).

Table 9 Code Letters Usually Applied to Ratings of Motors Normally Started on Full Voltage

Table 9
Code Letters Usually Applied to Ratings of Motors Normally Started on Full Voltage

Code Letters		F	G	H	J	K	L
Horse-	3-phase	15-up	10-7½	5	3	2-1½	1
power	1-phase	—	5	3	2-1½	1-¾	½

Table 10 Identifying Code Letters on AC Motors

Table 10
Identifying Code Letters on AC Motors*

NEMA Code Letter	Starting KV•A per HP
A	0.00-3.14
B	3.15-3.54
C	3.55-3.99
D	4.00-4.49
E	4.50-4.99
F	5.00-5.59
G	5.60-6.29
H	6.30-7.09
J	7.10-7.99
K	8.00-8.99
L	9.00-9.99
M	10.00-11.19
N	11.20-12.49
P	12.50-13.99
R	14.00-15.99
S	16.00-17.99
T	18.00-19.99
U	20.00-22.39
V	22.40-

* Wound rotor motor has no code letter.

NOTE: Code letters apply to motors up to 200 HP.

Table 11 Conversion - Heat and Energy

Table 11
Conversion — Heat and Energy

1 — Kilowatt =	1.341 horsepower 44,254 foot pounds/minute 56.883 Btu/minute
1 — Kilowatt Hour =	1.341 horsepower hours 2,655,217 foot pounds 3413 Btu
1 — British Thermal Unit (Btu) =	777.97 foot pounds 1054.8 watt seconds 0.000293 kilowatt hours 0.293 watt hours 0.000393 horsepower hours
1 — Horsepower Hour =	0.7457 kilowatt hours 1,980,000 foot pounds 2545 Btu
1 — Horsepower =	0.7457 kilowatt 745.7 watts 33,000 foot pounds/minute 42,418 Btu/minute 1.0139 metric horsepower

Table 12 Approximate Efficiencies - Squirrel Cage Induction Motor

Table 12
Approximate Efficiencies —
Squirrel Cage Induction Motor

HP	Full Load KW Required	Full Load Efficiency
½	0.6	68%
¾	0.8	71%
1	1.0	75%
1½	1.5	78%
2	1.9	80%
3	2.7	82%
5	4.5	83%
7½	6.7	83%
10	8.8	85%
15	13.0	86%
20	16.8	89%
25	21.0	89%
30	24.9	90%
40	33.2	90%
50	41.5	90%
60	49.2	91%
75	61.5	91%
100	81.2	92%
125	101.5	92%
150	122.0	92%
200	162.5	92%
250	203.0	92%
300	243.0	92%
350	281.0	93%
400	321.0	93%
450	362.0	93%
500	401.0	93%
600	428.0	93%

NOTE: Efficiencies listed are approximate only for new or near new motors. For accurate efficiency figures check motor nameplate data with motor manufacturer or manufacturer's representative.

Table 13 - Approximate Electric Motor Efficiency to Use in Calculating Input

Table 13 — Approximate Electric Motor Efficiency to Use in Calculating Input									
Motor Sizes	1 to 3 HP			5 to 15 HP			30 to 60 HP		
Load	½	¾	4/4	½	¾	4/4	½	¾	4/4
Direct Current (a) Shunt wound (b) Compound wound (c) Series wound	78	82	83	80	83	85	86	87	88
Alternating Current Single-Phase (a) Commutator type	65	72	75	75	78	80			
Two- or Three-Phase Squirrel Cage (a) General Purpose Normal starting current Normal starting torque	78	80	80	84.5	85	85	85	86	89
(b) Low starting current Normal starting torque				82	83	83	88	89	89
(c) Low starting current High starting torque				83	83	82	88	89	89
Slip Ring Motor				81	82	83	88	89	90
Synchronous Motor							85	88	89

It is to be noted that efficiency of electric motors varies with speed, type and line voltage. The above percentages are therefore approximate and are intended only to assist in calculating input. Where the margin of power of generator over actual requirements is shown to be quite close, it is well to obtain true efficiency of motors from motor manufacturer.

Table 14 Reduced Voltage Starters

Table 14
Reduced Voltage Starters

Type of Starter	Motor Voltage % Line Voltage	Line Current % Full Voltage Starting Current	Starting Torque % of Full Voltage Starting Torque
Full Voltage Starter	100	100	100
Auto Transformer 80% tap 65% tap 50% tap	 80 65 50	 68 46 30	 64 42 25
Resistor Starter Single Step (adjusted for motor voltage to be 80% of line voltage)	80	80	64
Reactor 50% tap 45% tap 37.5% tap	 50 45 37.5	 50 45 37.5	 25 20 14
Part Winding (low speed motors only) 75% winding 50% winding	 100 100	 75 50	 75 50

Marine Engine Performance Analysis

3600 Performance Analysis Rules of Thumb

Air Intake System:

Air Temp at Air Cleaner	49°C (120°F) Max.
Inlet Air Restriction	15 in-H_2O/5 in New Max.
Intake Manifold Air Temperature	65°C (150°F) Nominal 92°C (197°F) Alarm
Intake Manifold Air Pressure	Nominal Values in Perf Book Measure at part and full load
Crankcase Pressure/ Vacuum	–1 to + 2 in-H_2O (–0.25 to + 0.5 kPa) 2.5 in-H_2O (1 kPa) Alarm

Exhaust System:

Exhaust Stack Temperature	Nominal Temp in Perf Book 550°C (1022°F) Alarm
Individual Cyl Exhaust Port Temperature	50°C (122°F) Maximum Variation between Cyl
Exhaust Back Pressure	10 in-H_2O (2.5 kPa) Max. 0.8% Loss in fuel economy (increase in BSFC) for each 10 in-H_2O above 10 in-H_2O

Lubrication System:

Engine Oil to Bearing Temperature	85°C (185°F) Nominal 92°C (197°F) Alarm
Engine Oil to Bearing Pressure	450 kPa (65 psi) Nominal 320 kPa (46 psi) Alarm
Oil Filter Pressure Differential	100 kPa (15 psi) Max.

Fuel System:

Fuel Pressure . . . . 425-550 kPa (62-80 psi)
Fuel Supply Temperature. . . . . . *Distillate Fuel
29°C (85°F) Max. Desired 1% Power reduction for each 6°C (10°F) increase above 29°C (85°F) 65°C (150°F) Max. to prevent injector damage
Fuel Filter Pressure
Differential . . . . 70 kPa (10 psi) Max.
Fuel Pump Inlet
Restriction . . . . –39 kPa (–6 psi) Max.
Fuel Return Line
Restriction . . . . 350 kPa (51 psi) Max.

Cooling System:

Heat Exchanger System External Resistance
(Combined & Separate Circuit)
— Measure at engine outlet and compare to heat exchanger outlet (before regulators)
— Temperature Regulators 100% OPEN (blocked)
SPECS:

1000 RPM	90 kPa (13 psi)
900 RPM	73 kPa (11 psi)
720 RPM	47 kPa (7 psi)

Aftercooler Water Inlet
Temperature. . . . . 50°C (122°F) Nominal
*65°C (150°F) Max. under certain special conditions
Aftercooler Water Outlet
Temperature. . . . . 50°C (122°F) + Delta T
Oil Cooler Water Inlet
Temperature . . . . 50°C (122°F) Nominal
*65°C (150°F) Max. under certain special conditions
Oil Cooler Water Outlet
Temperature . . . . 50°C (122°F) + Delta T
Jacket Water Pump Inlet
Temperature . . . . 85°C (185°F) Nominal
Jacket Water Block Outlet
Temperature . . . . 85°C (185°F) + Delta T
A/C & O/C Water Pump
Inlet Pressure. . . . . –5 kPa (–20 in-H_2O) Min.
Jacket Water Pump Inlet
Pressure. . . . . 30 kPa (5 psi) Min.

General Service Information
ENGINE INSTALLATION & SERVICE HANDBOOK
Media Number -LEBV0915-05 Publication Date -01/01/1997 Date Updated -26/04/2006

LEBV09150018

Cat Marine/Industrial Engine Diagnostic Codes

Code	Description	Flash Code
1-11	Cylinder 1 Fault	72
2-11	Cylinder 2 Fault	72
3-11	Cylinder 3 Fault	73
4-11	Cylinder 4 Fault	73
5-11	Cylinder 5 Fault	74
6-11	Cylinder 6 Fault	74
17-05	Shut Off Solenoid Open Circuit	45
17-06	Shut Off Solenoid Short Circuit	45
22-13	Check Timing Sensor Calibration	42
23-02	Excessive Engine Power	48
25-05	Rack BTM Open Circuit	43
25-06	Rack BTM Short Circuit	43
24-02	Loss of Rack Sensor Signal	22
24-03	Rack Sensor Open Circuit	22
24-04	Rack Sensor Short Circuit	22
24-07	Rack System Fault	43
24-08	Invalid Rack Sensor Signal	
24-10	Rack Sensor Rate of Change	22
41-03	8 Volt Supply Above Normal	21
41-04	8 Volt Supply Below Normal	21
64-00	Backup Engine Overspeed Warning	35
64-02	Loss of Backup Engine RPM Signal	34
64-08	Backup Engine Speed Out of Range	33
68-01	Secndry Atm Pr Sensor Low Pres	
68-03	Secndry Atm Pr Sensr open/short to batt+	
68-04	Secndry Atm Pr Sensor short to ground	
68-10	Secndry Atm Pr Sensor Rate of Change	
69-00	High ACOC Coolant Temp Warning	
91-08	Invalid Throttle Signal	32
91-10	Throttle Sensor Rate of Change	32
91-13	Throttle Sensor Calibration	28

Code	Description	Flash Code
94-01	Low Fuel Pressure Warning	63
94-03	Fuel Pressure Sensor Open Circuit	37
94-04	Fuel Pressure Sensor Short Circuit	37
95-00	Fuel Filter Restriction Warning	
98-01	Low Engine Oil Level Warning	
99-00	Engine Oil Filter Restriction Warning	
100-01	Low Oil Pressure Warning	46
100-03	Oil Pressure Sensor Open Circuit	24
100-04	Oil Pressure Sensor Short Circuit	24
100-10	Oil Pressure Sensor Rate of Change	24
100-11	Very Low Oil Pressure	46
100-14	Low Oil Pressure Shutdown	
101-00	High Crankcase Air Pressure Warning	
101-14	High Crankcase Air Pressure Shutdown	
102-00	Boost Pressure Reading Stuck High	25
102-01	Boost Pressure Reading Stuck Low	25
102-03	Boost Pressure Sensor Open Circuit	25
102-04	Boost Pressure Sensor Short Circuit	25
102-10	Turbo Surge	
102-13	Boost Pressure Sensor Calibration	42
105-00	High In Manifold Temp Warning	64
105-03	In Manifold Temp Sensor Open Ckt	38
105-04	In Manifold Temp Sensor Short Ckt	38
105-11	Very High In Manifold Temp	64
106-01	Low Atmospheric Pressure Reading	26
106-03	Atm Pressure Sensor Open Circuit	26
106-04	Atm Pressure Sensor Short Circuit	26
106-10	Atm Pressure Sensor Rate of Change	26
108-03	Atmospheric Pr Sensor Open Circuit	26
108-04	Atmospheric Pr Sensor Short Circuit	26
110-00	High Coolant Temperature Warning	61

Code	Description	Flash Code
110-01	Low Coolant Temperature	
110-03	Coolant Temp Sensor Open Circuit	27
110-04	Coolant Temp Sensor Short Circuit	27
110-11	Very High Coolant Temperature	61
110-14	High Coolant Temperature Shutdown	
111-01	Low Coolant Level Warning	62
111-02	Coolant Level Sensor Fault	12
111-11	Very Low Coolant Level	62
127-00	High Trans Oil Pressure Warning	86
127-01	Low Trans Oil Pressure Warning	86
127-03	Trans Oil Pr Sensor Open Circuit	64
127-04	Trans Oil Pr Sensor Short Circuit	64
127-10	Trans Oil Pr Sensor Rate of Change	64
127-11	Very Low Trans Oil Pressure	86
168-01	Battery Voltage Below Normal	17
168-02	Intermittent Battery	51
172-00	High Inlet Air Temp Warning	64
172-03	Inlet Air Temp Sensor Open Circuit	38
172-04	Inlet Air Temp Sensor Short Circuit	38
174-00	High Fuel Temp Warning	65
174-03	Fuel Temp Sensor Open Circuit	13
174-04	Fuel Temp Sensor Short Circuit	13
175-00	High Engine Oil Temperature Warning	
175-01	Low Engine Oil Temperature	
175-03	Engine Oil Temp open/short to batt+	
175-04	Engine Oil Temp short to ground	
175-14	High Engine Oil Temperature Shutdown	
177-00	High Trans Oil Temperature Warning	81
177-03	Trans Oil Temp Sensor Open Circuit	67
177-04	Trans Oil Temp Sensor Short Circuit	67
177-11	Very High Trans Oil Temperature	81

Code	Description	Flash Code
190-00	Engine Overspeed Warning	35
190-02	Loss of Engine RPM Signal	34
190-08	Engine Speed Out of Range	33
190-10	Engine Speed Rate of Change	34
190-14	Engine Overspeed Shutdown	
232-03	5 Volt Supply Above Normal	21
232-04	5 Volt Supply Below Normal	21
241-00	5 Volt Open Circuit	21
241-01	5 Volt Short Circuit	21
241-02	8 Volt Open Circuit	21
241-03	8 Volt Short Circuit	21
248-09	CAT Data Link Fault	59
252-11	Incorrect Engine Software	50
252-12	Personality Module Fault	52
253-02	Check Customer or System Parameters	56
254-12	ECM Fault	53

Flash Code	Description
12	Coolant Level Sensor Fault
13	Fuel Temperature Sensor Fault
21	Sensor Supply Voltage Fault
22	Rack Position Sensor Fault
24	Oil Pressure Sensor Fault
25	Boost Pressure Sensor Fault
26	Atmospheric Pressure Sensor Fault
27	Coolant Temperature Sensor Fault
28	Check Throttle Sensor Adjustment
32	Throttle Position Sensor Signal Fault
33	Engine RPM Signal Out of Range
34	Engine RPM Signal Fault
35	Engine Overspeed Warning
37	Fuel Pressure Sensor Fault
38	Inlet Manifold Temperature Sensor Fault
42	Check Sensor Calibrations
43	Rack Subsystem Fault
45	Shut Off Solenoid Fault
46	Low Oil Pressure Warning
48	Excessive Engine Power
51	Intermittent Battery
52	Personality Module Fault
53	ECM Fault
55	No Detected Faults
56	Check Customer or System Parameters
58	CAT Data Link Fault
59	Incorrect Engine Software
61	High Coolant Temperature Warning
62	Low Coolant Level Warning
63	Low Fuel Pressure Warning
64	High Inlet Manifold Temperature Warning
64	Transmission Oil Pressure Sensor Fault
65	High Fuel Temperature Warning
67	Transmission Oil Temperature Sensor Fault
72	Cylinder 1 or 2 Fault
73	Cylinder 3 or 4 Fault
74	Cylinder 5 or 6 Fault
81	High Transmission Oil Temp Warning
86	Transmission Oil Pressure Warning

LEBV09150019

Caterpillar Sea Trial Rules of Thumb - Marine Engine Performance Specifications*

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*Excluding 3600.

Engine Jacket Water System:

JW Temp (From Cooler):

All except 3208 (355/375 HP) . . . 99° C-Delta T ° C/ 210° F-Delta T ° F Max.

3208 (355 and 375 HP) . . . . 102° C-Delta T ° C/ 215° F-Delta T ° F Max.

JW Outlet Temp (Before Reg):

All except 3208 (355/375 HP) . . . 99° C/210° F Max.

3208 (355 and 375 HP) . . . . 102° C/215° F Max.

JW Temp (After Water Pump):

All except 3208 (355/375 HP) . . . 99° C-Delta T ° C/ 210° F-Delta T ° F Max.

3208 (355 and 375 HP) . . . . 102° C-Delta T ° C/ 215° F-Delta T ° F Max.

Engine Lubrication System:

Oil Temperature to Bearings:

3200 . . . . 116° C/240° F Max.

3300, 3400, 3500, 3114/3116 . . . 110° C/230° F Max.

300 . . . . 104° C/220° F Max.

Oil Manifold Pressure:

3114/3116 . . . . 250 kPa/36 psi Min.

3200 . . . . 345 kPa/50 psi Min.

3300 . . . . 207 kPa/30 psi Min.

300, 3400, 3500 . . . . 276 kPa/40 psi Min.

Engine Fuel System:

Fuel Transfer Pump Pressure:

All except 3500 . . . . 172 kPa/25 psi Min.

3500 . . . . 379 kPa/55 psi Min.

Engine Exhaust Back Pressure:

Exhaust Back Pressure:

Naturally Aspirated . . . . 8.5 kPa/34 in-H_2O Max.

Turbocharged . . . . 6.7 kPa/27 in-H_2O Max.

3208 @ 435 HP . . . . 10.0 kPa/40 in-H_2O

3116 @ 300 HP . . . . 10.0 kPa/40 in-H_2O

*Excluding 3600.

Marine Engine Performance Specifications* (cont.)

Engine Crankcase Pressure:	
Crankcase Pressure:	
All except 3208	0.5 kPa/2 in-H_2O Max.
3208	1.0 kPa/4 in-H_2O Max.
Engine Air System:	
Inlet Air Temp @ Air Cleaner	49° C/120° F Max.
Engine Room Temperature	8° C/10° F above ambient (5.5° C)
Inlet Air Restriction	4 kPa/15 in-H_2O
Inlet Air Manifold Temp:	
Naturally Aspirated	49° C/120° F Max.
Turbocharged	163° C/325° F Max.
Turbocharged JWAC	118° C/245° F Max.
Turbocharged SCAC 85° F	52° C/125° F Max.
Turbocharged SCAC 100° F	66° C/150° F Max.
3208 High Performance (435 and 375 HP)	60° C/140° F Max.
Engine Aftercooler System:	
Aftercooler Inlet H_2O Temp:	
Turbocharged JWAC	99° C-Delta T ° C/ 210° F-Delta T ° F Max.
Turbocharged SCAC 85° F	29° C/85° F Max.
Turbocharged SCAC 110° F	43° C/110° F Max.
Aftercooler Outlet H_2O Temp.	
Turbocharged JWAC	99° C/210° F Max.
Turbocharged SCAC 85° F	52° C/125° F Max.
Turbocharged SCAC 110° F	66° C/150° F Max.
3208 (355 and 375 HP)	60° C/140° F Max.

*Excluding 3600.

General Rules of Thumb

English Units

Air Compressors:

BHP = 1/4 × cu. ft. per minute at 100 psi

Increase BHP 10% for 125 psi

Decrease BHP 10% for 80 psi

AMA HP for U.S.A. Tax Purposes:

$$\frac{ND}{2.5}$$

Where: N = No. of Cylinders

D = Piston Diameter in inches

Brake Mean Effective Pressure:

$$\text{BMEP (4-cycle)} = \frac{792{,}000 \times \text{BHP}}{\text{RPM} \times \text{Displacement}}$$

$$\text{BMEP (2-cycle)} = \frac{396{,}000 \times \text{BHP}}{\text{RPM} \times \text{Displacement}}$$

$$\text{BMEP (4-cycle)} = \frac{150.8 \times \text{Torque}}{\text{Displacement}}$$

Conveyors: 15 to 20° incline.

$$\text{BHP} = \frac{\text{Vertical lift in feet} \times \text{tons per hour}}{500}$$

Cooling:

Heat Exchanger Flow Rate

Raw water to jacket water 1:1 to 2:1

Submerged Pipe Cooling

1/2 Sq. ft. surface area per HP

With 85°F flowing raw water

Electricity:

Generator Capacity Required:

Motors:

1 kW per nameplate HP (motor running cool or warm to touch)

11/4 kW per nameplate HP (motor running hot to touch)

Horsepower Requirements:

11/2 BHP per kW of load or

$$\frac{kW}{0.746 \times \text{Gen. Eff.}}$$

Electric Sets:

Motor Starting Requirements:

Inrush kVa (Code F motor) = 5.5 × BHP

Inrush Current (Code F motor)= 6.2 × Full load rated current

1 kVa per HP at full load

Generator full load rated current capacity:

Voltage	Rated Current
120	6.01 × kW
208	3.47 × kW
240	3.01 × kW
480	1.50 × kW
2400	0.30 × kW
4160	0.17 × kW

Generator Cooling Requirements:

Air Flow - 150°CFM per kW loss × efficiency

Circuit Breaker Trip Selection:

1.15 to 1.25 × full load generator amp rating

Single Phase Rating of 3-Phase Generator:

60% of 3-phase rating

Generator Temperature Rise:

Increase 1°C for each 330 feet above 3300 feet

Fuel Consumption

BHP = GPH fuel × 19	Diesel	1/19 gal. per BHP-Hr.
BHP = GPH fuel × 11	Gasoline	1/11 gal. per BHP-Hr.
BHP = Cu. Ft. Hr. fuel × 1/8	Natural Gas*	8 to 9 cu. ft. per BHP-Hr.
kW = GPH fuel × 14	Diesel	1/14 gal. per kW-Hr.

*905 BTU gas.

Gas Compressor:

BHP = 22 RcVS

Where: Rc = Stage Compression Ratio

V = Million cu. ft./day

S = Number of Stages

Heat Rejection

% of Fuel Energy Consumed

BHP	33%
Jacket Water	30%
Exhaust	30%
Radiation	7%

Jacket Water

Prechambered engines

BTU/min = 36 × BHP

Direct injection engines

BTU/min = 27 × BHP

Oil Cooler	BTU/min. =	5 × BHP
Watercooled Manifold	BTU/min. =	7 × BHP
Torque Convertor	BTU/min. =	42.4 × BHP input × $\frac{(100 - \text{conv. eff.})}{100}$

Hours Per:

Year = 8760 (365 Days)

Week = 168 (7 Days)

Month = 720 (30 Days)

Oilfield Drilling:

Hoisting

$$BHP = \frac{\text{Weight} \times \text{FPM (assume 100 if unknown)}}{33{,}000 \times 0.85 \text{ (eff.)}}$$

Mud Pumps

$$BHP = \frac{\text{GPM} \times \text{lb./gal.} \times \text{(feet of head)}}{33{,}000 \times \text{pump efficiency (see pumps)}}$$

Rotary Table

Depth in feet	BHP Required
0- 4000	75
4000- 8000	100
8000-12000	150
12000-16000	200

On Site Power Requirements:

Based on 100,000 sq. ft. of office bldg., etc., and 40°N. latitudes

Electric Requirements:

600 kW continuous load

(air conditioning is absorption)

Use three - 300 kW units (2 prime and 1 standby)

Air Conditioning Compressor

400 tons prime load

Use two - 200 HP engines (No standby)

Pumps:

$$\text{Deep Well BHP} = \frac{\text{Feet of lift per 1000 GPM}}{3}$$

Pipe Line BHP = Barrels per hour × psi × 0.00053

$$\text{Any Liquid BHP} = \frac{\text{GPM} \times \text{lb/gal. (Liquid)} \times \text{feet of head}}{33{,}000 \times \text{pump efficiency}^{*}}$$

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*Efficiency

Centrifugal	
Single impeller, double suction	65-80%
Simple impeller, side suction	55-75%
Deep well turbine	65-80%
Reciprocating	75%

Refrigeration

One ton refrigeration = 200 BTU/Min. = 12,000 BTU/Hr.

One boiler HP = 33,475 BTU/Hr.

One ton compressor rating = One Engine HP

Auxiliary air conditioning equipment requires 1/4 HP per ton of compressor rating

Ice Plant:

Complete power requires 4-5 HP per daily ton capacity

Sawmill:

11/2 BHP per inch of saw diameter at 500 RPM

Increase or decrease in proportion to RPM

Swing Cut-Off Saw

24-inch	3 BHP
36-inch	7½ BHP
42-inch	10 BHP

Table Trimmer 71/2 to 10 BHP

Blower Fan 12-foot sawdust 3 to 5 BHP

Planer Mill 2 to 4 BHP per 100 board feet per hour 24 to 30-inch planers 15 to 25 BHP

Edgers

2 saws	12 to 15 BHP
3 saws	15 to 25 BHP
Slab saw	10 BHP
Jack Ladder	10 BHP

Approximate fuel consumption:

Softwood 1 gal. per 1000 board feet

Hardwood 1 gal. per 750 board feet

Propellor Shaft Size Selection:

For intermediate shaft and tailshaft in marine installations

$$D = 68.47 \sqrt[3]{\frac{HP}{RPM \times S}}$$

Where: D = Diameter in inches

HP = Horsepower

S = Torsional stress in PSI (usually 5000)

Shovels and Draglines:

Use manufacturer's recommendations.

Torque: (4 cycle only)

$$T \text{ in lb. ft.} = \frac{\text{Displacement} \times BMEP}{150.8}$$

$$T \text{ in lb. ft.} = \frac{5252 \times BHP}{RPM}$$

Torque Converters:

Peak output shaft horsepower:

Normally 80% of input horsepower for either single or three-stage converter

Output shaft speed at peak output horsepower:

Single-stage - 0.7 to 0.85 engine full load speed

Three-stage - 0.5 to 0.6 engine full load speed

Torque multiplication at or near stall:

Single-stage - 2.2 to 3.4 times engine torque

Three-stage - 3.6 to 5.4 times engine torque

Ventilation:

Natural 1/2 net square inch for each BHP

Blown 1/3 net square inch for each BHP

Metric Units

Air Compressors:

110 kW = 1 m^3/min @ 850 kPa

100 kW = 1 m^3/min @ 675 kPa

90 kW = 1 m^3/min @ 550 kPa

AMA Power for U.S.A. Tax Purposes:

$$\text{AMA Power} = \frac{ND^2}{1612.9}$$

Where: N = No. of Cylinders

D = Piston Diameter in millimeters

Brake Mean Effective Pressure:

$$\text{kPa (4-cycle)} = \frac{120{,}000 \times \text{kW}}{\text{RPM} \times \text{L}}$$

$$\text{kPa (2-cycle)} = \frac{60{,}000 \times \text{kW}}{\text{RPM} \times \text{L}}$$

$$\text{kPa (4-cycle)} = \frac{12.57 \times \text{N}\bullet\text{m}}{\text{L}}$$

Conveyors: 15 to 20° incline.

$$\text{kW} = \frac{\text{Vertical lift in meters} \times \text{metric tons per hour}}{138}$$

Cooling:

Heat Exchanger Flow Rate

Raw water to jacket water 1:1 to 2:1

Submerged Pipe Cooling

1 m^2 surface area per 16 kW with 30°C flowing raw water

Electricity:

Generator Capacity Required:

Motors:

11/3 kW per nameplate kW (motor running cool or warm to touch)

12/3 kW per nameplate kW (motor running hot to touch)

Engine Power Requirements:

1½ engine kW per kW of load or $\frac{kW}{Gen.\ Eff.}$

Electric Sets:

Motor Starting Requirements:

Inrush kVa (Code F motor) = 41/8 × nameplate kW

Inrush Current (Code F motor) = 6.2 × full load rated current

11/3 kVa per kW at full load

Generator full load rated current capacity:

Voltage	Rated Current
120	6.01 × kW
208	3.47 × kW
240	3.01 × kW
480	1.50 × kW
2400	0.30 × kW
4160	0.17 × kW

Generator Cooling Requirements:

Air Flow = 41/4 m^3 per kW loss × efficiency

Circuit Breaker Trip Selection:

1.15 to 1.25 × full load generator amp rating

Single Phase Rating of 3-Phase Generator:

60% of 3-Phase rating

Generator Temperature Rise:

Increase 1°C for each 100 meters above 1000 meters

Fuel Consumption

kW = L/h fuel × 4	Diesel	¼ L/kW•h
kW = L/h fuel × 2.2	Gasoline	½ L/kW•h
kW = m^3/h × 3	Natural Gas*	⅓ m^3/kW•h

*33 720 kJ/m^3

3

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*33 720 kJ/m

Gas Compressor:

kW = 777 Rc VS

Where : Rc = Stage Compression Ratio

V = Millions cubic meters per day

S = Number of Stages

Heat Rejection:

% of Fuel Energy Consumed

kW (output)	33%
Jacket Water	30%
Exhaust	30%
Radiation	7%

Jacket Water

Prechambered engines

kJ/min = 50 × kW

Direct injection engines

kJ/min = 38 × kW

Oil Cooler: kJ/min. = 7 × kW

Watercooled Manifold: kJ/min. = 10 × kW

Torque Convertor: kJ/min. = 60 × kW input $\times \frac{(100 - \text{conv. eff.})}{100}$

Hours Per:

Year = 8760 (365 Days)

Week = 168 (7 Days)

Month = 720 (30 Days)

Oilfield Drilling:

Hoisting

$$kW = \frac{kg \times m/min \text{ (assume 30 if unknown)}}{6120 \times 0.85 \text{ (eff.)}}$$

Mud Pumps

$$kW = \frac{L/min \times kg/L \times \text{(meters of head)}}{6120 \times \text{pump efficiency (see pumps)}}$$

Rotary Table

Depth in meters	kW required
0-1200	55
1200-2400	75
2400-3600	110
3600-4800	150

On Site Power Requirements:

Based on 10 000 m^2 of office bldg., etc. and 40°N latitude.

Electric Requirements:

650 kW continuous load (air conditioning is absorption)

Use three units approximately 325 kW each (2 prime and 1 standby)

Air Conditioning Compressor:

325 kW prime load

Use two engines approximately 170 kW each (No standby)

Pumps:

Deep Well kW = (meters of lift × L/min × 4640)

$$\text{Pipe Line kW} = \frac{\text{(Barrels/hour} \times kPa}{17\,400}$$

$$\text{Pipe Line kW} = L/H \times kPa \times 2\,775\,000$$

Pipe Line kW = L/H × kPa × 2 775 000

$$\text{Any Liquid kW} = \frac{L/min \times kg/L \text{ (liquid)} \times \text{(meters of head)}}{6120 \times \text{pump efficiency}^*}$$

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*Efficiency

*Efficiency	
Centrifugal	
Single impeller, double suction	65-80%
Simple impeller, side suction	55-75%
Deep well turbine	65-80%
Reciprocating	75%

Refrigeration:

One ton refrigeration = 3.5 kW

One boiler hp = 9.8 kW

One ton compressor rating = 0.75 kW

Auxiliary air conditioning equipment requires 1/5 kW per ton of compressor rating

Ice Plant:

Complete power requires 3.25-4.25 kW per daily ton capacity

Sawmill:

1 kW per 20 to 25 mm saw diameter at 500 RPM

Increase or decrease in proportion to RPM

Swing Cut-Off Saw

600 mm	2½ kW
900 mm	5½ kW
1050 mm	7½ kW

Table Trimmer 51/2 to 71/2 kW

Blower Fan 4 meter sawdust 21/4 to 33/4 kW

Planer Mill 5-10 kW m^3 per hour 600-750 mm planers 11 to 19 kW

Edgers

2 saws 9 to 11 kW

3 saws 11 to 19 kW

Slab saw 7.5 kW

Jack Ladder 7.5 kW

Approximate fuel consumption:

Softwood	0.16 L/m^3
Hardwood	0.21 L/m^3

Shaft Size Selection:

For intermediate shaft and tailshaft in marine installations

$$D = 365 \sqrt[3]{\frac{kW}{RPM \times S}}$$

Where: D = Diameter in millimeters

kW = Power in kilowatts

S = Torsional stress in MPa (usually 35)

Shovels and Draglines:

Use manufacturer's recommendations.

Torque: (4-cycle only)

$$N \bullet m = \frac{L\,(\text{displacement}) \times kPa\,(BMEP)}{12.57}$$

$$N \bullet m = \frac{P\,(kw) \times 9550}{RPM}$$

Torque Converters:

Peak output shaft kilowatts:

Normally 80% of input power for either single or three stage converter

Output shaft speed at peak output kilowatts:

Single-stage - 0.7 to 0.85 engine full load speed

Three-stage - 0.5 to 0.6 engine full load speed

Torque multiplication at or near stall:

Single-stage - 2.2 to 3.4 times engine torque

Three-stage - 3.6 to 5.4 times engine torque

Ventilation:

Natural 41/2 cm^2/kW

Blown 3 cm^2/kW

English to Metric Conversion Factor

English to Metric Conversion Factor

Symbol	When you Know	Multiply By	To Find	Symbol
Btu	BRITISH THERMAL UNIT	1055.06	JOULE	J
Btu/hp•h	BRITISH THERMAL UNIT/ HORSEPOWER-HOUR	0.00142	MEGAJOULES/KILOWATT-HOUR	MJ/kW•h
Btu/h	BRITISH THERMAL UNIT/HOUR	1055.06	JOULES/HOUR	J/h
Btu/min	BRITISH THERMAL UNIT/MINUTE	0.01758	KILOWATT	kW
Btu/ft^3	BRITISH THERMAL UNIT/ CUBIC FOOT	8.8906434	KILOCALORIES/CUBIC METER	Kcal/m^3
°C	CELSIUS (DEGREES)	[(1.8 C) + 32]	FAHRENHEIT (DEGREES)	°F
cu ft	CUBIC FEET	0.02832	CUBIC METER	m^3
cu ft/h	CUBIC FEET/HOUR	0.02832	CUBIC METER/HOUR	m^3/h
cfm	CUBIC FEET/MINUTE	0.02832	CUBIC METER/MINUTE	m^3/min
cu in	CUBIC INCH	0.01639	LITER	L
cu in	CUBIC INCH	0.00002	CUBIC METER	m^3
°F	FAHRENHEIT (DEGREES)	[0.555 (F-32)]	CELSIUS (DEGREES)	°C
ft/min	FEET/MINUTE	0.3048	METER/MINUTE	m/min
ft	FEET	0.3048	METER	m
ft H_2O	FEET OF WATER	2.98898	KILOPASCAL	kPa
gph	GALLON/HOUR	3.78541	LITER/HOUR	L/h
gpm	GALLON/MINUTE	3.78541	LITER/MINUTE	L/min

English to Metric Conversion Factor (cont.)

Symbol	When you Know	Multiply By	To Find	Symbol
hp	HORSEPOWER	0.7457	KILOWATT	kW
in HG	INCH OF MERCURY	3.37638	KILOPASCAL	kPa
in	INCH	25.4	MILLIMETER	mm
in H_2O	INCH OF WATER	0.24908	KILOPASCAL	kPa
kW	KILOWATT	56.86903	BRITISH THERMAL UNIT/MINUTE	Btu/min
L	LITER	61.0237	CUBIC INCH	cu in
μ	MICRON	1.0	MICROMETER	μm
lb	POUND	0.45359	KILOGRAM (MASS)	kg
lb	POUND	4.44822	NEWTON (FORCE)	N
lb ft (ft-lb)	POUND FOOT	1.35582	NEWTON METER	N•M
lb in (in-lb)	POUND INCH	0.11299	NEWTON METER	N•M
lb/in	POUNDS/INCH	0.17513	NEWTON/MILLIMETER	N/mm
lb/in	POUNDS/INCH	175.127	NEWTON/METER	N/m
lb/HP-h	POUND/HORSEPOWER-HOUR	608.277	GRAM/KILOWATT HOUR	g/kW•h
lb/h	POUND/HOUR	0.45359	KILOGRAM/HOUR	kg/h
m^3	CUBIC METER	61023.7	CUBIC INCH	cu in
psi	POUNDS/SQUARE INCH	6.89476	KILOPASCAL	kPa
US qt	US QUART	0.94635	LITER	L
ft^2	SQUARE FEET	0.0929	SQUARE METER	m^2
in^2	SQUARE INCH	6.4516	SQUARE CENTIMETER	cm^2
US gal	US GALLON	3.78541	LITER	L

Energy

Energy

Unit	Btu	Cal	ft-lb	J	Therm	Kcal
British Thermal Unit	1	252	778	1055.056	0.00001	0.252
Calorie	0.00397	1	3.08866	4.185	0.002519	0.001
Foot-Pound	0.001285	0.323765	1	1.356	0.000816	0.003089
Joule	0.000948	0.23895	0.73745	1	0.01055	0.000239
Kilocalorie	3.96825	1000	3089	4185.0	2.519	1

1 Therm = 100,000 Btu

Btu per sq foot per min = 0.1220 watts per square inch

Btu per cu foot = 8.899 kg-cal/m^3

Btu per pound = .5556 kg-cal/kg

Power

Power

Unit	Btu/min	ft-lb/min	hp	J/min	Metric hp	kW	W
Btu/min	1	778.2	0.02358	1055.0	0.02391	0.017584	17.5843
ft-lb/min	0.00128	1	0.00003	1.3504	0.00003	0.00002	0.0226
Horsepower	42.4	33000	1	44791	1.014	0.74570	745.7
Joules/min	0.00095	0.7405	0.0000223	1	0.0000226	0.0000166	0.016668
Metric hp	41.827	32550	0.98632	44127	1	0.73549	735.498
Kilowatt	56.8690	44250	1.34102	59997	1.35962	1	1000
Watt	0.05687	4425	0.00134	59.9968	0.00136	0.001	1

Length

Length

Unit	mm	in	ft	yd	m	km	mile
mm	1	0.03937	0.003281	0.001094	0.001	0.00001	—
in	25.4	1	0.08333	0.02778	0.0254	0.00003	—
ft	304.8	12	1	0.33333	0.3048	0.00030	—
yd	914.4	36	3	1	0.9144	0.00091	—
m	1000	39.3701	3.28084	1.09361	1	0.001	0.00062
km	1000000	39370.1	3208.84	1093.61	1000	1	0.62137
mile	1609340	63360	5280	1760	1609.34	1.60934	1

Volume and Capacity

Volume and Capacity

Unit	in^3	ft^3	yd^3	mm^3	m^3	U.S. gal	Imp gal	liter
in^3	1	0.0058	0.00002	16387.1	0.00002	0.00432	0.00361	0.01639
ft^3	1728	1	0.03704	28.3168 x 106	0.02832	7.48052	6.22883	28.3169
yd^3	46656	27	1	764554	0.76455	201.974	168.178	764.555
mm^3	6.1×10^{-5}	4.0×10^{-8}	—	1	—	2.6×10^{-7}	2.2×10^{-7}	1.0×10^{-6}
m^3	61023.7	35.3147	1.30795	1000000	1	264.172	219.969	1000
U.S. gal	231	0.13368	0.00495	3785410	0.00378	1	0.83267	3.78541
Imp gal	277.419	0.16054	0.00595	4540090	0.00455	1.20095	1	4.54609
liter	61.0237	0.03531	0.00131	1000000	0.001	0.26417	0.21997	1
acre-ft	—	43560	1613.33	—	1233.48	325851	271335	—

1 board-foot = 144 in^3
1 bushel = 1.244 ft^3
1 bushel = 4 pecks

Weight

Weight

Unit	Kilograms	Ounces Avoirdupois	Pounds Avoirdupois	Tons Short	Tons Long	Tons Metric
1 Kilogram	1	35.27	2.205	—	—	—
1 Ounce	0.02835	1	0.0625	—	—	—
1 Pound	0.4536	16	1	—	—	—
1 Short Ton	907.2	32,000	2,000	1	0.8929	0.9072
1 Long Ton	1016	35,840	2,240	1.12	1	1.016
1 Metric Ton	1000	35,274	2,205	1.102	0.9842	1

1 grain = 0.064799 gram

Angle

1 quadrant = 90 degrees
1 quadrant = 1.57 radians
1 radian = 57.3 degrees

1 degree = 60 minutes
1 minute = 2.9×10^{-4} radian

Pressure and Head

Pressure and Head

Unit	mm/hg (0°C)	in/hg (0°C)	in H_2O (39°F)	ft H_2O (30°F)	lb/in²	kg/cm²	bar	Atmospheres (14.7 psi)	kPa	MPa
mm/hg	1	0.03937	0.53526	0.0446	0.01934	0.00136	0.00133	0.001315	—	—
in/hg	25.4	1	13.5955	1.13296	0.49115	0.03453	0.03386	0.03342	—	—
in H_2O	1.86827	0.07355	1	0.08333	0.03613	0.00254	0.00249	0.00246	0.249	—
ft H_2O	22.4192	0.88265	12	1	0.43352	0.030479	0.02989	0.02950	2.989	—
lb/in²	51.7149	2.03602	27.6807	2.3067	1	0.07031	0.06895	0.06805	6.895	0.0069
kg/cm²	735.559	28.959	393.71171	32.80931	14.2233	1	0.98067	0.96784	98.067	0.098
bar	750.062	29.530	401.4742	33.45618	14.504	1.01972	1	0.98692	101.325	0.1
kPa	7.50062	0.29530	4.014742	0.3345618	0.145038	0.0101972	0.010000	0.00986920	1	0.001
MPa	7500	295.3	4014.7	334.6	145	10.20	10	9.87	1000	1

Flow

Flow

Unit	U.S. gal/min	Million U.S. gal/day	ft³/s	m³/h	L/s
1 U.S. gpm	1	0.001440	0.00223	0.2270	0.0631
1 Million gal/day	694.5	1	1.547	157.73	43.8
1 ft³/s	448.8	0.646	1	101.9	28.32
1 m³/h	4.403	0.00634	0.00981	1	0.2778
1 L/s	15.85	0.0228	0.0353	3.60	1

MCFD = 1000 cubic feet per day
MMCFD = 1 000 000 cubic feet per day
lb/bhp-hr × 607.73 = g/kW-hr

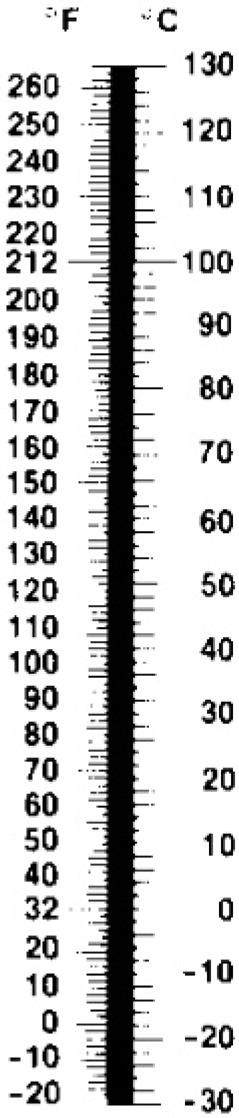
Area

Area

Unit	mm²	in²	m²	ft²
mm²	1	0.155	—	—
in²	645.16	1	0.00064516	0.006944
m²	10000	1550	1	10.764
ft²	92900	144	0.0929	1

1 sq mile = 640 acres
1 acre = 4840 yd²
1 cir mil = 7.854 × 10[illegible] in[illegible]
1 cir mil = .7854 mils²
1 cir mil = 5.067 × 10[illegible] cm²

Temperature Conversion



$$°F = (1.8 \times °C) + 32$$

$$°C = 0.5555\,(°F - 32)$$

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Mathematical Formulas

Trigonometric Relations

$$\sin O = \frac{y}{r}$$

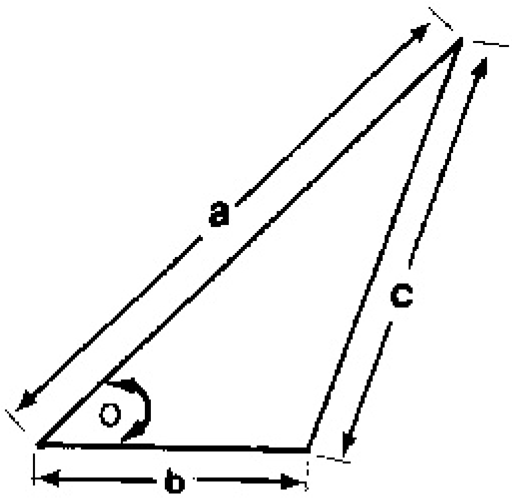
$$\cos O = \frac{x}{r}$$

$$\tan O = \frac{y}{x}$$

$$\sin^2 O + \cos^2 O = 1$$

$$e = \cos O + i \sin O \quad i = \sqrt{-4}$$

Law of Cosines



$$a^2 + b^2 - 2ab \cos O = c^2$$

Physics Formulas

$$\textbf{Velocity} = \frac{\text{Distance}}{\text{Time}} \qquad \textbf{Distance} = (\text{Velocity})(\text{Time})$$

$$\textbf{Time} = \frac{\text{Distance}}{\text{Velocity}} \qquad \textbf{Acceleration} = \frac{\text{Difference in Velocity}}{\text{Difference in Time}}$$

$$\textbf{Force} = (\text{Mass})(\text{Acceleration}) \qquad \textbf{Mass} = \frac{\text{Force}}{\text{Acceleration}}$$

$$\textbf{Acceleration} = \frac{\text{Force}}{\text{Mass}} \qquad \textbf{Momentum} = (\text{Mass})(\text{Velocity})$$

$$\textbf{Work} = (\text{Force})(\text{Distance})$$

$$\textbf{Work} = (\text{Mass})(\text{Acceleration})(\text{Distance})$$

$$\textbf{Power} = \frac{\text{Work}}{\text{Time}}$$

Heat = (Mass)(Specific Heat)(Temperature Change) or **Heat** = (M)(C)(Delta T)

Where:

M = Mass

C = Specific Heat

Delta **T** = Temperature Change

Btu = Heat required to raise 1 pound of water 1°F.

Calorie = Heat required to raise 1 gram of water 1°C.

Absolute zero is the temperature at which matter has given up all thermal energy.

Absolute zero = 0° Kelvin(K) or -273° Centigrade(C) or -459° Fahrenheit(F)

Caterpillar Numerical Code

The Caterpillar numerical code contains the date of shipment. This date is translated to a format of day, month, and the last two digits of the year and then coded into a six-digit sequence with no spaces in between digits. When the day or month is less than ten, a zero is inserted before the number to maintain the six-digit sequence.

Use the following legend to decode the date:

0	1	2	3	4	5	6	7	8	9
N	U	M	E	R	A	L	K	O	D

Example:

December 18, 1985, is translated to 181285 which is coded UOUMOA

September 7, 1985, is translated to 070985 which is coded NKNDOA

Diesel Engines	
ABS	Agco-Sisu
Akasaka	Baudouin
BMW	Bukh
Caterpillar	CHN 25/34
Cummins	Daihatsu
Detroit	Deutz
Doosan-Daewoo	Fiat
Ford	GE
Grenaa	Guascor
Hanshin	Hatz
Hino	Honda
Hyundai	Isotta
Isuzu	Iveco
John-Deere	Kelvin
Kioti	Komatsu
Kubota	Liebherr
Lister	Lombardini
MAK	MAN B&W
Mercedes	Mercruiser
Mirrlees BS	Mitsubishi
MTU	MWM
Niigata	Paxman
Perkins	Pielstick
Rolls / Bergen	Ruggerini
Ruston	Scania
Shibaura	Sisu-Valmet
SKL	Smit-Bolnes
Sole	Stork
VM-Motori	Volvo
Volvo Penta	Westerbeke
Wichmann	Yanmar

Machinery	
ABG	Airman
Akerman	Ammann
Astra	Atlas Copco
Atlas Weyha.	Atlet
Bell	Bendi
Bigjoe	Bobcat
Bomag	BT
Carelift	Case
Caterpillar	Cesab
Challenger	Champion
Claas	Clark
Combilift	Crown
Daewoo-Doosan	Demag
Deutz-Fahr	Dressta

Machinery	
Drott	Dynapack
Extec	Faun
Fendt	Fiat
Fiatallis	Flexicoil
Furukawa	Gehl
Genie	Grove-gmk
Halla	Hamm
Hangcha	Hanix
Hanomag	Hartl
Haulpack	Hiab
Hidromek	Hino truck
Hitachi	Hyster
Hyundai	IHI
Ingersoll-rand	JCB
JLG	John-Deere
Jungheinrich	Kalmar
Kato	Kioti
Kleeman	Kobelco
Komatsu	Kramer
Kubota	Lamborghini
Landini	Liebherr
Linde	Link-belt
Manitou	Massey-Ferg.
Mccormick	MDI-Yutani
Mitsubishi	Moxy
Mustang	Neusson
New-Holland	Nichiyu
Nissan	OK
OM-Pimespo	others-tech
Pel-Job	PH-mining
Poclain	Powerscreen
Same	Samsung
Sandvik	Scania
Schaefer	Schramm
Sennebogen	Shangli
Shibaura	Steiger
Steinbock	Steyr
Still	Sumitomo
Super-pac	Tadano
Takeuchi	TCM
Terex	Toyota
Valpadana	Venieri
Versatile	Vogele
Volvo	Weidemann
Wirtgen	Yale
YAM	Yanmar