Engines on biogas for generators with a maximum power of fifty kW_e

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Introduction

Electricity is in many areas of (sub)tropical countries not available or unreliable. Blackouts are quite common in rural areas and generators operate for a significant number of hours per year. There are several millions small generators with four-stroke internal combustion engines (fig.1).

Stationary generators can be operated with biogas, reducing the reliance on fossil fuels. Biogas consists typically of 55 - 65 % methane, 35 - 45 % carbon dioxide and traces of water vapor and hydrogen sulfide. It is a renewable fuel and can be produced locally from agricultural residues. In rural areas biogas can be cheaper than diesel fuel.

Load profile

Electricity use during the day follows a certain pattern and varies with the seasons. It is also dependent on the degree of development (lighting, TV, fans, air-conditioning, water pumping, refrigeration, mobile phone antennas and all types of small businesses). In figure 2 the load profile of some Nepalese households is given, in

Figure 3 that of a Malaysian school and in fig 4 the profile of a town of 10 000 inhabitants in Mauritania.

Fig 2 Daily load profile of some households in Nepal (Bandari 2010)

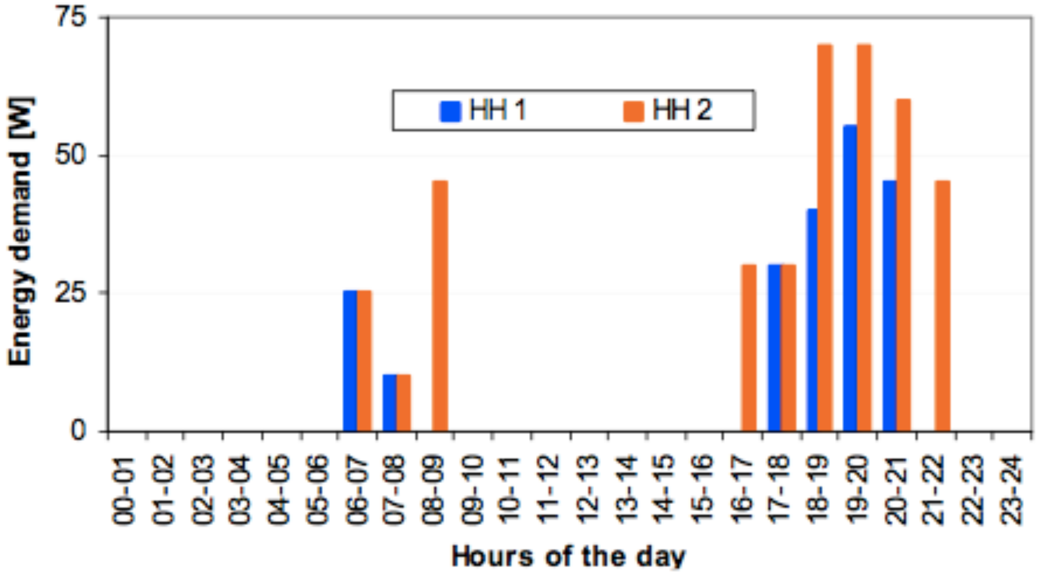


Figure 7.15: Daily load profile of individual household

Fig. 3 Daily load profile of a school in Malaysia (Mahmoud 2010)

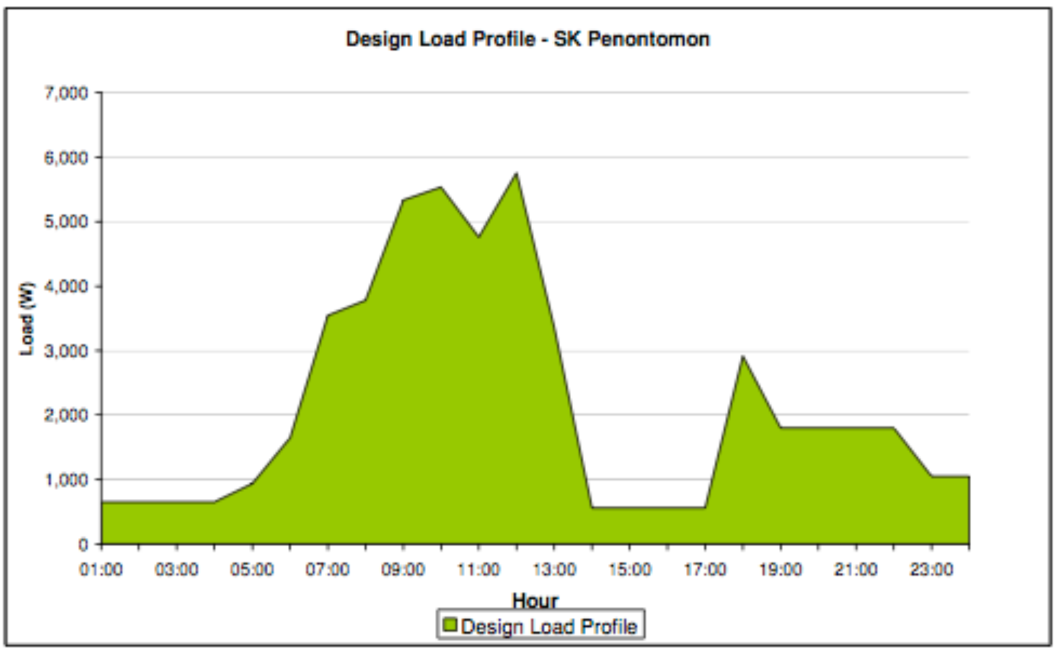
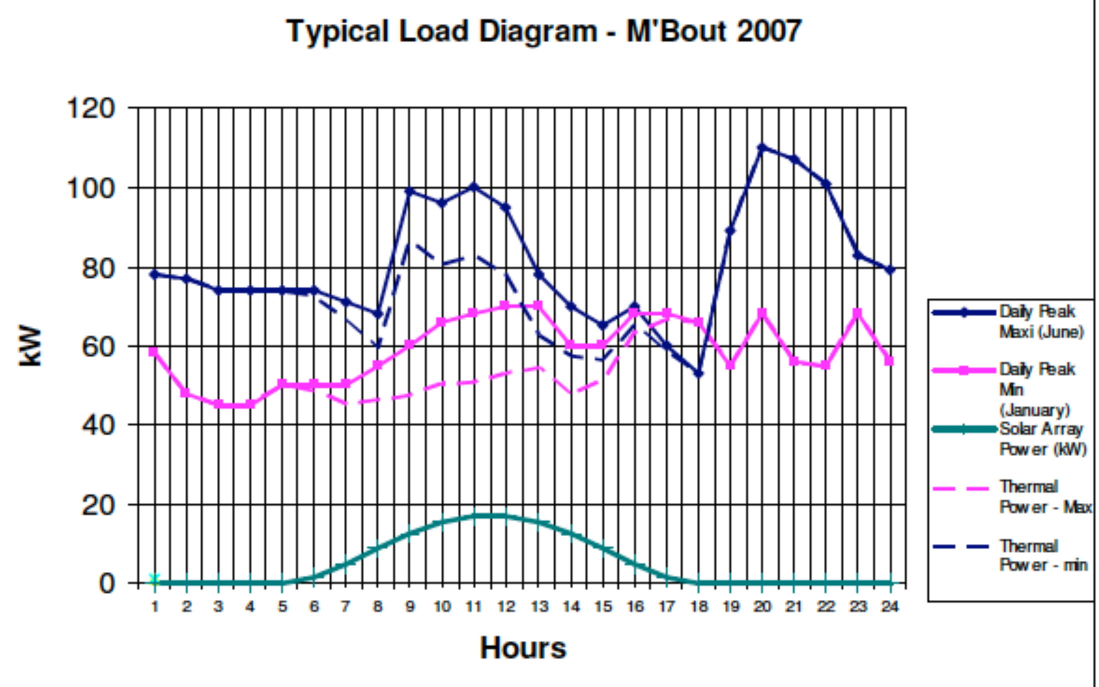


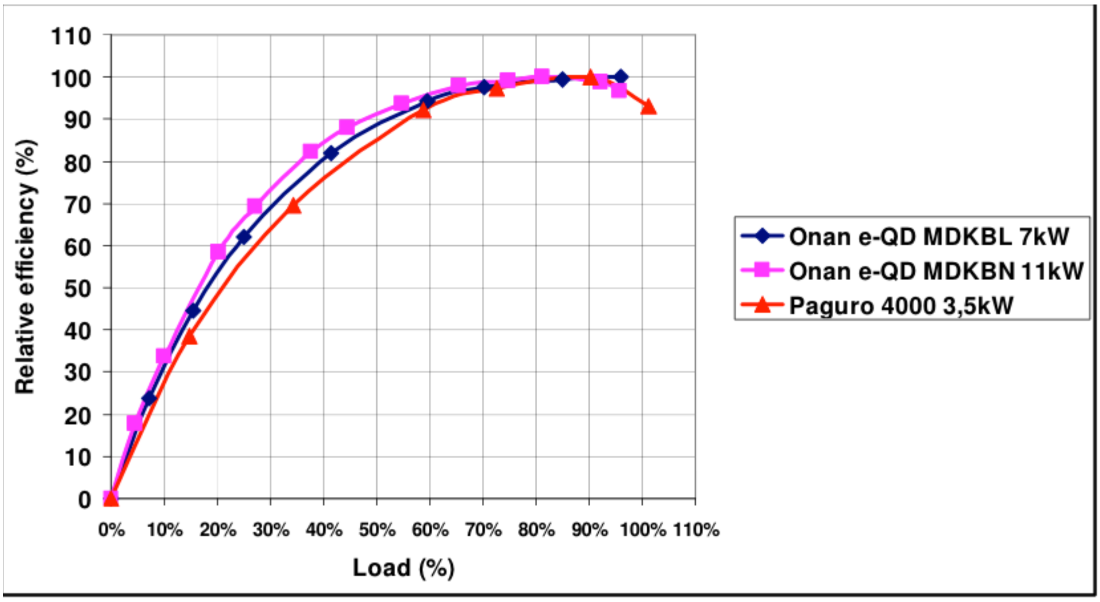
Figure 3.3 : Daily load profile for SK Penontomon.

Fig 4 Load profile of a Mauretanian town (ann. 2007)



Engines run most economically at 40 to 100 % of their nominal capacity. Thermal efficiency decreases with 20 % at loads under 40 % (Fig.5). Petrol powered generators have an efficiency of 17 % (Honda factory information) and diesels around 25 % (www.victronenergy.nl). Fuel costs account for about 70 % of the generating costs in small electricity grids (Ann. 2007). It is therefore economically to use at least two generators of which one is switched on only during peak demand.

Fig. 5 Relative efficiency against load for small diesel generators (from Victron Energy)



Graph 20: Relative efficiency against % load

The minimum nameplate capacity of generators is around 1 kW$_e$. Smaller systems are best served with photovoltaic and batteries. Even larger systems can be converted to photovoltaic. This depends on the load profile and acceptable investment costs.

Fans, refrigerators, well pumps, air conditioners and power tools require starting currents that are three to six times more than the current during normal operation. Some pumps (e.g. Grundfoss) have a soft start capability, reducing the maximum current for start-up, but other equipment lack this. The generator will normally run at less than 30 % of nameplate capacity when sized to the start-up current of the equipment. This will increase fuel consumption by 50 %. Voltage sag restorers can provide the start-up current for these appliances.

Modified petrol engines

A number of small four stroke petrol engines modified for biogas have been documented (Ehsan et al. 2005; Kubota AE2400LX, Lee 2010; Honda GC160 E and Bui et al. 2007; Honda GC160 E). A simple modification is to place a mixer between the air filter and the motor inlet (Ehsan et al. 2005). The data are summarized in table I.

Table I Petrol engines modified for biogas

	Cylinder volume cc	Compression rate		Ignition timing biogas	Power petrol kW_e	Power biogas kW_e	Specific power Biogas kW_e/l	Efficiency biogas %
		Petrol	Biogas					
Kubota AE2400LX	200				1.6	0.8	4.0	9
Honda GC160 E	160	8.5:1	8.5:1	20	No data	0.8	5.0	13
Honda GX 120	120	7.5:1	7.5:1	25	2.2	0.9	7.5	11
A Honda 3000 iS at 2.3 kW has an efficiency of 13.5 % on petrol (Olson 2011)								

Bui et al. (2007) used a CO2 scrubber to increase the methane content to 80 % and could obtained a power on biogas to 40 % of that on petrol.

The tests by Ehsan et al. (2005) indicate that an increase of the methane content from 55 to 60 % will increase power to 75 % of that of petrol. At the same time the thermal efficiency is increased from 8 to 12 % (Table II). Honda brought out a 1.6 kW (160 cc) tri-fuel generator in Pakistan. The power on methane (100 %) is 65 % of that on petrol.

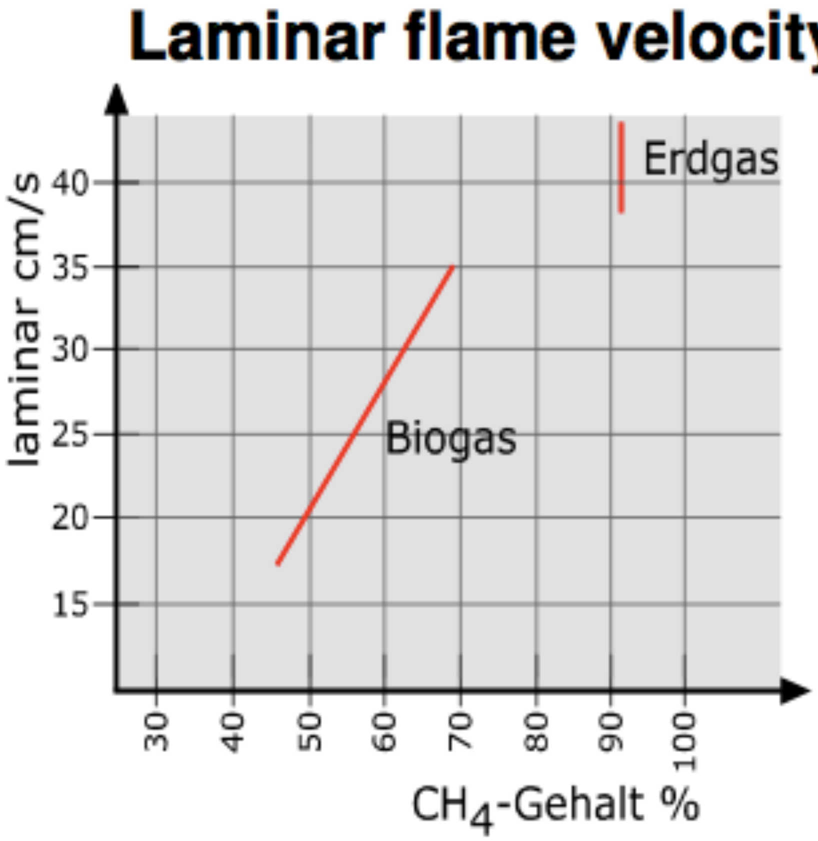
Table II effect of methane content on power and efficiency of engines running on biogas.

Author	Engine	Fuel CH_4	Power kW_e	Efficiency
Ehsan et al. 2005	Kubota AE2400LX	100 %	1.4	16 %
		70 %	1.3	13 %
		60 %	1.2	13 %
		55 %	0.8	9 %
		Petrol	1.6	12 %
Bui et al. 2007	Honda GX 120	80%	0.9	16 %
		Petrol	2.2	20 %
Lee 2010	Honda GC160 E	100 %	0.8	19 %
		85 %	0.8	17 %
		75 %	0.8	15 %
		50 %	0.8	11 %

Gasoline engines running on biogas will not produce the same power as on gasoline. Methane requires more oxygen (air) than petrol. The evaporation of gasoline lowers the temperature of the incoming gas and increases its density. Less air will enter the cylinder with biogas as fuel than with petrol for the same pressure drop and the same hydraulic resistance of the air filter, throttle, carburetor, inlet piping and inlet valve. The higher gas temperature for biogas will decrease the thermal efficiency.

The laminar flame propagation velocity for biogas depends on the methane concentration (fig 6). This velocity is lower than that of gasoline (0.5 m/s). It takes thus longer for complete combustion of the mixture. Advancing the ignition timing can in part compensate this delay (Fig. 9).

Fig 6 Laminar flame velocity for biogas (Schnell)



Dual fuel engines

Dual fuel engines require a significant amount of pilot fuel to ignite the biogas air mixture. Liquid fuel is also used to cool the injectors and to prevent end gas knock.

Hot gases remaining in the headspace of the previous cycle are mixed with the methane/air mixture. There remain pockets of hot gas, as mixing is not perfect. These pockets heat-up nearby fresh gas. This gas is further heated by radiation from the flame front during the expansion cycle. Pressure waves will compress this fresh gas and this gas will heat up adiabatically until it combusts spontaneously, increasing the amplitude of the pressure wave. These waves are called end gas knock (Turner et al. 2006)

Dual fuel engines have a higher thermal efficiency compared to gas engines due, to the higher compression rate. Schnell Zundstahlmotoren (www.schnellmotor.de) has sold over 3000 generators with dual fuel engines. The maximum capacity of these generators is 1 000 kW_e. Dual fuel engines are also used in ship propulsion and in trucks.

Kerkhof (2008) has studied a 10 kW (Deutz) dual fuel (biogas and jatropha oil) generator. Sixty percent of the diesel fuel (energy) could be substituted with biogas. Higher percentages could not be used due to knock phenomenon.

Tippayawong et al. (2010) looked at the long time behavior (3500 h) of a 5.5 kW generator producing 3.5 kW (1500 rpm). Pilot diesel fuel was 20 % (in energy).

Imiolek et al. 2011 tested a small generator (Mitsubishi) with methane and diesel fuel. The engine was modified with a common rail fuel system and a piezo-electric injector. They could operate with 3% diesel fuel. They used a high pressure for diesel fuel injection (40 MPa). This improves the combustion behavior, thereby reducing end gas knock. A speed of 2 200 rpm would be optimum both for engine life and fuel consumption (Hengst et al. 2009). No mention was made of end of cycle knock.

Ehsan et al. 2010 tested a 11 kW (Brake power) Dongfeng engine on diesel and methane fuel. At 70 % of the nameplate power only 12 % diesel was required. At maximum power (77 % of name late power) 30 % diesel had to be injected. Schnell-zundstrahlmotoren modifies Sisu diesel engines for duel fuel applications.

Frederiks (2012) tested a 7.5 kWe lister engine used as a multifunctional platform in Mali.

Table III Dual fuel engines

Engine	Displa-cement cc	Speed rpm	Rated output kW_e	Compression ratio	Injection °	Reference
Lister	1 500	750	7.5			Frederiks 2012
Mitsubishi	411	2 400	5.5	18	16	Tippayawong et al. 2010
Hatz	462	3 000	8.8	21	14	Imiolek et al. 2011
Dongfeng	903	2 200	11.2	20	17	Ehsan et al. 2010
Deutz	1 100	2 000	12	17	24	Kerkhof 2008
Sisu	3 300	1 500			Electronic	Factory specs

Table IV Dual fuel tests

Engine	Speed rpm	Test output kW_e	Methane %	diesel fuel energy %	Efficiency %
Lister	750	2 .8	60	36	13
		2.0	60	44	11
Mitsubishi	1 500	1.5		20	
Hatz	3 000	4.0	100	3	18
Dongfeng	2 200	7.9	100	12	29
Deutz	2 000	10	100	40	32
		10	60	40	34
		8	60	30	28
Sisu	1 500	30.0	50	8	39

Generators operate normally at 1500 or 3 000 rpm simulating the electric grid. This will not give the highest efficiency and highest replacement of diesel fuel at part load.

Dengler et al. (2011) have developed a control system in which the engine runs always at its point of maximum efficiency. They have a generator with multi poles. This results in a variable high frequency. This frequency is rectified and using a frequency modulator the outlet frequency and voltage are set at 50 Hz and 220 V. This has the disadvantage that losses are incurred at the maximum power level.

Data for the Fischer-Panda 40i (3.5 kW_e) generator with this inverter technology do not show any improvement in efficiency at part load (ann. 2008). The advantages are however less noise and less wear.

The Hatz engine is one of the smallest diesel generators with 2 kW_e output at 3 000 rpm. It is with 60 kg quite heavy. The German and British armies use Hatz generators. The company has representatives in many countries. Shijiazhuang Houfeng offers 1.5 kWe (at 2600 rpm; 170 cc) generators with an fuel consumption of 340 g/kWh (factory information)

Conclusions

- There is an optimum between the amount of diesel fuel required and the thermal efficiency.
- The fraction of biogas in dual fuel engines can be improved with modifications in the fuel injection system.
- Electronic injection timing with a knock sensor can minimize diesel fuel consumption and maximize power output.

Gas engines

Gas engines have spark ignition. Ignition is faster than in diesel engines leading to higher peak pressures. The compression ratio is therefore lower. A large fraction of the generators on biogas and methane are equipped with gas-engines as prime movers.

Sinertec produces a 5.5 kW_e methane based generator using a Fichtel and Sachs engine with an efficiency of 28 % (Factory information)

Kinorn (2007) and Siripornakarachai S., (2008) fitted a venturi at the position of the carburetor, increased the advance of the ignition timing and increased the compression ratio using different cylinder heads on a small generator and car engine. Siripornakarachai S., (2008) modified a diesel bus engine by adding a spacer between the engine head and body.

Schnell-Zundstrahlmotoren produces 55 kW_e gas engines with 33% efficiency (Factory information). A same size dual fuel generator has an efficiency of 40 % (Factory information)

Table V Gas engines

	Cylinder volume cc	Compression rate	Methane content	Power biogas kW_e	Specific power Biogas kW_e/l	Efficiency biogas %
Nissan GA-16 DE	400	11.0:1	58	5.2	13.0	26
Honda GX120 E	120	10.0:1	58	1.1	9.2	11
Sachs	578		100	5.5	9.5	28
Sisu	4 900	9.6:1		55.0	11.2	33

Fig 7 Modified venturi for the mixing of air with biogas

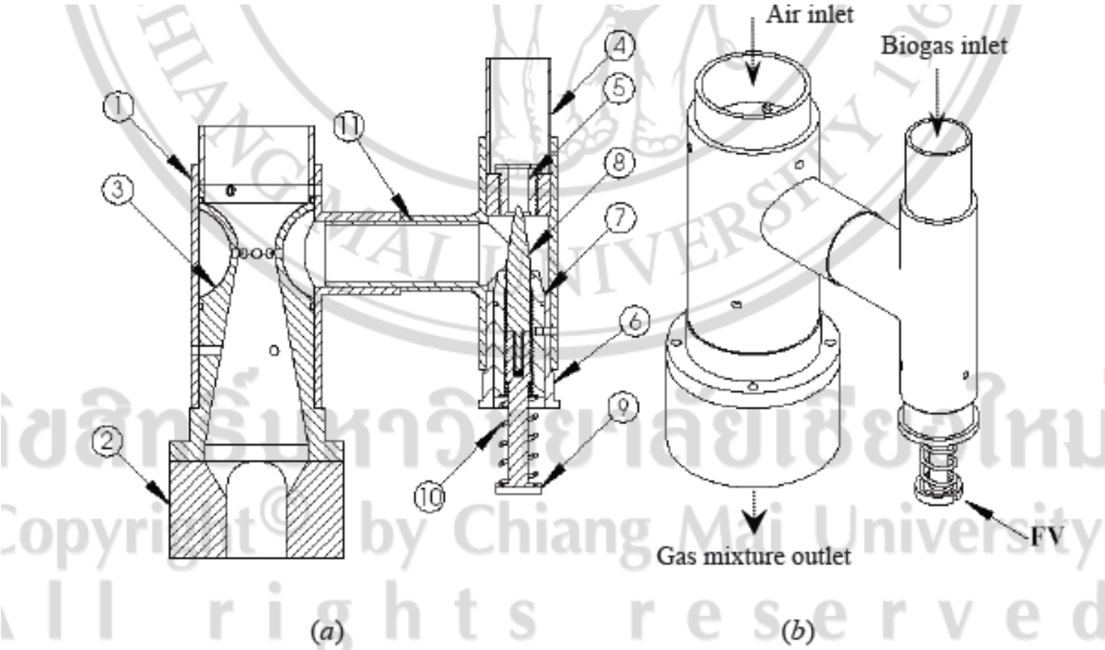


Figure 3.1 Schematic diagram of the 1.6 liter biogas carburetor design: (*a*) cut-away view of eleven components are; (1) venturi housing, (2) venturi base, (3) venturi-mixer, (4) metering housing, (5) main jet, (6) metering adjusting nut spacer, (7) metering adjusting nut, (8) metering needle, (9) metering adjusting screw, (10) return spring, and (11) pipe junction, and (*b*) isometric drawing.

Fig 8 Effect of compression ratio on power output

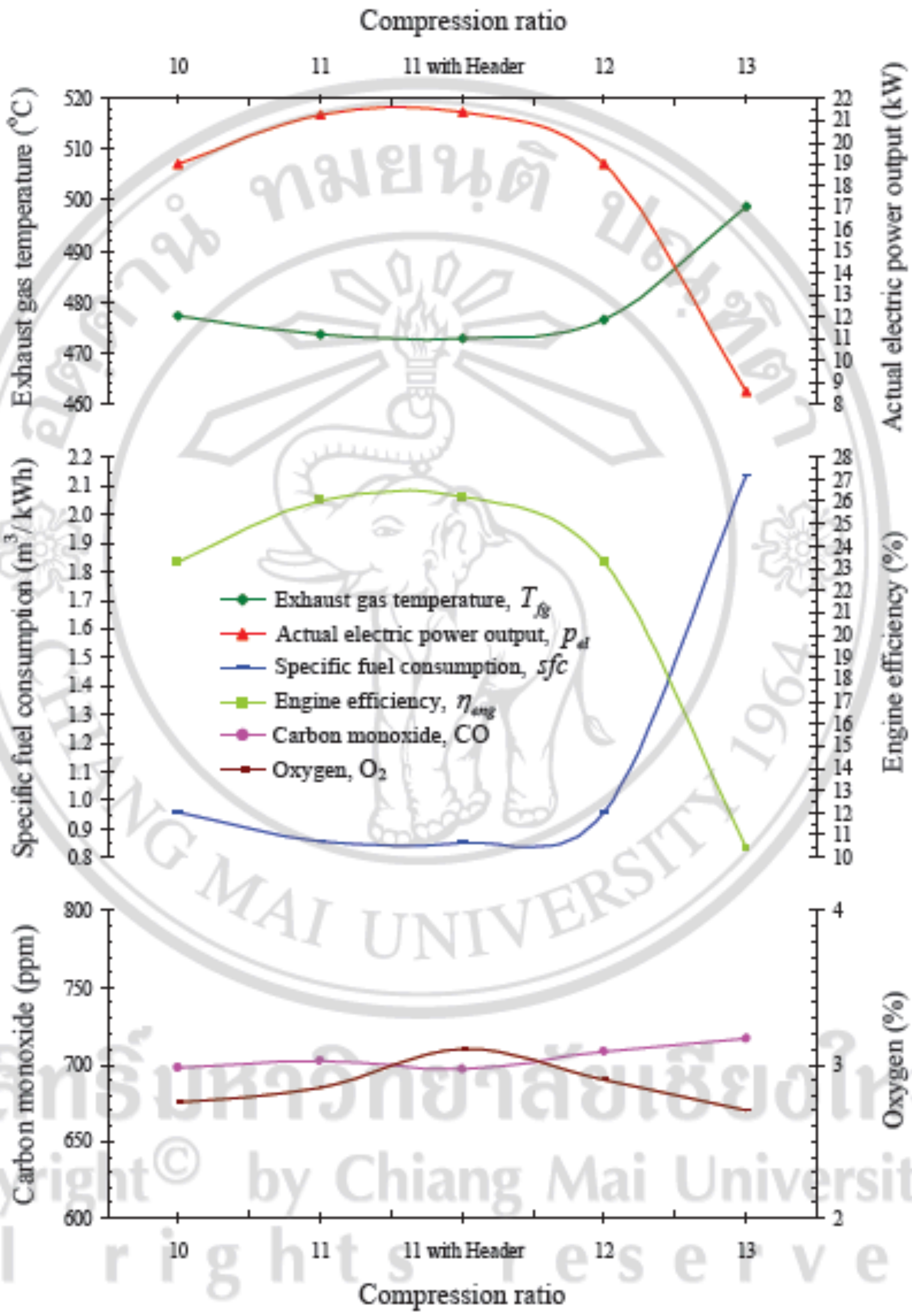
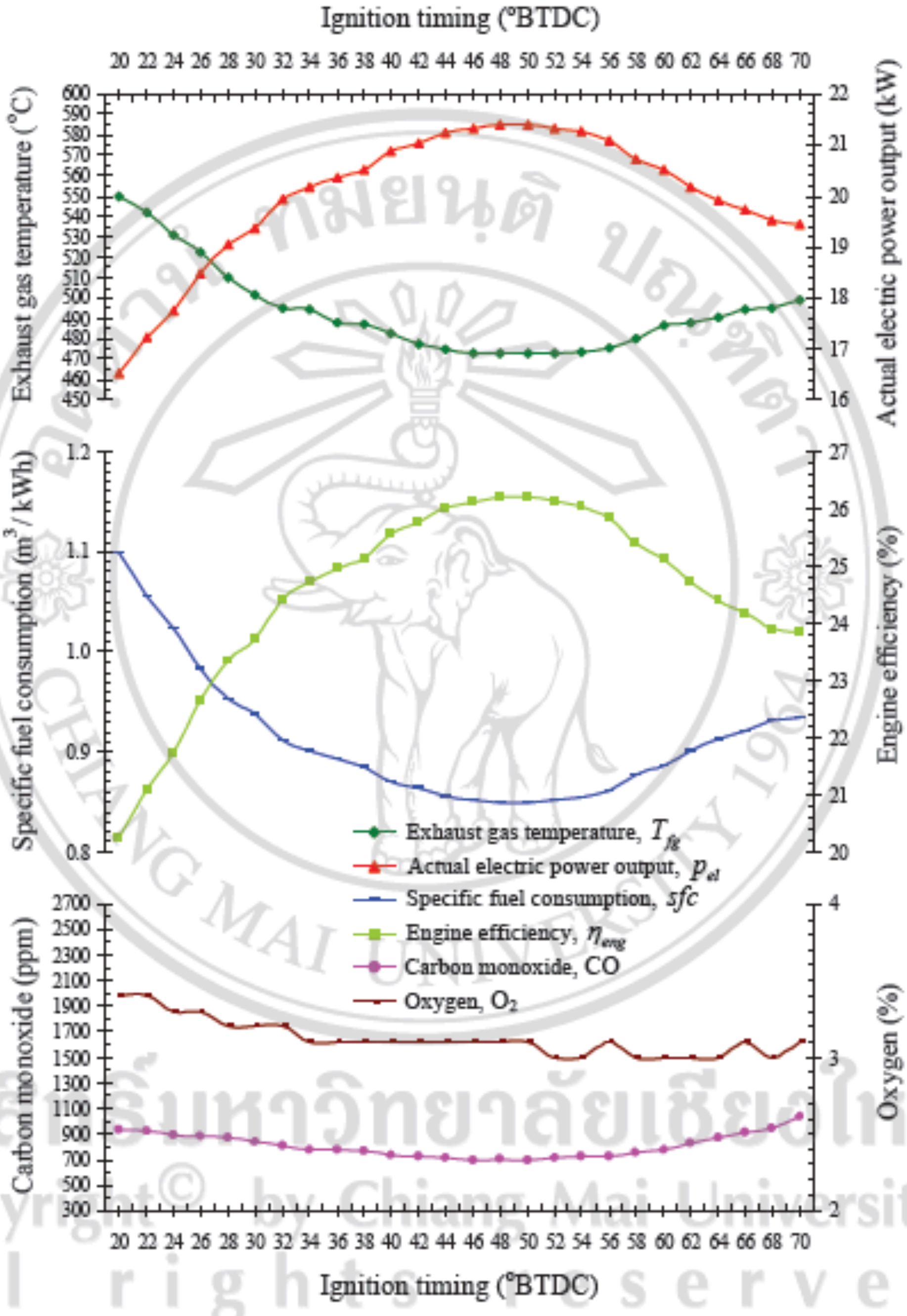


Fig 9 Effect of ignition timing on power output



Service live (time between overhauls)

Service life is influenced by:

- Materials and quality of construction
- Quality of installation
- Engine load factors (Overload!)
- Temperature of operation
- Quality of biogas (H_2S)
- Quality of lubrication oil
- Interval of oil, oil-filter and air-filter changes.

A German site (www.endress-strohmerzeuger.de) makes only a distinction between fast running generators and slower running generators on liquid fuels.

- Service life of 3 000 rpm one cylinder generators will be a 3 000 h.
- Service life of a 3 000 rpm generator sets will be 5 000 h.
- Service life of a 1 500 rpm generator sets will be 10 000 h.

An American site (www.allworldsdieselgen.com) has a more complex estimation of the service life of generators.

Fuel	Quality	Speed rpm	Cooling	Service life h
Gasoline	Contractor grade	3 600	air	2 000 – 3 000
Gasoline	Industrial grade	3 600	liquid	5 000 – 6 000
Diesel	Contractor grade	3 600	air	2 500 – 4 000
Diesel	Industrial grade	3 600	liquid	10 000 – 12 000
Diesel	Industrial grade	1 800	liquid	15 000 - 20 000

One Honda EV 2000 generator (3 6600 rpm) ran for 12 000 h and an other for 7 000 h.

Discussion

The choice for engine type depends on load profile (Power and number of hours per day used) and the acceptable ratio between investment and operating costs. The required thermal efficiency is a trade off between the extra costs for the engine versus the extra investment in the biogas plant and depends also on the availability of substrates to produce biogas. Further considerations are the local availability of engines, parts and diesel fuel. The pilot fuel in dual fuel engines can also be provided by locally produced plant-oil.

Points to be clarified:

- Simple systems to modify ignition and injection timing
- Optimization of dual fuel engines with plant oil
- Low cost voltage sag restorers
- Service life of small generators

Conclusions

Modified petrol engines (with adjusted timing) can be used where a few kW_e for only several hours per day are required.

Small diesel engines are used for many purposes in rural areas (two wheel tractors, threshing machines and pumps). These can be modified for dual fuel operation and connected to generators. The same holds for (imported) diesel car, bus and truck engines.

Gas engines are indicated in places where there are abundant substrates for biogas and the investment costs for biogas installations are low. Car, bus and truck engines can be modified to gas engines.

Table VI Advantages and disadvantages of engines for biogas

Engine	Advantages	Disadvantages
Modified gasoline	- Low investment costs - Availability	- Service life - Fuel consumption
Dual fuel	- Service life - Low fuel consumption - Availability	- Diesel fuel required - Modification required for optimal fuel consumption - Extreme wear at low power operation
Gas engine	- Service life - Investment costs	- Specialized spark plugs required - Spare parts - Low thermal efficiency

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