ITDG
PRACTICAL ANSWERS TO POVERTY

technical brief

DIESEL

Introduction

The internal combustion (IC) engine has been the main provider of shaft power since the early part of the 20th century. Their light, compact design and the easy availability of relatively cheap petroleum fuels meant that the IC engine soon ousted the bulkier steam engine and there has been no looking back. Hundreds of millions of IC engines have since been produced and although the vast majority have been fitted in motor vehicles, they have been put to such diverse uses as powering electricity producing generators, ships and boats, agricultural and agro processing machinery and many industrial applications. They are extremely versatile with a very high power to weight ratio.

In developing countries the IC engine has been used for many decades and plays a very important role in providing power for rural applications. Many stand-alone units provide power for milling, small-scale electricity production, water pumping, etc. They are readily available, commercially, off-the-shelf in most major towns and cities in developing countries in a range of sizes for various applications. There is usually a well-established spare parts and maintenance network, both at urban and rural centres.

Figure 1: Diesel-driven pump ©ITDG

There are two main types of IC engine and they can be simply categorised by the type of fuel used; petrol (gasoline) or diesel. The petrol engine is widely used for small vehicles and light applications whereas diesel engines are more suited to continuous running for lengthy periods at higher load ratings and are therefore used more widely for stationary applications and commercial vehicles.

Principles of operation of the IC engine

As mentioned above the main distinction in common engine types is that of the fuel used. The combustion process in the petrol engine and the diesel engine differ in the following significant features: in the petrol engine the petrol and air mixture is drawn into the cylinder, compressed (compression ratio ranging from 4:1 to 10:1), and ignited by a spark introduced by an electrical system. In the diesel engine, on the other hand, air alone is drawn into the cylinder and is compressed to a much higher ratio (14:1 to 25:1) than in the petrol engine. As a result of this compression the air is heated to a temperature of 700 – 900 ^{o}C. Only then is a certain quantity of diesel fuel injected in to the cylinder and because of the prevailing high temperature the fuel ignites spontaneously. Hence the petrol engine is often referred to as the spark ignition (SI) engine and the diesel as the compression ignition (CI) engine.

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Secondly, there is the sub-division according to cycle type; the two stroke or four stroke cycle. This categorisation differentiates between engines, which have an ignition phase on every revolution of the crankshaft or every other revolution. The method for mixing and injecting air and fuel is different for the two cycle types. The bulk of IC engines use the four stroke cycle, based on the cycle first proposed by Alphonse Beau de Rochas in 1862 and later developed by Nikolaus Otto (petrol) and Rudolph Diesel (diesel). Below we will look at the principle of operation of the four-stroke engine.

The four stroke cycle - diesel engine (refer to Figure 2)

1st stroke: induction stroke - while the inlet valve is open the descending piston draws in fresh air.
2nd stroke: compression stroke - while the valves are closed the air is compressed to a pressure of up to 25 bar.
3rd stroke: ignition and power stroke - fuel is injected while the valves are closed (fuel injection actually starts at the end of the previous stroke), the fuel ignites spontaneously and the piston is forced downwards by the combustion gases.
4th stroke: exhaust stroke - the exhaust valve is open and the rising piston discharges the spent gases from the cylinder.

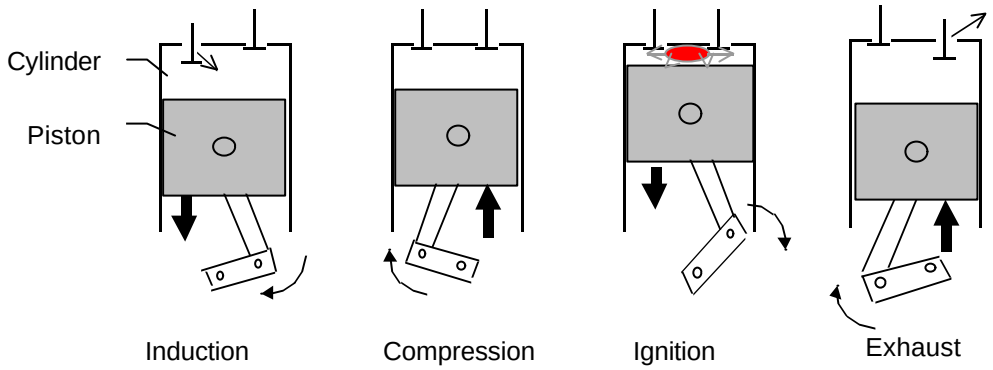

Figure 2. The four-stroke Diesel cycle

Since power is developed during only one stroke, the single cylinder four-stroke engine has a low degree of uniformity. Smoother running is obtained with multi cylinder engines because the cranks are staggered in relation to one another on the crankshaft. There are many variations of engine configuration e.g. 4 or 6 cylinder, in-line, horizontally opposed, vee or radial configurations.

The Table below shows a comparison of the relative practical advantages and disadvantages of petrol and diesel engines.

Diesel	Petrol
Pros Lower fuel costs Higher efficiencies Readily available for a wide range of sizes and applications Lower running speeds	*Pros* Light - hence more portable Lower capital costs Cheaper to maintain Higher running speeds
Cons Maintenance is more expensive Heavier and bulkier for a given power Higher capital cost Pollution	*Cons* Not so durable - especially under continuous long-term usage Lower efficiency for equivalent power Fuel more expensive Narrower range of off-the-shelf engines available - smaller engines more readily available Pollution

Application and choice of engine

To make a decision as to the type of engine, which is most suitable for a specific application, several factors need to be considered. The two most important are the power and the speed of the engine. The power requirement is determined by the maximum load. The engine power rating should be 10-20 % more than the power demand imposed by the end use. This prevents overloading the machine by inadvertently adding extra load, during starting of motors or some types of lighting systems or as wear and tear on the machinery pushes up its power consumption.

For example, a generator with a required output of 10 kW (kilowatts) and an efficiency of 75% would require an engine of the following capacity;

Output requirement	10 kW
Efficiency	0.75
Shaft power requirement	10 / 0.75 = 13.3 kW
Engine power requirement	13.3 kW x 10% = 14.63 kW

Since engine power is usually given in horse power (1 h.p. = 0.746 kW), we would choose an engine of size 19.6 h.p. or the next standard size *above* this figure.

Another important factor when choosing an engine is speed. Speed is measured at the output shaft and given in revolutions per minute (r.p.m.). An engine will operate over a range of speeds, with diesel engines typically running at lower speeds (1300 - 3000 rpm) and petrol engines at higher speeds (1500 - 5000 rpm). There will be an optimum speed at which fuel efficiency will be greatest. Engines should be run as closely as possible to their rated speed to avoid poor efficiency and build up of engine deposits due to incomplete combustion, which will lead to higher maintenance and running costs. To determine the speed requirement of an engine we again look at the requirement of the load. For some applications the speed of the engine is not critical but for other applications, a generator for example, it is important to get a good speed match. If a good match can be obtained then direct coupling is possible; if not, then some form of gearing will be necessary, a gearbox or belt system for example, which will add to the overall cost and reduce the efficiency.

There are various other factors that have to be considered when choosing an engine for a given application. These include the following: cooling system, abnormal environmental conditions (dust, dirt, etc.), fuel quality, speed governing (fixed or variable speed), poor maintenance, control system, starting equipment, drive type, ambient temperature, altitude, humidity, etc. Suppliers or manufacturers literature will specify the required information when purchasing an engine.

The efficiency of an engine depends on various factors, e.g. load factor (percentage of full load), engine size, and engine type. Some typical figures are given below. Other power system efficiencies are also quoted for comparison.

Type of engine	Efficiency (as a percentage)
5 kW petrol engine (full load)	15
5 kW diesel engine (full load)	25
5 kW diesel engine (20% load)	10
50 kW diesel engine (full load)	35
500 kW diesel engine (full load)	45
50W windmill (battery charger)	15
500 kW wind turbine	40
5 kW hydro electric system	60
500 kW hydro electric system	85

Source: The Power Guide, IT Publications, 1994.

Uses and Power Requirements

As mentioned earlier there is an almost limitless range of applications for the diesel or petrol engine. Some typical rural applications and their power requirements are shown below:

Application	Typical Power Requirement
Small scale irrigation pumps	2 - 15 kW
Small scale electricity generation	2 - 50 kW
Battery charging	500 W
Grain milling or threshing	5 - 15 kW

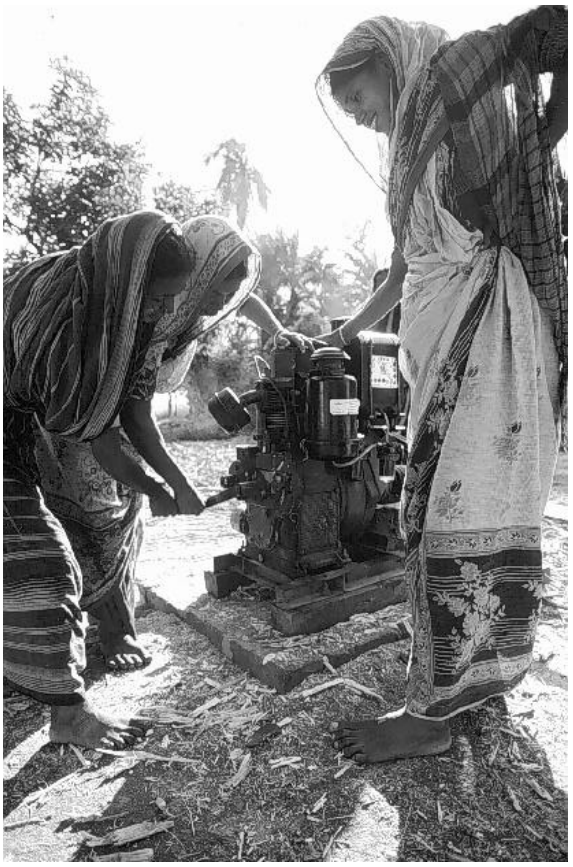

Figure 3: Diesel Engines are used throughout the world. ©Neil Cooper/ITDG

Diesel Generator Sets

Due to their widespread use throughout the world, diesel generator sets deserve a further mention. Diesel generating sets come in a wide range of commercially available sizes, from about 5 kW up to 30 MW (30,000 kW).

They are long lasting and will usually have a useful lifespan of 7 -10 years (30,000 hours running time), but this can be drastically reduced if maintenance is poor.

They are used by individuals, electricity utilities and businesses and are often used to supply a small electrical grid in remote areas where the national grid has not yet reached. They are usually fitted with a governor which automatically controls the speed of the machine as the load varies, maintaining constant voltage and frequency. Efficiency depends on the loading of the machine and where the load pattern (pattern of electricity consumption throughout the day) requires, two or more smaller machines are used to achieve higher fuel efficiency. Diesel generator sets, being somewhat noisy, are usually sited in a separate power house away from the premises or outside the town (depending upon their application).

Petrol generator sets come in smaller sizes - from 500W up to several kW - and tend to have a much shorter lifespan (5000 hours running time) than their diesel counterparts. They are more suited to mobile, very small scale electricity needs.

Alternative fuels
IC engines have been designed to operate on petroleum fuels; however, their operation is not confined to these fuels. Ethanol and methanol (also known as alcohols) substitute directly for petrol (gasoline), and vegetable oils can substitute directly for diesel fuels. Since the 1970's the threat of more expensive petroleum fuels has encouraged the examination of these and other alternatives produced from biomass. Ethanol is already used commercially as an engine fuel in Brazil and, when blended with petrol to form the blend known as gasohol, in a number of other countries. The availability of alternative fuels for IC engines means that for the foreseeable future IC engines are still serious contenders for stationary applications to provide shaft power, particularly at the lower end of the power range.

Renewable energy sources

One of the current issues when considering the type of power system for use in rural areas of the developing world is whether it is better to use fossil fuel technology or to use locally available renewable resources. Many renewable energy technologies are now fully mature and costs are competitive with those of technologies relying on fossil fuels, especially when running costs are considered. Renewable energy sources, such as solar power, hydro power, biomass energy, etc., can be harnessed locally, are usually inexpensive or free (which brings down the running costs), and are less damaging to the environment (another issue which many governments are taking seriously nowadays). Also, the dependence upon external market fluctuations is removed, transport costs are eliminated and, as concern grows over the future supplies of fossil fuels, sustainability has become another issue which many people are considering when choosing their power supplies.

In some cases hybrid or mixed systems are used to provide a flexible and cost effective alternative to pure diesel or petrol systems. These are systems which combine two or more technologies which enhance one another's capabilities. For example, a wind turbine can be used in conjunction with a diesel generating set. When the output from the wind turbine drops below a certain power level, due to lack of wind, the diesel generator can be switched in to compensate. These systems can be a combination of purely renewable energy technologies or combine fossil fuel energy technologies depending on the circumstances. Careful planning is needed when considering such a system.

Cost

Obviously cost plays an important role in the choice of technology for rural applications. There are two main costs to consider when contemplating your options - the investment cost and the running costs. For diesel systems the investment costs tend to be relatively low compared with renewable energy technologies while the running costs will be high. Running costs will also vary widely as there are many factors which will determine the actual cost of the power supplied - generating capacity, load factor, efficiency, fuel costs, etc. It is worth bearing in mind that, in the long term, the fuel costs for a diesel or petrol engine will be high compared with the capital cost and this often causes problems where there are no guaranteed funds or income for fuel purchase. Many machines sit idle in the developing world due to lack of funds for fuel purchase. In many developing countries foreign exchange shortages mean that there can be regular shortages of fuel. Theft of fuel is also commonplace. As a general rule, the larger the number of consumers the lower the unit cost. See the 'cost comparison fact sheet' in this series for information and comparisons on costs of different power supply sources.

Suppliers, spare parts and maintenance

One important factor to consider when purchasing an engine is the availability of spare parts in the country. If there is a dealership or supplier for the manufacturer of the machine you will be buying within the country, then there should be no problem obtaining spare parts. Indeed many machines are now manufactured in developing countries. There is usually a wide range of manufacturers represented in major towns and cities in most countries throughout the world. It is worth checking this before purchase. Some countries are affected by embargoes or trade restrictions which can make it difficult to find spares.

Maintenance of any machine in the developing world is a recurring theme, which has been given a great deal of attention but still presents many problems. It is important to ensure that the machine will be regularly maintained by a competent craftsperson. In remote rural areas this can present problems. There is often no one in the area who is knowledgeable of your machine (and letting unskilled people maintain the machine can be worse than doing nothing at all!) and it will be very expensive to bring in a skilled mechanic from the nearest town (which may be several days away) to carry out the maintenance. It is often worth considering sending a local person for training so that the maintenance will be carried out regularly and competently.

Resources

1. *The Power Guide*, IT Publications, 1994.
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3. Fenn, John B., *Engines, Energy and Entropy*, a Thermodynamics Primer, W.H. Freeman and Company, 1982.
4. *How things Work*, Heron Books, London, 1963.
5. Foley, Gerald, *Electricity for Rural People*, Panos Publications Ltd., 1990.

Other Books of interest

Diesel and Gas Turbine Worldwide Catalogue: Engine Power Products Directory and Buyers Guide, Diesel and Gas turbine Publications, Wisconsin, USA
Grauw, C., *Getting the most from your Diesel Engine*, Botswana Technology Centre, Gaborone, Botswana, 1987.
Stone, R. *Introduction to Internal Combustion Engines*, Macmillan, London, 1992.

Manufacturers / Suppliers

Note: This is a selective list of suppliers and does not imply ITDG endorsement.

Lister-Petter (diesel engines) Ltd, Long Street, Dursley, Gloucestershire GL11 4HS,.U.K.
Tel.: +44 (0)1453 544141, Fax: +44 (0)1453 546732, Website: http://www.lister-petter.co.uk.
Manufacturer and supplier of diesel engines.

F.G. Wilson Engineering Ltd., Group Headquarters, Old Glenarm Road, Larne, Co. Antrim, BT40 1EJ Northern Ireland, U.K.
Tel: +44 (0)28 2826 1000, Fax: +44 (0)28 2826 1111, Website: http://www.fgwilson.com
With offices in the following countries:
France, Germany, Spain, Australia, Brazil, Hong Kong (China), China, Russia, Singapore, South Africa, United Arab Emirates, U.S.A.
Manufacturer of Diesel Generator Sets from 8 to 6500 kVA

Pumpsets Ltd., Walworth Industrial Estate, PO Box 1615, Andover, Hants. SP10 5NP, U.K.
Tel: +44 (0)1264 333 737 or 811 094, Fax: +44 (0)1264 333 108 or 811 095, Website: http://www.pumpsets.com.
Suppliers of pumping equipment - including diesel, human powered and Oxfam Emergency Kits.