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2007 Performance Specs

Gas Turbine Evaluation, Selection, Application

On the Cover: GE Energy LMS100 simple cycle plant nominally rated at 100 MW and 45% efficiency for peaking, mid-range and base load operation.

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Working insight into the gas turbine design rating factors

This edition of Gas Turbine World's annual *Performance Specs* issue is published as an update of the design ratings published in the *2006 Handbook*.

As a common denominator, ratings are referenced to base load operation at 59°F sea level site conditions on natural gas fuel (distillate for marine gas turbines).

Simple cycle, mechanical drive and marine propulsion ratings are generally quoted for gross output conditions without allowance for parasitic power consumption, gearbox losses, and pressure drop across intake and outlet ducting.

Combined cycle ratings, in contrast, quote net plant output and heat rate (efficiency) for an optimized standard reference plant design without supplementary firing, taking into account gas turbine and HRSG pressure drop losses.

In all cases, for electric power plants, quoted output and heat rate are measured across the generator terminals. Mechanical drive ratings are quoted at the gas turbine output shaft coupling.

Although the design performance ratings appear in separate reference sections, grouped according to application, many of the column headings are the same even though performance parameters and units differ.

Column headings. These column headings and units are the same for all sections:

Year is the release date of the first production unit in the model series. A code number or letter at the end of the model designation usually (not always) denotes an upgrade in the design series.

ISO base rating is the continuous power output available for 6,000 hours or more a year without exceeding normal gas turbine wear and maintenance. Rated for 59°F (15°C) sea level site conditions, zero inlet and outlet losses, operation on natural gas fuel (distillate for marine gas turbines).

Heat rate is a measure of the rate of fuel energy input divided by power output. For gas turbines, it is based on lower heating value (LHV) as opposed to the higher heating value (HHV) on which fuel requirement and contract price are based.

Efficiency is a measure of power output divided by the rate of fuel energy input. It is based on gross power output for simple cycle plants and net power for combined cycles.

Pressure ratio is a measure of the gas turbine compressor discharge pressure divided by the atmospheric pressure of the air entering the gas turbine intake. Generally, as design pressure ratio increases, so does efficiency and power output for a given mass flow.

Flow relates to compressor discharge air flow through the gas turbine specified in pounds per second – as opposed to "mass flow" which combines air and fuel flow at base load output conditions. In general, an increase in flow rating is usually associated with an increase in gas turbine power output.

Turbine speed refers to design speed of the output shaft. Direct drives for power generation run at 3000 rpm for 50 Hz, 3600 rpm for 60 Hz, and 3300 rpm as an optimized compromise for 50 or 60 Hz applications. High-speed gas turbine designs, associated with smaller machines, require a gearbox to match load speeds.

Exhaust temperature is measured at the outlet of the gas turbine exhaust duct. Low exhaust temperatures are indicative of high simple cycle efficiency. But, for waste heat recovery, those same low temperatures limit the amount of HRSG steam that can be generated without supplementary firing.

Correction factors. Gas turbine performance is adversely affected by high ambient temperature conditions, at high site elevations, and by flange to flange pressure drop.

Referenced to ISO ratings at 59ºF sea level without losses, you can figure on actual performance ratings to predictably fall off as a function of site conditions and installation losses:

Temperature. Gas turbine output will drop 0.3 to 0.5% for every 1°F rise in ambient air temperature (over 59ºF) with a proportionate increase in heat rate.

Elevation. Every 1,000-ft increase in site elevation (above sea level) will see a 3.3% reduction in gas turbine power output.

Inlet loss. For each inch water gauge (wg) of inlet pressure drop, figure on a

Efficiency Conversion Shortcuts

$$\textbf{Efficiency} = \frac{3413}{\text{Btu/kWh}} = \frac{2545}{\text{Btu/hp-hr}} = \frac{0.138}{\text{lb/hp-hr}}$$

$$\textbf{Efficiency} = \frac{860}{\text{kcal/kW}} = \frac{641}{\text{kcal/hp-hr}} = \frac{0.063}{\text{kg/hp-hr}}$$

This is a useful reference for calculating fuel requirements

Multiply by a factor of 1.06 for liquid fuels and 1.11 for natural gas

Gas turbine performance is calculated on the basis of the lower heating value (LHV) of the fuel to be burned.

Purchase contracts for the amount of fuel required, however, are determined by the higher heating value (HHV) of that fuel.

The difference between the lower and higher heating value is Btu content that you pay for, but never see as gas turbine output.

Technically, it is difficult to explain. But it all has to do with fuel-bound hydrogen that forms water as a byproduct of combustion and is wasted.

HHV is measured on the basis of the chemical energy in the fuel, which accounts for the total heat given up when the fuel is burned — including formation of water vapor — while LHV measures the useable energy.

The bottom line is that some 6 percent by weight of liquid fuels ends up being "wasted" in the gas turbine combustion process versus 11 percent for natural gas fuel.

Or, put another way, you must increase LHV fuel consumption by a factor of 1.06 for liquid fuels and by a factor of 1.11 for natural gas.

Cycle studies for gas turbine projects are carried out on an LHV basis and fuel requirement on an HHV basis.

In short, figure on having to buy more fuel than you might expect by using the heat rate in the performance specifications to calculate your fuel requirements.

Bulk liquid fuels. This table lists the bulk weight of common liquid fuels. For reference, one 42-gallon barrel of liquid fuel is equivalent to about 3500 cubic feet of still gas.

Fuel Type	Gravity at 60°F (Average)	Gallons per Pound	Pounds per Gallon	Pounds 42-Gal Barrel	Barrels per Short Ton (2000 lbs)	Barrels per Metric Ton (2205 lbs)
Crude oil (U.S. imports)	25.6	0.13333	7.500 lb	315 lb	6.349 bbl	6.998 bbl
Crude oil (U.S. domestic)	36.0	0.14217	7.034 lb	295 lb	6.770 bbl	7.463 bbl
Distillate oil	31.3	0.13817	7.237 lb	304 lb	6.580 bbl	7.253 bbl
Residual oil	18.0	0.12687	7.882 lb	331 lb	6.041 bbl	6.660 bbl
Liquefied petroleum gas	—	0.22104	4.524 lb	190 lb	10.526 bbl	11.603 bbl

Btu content (HHV). This table lists higher heating value Btu-content of those fuels. For gas turbine calculations, figure on an LHV of 18,400 Btu/lb for distillate or crude oil.

Fuel Type and Bulk	42-Gal bbl Crude Oil	1000-Cu ft Natural Gas	42-Gal bbl Distillate	42-Gal bbl Residual	42-Gal bbl LPG
Btu content x 10^6	5.800 Btu	1.035 Btu	5.825 Btu	6.287 Btu	4.011 Btu
Crude oil (42-gal barrel)	1.000	5.604	0.996	0.923	1.446
Dry natural gas (l000 cu ft)	0.178	1.000	0.178	0.165	0.258
Distillate oil (42-gal barrel)	1.004	5.628	1.000	0.927	1.452
Residual oil (42-gal barrel)	1.084	6.074	1.079	1.000	1.567
Liquefied gas (42-gal barrel)	0.692	3.875	0.689	0.638	1.000

Working insight into combined cycle powerplant design ratings

Combined cycle ratings in the *Performance Specs* are referenced to standardized single-shaft and multi-shaft OEM plant design operation at base load output and 59°F sea level site conditions on natural gas fuel.

The ratings are quoted for net plant output and efficiency measured across the electric generator terminals, with allowances for gas turbine losses, parasitic auxiliary plant loads, conservatively designed unfired HRSG and optimized steam cycle conditions.

Design configurations. Single-shaft plants consist of a gas turbine, unfired HRSG, steam turbine and generator, with the gas turbine and steam turbine coupled to opposite ends of the generator.

Multi-shaft plants are generally designed around one or more gas turbine generator and HRSG combinations, which supply steam through a common header to a single steam turbine generator.

As "standardized reference plants" their systems design is optimized for the best combination of gas turbine and steam turbine power output to maximize efficiency.

In general, they are based on conservative design conditions for HRSG, steam cycle, and steam turbine to provide a practical balance between high combined cycle power plant performance and cost.

More aggressive overly optimistic design and cycle parameters can produce up to 1.5% higher efficiencies than conservatively engineered plants but end up making the plant too costly to build.

Design variables. Take, for example, a typical 2x1 combined cycle plant nominally rated at 530 MW output and 6015 Btu/kWh heat rate designed around high-temperature F-technology gas turbines.

Assign the following design conditions for comparative evaluation purposes: standard 4 inch pressure drop (wg) across the gas turbine air inlet filters, a hypothetical HRSG with zero pressure drop, wet cooling tower, and 1.5 inch HgA (38.10 mm) exhaust pressure on the steam turbine.

Then let's see what happens when you start changing key design conditions.

HRSG. A conservatively de-signed HRSG installation would have a pressure drop of about 10 inches (for this plant).

Typically, that would produce a 1.1% loss in power output (6 MW) and 1.7% higher heat rate (100 Btu) for a net plant output of 524 MW and 6115 Btu/kWh heat rate.

The same HRSG, equipped with an SCR and CO catalyst section for emissions control, would increase pressure drop to around 14 inches.

That would produce a 1.5% loss of power (8 MW) and 2.1% higher heat rate (126 Btu) ending up with a net plant output of 522 MW and 6141 Btu/kWh heat rate.

Gas turbine. Now let's see how changes in gas turbine exhaust flow and temperature into the HRSG impact on plant output.

A 1% decrease in gas turbine exhaust flow, for example, is equivalent to a 1% reduction in steam flow.

And a 5°F decrease in gas turbine exhaust temperature is equivalent to a 1% reduction in steam flow or a 2°F reduction in steam temperature.

Steam cycle. Although most combined cycle reference plants incorporate a wet cooling tower design, OEMs seldom specify condenser design parameters or approach temperature.

The "approach temperature" for steam condenser design is the difference between the incoming cooling water and the outgoing cooled condensate. Ideally, you want as small a delta as possible within economic constraints.

It is also rare to find any mention of steam cycle cooling water conditions or type cooling system design on which the ratings are based.

(A once-through cooling system can be used but that requires a lake, river or sea for direct condenser cooling and lots of pumping power — unless the plant is sited in the fjords of Norway with ice water available for cooling.)

The design goal is a reasonably low approach temperature, for good performance, consistent with reasonable cost. A 5ºF approach temperature, for exam-

Handy Conversion Factors

deg C = (°F – 32) ÷ 1.8	lb x 0.454 = kg	lb/hph x 0.608 = kg/kWh
deg F = (1.8 x °C) + 32	kg x 2.205 = lb	kg/kWh x 1.644 = lb/hph
kW x 1.341 = hp	Btu x 1.055 = kJ	hph x 2.685 = MJ
hp x 0.746 = kW	kJ x 0.948 = Btu	MJ x 0.373 = hph
1 kWh = 859.8 kcal = 3413 Btu	Btu/lb x 2.326 = kJ/kg	J x 0.239 = calorie
1 hp-hr = 0.746 kWh = 2545 Btu	kJ/kg x 0.430 = Btu/lb	calorie x 4.187 = J

Combined Cycle Reference Plants

Model	Year	Net Plant Output	Heat Rate Btu/kWh	Net Plant Efficiency	Heat Rate kJ/kWh	Condenser Vacuum (Hg)	Gas Turbine Power	Steam Turbine Power	No. & Type Gas Turbine	Comments
Alstom (50 Hz)										
KA8C2-2	1998	165 000 kW	6783 Btu	50.3 %	7156 kJ	45	*****	*****	2 x GT8C2	dual pressure non-reheat HRSG
KA11N2-2	1993	344 800 kW	6647 Btu	51.3 %	7013 kJ	45	*****	*****	2 x GT11N2	dual pressure non-reheat HRSG
KA13E2-1	1993	252 800 kW	6458 Btu	52.8 %	6813 kJ	45	*****	*****	1 x GT13E2	dual pressure non-reheat HRSG
KA13E2-2	1993	507 400 kW	6435 Btu	53.0 %	6789 kJ	45	*****	*****	2 x GT13E2	dual pressure non-reheat HRSG
KA13E2-3	1993	763 200 kW	6417 Btu	53.2 %	6770 kJ	45	*****	*****	3 x GT13E2	dual pressure non-reheat HRSG
KA26-1	1996	424 000 kW	5850 Btu	58.3 %	6172 kJ	45	*****	*****	1 x GT26	with once through cooler
KA26-2	1996	850 300 kW	5835 Btu	58.5 %	6156 kJ	45	*****	*****	2 x GT26	with once through cooler
KA26-2 ICS	2006	857 700 kW	5785 Btu	59.0 %	6103 kJ	45	*****	*****	2 x GT26	with once through cooler
Alstom (60Hz)										
KA8C2-2	1998	163 500 kW	6837 Btu	49.9 %	7213 kJ	45	*****	*****	2 x GT8C2	dual pressure non-reheat HRSG
KA11N2-2	2001	348 500 kW	6582 Btu	51.8 %	6944 kJ	45	*****	*****	2 x GT11N2	dual pressure non-reheat HRSG
KA24-1	1998	278 900 kW	5978 Btu	54.1 %	6307 kJ	45	*****	*****	1 x GT24	with once through cooler
KA24-2	1998	560 000 kW	5955 Btu	57.3 %	6282 kJ	45	*****	*****	2 x GT24	with once through cooler
Ansaldo Energia (50 Hz)										
COBRA 164.3A	*****	115 400 kW	6301 Btu	54.2 %	6648 kJ	*****	75 550 kW	41 800 kW	1 x V64.3	ISO based performance with
COBRA 264.3A	*****	232 900 kW	6242 Btu	54.7 %	6586 kJ	*****	151 100 kW	85 770 kW	2 x V64.3	4"/12" losses for all models
COBRA 194.2	*****	246 400 kW	6599 Btu	51.7 %	6962 kJ	*****	161 300 kW	90 100 kW	1 x V94.2	
COBRA 294.2	*****	499 200 kW	6515 Btu	52.4 %	6873 kJ	*****	323 000 kW	186 600 kW	2 x V94.2	
COBRA 394.2	*****	747 100 kW	6529 Btu	52.3 %	6889 kJ	*****	483 900 kW	278 200 kW	3 x V94.2	
COBRA 194.3A	*****	411 600 kW	5900 Btu	57.8 %	6225 kJ	*****	277 800 kW	140 900 kW	1 x V94.3A	
COBRA 294.3A	*****	820 300 kW	5922 Btu	57.6 %	6248 kJ	*****	556 000 kW	278 800 kW	2 x V94.3A	
Bharat Heavy Electricals (50 Hz)										all ratings on natural gas fuel
CC105P	1988	38 500 kW	8180 Btu	41.7 %	8630 kJ	*****	25 900 kW	18 200 kW	1 x MS5001	dual pressure
CC205P	1988	77 800 kW	8110 Btu	42.1 %	8550 kJ	*****	51 800 kW	27 200 kW	2 x MS5001	dual pressure
CC305P	1988	117 200 kW	8070 Btu	42.3 %	8510 kJ	*****	77 700 kW	41 400 kW	3 x MS5001	dual pressure
CC106B	1997	64 300 kW	6960 Btu	49.0 %	7340 kJ	*****	41 600 kW	23 800 kW	1 x MS6001B	dual pressure
CC206B	1997	130 700 kW	6850 Btu	49.8 %	7320 kJ	*****	83 200 kW	49 400 kW	2 x MS6001B	dual pressure
CC106C	2004	62 700 kW	6315 Btu	54.1 %	6660 kJ	*****	41 700 kW	21 900 kW	1 x MS6001C	dual pressure
CC206C	2004	126 200 kW	6275 Btu	54.4 %	6620 kJ	*****	83 400 kW	44 700 kW	2 x MS6001C	dual pressure