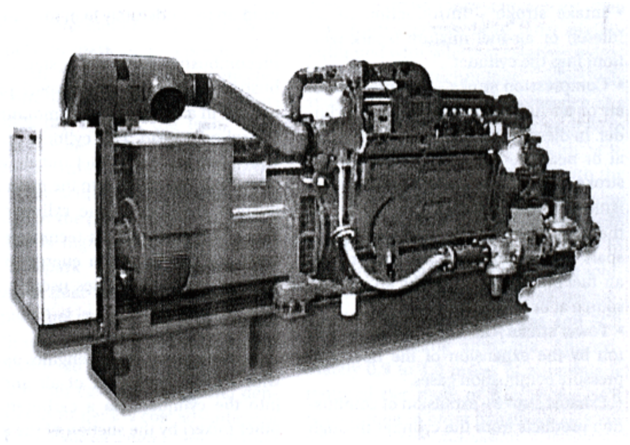
A Promising Alternative

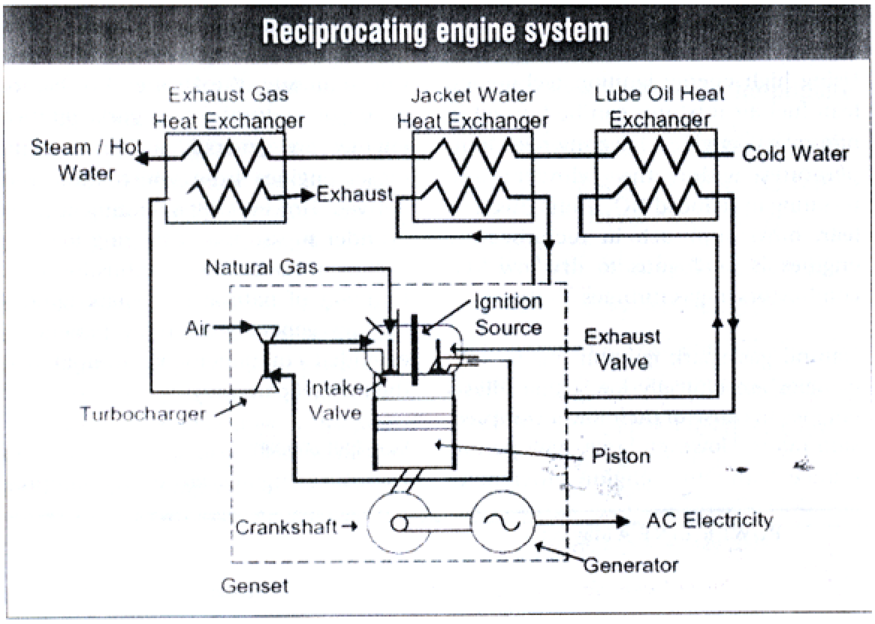
Gas engine process and applications

Reciprocating engines in general and gas engines in particular have emerged as very competitive prime movers for the power generation market. This is evidenced by the tremendous worldwide growth in engine sales. Diesel engines are the leading prime mover in this range due to their low first-cost position and popularity in emergency and standby power applications. But the positioning of gas engines has improved vis-à-vis diesel engines and gas turbines.



This growing popularity of gas engines is due to a number of reasons. Natural gas engines offer low first cost, fast start-up, proven reliability when properly maintained, excellent load-following characteristics and significant heat recovery potential.

Electric efficiencies of natural gas engines range from 28 per cent LHV for small stoichiometric engines (<100 kW) to over 40 per cent LHV for very large lean burn engines (> 3 MW). Waste heat can be recovered from the hot engine exhaust and from the engine cooling systems to produce either hot water or low pressure steam for CHP applications. Overall, CHP system efficiencies (electricity and useful thermal energy) of 70 to 80 per cent are routinely achieved with natural gas engine systems. As gas engines raise their specific output (kW/l), they close the gap with diesel engines on an output and specific-cost (Rs per kW) basis. This also improves their positioning relative to gas turbines.



Basic engine processes

There are two primary reciprocating engine designs relevant to stationary power generation applications- the spark ignition Otto-cycle and diesel cycle engine. The essential mechanical components of the Otto-cycle and diesel-cycle are the same. Both use a cylindrical combustion chamber in which a close-fitting piston travels the length of the cylinder. The piston connects to a crankshaft that transforms the linear motion of the piston into the rotary motion of the crankshaft. Most engines have multiple cylinders that power a single crankshaft.

The primary difference between the Otto and diesel cycles is the method of igniting the fuel. Spark ignition engines (Otto-cycle) use a spark plug to ignite a pre-mixed air-fuel mixture introduced into the cylinder. Compression ignition engines (diesel-cycle) compress the air introduced into the cylinder to a high pressure, raising its temperature to the auto-ignition temperature of the fuel that is injected at high pressure.

Both the spark ignition and the diesel four-stroke engines most relevant to stationary power generation applications complete a power generation applications complete a power cycle in four strokes of the piston within the cylinder.

- Intake stroke- introduction of air (diesel) or air-fuel mixture (spark ignition) into the cylinder.
- Compression stroke-compression of air or air fuel mixture within the cylinder. In diesel engines, the fuel is injected at or near the end of the compression stroke (top dead centre or TDC), and ignited by the elevated temperature of the compressed air in the cylinder. In spark ignition engines, the compressed air-fuel mixture is ignited by an ignition source at or near TDC.
- Power stroke-acceleration of the piston by the expansion of the hot, high pressure combustion gases.
- Exhaust stroke- expulsion of combustion products from the cylinder through the exhaust port.

Natural gas spark ignition engines

Spark ignition engines use spark plugs, with a high-intensity spark of timed duration, to ignite a compressed fuel-air mixture within the cylinder. Natural gas is the predominant spark ignition engine fuel used in electric generation and CHP applications. Other gaseous and volatile liquid fuels, ranging from landfill gas propane to gasoline, can be used with the proper fuel system, engine compression ratio and tuning.

Natural gas engines for power generation applications are primarily four stroke engines available in sizes of up to about 5 MW. Depending on the engine size, one of two ignition techniques ignites the natural gas:

Open chamber – the spark plug tip is exposed in the combustion chamber of the cylinder, directly igniting the compressed fuel-air mixture. Open chamber ignition is applicable to any engine operating near the stoichiometric air-fuel ratio up to moderately lean mixtures.

Availability of gas engines

	Gas engines		**Gas turbines**	
	(80-800 kW)	**(>800 kW)**	**(1-5 MW)**	**(5.25 MW)**
Availability factor	94.5	91.2	92.7	90.0
Forced outage	4.7	6.1	4.8	6.5
Scheduled outage factor	2.0	3.5	3.0	4.1

Pre-combustion chamber – a staged combustion process where the spark plug is housed in a small chamber mounted on the cylinder head. This cylinder charges with a rich mixture of fuel and air, which upon ignition shoots into the main combustion chamber in the cylinder as a high energy torch. This technique provides sufficient ignition energy to light off lean fuel-air mixtures used in large bore engines.

The simplest natural gas engines operate with natural aspiration of air and fuel into the cylinder (via a carburetor or other mixer) by the suction of the intake stroke. High performance natural gas engines are turbocharged to force more air into the cylinders. Natural gas spark ignition engines operate at modest compression ratios (compared with diesel engines) in the range of 9:1 to 12:1 depending on engine design and turbo-charging. Modest compression is required to prevent auto-ignition of the fuel and engine knock, which can cause serious engine damage.

Using high energy ignition technology, lean fuel-air mixtures can be burned in natural gas engines, lowering peak temperatures within the cylinders and resulting in reduced NO_x emissions. The lean burn approach in reciprocating engines is analogous to dry low-NO_x combustors in gas turbines.

Natural gas spark ignition engine efficiencies are typically lower than diesel engines because of their lower compression ratios. However, large, high performance lean burn engine efficiencies approach those of diesel engines of the same size. Natural gas engine efficiencies range from about 28 per cent (LHV) for small engines (<50 kW) to 42 per cent (LHV) for the largest high performance, lean burn engines. Lean burn engines tuned for maximum efficiency may produce twice the NO_x emissions as the same engine tuned for minimum NO_x. Tuning for low NO_x typically results in a sacrifice of 1 to 1.5 percentage points in electric generating efficiency from the highest level achievable.

Many natural gas spark ignition engines are derived from diesel engines, that is they use the same block, crankshaft, main bearings, camshaft and connecting rods as the diesel engine. However, natural gas spark ignition engines operate at lower brake mean effective pressure (BMEP) and peak pressure levels to prevent knock. Due to the derating effects from lower BMEP, the spark ignition versions of diesel engines often produce only 60 to 80 per cent of the power output of the parent diesel.

Manufacturers often enlarge cylinder bore about 5 to 10 per cent to increase the power, but this is only partial compensation for the derated output. Consequently, the Rs per kW capital costs of natural gas spark ignition engines are generally higher than the diesel engines form which they were derived. However, by operating at lower cylinder pressure and bearing loads ad well as in the cleaner combustion environment of natural gas, spark ignition engines generally offer the benefits of extended component life compared to their diesel parents.

Dual-fuel engines

Dual-fuel engines are diesel compression ignition engines predominantly fuelled by natural gas with a small percentage of diesel oil as the pilot fuel. The pilot fuel auto-ignites and initiates combustion in the main air-fuel mixture. Pilot fuel percentages can range from 1 to 15 per cent of total fuel input. Duel-fuel operation is a combination of diesel and Otto-cycle operation, with reduction in the percentage of pilot fuel used it approaches the diesel-cycle more closely. Most dual fuel engines can be switched back and forth on the fly between dual fuel and 100 per cent diesel operation. In general, because of lower diesel oil usage, NO_x, smoke, and particulate emissions are lower for duel-fuel engines than for straight diesel operation – particularly at full load. Particulate emissions reduction in diesel oil consumption while the level of NO_x reduction depends on combustion characteristics. However, CO and unburned hydrocarbon emissions are often higher, partly because of incomplete combustion. There are three basic types of duel-fuel engines.

Conventional, low pressure gas injection engines- These typically require about 5 to 10 per cent pilot fuel and may be derated to about 80 to 95 per cent of the rated diesel capacity to avoid detonation. The turndown ratio of the diesel fuel injection system sets the minimum pilot fuel requirement. Conventional diesel injectors cannot reliably turn down to less than 5 to 6 per cent of the full-load injection rate. Natural gas input is controlled at each cylinder by injecting gas before the air intake valves open. NO_x emissions of conventional duel-fuel engines are generally in the 5 to 8 gm per kWh range (compared to lean burn natural gas engines with NO_x emission in the 0.7 to 2.5 gm per kWh range).

High pressure gas injection engines - These to reduce derating by injecting natural gas at high pressures (3,600 to 5,100 psig) directly into the main combustion chamber as the pilot fuel is injected. However, the parasitic power for gas compression can be as high as 4 to 7 per cent of the rated power output – partly offsetting the benefit of reduced derating. This technology has not proved particularly popular because of this issue and the additional equipment costs required for gas injection. Pilot duel consumption is typically 3 to 8 per cent and NO_x emissions are generally in the 5 to 8 gm per kWh range.

Micropilot prechamber engines – These are similar to spark ignition prechamber engines is that the pilot fuel injected into a prechamber provides a high-energy torch that ignites the lean, compressed fuel-air mixture in the cylinder. Leaner mixtures than spark ignition engines are achievable since the energy provided by the diesel-fuelled micropilot chamber is higher than that obtained with a spark ignition prechamber. Micropilot duel-fuel engines with 1 per cent pilot fuel can operate at or close to the diesel engine’s compression ratio and BMEP, so little, if any, derating occurs. In this case the high power density and low Rs. per kW cost advantage of the original diesel engine are retained and engine efficiency at 75 to 100 per cent load is close to that of the 100 per cent diesel engine. NO_x and other emissions are comparable to those of lean burn spark ignition prechamber engines (NO_x emissions in the 0.7 to 2.5 gm per kWh range). These engines must be equipped with conventional diesel fuel injectors in order to operate on 100 per cent diesel.

Emissions

NO_x emissions are usually the primary concern with natural gas engines and are a mixture of (mostly) NO and NO_2 in variable composition. In measurement, NO_x is reported ad parts per million by volume in which both species count equally (for example, ppmv at 15 per cent O_2, dry). Lean burn natural gas engines produce the lowest NO_x emissions.

Stoichiometric and rich burn engines generally have lower efficiencies than lean burn engines. Lean burn engines equipped with selective catalytic reduction (SCR) technology selectively reduces NO_x to N_2 in the presence of a reducing agent. NO_x reductions of 80 to 90 per cent are achievable with SCR. Higher reduction are possible with the use of more catalyst or more reducing agent, or both. The two agents used commercially are ammonia (NH_3 in anhydrous liquid from or aqueous solution) and aqueous urea. Urea decomposes in the hot exhaust gas and SCR reactor, releasing ammonia. Approximately 0.9 to 1.0 moles of ammonia is required per mole of NO_x at the SCR reactor inlet in order to achieve an 80 to 90 per cent NO_x reduction.

CHP applications

Potential distributed generation applications for reciprocating engines include standby, peak shaving, grid support, and CHP applications in which hot water, low pressure steam or waste heat-fired absorption chillers are required. Reciprocating engines are also used extensively as direct mechanical drives in applications such as water pumping, air and gas compression and chilling/ refrigeration. While the use of reciprocating engines is expected to grow in various distributed generation applications, the most prevalent on-site generation application for natural gas SI engines has traditionally been CHP, and this trend is likely to continue. The economics of natural gas engines in on-site generation applications is enhanced b effective use of the thermal energy contained in the exhaust gas and cooling systems, which generally represents 60 to 70 per cent of the inlet fuel energy.

Reference book:

Power Line, May 2005