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SCOPE

This section presents a general introduction to the application of gas turbines and reciprocating engines for process plant services in the Downstream segment of ExxonMobil's business. Introductory information and basic utility estimating data are included. Application of these drives to electric, compression, pumping, or materials handling services is complex and specialized. Further reference to industry association and manufacturer's data, augmented with machinery specialist consulting, is normally required to perform specific service designs.

REFERENCES

DESIGN PRACTICE (BESIDES OTHER SECTIONS OF THIS SECTION)

Section VIII-M Combustion Calculations

GLOBAL PRACTICES

GP 10-8-1 Combustion Gas Turbines

GP 10-11-1 Sizing of Drivers and Transmissions for Compressors, Fans, and Pumps

OTHER REFERENCES

API 616, *Gas Turbines for the Petroleum, Chemical, and Gas Industry Services*

BSI BS 5514 Part 1, *Reciprocating Internal Combustion Engines - Performance,* Part 1, 1996

Diesel and Gas Engine Progress, Annual Catalog Issue

Gas Turbine World's Annual Performance Specifications Edition, Gas Turbine World Magazine, PO Box 447, Southport, CT 06490

GTPRO *Personal Computer Software For Gas Turbine Simple And Combined Cycle Analysis*, Thermoflow, Inc., 888 Worcester Street, Wellesley, MA 02181

Heywood, J.B, *Internal Combustion Engine Fundamentals*, McGraw-Hill, New York, 1988

ISO 3046-1, *Reciprocating Internal Combustion Engines - Performance*, Part 1, 4th Edition, 1995

Pounder, C.C. et al, *Diesel Engine Principles and Practice,* George Newnes Ltd., London, 1962

DEFINITIONS

The nomenclature and definitions presented here are those conventionally used in the rotating machinery field. They are not all-inclusive of symbols and definitions commonly applied to compression service and process plant design. They are presented here as a convenient additional reference for the process designer. See **Section XI-A,** *Compression Service Design Procedures,* for normal compression service nomenclature. See **DP Section VIII** for heat recovery system design nomenclature and discussion of combustion.

Separable Engine - An engine that is mounted independent of the load compressor. It is also appropriately termed a **Separate Engine.**

Integral Engine - An engine that incorporates load compressor cylinders mounted on the same crankcase.

Gas Engine - An engine which operates on gaseous fuel with ignition by an electric spark. Often, it is called a **Spark Ignition (SI)** engine.

Diesel Engine - One that operates with either liquid or gas as primary fuel. Ignition is caused by the heat of compression. It may also be called a **Compression Ignition (CI)** engine. What is commonly termed “Diesel Engine" is one which uses liquid fuel only. A **“Gas-Diesel"** is one which uses gas as the primary fuel and a small amount of pilot oil that will readily ignite at the temperature reached in the compression stroke. Pilot oil is usually more than 5% of the total engine fuel. This type is usually available as a **“dual-fuel"** engine which has the capability of running with either gas or liquid as the primary fuel.

Four-Stroke-Cycle - An engine cycle in which the piston traverses the cylinder four times. This is the typical cycle of a modern automobile engine and consists of an “intake stroke" to fill the cylinder, “compression stroke" to compress the air or air-fuel mixture to the point of ignition, “power stroke" to push the piston down the cylinder as the ignited gases expand and do work, and the “exhaust stroke" during which the piston pushes the expanded combustion gases out of the cylinder. Two revolutions of the crankshaft are required to complete a four-stroke-cycle.

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DEFINITIONS (Cont)

Two-Stroke-Cycle - An engine cycle in which the piston traverses the cylinder only twice. Intake occurs when the piston exposes the intake ports at the end of the power and exhaust stroke. Compression and ignition occur in the first stroke. The power stroke concludes with opening of the exhaust valves. Because the two-stroke-cycle design has a power stroke twice as often as a four-stroke-cycle engine of the same speed, two-stroke-cycle engines generally are smaller and of lighter weight for the same power output. The absence of mechanically operated intake valves also makes them simpler. (Some models also eliminate mechanical exhaust valves.)

Supercharging - The process of charging the engine inlet with air at higher than atmospheric pressure. Almost all large industrial engines are supercharged by an exhaust gas turbine driven combustion air compressor, or **"turbocharger."** This charge air is cooled in a heat exchanger before admission to the intake manifold to increase air density and increase the amount (of oxygen) admitted to the cylinders. This increases power output about 50 to 75% for the same physical size engine and also improves the efficiency by about 5 percentage points.

Natural Aspiration - A simple arrangement with no inlet supercharging.

Exhaust Scavanging - Artificial depression of exhaust pressure to achieve more work from the cylinder and clear exhaust gases prior to the inlet portion of the cycle. This technique is sometimes used on two-stroke-cycle engines that are not turbocharged.

Open Cycle Gas Turbine - The open cycle with once-through atmospheric air flow is the only one presently applied for compressor drive. Experimental **closed cycle** models in various forms (with air, coal gas, mercury vapor, helium, etc., as the working medium) have been applied for power generation over the last 25 years. Both open and closed cycle gas turbines are examples of **Brayton Cycle** thermodynamics.

Simple Cycle Gas Turbine - The simple cycle is one in which the working medium (atmospheric air) passes successively through the compressor, combustor, and turbine. Simple cycle gas turbine efficiencies depend mainly on operating pressure (ratio), and turbine inlet temperature. Gas turbines derived from aircraft engines have simple cycle efficiencies as high as 42%. Modern, heavy duty gas turbines have simple cycle efficiencies of 34%.

Regenerative (Recuperative) Cycle - The regenerative cycle includes a heat exchanger (regenerator) which transfers heat from the flue gas (@ 750 to 950°F (400 to 510°C) to the compressed precombusted air prior to fuel injection. Some utility companies and many gas transmission gas turbine - compressor stations use the regenerative cycle to improve efficiency by about 4 to 7 percentage points. However, more modern simple cycle units with higher firing temperatures, have markedly reduced this advantage. Recuperative gas turbines are now rarely applied in sizes over 10,000 horsepower.

Single-Shaft and Multiple Shaft Gas Turbines - Single-shaft designs have the combustion air compressor, turbine wheel, and power takeoff all on a single rotor. Two-shaft and three-shaft designs have "spools" consisting of compressor and turbine segments straddling lower pressure spools. Another two shaft arrangement has the combustion air compressor and high-pressure turbine wheels arranged on one shaft (or in spool fashion on two shafts). Low-pressure turbine wheels are on a separate shaft for power takeoff. This arrangement is said to consist of a **gas generator** and a **power turbine** and is usually more expensive than the single-shaft design. This arrangement allows each shaft to run at different optimum speeds and allows more speed variation on the output shaft.

Industrial and Aircraft (Aero) Derived Gas Turbines - The industrial type is of much heavier construction, and typically uses lower turbine inlet temperatures. Jet engine designs use a separate aircraft type engine (air compressor and compressor turbine) as a high pressure hot gas generator to drive a separate power turbine (i.e., only available in multiple shaft configurations). The jet engine type is slightly less expensive (-10%) and is typically 1 to 2% points higher in efficiency than the industrial two-shaft, but its continuous run length and running time between overhaul shorter. It has not been applied in continuous duty for refinery compressor drives. The jet engine type has been applied by ExxonMobil in refinery power generation and for compression services in Upstream facilities where availability is not as critical as in a refinery compression service.

Heat Recovery Steam Generator (HRSG) - A boiler which recovers the heat from the hot exhaust of a gas turbine (or diesel engine). Instead of transferring exhaust heat to the combustion air, process plants improve overall cycle efficiency by using exhaust heat to generate steam. The steam boiler does not adversely affect the gas turbine reliability as a regenerator does. Exhaust heat recovery can improve the overall cycle efficiency to 55 to 85% (based on lower heating value (LHV) of turbine fuel). Also employed are boiler feedwater preheaters, water purification evaporators, and process heaters. The exhaust gases can also be used as combustion air for a process furnace since 70 to 80% of the oxygen is still in the exhaust gas. HRSGs may be provided with duct burners (fired HRSG), heating the gas turbine exhaust gas to produce additional steam.

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DEFINITIONS (Cont)

Combined Cycle - The combined cycle adds a conventional Rankine cycle to the exhaust heat provided by the gas turbine's Brayton Cycle. A steam generator recovers the heat and produces power via a steam turbine. The steam turbine may be a condensing type for conventional power plants, or a backpressure type after which the low energy steam is used in an industrial process or for residential district heating.

Cogeneration - A popular term in contemporary industrial processes, from paper mills to olefins plants and refineries, cogeneration is typically associated with the generation of electric power and heat for process uses in the form of steam. **Combined Heat and Power (CHP)** has a similar meaning, except that the heat transport medium may not be steam.

RECIPROCATING ENGINES

BACKGROUND

Reciprocating engines have the following **advantages** over other driver types for compressor drive:

Packaged unit requiring minimum offsite facilities.

High thermal efficiency (28 to 32% for naturally aspirated, 34 to 42% for turbocharged models) for relatively low power applications or compression duties with low stream rates. Engines are most often found in refineries of 25 kbbl/day or lower crude capacity.

Low speed level of 2.5 to 18 rev/s (150 to 1,000 rev/min), which is especially suitable for directly driving reciprocating compressors and power generators.

Integral gas engines minimize the plot area requirement for reciprocating engine driven compressor units.

Some exhaust heat recovery is possible. This is widely utilized in onsite power plants but rarely in process plants.

Some **disadvantages** of applying reciprocating engines to compressor drive are:

Short run lengths. Minor overhauls are required at 1,000 to 2,000 hour intervals; therefore, multiple units are required for process continuity.

High maintenance costs relative to other driver types.

Low speed level requires gearing to drive loads other than reciprocating compressors and synchronous generators.

High operator manning requirements.

High NOx emissions.

TYPE SELECTION

Integral gas engines may be selected for driving reciprocating compressors in process services with low stream rates. For refinery applications, the choice between the gas or diesel engine depends on the availability and cost of the different fuel supplies. The choice between two-stroke-cycle and four-stroke-cycle is a detailed engineering consideration and depends on the importance of each type's characteristics. Four-stroke-cycle engines have higher thermal efficiency, consume less lubricating oil, are smoother running, and easier starting than two-stroke-cycle engines. Two-stroke-cycle engines have no inlet valves, may have no exhaust valves, require less displacement for the same horsepower and therefore may have fewer cylinders. These differences are usually small, however, particularly in the turbocharged models. Four-stroke-cycle engines have a speed range down to 60% of rated speed while two-stroke-cycle engines are limited to 70% of rated speed as a minimum.

SIZING

See **GP 10-11-1** for load factors.

Engines are rated for site ambient conditions (maximum temperature and humidity, minimum pressure). Ratings and correction factors for inlet temperature, pressure, and humidity vary according to the standard used to determine the rating. To ensure correct derating, consult machinery specialists for appropriate derating of specific models. The following section provides basic guidelines for site rating.

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RECIPROCATING ENGINES (Cont)

SITE RATING

It is then necessary to adjust the ISO standard rating to the specific conditions at the installation site. The engine manufacturer should specify the continuous rating at the site conditions, including contract fuel, and the recommended accessories and control systems in service. Corrections shall be allowed for the following:

Maximum Ambient Temperature

If maximum power is required during maximum ambient temperature, approximately 1 percent deration for each 10°F (5.5°C) above standard conditions. If a turbocharger is used, the aftercooler water temperature is should be limitied to 130°F (54°C).

Altitude Correction

Approximately 2 percent deration for each 1000 ft (305 m) above 3000 ft (915 m) elevation.

Fuel Quality

The engine manufacturer should be provided with a complete fuel gas composition analysis including inerts and H_2S. The fuel gas shall have no liquid hydrocarbons or liquid water. If these are present, it may be necessary to install coalescing filters or separator drums to remove the liquids. The H_2S content should be generally less than 0.1 mol percent. Generally, the total of C_4 and heavier in the fuel gas shall be less than 0.30 mol percent for high speed rated engines.

Fuel / Air Ratio Controls

Spark ignition engines should be equipped with the high quality ignition systems and have control systems to adjust the fuel/air ratio and ignition timing. The ignition timing system should be equipped with a detonation sensor and circuitry to retard the ignition somewhat if detonation is detected. If the engine is not equipped with a detonation sensing system, and if the fuel quality is variable, an additional deration factor of 2 percent should be applied.

Maintenance Deration Factor

The ratings specified above by the manufacturer assume that the engine will receive excellent maintenance attention (such as in a large power plant) with mechanics available 24 hours per day, good spare parts and an onsite machine shop.

For a normal oilfield application with no assigned mechanics, and/or remote locations, an additional 5 percent deration factor shall be applied.

UTILITY REQUIREMENTS

Fuels

1. **Properties -** Gaseous fuels with heating value (LHV) of 800 Btu/scf or higher will allow full rated output in a standard gas engine. With special engineering, fuels as low as 500 Btu/scf can be used in some models but the engine will not develop full power rating. Power must also be derated for gas fuels containing high percentages of hydrogen, propane, butane, and similar gases with a tendency for pre-ignition. Since derating depends on the model chosen, this cannot be done until specific model choices are considered, during the detailed engineering phase. Full details of the gas constituents must be specified to ensure correct proposals by vendors.

   Sulfur content of the fuel gas must be limited, with a maximum of 10 grains per 100 scf (215 mg/m^3) of H_2S ensuring best operation.

   Fuel consumption for gas engines is stated in Btu/bhp-hr usually based on a gas with 1000 Btu/scf (37.3 MJ/m^3) LHV. Always specify the *lower* heating value of the fuel, since this is the energy that the engines can utilize (the products of combustion are not condensed). Depending on the model chosen and load driven, gas engines consume between 6000 to 8500 Btu/bhp-hr. For consumption estimates, use 6500 Btu/bhp-hr at full load and 8500 Btu/hp-hr at 1/2 load. For sizing the fuel gas system, assume 8500 Btu/bhp-hr (LHV) to provide control flexibility and to account for efficiency deterioration between maintenance periods.

   Fuel gas for “dual fuel" engines can have a lower heating value as low as 450 Btu/scf, although, as in gas engines, special engineering is required and full power may not be available. Full load gas consumption ranges from 6000 to 6500 Btu/bhp-hr; use 6500 Btu/bhp-hr for estimating purposes. To this must be added the pilot oil consumption. (See *Liquid Fuels*.)

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