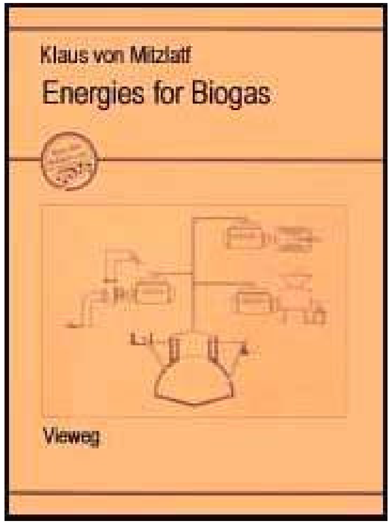

Engines for Biogas (GTZ, 1988, 133 p.)

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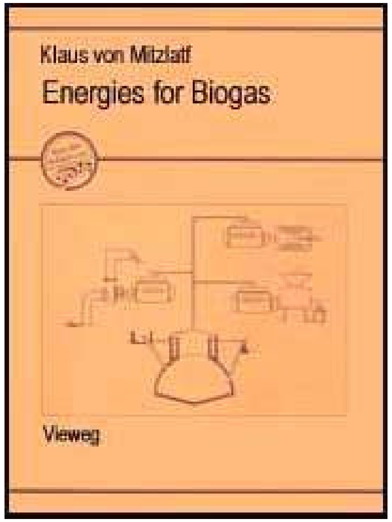

Engines for Biogas (GTZ, 1988, 133 p.)

Klaus von Mitzlaff

Theory, modification, economic operation

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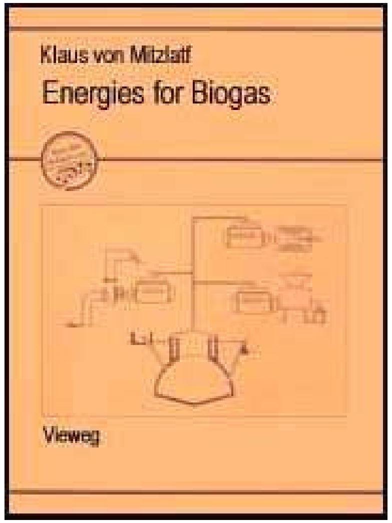


Engines for Biogas (GTZ, 1988, 133 p.)

7. Planning a biogas engine system

7.1 The biogas engine as a module integrated into an energy system

The supply of mechanical or electric power from biogas is only feasible using a biogas engine. The installation of a biogas engine however requires an appropriate planning of the fuel production and also the consumption/operation procedures. This is a crucial exercise which can usually be-avoided when the power is purchased from an electric grid.

As an engine in general does not supply energy, but rather transforms one form of energy, here biochemical, into another form, mechanical energy, its operation requires a source of energy on one side and s consumer of the energy on the other. The coordination of the energy source (biogas production plant), the transformer (engine) and the consumer (driven machine) is therefore of utmost

importance for a technically and economically satisfactory performance of the whole system.
The following parameters have an influence on the system's performance:

a) Technical Parameters

- Biogas production in the biogas plant under consideration of the plant's size, inputs and operation as well as the reliability of the gas supply system.
- Power demand of the driven equipment with regard to its anticipated fluctuation or the anticipated point of continuous operation.
- Demand of low and medium temperature heat from engine's waste heat (cogeneration).
- Daily schedule of operation with regard to biogas consumption, plant size and necessary gas storage capacity.
- Speed or speed range of the driven machine and the engine.
- Mode of control, manual or automatic.
- Local availability of engine service, spare parts, technical expertise and sufficiently competent operating personnel.
- Anticipated development of energy supply and demand in the future.

b) Economic Parameters

- Price of biogas plant cum ancillaries.
- Price of engine cum modification.
- Price of driven machine and energy distribution system (electrical wiring, water system, etc.) unless already existing.

- Operational cost of biogas system, i.e plant, engine and driven machine.
- Cost of the system's service and maintenance.
- Capital costs (interest rates, pay back periods, etc.).
- Expected revenue from provision of selling energy or services, including the use of the engine's waste heat.
- Savings by the omission of cost for other fuels or forms of energy.
- Anticipated development of economic parameters (inflation, laws, regulations, fuel taxes, etc.).

c) Alternative Possibilities of Power Supply

- Electric motors under consideration of availability, reliability and price of electricity from another (e.g. public) supplier.
- Small hydropower in favorable areas for direct drive of machines or generation of electricity.
- Wind power in favorable areas under consideration of the schedule of power demand and the wind regime.
- Diesel, petrol, alcohol or LPG as engine fuels under consideration of availability, price and given infrastructure for a reliable supply.

To summarize, a biogas engine is only one module in a system and can only perform to satisfaction when all other components are well integrated. Furthermore the economic and boundary conditions, realistically assessed, have to be more favorable than for alternative solutions. Last but not least the actual situation sur place, the availability of technical equipment and expertise or other constraints can significantly influence the choice of the system and the planning process as a whole.

7.2 Economic and Operational Considerations

There are different basic situations out of which the use of biogas for the generation of mechanical or electric energy may be considered.

a) Biogas availability or potential

- A biogas plant already exists and the gas yield is larger than what is already consumed in other equipment or the yield could be increased.
- Organic matter is available and otherwise wasted; the boundary conditions allow for anaerobic digestion.
- Environmental laws enforce anaerobic treatment of organic waste from municipalities, food industries, distilleries, etc.

b) Demand for mechanical power

- Other fuels are practically not available.
- Other sources of energy or fuels are more expensive or their supply is unreliable.
- Having a fuel at one's own disposal is of specific advantage.

c) Possible revenue through selling mechanical power, electric power or related services to other customers (e.g. the public electricity supply company).

In all cases it is essential to combine the modes of the generation of the fuel and its consumption. While the biogas is produced in a continuous mode, the demand for power, hence fuel, is often discontinuous. Biogas, unlike liquid fuels, can be stored in larger quantities either in a compressed form requiring special efforts or

in large, low pressure storage tanks. However, both ways are costly. This provides an incentive to avoid extensive storage through a well balanced production and consumption of biogas.

One way of equalizing the demand profile (Fig. 7.1) is the continuous operation of the engine, hence continuous fuel consumption. Instead of operating a powerful machine and engine for a short period per day the same service can often be obtained by a smaller system operating for a longer period. A similar effect is reached by the operation of different equipment in a sequence rather than at one time, e.g. water is pumped overnight while grains are milled during the day. The smaller system not only requires lower investment itself, but it also requires smaller or no gas storage capacities. The planning of the operational schedule of the equipment has a considerable effect on the economics and feasibility of biogas engine projects.

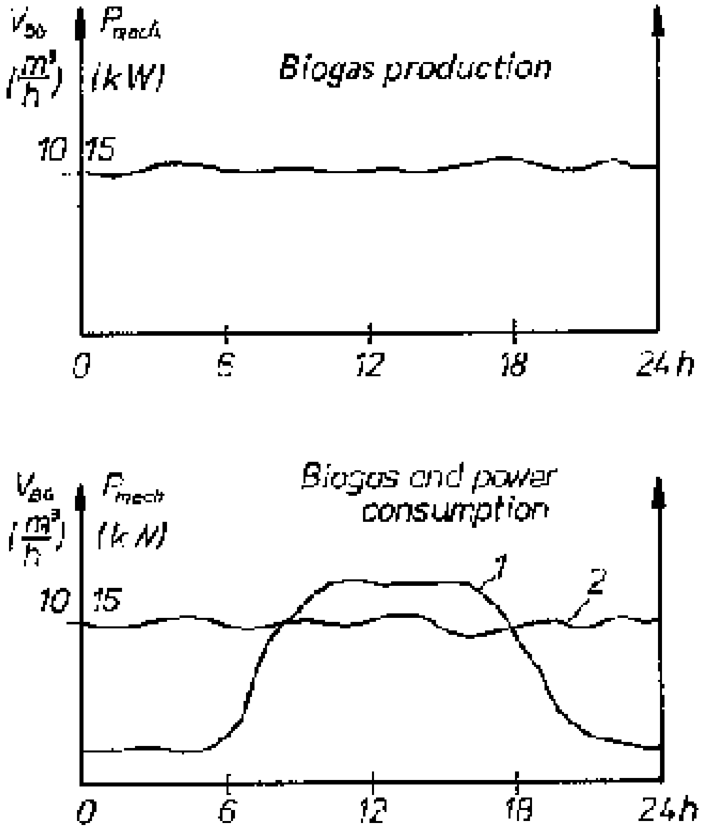


Fig. 7.1: Fuel and power production vs. consumption/demand profile. 1 typical example for operation of machines during the day and little lighting at night, 2 demand balanced and adapted to biogas production.

In cases where biogas is used for electricity generation, the mode of operation, i.e. in an isolated grid or in parallel to an existing larger grid (e.g. public utility), further influences the power demand situation and the choice of the gen-set's power class.
The principal different solutions are discussed further below.

7.2.1 The Specific Situation of Electricity Generation in Grid Parallel Operation

Above all, the economic viability of supplying electricity or mechanical energy to a place which has access to electricity needs to be thoroughly assessed. The mere demand for mechanical power could easily be satisfied by an electric motor which is usually less than half as expensive as an engine and needs far less efforts regarding operation, service and maintenance. The economic justification of the investment for the installation of a biogas-driven gen-set in this situation can only be based on high costs for the purchased electric energy or from severe operational problems through poor reliability of the public electricity supply.
A high degree of utilization of the biogas energy, i.e. power (approx. 30 %) and waste heat (approx. 5070), is often required to achieve the necessary return. Other justifications than economic ones tend to lose actuality, especially when the simple return to another supply system can make life easier.

The aspect of convenience of receiving power from a grid instead of operating, servicing and maintaining a gas engine cum biogas plant should not be underestimated. Even with smaller problems in the biogas engine systems it appears to be a quick and easy solution to revert to drawing power from the grid instead of trying to tackle the system's problems. The operation of a biogas engine always requires more competent and committed personnel who could be dispensed with when power is purchased from outside. The availability of competent manpower can be crucial for the success of a biogas engine project.

Needless to say, the reliability of one's own biogas engine system is vital, especially when the agreement with the utility stipulates penalty-like conditions for drawing electricity from the public grid.

Operation of a gen-set in grid parallel operation requires specific technical

equipment, such as a synchronization unit, safety switch gear for power failures from either side and a sensitive speed control system to secure operation at the grid-synchronous frequency (speed). The extra equipment involves corresponding investment. The connection of a gen-set to an outside grid can only be done in cooperation with the owner or administration of this grid.

While the technical problems can thus be solved, the operation turns out to be more sensitive. The conditions for receiving electricity from the grid are usually different from the ones for supplying electricity to the grid. Public utilities sometimes pay a low price for electricity they buy from small producers while they charge a high price when the same client needs to draw electricity from-the public grid.

As long as the customer's own electricity production remains lower than his demand, he remains a net consumer, substituting his demand as far as the biogas production and the power class of the gen-set allow. The price for the remaining electricity still purchased from the grid may well be the standard consumer price. If the utility does not agree to grid parallel operation, one can decide to make some of one's own power consumers detachable with a changeover switch and satisfy their power demand directly from the biogas gen-set in a separate isolated grid. In case of problems with the biogas gen-set this "sub-grid" can be switched back to the main grid. The economiy of this operation is based on the reduction of power costs by one's own substitution system.

Wherever one's own power production is constantly higher than one's own demand, the economy of the system is based on saving the previous power cost for one's own consumption together with the revenue from the power supplied to

the grid. As a net supplier, however, one sometimes has to face specifically high power purchase prices in case one's own system is out of service. Some agreements with public utilities therefore include a certain allowable amount of purchase from the grid per month or year to cover service periods and unforeseen failures. For any purchase above the stipulated amount a penalty price may be charged by the utility.

Similar considerations count in cases where the daily biogas production and the power demand are equal. While during low demand periods power is supplied to the public grid, in peak demand periods power is purchased from it. If favorable conditions can be negotiated with the public utility, the biogas gen-set can be designed for continuous operation in accordance with the continuous biogas production rate.

7.2.2 Biogas Production Exceeds Demand for Mechanical/Electric Energy (see Fig. 7.2)

7.2.2.1 Isolated Operation

Other potential energy users should be sought or further developed such as heating, cooking, lighting, baking, roasting, drying, etc. Their operational schedule needs to consider the engine's schedule aiming at a balanced biogas demand profile, thereby matching the production profile as far as possible. The choice of the engine's power class will be dependent on the power required by the driven equipment with the aspect of using smaller, less power-consuming equipment and engine but extending operation time.

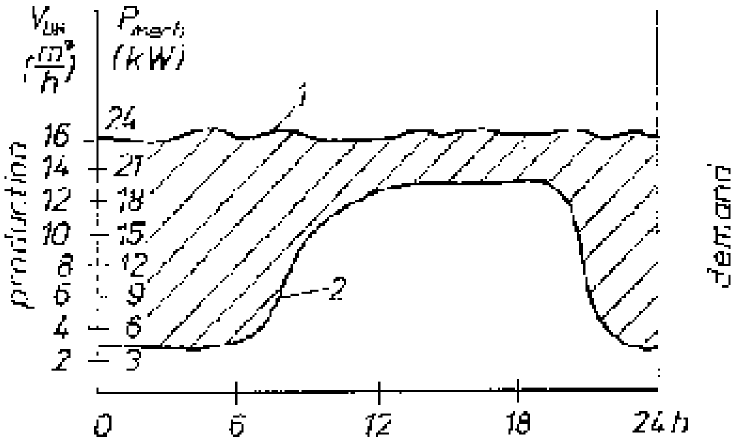


Fig. 7.2: Daily profiles: 1 biogas/potential power production' 2 own power demand. Surplus of biogas for a) other direct utilization or b) extra power production and supply to outside parallel grid. //// excess biogas production.

7.2.2.2 Grid Parallel Operation

Excess electricity produced but not utilized directly can be supplied to the (public) network, receiving revenue or saving other fuels in the parallel operating engine/generator sets. As the operation is continuous, the choice of the engine's/generator's power class depends on the available biogas production rate. The savings and earnings from the excess electricity produced from biogas have to provide an economic incentive to invest in a larger biogas plant, engine and generator than actually needed to satisfy one's own demand. Another alternative is to simply reduce the power output of the gen-set and follow the demand profile, i.e. operate similarly to the isolated mode. At very low demand however the gen-set will operate with a low efficiency too.

7.2.3 Biogas/Power Demand Exceeds Production (see Fig. 7.3)

7.2.3.1 Isolated Operation

Further to the exploitation of all possibilities to raise biogas production the power demand which cannot be satisfied by biogas will have to be satisfied through other fuels such as diesel, petrol, LPG or alcohol. Here the dueal fuel diesel gas engine offers a specific advantage as it can operate not only at fluctuating rates of biogas but also at a comparatively high efficiency in part load operation. This makes the diesel gas engine an ideal choice for uneven power demand profiles in cases of insufficient biogas supply. The power class of the engine to be chosen depends on the demand of the largest single consumer or the sum of the consumers operating simultaneously.

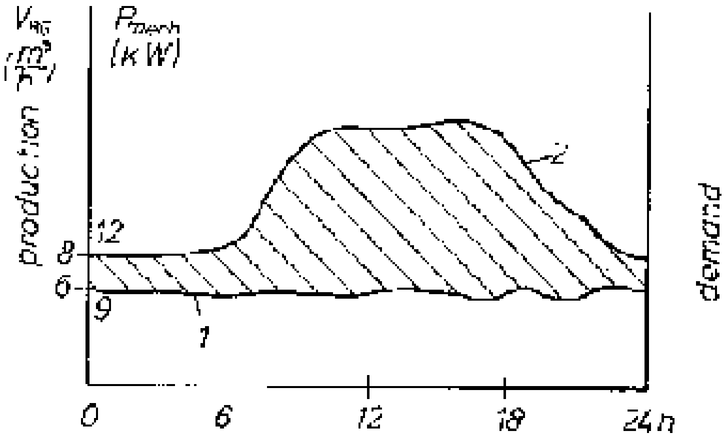


Fig 7.3: Daily profiles: 1 biogas and potential power production, 2 power demand, shortage in biogas/// power production. Power shortage to be compensated by other fuels/energies in isolated operation or by purchase of electric power from grid in parallel operation.

Building a storage for unutilized biogas from low demand hours for supplementation in high demand hours is one solution and will find its economic

justification in relation to the cost and availability of the supplementary fuel saved by the storage. Last but not least the power demand on the biogas engine system may be lowered by using other means to satisfy it or to refrain from its satisfaction partly.

7.2.3.2 Grid Parallel Operation

In cases where the electric supply from another grid already exists, the biogasdriven gen-set only supplements part of the demand. The project as such remains a net consumer. The power class of the engine and generator is chosen in accordance with the biogas production rate (1 m^3/h - 1.5 kW mech).

The gen-set should be operated continuously to avoid storage.

7.2.4 Power Demand Partly Higher, Partly Lower than Biogas Fuel Production

7.2.4.1 Isolated Operation

As long as the biogas produced during the low demand hours can satisfy the additional requirements in the high demand period intermediate storage is a possible solution. Wherever the excess power demand cannot be satisfied by stored biogas, additional fuel is required with the diesel gas engine offering a good solution.

Any remaining biogas can serve other useful purposes.

The engine's power class is chosen in accordance with the power required from

the largest consumer or the sum of the requirements of equipment necessarily operated simultaneously.

7.2.4.2 Grid Parallel Operation

If the biogas-driven gen-set is operated in combination with diesel-driven gen-sets within a larger isolated network under a common administration the savings are directly felt in the reduction of the diesel fuel consumption of the other gen-sets. The biogas-driven gen-set's power class is chosen in accordance with the biogas production rate and is operated continuously.

In combination with a public utility the choice of operation and power class of the engine is largely a function of the contract concerning the tariffs for supply to the grid and drawing from the grid (see Chapter 7.2.1). A detachable cub-network for isolated operation of selected equipment may be an alternative as then the project remains a net consumer of electricity.

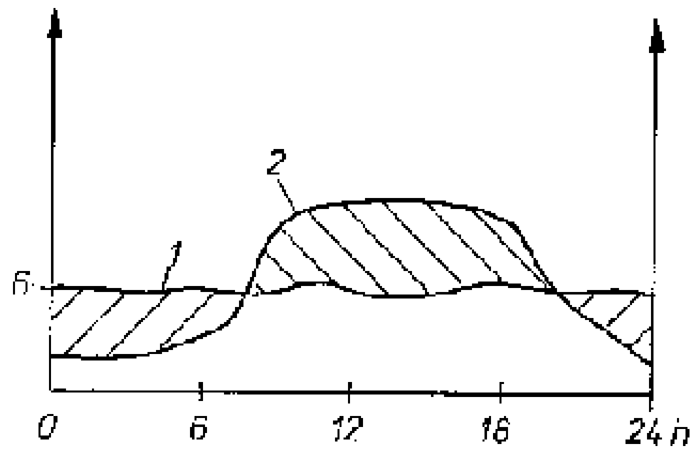


Fig 24: Daily profiles: 1 biogas and potential power production, 2 power demand;

option for storage of excess biogas for periods of biogas shortage. /// excess biogas production biogas shortage

7.2.5 Investment and Operational Cost

Investment for the biogas engine system will differ from case to case, depending on what is actually required for completion of the system:

- biogas plant, gas storage,
- biogas piping and instrumentation,
- engine cum modification,
- driven machine cum transmission,
- civil works, i.e. foundations, sheds, fences, etc.,
- wiring, piping, switchgear.

Often the biogas plant already exists or is being built as a biological treatment plant for wastes, residues or other. It is therefore not part of the investment for the engine system. In other cases an engine cum driven machine is already there while a plant, its infrastructure and engine modification are needed.

The operational costs involve the manpower, service and maintenance of the system as mentioned earlier. Again, if for instance the operation of the plant is done and paid for under a different aspect, e.g. waste treatment, the "biogas fuel price" is lowered as it only needs to consider the efforts for gas preparation, e.g. piping, storage, measuring,etc. Further influence on the fuel price comes from the production rate of the biogas plant.

The establishment of a biogas fuel price (per m^3 or per kWh) is useful where a

biogas engine competes against differently fueled engines or electric power Whatever the actual situation, biogas will never be a fuel absolutely "free of charge."

7.2.6 Two Critical Remarks

The evaluation of the economic parameters is subject to the individual situation in the country and region concerned. The economic analysis of the many different cases would not only be tedious but, being a subject of its own, would go beyond the framework of this publication. Even though the issues are mentioned here, some projects may require a deeper economic analysis. The use of more specialized literature on the economics of renewable energy systems [18] and of the planning, design and operation of the biogas production plants [3, 4, 5, 6] is therefore recommended.

After careful consideration of the planning parameters the solution to refrain from a biogas engine venture and to obtain the services expected from the biogas system in an alternative way may appear reasonable. The "zero" solution should not prematurely or categorically be excluded in the planning process. The more reasons for doubt about the feasibility of such a project, the greater is the possibility of eventual failure. The waste of effort and economic resources involved is a pity, all the more so when these resources are scarce. Another aspect is that the biogas technology is still new in some areas and is not approved of by everyone. A failure of a biogas engine project would only discourage further projects which might have become successful in their specific situation.

7.3 Adaptation of plant, engine and driven machine

7.3.1 Dimensioning of Biogas Plant and Gas Storage

One of the determining factors for the dimensioning of the biogas plant is the biogas production needed to satisfy the fuel demand for the production of mechanical/ electric power per day. The combining figure is the biogas consumption of an engine per unit of mechanical power produced, i.e. the specific fuel consumption. It ranges from 0.5 . . . 0.8 m³/kWh and is largely dependent on gas quality, temperature, pressure as well as the engine's own efficiency and point of operation. (For determination of the actual calorific value of the biogas see Chapter 4.2. For guidelines for the design of a biogas plant see Appendix V.)

If the anticipated mode of operation of the engine cum driven machine is continuous the biogas plant must be designed to continuously produce the amount of biogas demanded by the engine at the required power output. The daily consumption of the engine is established by

$$\frac{\text{operation time}}{\text{day}} \cdot \left(\frac{h}{d}\right) \cdot \left(\frac{m^3}{kW \cdot h}\right) \cdot P(kW) = f_C\left(\frac{m^3}{d}\right)$$ **(Equ. 7.1)**

The production rate of the biogas plant may need to be bigger than the calculated value for the engine if other gas consumers are operated at the same time (cooking, heating, lighting).

In the case of non-continuous operation of the engine, e.g. only several hours per day at different loads, the plant still needs to produce the required amount of biogas needed each day but at a lower production rate per hour than consumed by the engine. A storage gas holder can be filled while the engine remains idle. It is emptied while the engine is in operation and consumes more than the plant

produces. The actual volume of the gas holder is a function of the plant production rate, engine consumption as well as the frequency and duration of the engine operation periods. The following example shall demonstrate the interdependence of the above-mentioned parameters:

-Anticipated machine power demand (= engine operational power output): P = 10kW
-specific fuel consumption: sfc = 0.6 m^3/kWh i.e. consumption per hour: fc = 6 m^3/h
-specific gas production rate:

sgp = 0.8 · m^3/m^3 plant · day

operational daily schedules, alternative:

a) continuously,
b) 8 hours once a day,
c) 4 hours twice a day with 8-hour standstill between each operational period.

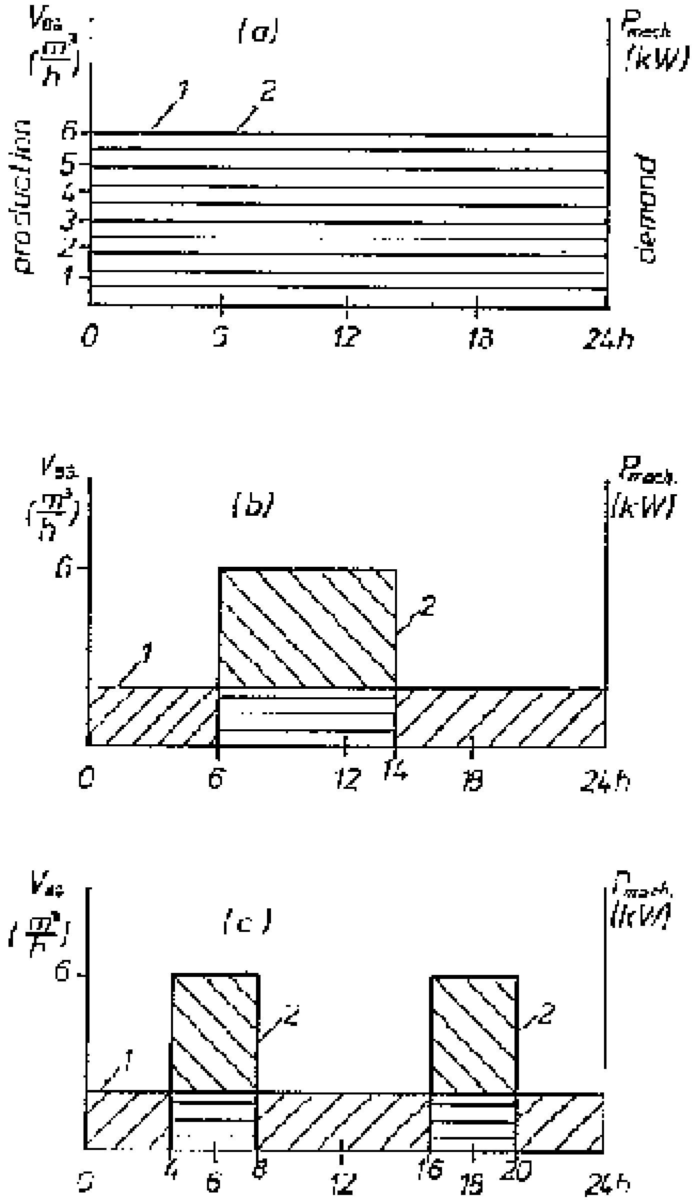


Fig. 7.5: Daily production and demand profiles for the example. - biogas production directly consumed. /// excess biogas production for storage, \biogas drawn from store to cover for actual shortage.

Solutions:

a) The plant needs to produce a daily volume rate Vbg of

Vbg = 24 h/d · 0.6 m^3/kWh ·10 kW = 144 m^3/d (see Equ.7.1)

144 m^3/d of biogas. Its size, i.e. digester volume Vd, can be established by

Vd=Vbg·(1/sgp) (Equ. 7.2)

$$= 144 m^3/d \cdot \frac{1}{0.8 m^3/(m^3_{plant} \cdot d)}$$

The plant size is 180 m^3; extra gas storage is theoretically not necessary.

b) Plant production rate per day

Vbg = 8 · 0.6 · 10 = 48 m^3/d

or per hour

Vbg = 48/24 = 2 m^3/h

Plant size (digester volume)

Vd = 48· 1/0.8 = 60 m^3

Gas storage capacity

The gas storage capacity needs to consider the rate of production as well as the rate and the period of gas consumption. In this example gas is needed at a rate of 6 m^3/h for an operational period of eight hours. The gas volume consumed per period is 6 8 =48 m^3.

The production of gas was found to be V'bg = 2 m^3/h which results in a volume produced of 8 2 = 16 m^3 during the operational period.

The gas storage volume Vs only has to cater for the difference between the volume consumed and produced during the operational period to (in h):

$Vs = (fc \cdot to) - (Vbg \cdot to)$ (Equ. 7.3)

$Vs=to\ (fc-Vbg)$

In this specific case the storage volume is

$Vs = 8h(6m^3/h-2m^3/h)=32m^3$.

c) Plant production rate per day

$Vbg=8 \cdot 0.6 \cdot 10= 48m^3/d = 2m^3/h$

Plant size (digester volume)

$Vd = 48 \cdot (1/0.8) = 60\ m^3$

Gas storage capacity

In this case the operational time of eight hours per day has been split into two periods of four hours each. The gas storage volume

$V_s = 4\ h\ (6\ m^3/h - 2\ m^3/h) = 16\ m^3$

is only half as large as in the previous case where the machine was operated in one long period instead of two shorter ones. The digester size is not affected.

In the above example it was assumed that the standstill periods between the operational periods were equally long so that sufficient time for refilling was available. If frequency and duration of operational and standstill periods are unequally distributed the gas store will have to be suitably larger. A balance calculation with the production rate and time will be useful to ensure that the gas store is always full enough for the next operational period.

For reasons of fluctuations in the gas production and the fuel consumption a certain storage volume should however always exist.

Likewise storage tanks should always be oversized by about 10%.

Existing storage capacity within the digester (depending on type) reduces the required storage volume accordingly.

The examples show that there is an incentive to consider the effect on the gas storage volumes when planning the daily operational schedules of engine and driven machine. On the other hand it will not be very advantageous for the engine to be operated in short stop-and-go periods only as the phases of warming up and cooling down (condensation) expose an engine to more wear and tear than normal

operation. A compromise has to be found between the lower investment for a smaller gas storage and the risk (cost) of a possibly shorter life span of the engine. Two periods of operation per day may serve as an orientation value whilst the actual economic situation or other boundary conditions may provide good reasons to decide differently.

7.3.2 Choice of Engine

An engine is mainly specified by its type and by its maximum (rated) power at its maximum speed (e.g. "diesel engine, 30 kW at 2000 1/min or rpm"). What this means is that it may well be operated at lower speeds and power output but not above the maximum data given. An operation at lower power and speed than the maximum will often be found more economic in terms of fuel consumption and engine life. When considering the purchase of an engine one should not confuse the maximum or rated performance as given in the technical specification of an engine with the optimum performance in economic terms. The engine's performance curves, i.e. power, torque and specific fuel consumption vs. speed, are much more useful in determining the point of operation and selecting an engine that will meet the driven machine's rquirements while it operates at a high efficiency.

The determination of the main operational parameters of an engine, i.e. range of power and speed, is largely a function of the requirements of the driven machine. The choice of engine type, however, follows the availability, the market situation (price) for fuel, spares and service and some other operational parameters like the required type of control, fuel availability, etc. The following elaborations shall explain the relevance of these parameters in more detail.

For a better distinction between the different power terms the following definitions shall be used:

Peng,r rated (maximum specified) engine power,
Peng,a actual operating engine power,
Pmach power required by driven machine,
Pgen power required by electric generator,
Pel electric power produced by electric generator.

7.3.2.1 Engine Speed

Every machine has a certain but limited speed range within which it can be operated. Within this range lies a point or narrow range of optimum operation where the specific fuel consumption is relatively low. The longer the engine is operated, the more relevant are the savings in fuel (cost) when the engine operates in or near its optimum performance.

Fig. 7.6 shows that the specific fuel consumption has a minimum value at about 80 . . . 90% of the maximum (rated) speed nr. The maximum obtainable power at this speed, i.e. 80% of the rated speed mark is again about 80% of the rated power. For reasons of fuel economy and engine life the operational speed should therefore be selected within the optimum range, e.g. 70 . . . 90% in the above example. If the speed of the driven machine is equal or near the optimum speed of the engine, direct shaft drive is possible, otherwise a V-belt transmission or gear can be used to adapt the speeds of the two machines as required.

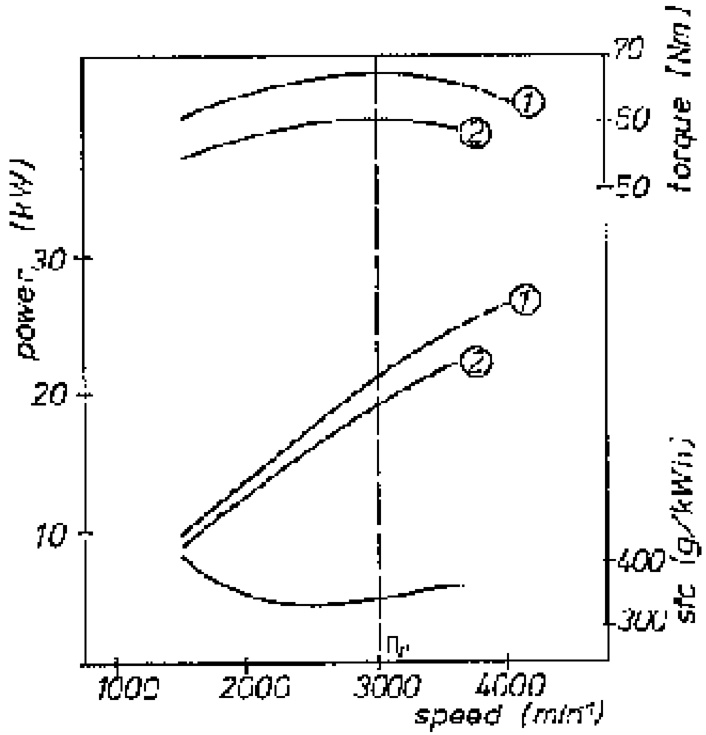


Fig. 7.6: Typical engine performance curves showing the power, torque and specific fuel consumption as a function of the speed. 1 maximum shortterm performance, 2 allowable performance for continuous operation.

Some driven machines (pumps, generators) are available in speed versions of 1500 1/min and 3 000 1/min (or 1800/3 600 for 60 Hz).

The high speed versions require a high speed engine for direct coupling. For a similar power range high speed engines are smaller, hence cheaper to buy (Otto), but have a lower efficiency in biogas operation and a lower life expectancy.

7.3.2.2 Engine Power

When looking at the power output in selecting an engine one needs to consider the future main regime of operation:

- continuous, i.e. periods each longer than about one hour, or
- non-continuous, i.e. shorter periods.

For shorter periods the engine may be operated at its maximum power obtainable at the selected speed, i.e. about 80% of the maximum rated speed following the speed/fuel argument above. Subsequently the power required by the driven machine Pmach should not exceed 80% of the engine's rated power if specified at maximum speed:

Pmach = 0.8 · Peng,r (Equ. 7.4)

For continuous operation, which is the more usual mode, the power output needs to be lower than the maximum rated. Engine manufacturers themselves often quote two different types of power, maximum power and continuous power. For a given (or selected) speed the continuous power is usually between 10% and 20% lower than the maximum power (see Fig. 7.6) as the specific fuel consumption, which is not constant over the whole power range, has its lowest value at 80 . . . 90% of maximum power. The power demanded by the machine shall therefore equal 80 . . . 90% of the engine's maximum power at the selected speed. In other words, in continuous operation the power selected for optimum fuel economy is now reduced by two issues. One reduction is caused by selection of the optimum speed (see Equ. 7.4) and another one by operating at a lower power output than possible to improve the fuel consumption even further:

$P_{mach} = 0.8 \cdot 0.8 \cdot P_{eng,r}$ (Equ. 7.5)

The engine selected for a given power demand from a machine will hence have a higher maximum power output:

$P_{eng,r} = 1/(0.8 \cdot 0.8) \cdot P_{mach} = 1.56 \cdot P_{mach}$ (Equ. 7.6)
i.e. more than 50% greater than the power at which it will later have to operate.

The type of engine, i.e. diesel or petrol, chosen for modification has a further influence on the power rating of the selected engine.

Diesel engines do not significantly lose power when operated in dual fuel mode. They therefore only need to follow the selection criteria explained above.

Diesel engines modified into Otto engines or modified petrol engines are subject to a decrease of about 20 % of their former performance after modification to a biogas engine because of a decrease in volumetric efficiency. In other words, the choice of the power class of an Otto engine needs to consider the

> **-lower output in continuous operation for reasons of speed and fuel economy as explained earlier, and the**
> **- lower power output as a result of modification, i.e. reduction of volumetric efficiency.**

The power rating of the still unmodified Otto engine in relation to all mentioned criteria is

$P_{eng,r} = 1/(0.8 \cdot 0.8 \cdot 0.8) \cdot P_{mach} = 1.9 \cdot P_{mach}$ (Equ 7.7)

i.e. almost two times the actual power demand in operation with biogas.

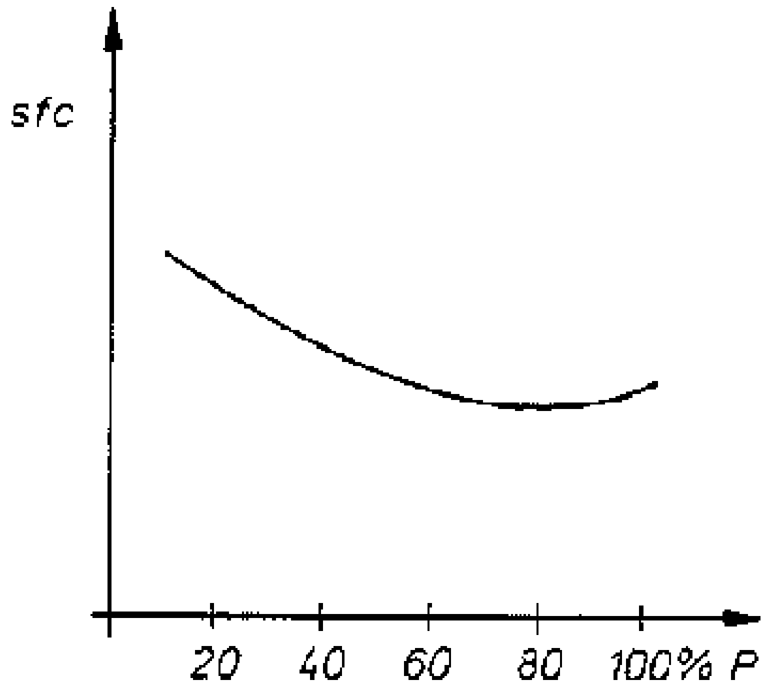


Fig. 7 7: Specific fuel consumption, sfc, as a function of power output at constant speed (schematic)

In case an Otto engine is expected to operate at a much lower speed than 80% of what was specified for its original power output (e.g. 1500 1/min instead of 4000 1/min), the expected power output decreases even further, almost by the same rate as the speed (see Fig. 6.1). This may explain why commercially available Otto gas engines produce only about 10 kW per lifer displaced volume at a low speed (2 000 1/min) while a standard vehicle petrol engine produces about 30 kW per lifer at higher speeds (5 000 1/min).

The above analysis while useful for the understanding of the influential factors for

the engine selection shall however be understood as a guideline rather than an instruction to be followed too strictly. Some engines are operated within a range of speeds, not one speed only. Others are only rarely operated so that the fuel economy is a secondary aspect. When calculating the power rating for an engine to be purchased one will not often find the exactly required engine but choose a smaller or larger one. Otto engines however should not be oversized more than necessary to prevent operation at partial load with lower efficiency. Dual fuel engines do not lose much efficiency in partial load.

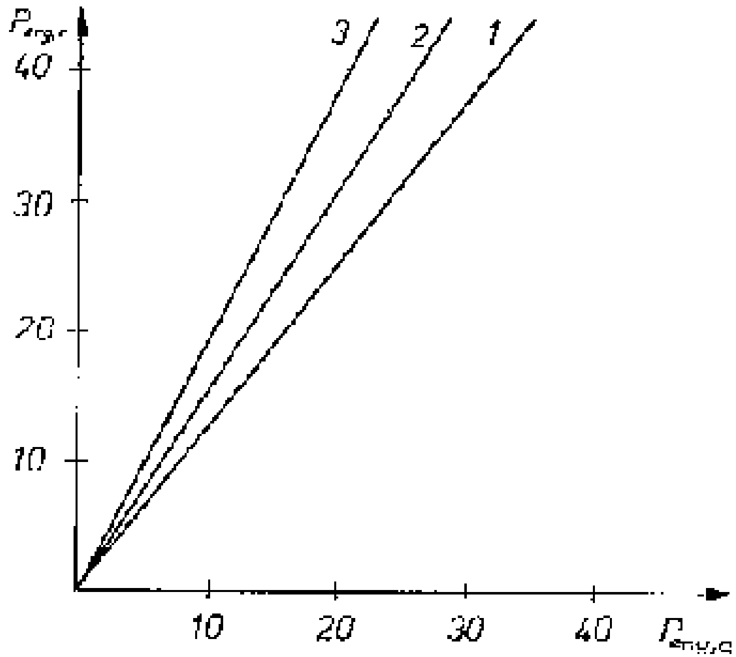


Fig. 7.8: Relation of rated power of engine (before modification), Peng,r and its actual power output Peng a at optimal economic conditions with biogas. Operational speed = 0.8 X max. speed. 1 diesel gas (dual fuel) engine operating short periods only, 2 as 1 but operating continuously, 3 Otto biogas engine, continuous operation.

The power considerations above have normally been considered by manufacturers of commercially available biogas engines. They can therefore be ordered specifying the actual power demand/speed of the driven machine. "Oversizing" by 10 . . . 20% is necessary when these engines are originally designed for LPG or natural gas but not specifically for biogas.

7.3.2.3 Engine Availability and Price

The above-mentioned selection criteria may be affected by considerations of the engine's price, its own availability and the availability of spares and service when necessary. A larger engine which may run more slowly and at a lower fuel consumption rate may be more expensive, also in terms of service and maintenance. A realistic anticipation of running costs (lubricant, service, manpower) and the actual operational periods is therefore necessary.

In other cases a certain engine may already be available and the question of purchasing another one does not arise at all.

7.3.2.4 Engine Control

The anticipated mode of control, i.e. whether automatic or manual, may be decisive for the engine type. Diesel gas engines can be automatically controlled using their governor while Otto engines usually need additional equipment for that purpose.

7.3.2.5 Fuel Consumption

The fuel consumption is mainly dependent on the demand of mechanical power

from the driven equipment or the demand of electric power from the grid or connected consumers. The type of the engine, the modification and the individual engine efficiency however also play their role in the actual fuel demand. The nomogram in Fig. 7.9 gives a random relation between biogas production and mechanical/electric power obtainable for diesel gas and Otto gas engines. As some simplifying assumptions had to be made, the nomogram is to be seen as a planning instrument rather than for the final calculations in designing the system.

7.3.2.6 Fuel Availability

In cases where the supply of fuel is not assured an alternative or auxiliary fuel would be required. Diesel dual fuel engines provide an option to use diesel fuel at any time and at any rate. On the other hand they require a supply of diesel fuel together with biogas. Otto engines are independent of liquid fuel supply. They may use LPG in case of biogas scarcity or run on alcohol or petrol again if the carburetor has been retained in its original function.

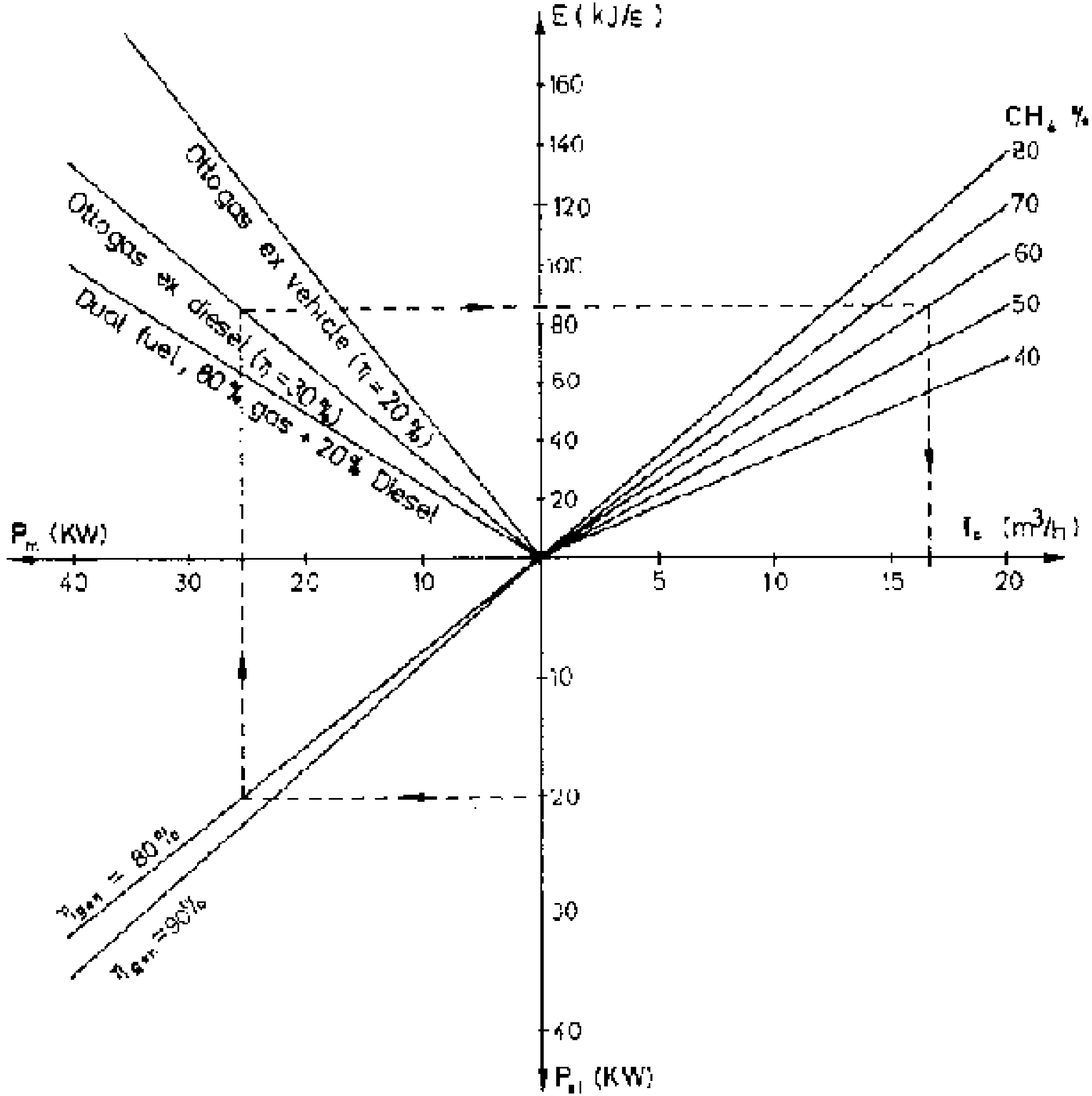


Fig. 7.9: Nomogram for the relation of fuel consumption/fuel demand fc, biogas

quality CH_4%, fuel energy flow E, type of engine used, mechanical power output Pm, electric generator efficiency ngen, and electric power output Pel. Basic gas data assumed: temperature 25 °C, pressure 960 mbar, ref. humidity 100%. Example for the use of the nomograph:

Given data:	el. power required	Pel= 20 kW
	generator efficiency	ηgen = 80%
	engine chosen	Ottogas ex-diesel
	biogas available	CH_4% = 60
Result:		fuel consumption fc = 16.7 m³/h
	specific overall fuel consumption	sfc =16.7/20 = 0.835 m³/Kwh

7.3.2.7 Expected Engine

It is common knowledge that diesel gas engines or Otto engines on the basis of diesel engines are more appropriate for longer service than ex-vehicle Otto engines. Their higher price, however, requires justification by long and frequent periods of operation respectively. In general slow running engines last longer than fast ones but are larger and more expensive.

7.3.3 Choice and Operation of Driven Machine

The kind of driven machine chosen is clearly a function of the required service. For the final determination of the machine's type and size, however, there are a few more considerations to be made with respect to the consequences for the engine

and even the biogas supply side. It is therefore of advantage for the economy of the whole system if possible alternatives for the future service and operational schedule can be anticipated (see also Chapter 7.2).

A good example is the filling of a water storage tank which requires a certain amount of water daily. The energy for the daily job of water lifting shall be 400 kW and remains constant irrespective of the type of pump, engine and operational schedule requirements. Likewise the size or daily gas production rate of the biogas plant is not effected under the simplifying assumption of a uniform efficiency of engine and pump. The interdependence of pumping schedule, gas storage and size of pump and engine, however, shows a significant difference in results (see table below).

Interdependence of operational schedule, biogas storage and power of engine and driven machine (pump)

Operational schedule selected (frequency	**Mechanical (pump) power required (kW)**	**Gas storage (kWh/m^3)[1]**	**Engine rated power (kW)[2]**
X h/d)			
1 X 4	100	333/56	133
2 X 2	100	167/28	133
1 X 12	33	200/33	44
2X 6	33	100/17	44
1 X 24	17		23

0[3]

[1] For biogas with 60% CH_4 at standard conditions.

[2] Assuming Pmach = 0.75 Peng.

[3] 0-storage is merely theoretical; a minimum storage of 1-fur operation should be provided.

The cheapest solution in terms of investment is obviously a small machine set, no or only little biogas storage and a continuous service. It is recommendable as long as continuous supervision, service and maintenance are assured. Under further consideration of the effect of continuous service on the engine's life span, necessary overhauls, the fact that an engine cum machine may already exist and other external factors, one might however have to select another schedule as an appropriate compromise.

7.3.4 Choice of Transmission

The transmission not only serves to connect the shafts of the engine and the driven machine, but it also provides for a possibility of an alteration of speeds and speed ratios.

Common engine speed ranges are:

- n =1 300 . . . 3 000 min^{-1} (rpm) for diesel engines
- n = 1500 . . . 5 000 min^{-1} (rpm) for petrol engines

whereby each engine should be operated at its optimal speed range as explained in Chapter 7.3.2.

Machine speeds can also have different ranges but are often designed to match with standard speeds of electric motors in order to facilitate a direct connection via elastic coupling or shaft.
Standard speeds for electric motors (AC) and direct driven machines are:

- **n = 1 500 min^{-1} or 3 000 min^{-1} for a frequency of 50 Hz**
- **n = 1800 min^{-1} or 3 600 min^{-1} for a frequency of 60 Hz.**

These speeds may well coincide with the optimum speed range of an engine so that direct coupling or shaft drive is possible. Direct coupling, however, requires matching flanges of engine and machine housings for direct mounting of a rubber-damped coupling at the crankshaft. Otherwise an external coupling with rubber elements or a propeller shaft is required. All direct drives cause the directions of rotation of engine and machine to be opposite. They offer the better solution for the drive of equipment that requires a high degree of speed (frequency) stability, e.g. electric generators.

Should the direction of rotation not meet the above conditions or should the speeds of machine and engine not coincide well enough, a transmission with V-belts or flat belts and pulleys is recommended.
The transmission ratio is determined by the ratio of diameters of the pulleys Deng/Dmach:

$$n_{eng}/n_{mach} = D_{mach}/D_{eng} \quad \text{(Equ. 7.8)}$$

Flat belts are still used in places where V-belts are scarce. Their advantage is that they can be cut to size from a long piece and joined together with a clamp which

also allows repair. More slip and power loss through friction as well as the fact that they tend to run off the pulleys when not properly aligned is however disadvantageous.

While the direct transmission by shaft or rubber-damped coupling is almost free of power losses, slip and friction consume a certain amount of the power transmitted from the engine. For V-belts the power loss ranges from 3 . . . 8%, for flat belts from 10 . . . 20%. A transmission efficiency T can be defined as

$$\eta_T = \frac{P_{mech}}{P_{eng,a}} = 0.8 \cdots 0.97$$ **(Equ. 7.9)**

so that finally the actual power demand from the engine in case of belt transmission is

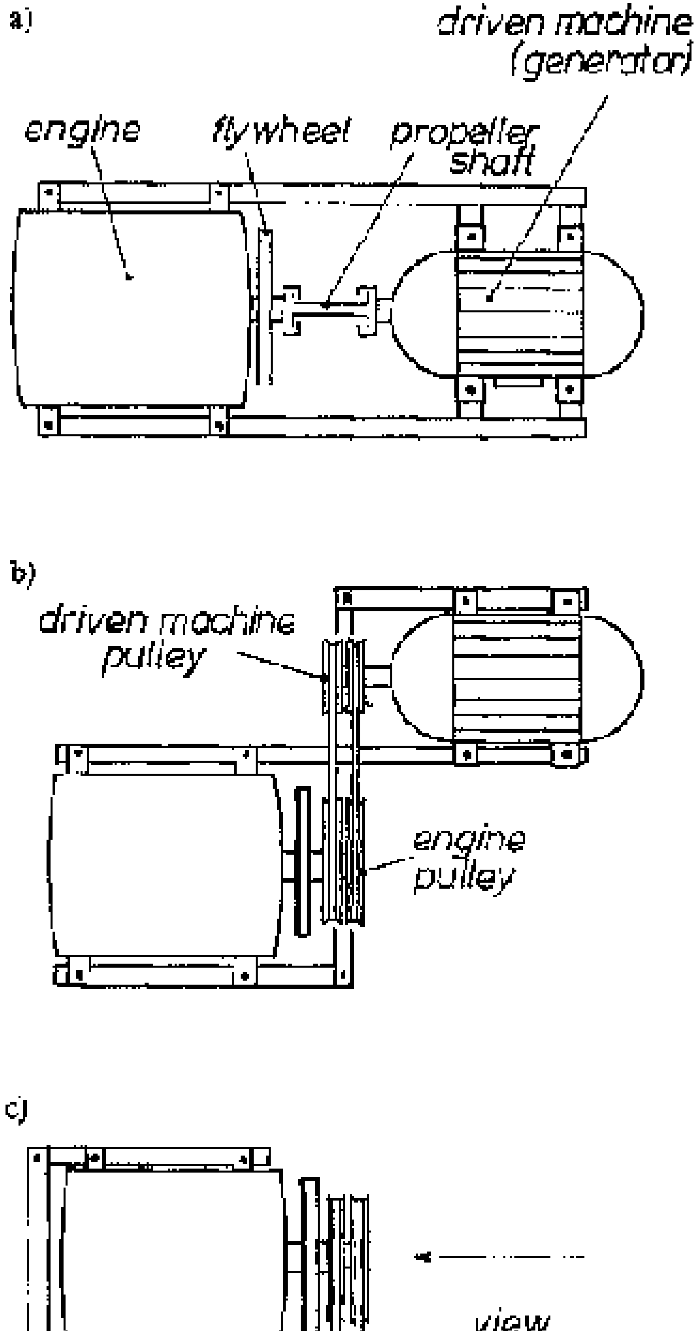
$$P_{eng,r} = \frac{1}{\eta_T} \cdot P_{mech}$$

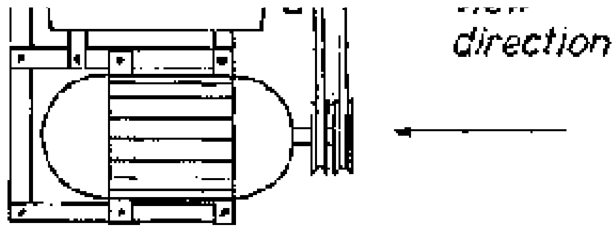
i.e. Iarger than the power demand at the machine shaft. For direct coupling without losses assume η_T = 1

The transmission of power by belts imposes a radial load on the bearings of both engine and machine. While most driven machines and stationary engines are designed to also operate with V-belts (see specifications), most vehicle engines are designed to transmit their power by an axial connection to their gearbox. The radial load may therefore be harmful to the engine's crankshaft bearing.

In cases of doubt a separate axial shaft for the pulley with its own bearings for

holding the radial load will resolve the problem (see Fig. 7.10, d).





d)

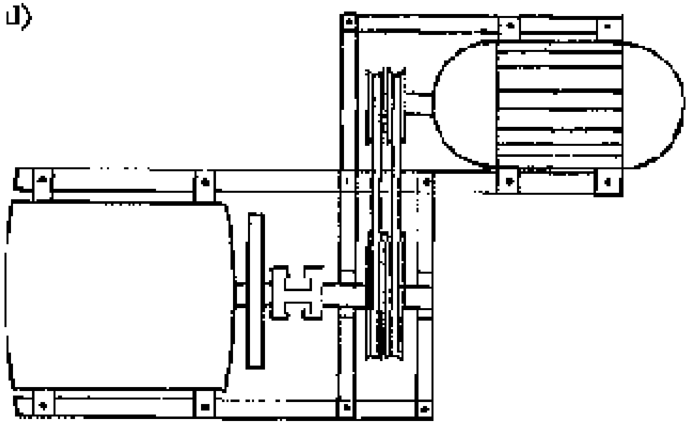


Fig 7.10: Alternative positioning of engine and driven machine depending on direction of rotation and type of transmission. Direction of rotation is given as viewed facing the shaft ends, example c).

a) Propeller shaft, transmission ratio 1: 1; engine rotation: anticlockwise, machine rotation: clock- wise.
b) V-belt and pulleys, transmission ratio variable with pulley diameters; engine rotation: anticlock- wise, machine rotation: clockwise.
c) as in b); engine rotation: anticlockwise, machine rotation: anticlockwise.
d) as in b) but extra propeller shaft and pulley bearings to hold radial load; for engines with shaft bearing not designed for radial drive (vehicle engines).

Belt drive offers an additional advantage for cases where the engine has difficulties to start up while already pulling the machine under load. The belt can be loosened to allow the engine to first gain speed. It is then gradually tightened (on the unloaded side!) with a tensioner until the machine has also gained its speed. With very frequent start-ups in this way the wear and tear of the belts will however naturally increase.

An alteration of the direction of rotation between engine and machine can be effected by placing the engine and the machine either beside each other or in a row. Other alternatives for transmission are gears, either open or in a casing (gearbox). They are however much more expensive, require lubrication and may only be economically justified for continuous service in terms of years and for larger machines.

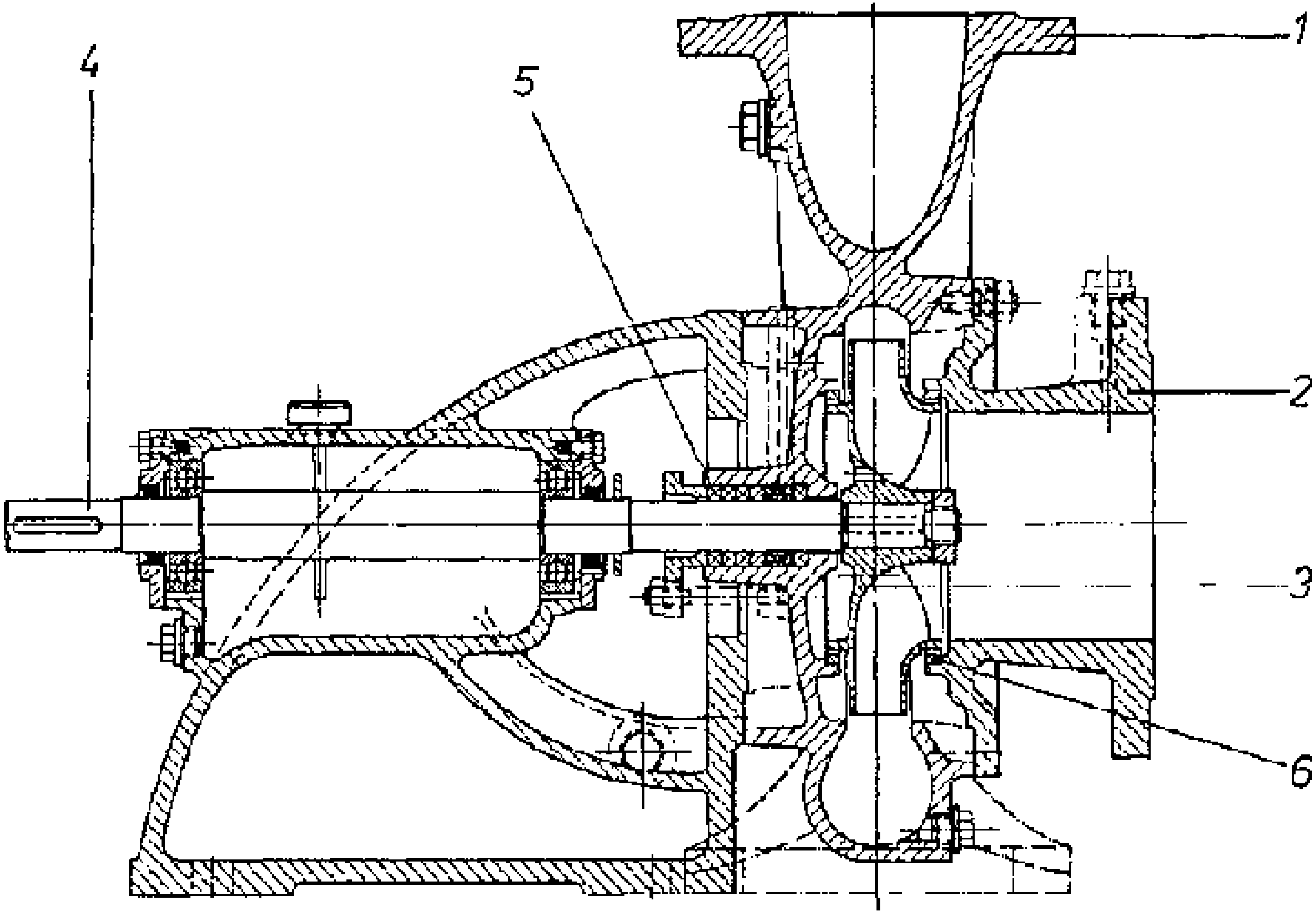


Fig. 7.11: Cross-sectional view of single-stage centrifugal pump (KSB).

1 discharge (pressure) flange with diffusor, 2 inlet (suction) flange, 3 impeller, 4 drive shaft, 5 stuffing box, 6 impeller/casing seal.

The other transmission elements are standard components, easy to manufacture (pulleys) or to be obtained even from unserviceable vehicles (propeller shafts).

Both pulleys and shafts require an adapting flange or hub to be connected to the shaft (flywheel) of the engine and of the machine respectively. These flanges require precision in manufacture for reasons of rotation balance. An unbalanced shaft or pulley brings about destruction of the shaft bearings prematurely.

7.4 Engine and machine, two common examples

7.4.1 Engine and Water Pump

Water pumping, whether for municipal, industrial or agricultural purposes, cares for a substantial demand of mechanical energy. The most common type of pump is the centrifugal pump built in single-stage versions up to about 100 m waterhead or in multistage versions for higher heads.

A pump transforms mechanical energy into hydraulic energy and has, like other energytransforming machines, its specific performance characteristics. An example is shown in Fig. 7.12

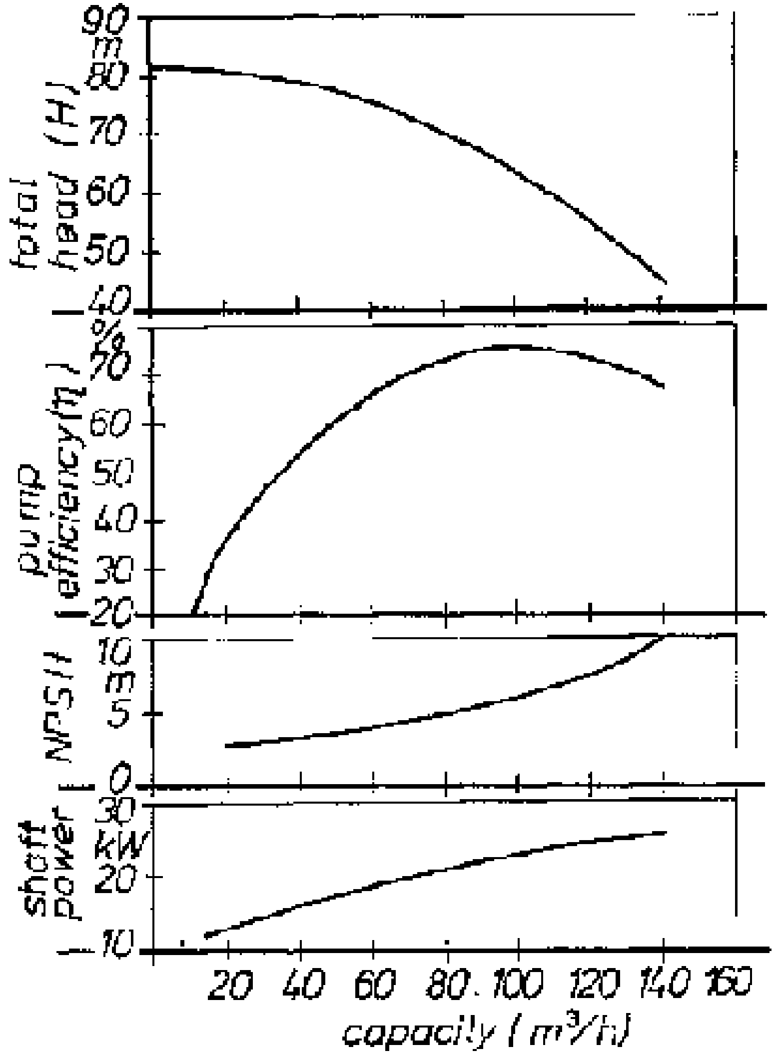


Fig. 7.12: Characteristic curves of a radial centrifugal pump at constant speed (KSB)

The charts of Fig. 7.12 demonstrate the essential pump parameters and their interdependence:

-The head (sometimes given in pressure rise /p) increases when the

capacity Q (or volume flow rate) decreases.
-The power demand increases with the capacity Q even though the head decreases. The influence of the increasing capacity is stronger.
-The efficiency has its maximum at the "design point" of the pump, i.e. at the values of capacity, head and speed chosen to provide the basic data for the design of the impeller and the volute casing.

The power demand of a pump is established by the following equation:

$$P = Q \cdot H \cdot g \cdot \rho \cdot \frac{1}{\eta_p} \cdot \frac{1}{1000} (kW)$$ **(Equ. 7.10)**

with: Q = capacity in m^3/s, H = total head in m, g = gravity constant (9.81 m/s^2), p = density (water: 1 000 kg/m^3), p = pump efficiency (0.5 . . . 0.75).

A centrifugal pump's design data (Q, H, P) are either specified at one selected speed n (on the nameplate) or given in a performance diagram similar to the one given in Fig. 7.12 supplied with the pump.

While centrifugal pumps are designed to match with standard electric motor speeds (see Chapter 7.3) they may well be operated at other shaft speeds, preferably below the design speed. When operated at a lower speed than specified, the values of capacity, head and power demand change as follows (indexed 1 at specified speed, 2 at actual speed):

$$Q_2 = Q_1 \cdot \frac{n_2}{n_1}$$ **(Equ. 7.11)**

$H_2 = H_1 \cdot (\frac{n_2}{n_1})^2$ **(Equ. 7.12)**

$P_2 = P_1 \cdot (\frac{n_2}{n_1})^3$ **(Equ. 7.13)**

In cases where the pump is specified by its pressure rise /p rather than by its head H, use the transformation

$\Delta p = \rho \cdot g \cdot H (in \cdot N/m^2)$ **(Equ. 7.14)**

Some pump manufacturers supply diagrams indicating the pump's performance at different speeds as in Fig. 7.13.

As can be seen from Fig. 7.13 a change in speed results in a new characteristic curve. Speed variation provides a practical way of control for head and capacity. This mode of control is far more energy-economic than throttling the flow with a valve, as the pump and hence the engine would consume extra energy to overcome the flow resistance produced by the throttle valve. As engines can vary their speed, engine-driven pumps should be speed-controlled.

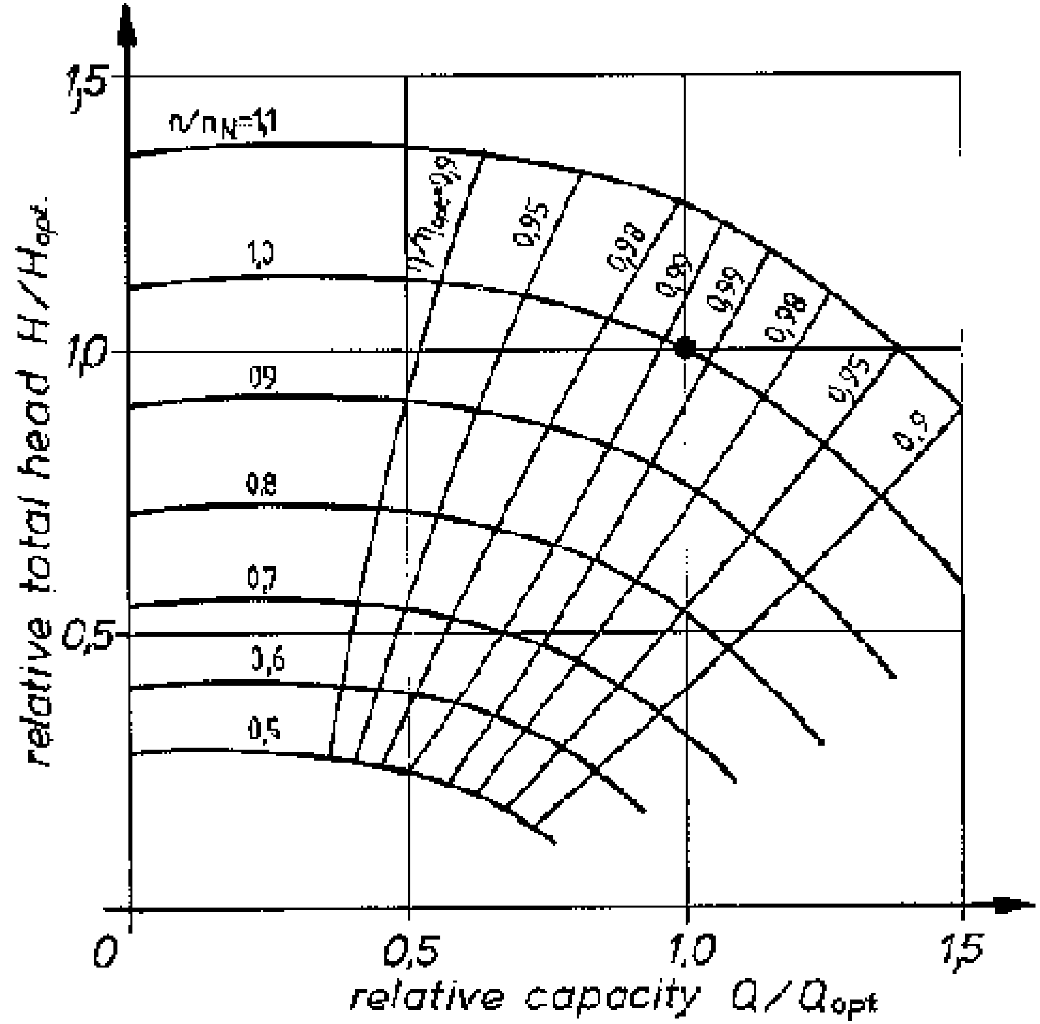


Fig. 7.13: Performance chart of a speed-controlled centrifugal pump (KSB)

Centrifugal pumps should never be throttled on their suction (inlet) side because of cavitation which wild gradually damage the impeller. However, as a valve on the pressure side is usually necessary for facilitating the start-up of the engine it can also be used for capacity control. The valve is to be kept closed when the engine is started and after one or two minutes gradually but fully opened. Priming

of centrifugal pumps is necessary on the suction side if the pump does not suck water by itself (self-priming pump). Dry running of pumps is to be avoided.

The pump's performance chart and the other equations given will be useful for the specification of the engine in terms of power and speed. The engine should be chosen with the aim to match the operational point (or range) of the pump with the most fueleconomic point (or range) of the engine. The example below shall demonstrate the procedure.

Example:

Given situation: Water is to be supplied to a cattle farm with a daily consumption of 1 500 m³. The farm's buffer tank is located 40 m above the level of a river from which water shall be pumped. The flow resistance in the piping is estimated at an equivalent of 10 m; the total head for the pump is therefore 40 + 10 = 50 m. The pump available shall have the characteristics shown in Fig. 7.12; the speed specified is n = 3 000 1/min .

Step 1:
Transform the capacity into units matching the pump's diagrams and the formula for power:

$$Q = 1\,500\ m^3/d : 24\ h/d = 62.5\ m^3/h$$
$$Q = 62.5\ m^3/h : 3\,600\ s/h = 0.0174\ m^3/s$$

Step 2:
Establish the actual power demand using Equ. 7.10 and the efficiency from the pump chart at Q = 62.5 m³/s:

$$P = 0.0174 \cdot 50 \cdot 9.81 \cdot \frac{1}{0.67} \cdot \frac{1}{1000}$$

P = 12.74 kW

From the performance diagrams at Q = 62.5 m³/h the pump produces a head of H = 74 m and requires a power of P = 19 kW. If the pump was operated at its designed shaft speed of n = 3 000 min^{-1} water would be jetted into the tank at high speed, unnecessarily consuming extra power. The power difference between the diagram value and the one calculated would be wasted, hence extra fuel for the engine. A reduction of speed will solve the problem.

Step 3:
Adapt given pump to given situation using Equ. 7.13

$$n_2 = n_1 \cdot (\frac{P_2}{P})^{1/3} = 3000 \cdot (\frac{12.74}{19.0})^{1/3} = 2626 min^{-1}$$

n2/n1= 2626/3000 = 0.875

The new head at Q = 62.5 m³/s, using Equ. 7.12

$$H_2 = H_1 \cdot (\frac{n_2}{n_1})^2 = 74(0.0875)^2 = 53.5 m$$

H=53.5 m is sufficient for the given case of H = 50 m.

Step 4:
Specification of the engine (still unmodified) Data required by the machine (pump)

- operational speed n_{mach} = 2 626 1/min
- operational continuous power P= 12.74 kW

a) Otto engine (ex-petrol)

rated engine power $P_{eng} = 1.95 \cdot P_{mach}$ =24.8 kW

rated engine speed $n_{eng} = 1/0.8 \cdot n_{mach}$ =3 283 1/min

A petrol engine to be purchased for modification should have a rated power of about 25 . . . 30 kW at a speed of about 3 300 . . . 4 000 1/min. Suitable engines are found in a variety of vehicles with a cubic capacity of about 1.5 . . . 2.0 lifers. An Otto (ex-vehicle) engine would however be less recommended in a case of continuous operation. With estimated overhaul periods of about 3000 . . . 4 000 hours it needs a total overhaul after every six months.

b) diesel engine for dual fuel operation

rated engine power $P_{eng,r} = 1.56 \cdot P_{mach}$ =19.9 kW

rated engine speed $n_{eng} = 1/ 0.8 \cdot n_{mach}$ =3238 1/min

The speed appears to be fairly high for a diesel engine, especially the stationary type. For a transmission using V-belts it is recommended to use an engine with a lower speed, preferably between 1 500 . . . 1 800 1/min. The rated maximum power should be 20 . . . 25 kW. Suitable diesel engines would be types with two or three cylinders, stationary, with a capacity of 2.0 . . . 2.5 lifers.

c) ready-made Otto gas engine (possibly exdiesel)

The specifications given by commercial suppliers already consider the reductions explained earlier for engines to be modified. Such engines can be ordered giving the specified machine data. A little reserve in power and speed, however, may be useful in case the machine requires a higher performance.

Step 5:
Establishing the biogas fuel consumption fc per day

a) Otto engine (self-modified) with
sfc = 0.6 . . . 0.8 m^3/kWh
fc = sfc · P · operation time = 0.6 . . . 0.8·12.74 · 24 = 183 . . . 245 m^3/d

b) diesel dual fuel engine with
sfc = 0.5. . . 0.7 m^3/kWh
fc = 0.5 . . . 0.7 · 12.74 · 24 = 153 . . .214 m^3/d

c) ready-made Otto gas engine with
sfc = 0.5 . . . 0.7 m^3/kWh
fc = 153 . . . 214 m^3/d

Step 6:
Dimension of biogas plant (digester) volume V_{dig}

The specific production rate (spr) of a biogas plant depends on factors like input material, retention time, temperature, etc. as explained in the relevant literature [4, 5]. Practicable values range from 0.3 . . . 1.0 m^3 biogas/m^3 digester volume

and day, a range which shows the necessity for a fairly realistic establishment of the spr value. Assuming a value of spr = 0.8 for this example the digester volume is for

a) Otto engines (self-modified)

$V_p = fc/spr = 183...245/0.8 = 229 . . .306 m^3$

b) diesel dual fuel and ready-made gas Otto engines

$V_p = 153...214/0.8 = 179...268 m^3$

In order to compensate for fluctuations a 10% oversizing of the biogas plant is recommended. A small gas storage, possibly integrated into the; digester anyhow, of 5. . .10% of the daily production is furthermore useful. Considerations of future increases in water demand have to be made before final planning.

The pump chosen here can easily cater for about twice the capacity (see its per. formance diagram) but would need a larger engine. A slight oversizing of the engine is useful as during operation the piping may gradually become clogged by deposits. Some extra power helps to rinse or unblock the piping or overcome the resistance put up by the deposits.

As an alternative to the given example the following version is possible:

- **pumping time 12 hrs/day,**
- **pump capacity 125 m^3/h,**
- **engine power rating about 40 kW,**
- **farm water storage tank volume min: 750 m^3,**

- biogas storage tank volume min: 120m³.

The advantage of a shorter daily operation period (manpower) and a larger interval between the overhauls is likely to be out-weighed by the extra investment for a larger engine and storage tanks for water and biogas.

7.4.2 Biogas Engine and Electric Generator ("Biogas Gen-Set")

The generation of electrical energy represents another suitable option for the utilization of the energy potential of biogas. Electric generators, which can be driven by a choice of turbines and engines, are available in a large variety of sizes and types from various manufacturers. They are usually designed according to standards and enjoy a generally good reputation in terms of reliability, easy maintenance and a relatively low price as the smaller and medium sizes are manufactured in larger series.

Electric alternating current (AC) generators are designed in two different types:

- synchronous,
- asynchronous.

The synchronous type requires a direct current (DC) exitation, either from an external source (e.g. battery) or from an integrated exitation system, the latter of which are known as brushless, self-exitating generators. The frequency of the AC current produced is a function of the rotor (shaft) speed and the number of pole pairs in the stator:

$F = n \cdot Pp \cdot 1/60$ (Equ. 7.15)

with: F = frequency in Hz or s^{-1}, n = speed in min^{-1}, Pp = number of pole pairs.

Example:

n = 1 800 min^{-1}
Pp = 2
F = ?

F = 1 800min^{-1} · 2 ·1/60= 60 Hz

The frequency of AC produced from a synchronous generator can be only as stable as the engine speed control system allows. For consumers which require extreme frequency stability the engine needs an adequately sensitive control system. For consumers like electric motors for water pumps or grain mills which can tolerate within certain limits operation with fluctuating frequency, hence speed, a synchronous generator and an engine with a standard control system are well suited.

Asynchronous generators guarantee frequency stability by means of their specific way of exitation. This is achieved by appropriately dimensioned capacitors in isolated operation or taken from the grid frequency in grid parallel operation. An asynchronous electric machine works as a generator as long as its rotor speed is slightly higher than the exact speed for synchronous operation (see Equ. 7.14), the "synchronous speed". It will however work as a motor and consume electricity when operating at a speed lower than the synchronous speed.

This specific feature principally allows the use of standard asynchronous motors

as generators. In isolated grid operation, however, a well calibrated exitation system is to be connected, while for grid parallel operation no alterations are required.

Synchronous motors on the other hand require some modification with respect to their exitation systems when used as generators.
Competent expertise is necessary in this case.

The direction of rotation of the generator rotors is usually optional; the connections to the grid will have to be made in accordance with its actual direction of rotation. In case the connection and the direction of rotation do not match the following alterations should be made:

> **- for 2-phase:**
> **exchange the connections**
> **plus for minus,**
> **minus for plus,**
> **earth remains unchanged;**
>
> **- for 3-phase:**
> **exchange any two out of the three connections, e.g.**
> **U for V,**
> **V for U,**
> **W,N and earth remain unchanged.**

In a case where the gen-set is the only supplier of electricity in an isolated grid a wrong connection results in a wrong direction of rotation of the connected electric

motors with possible damage to the driven equipment. In grid parallel operation the phase sequence in three-phase grids must first be established (with a three-phase sequence indicator) before the generator is connected accordingly. Wrong phase connection can damage the generator-severely.

The connection data differ from one country to another. The most commonly used systems are the following two:

- 50 Hz, 220 . . .230 V, 2-phase
50 Hz, 380 . . 400 V, 3-phase
- 60Hz, 110V, 2-phase
60 Hz, 254V, 2-phase
60 Hz, 440V, 3-phase

For the specification of a generator the following data are required:

- Electrical connection data (as above): phase, voltage, frequency;

- Speed: The generator speed should be selected with a view to direct transmission, i.e. propeller shaft or rubber-damped coupling. For diesel gas engines or Otto engines modified from diesel engines a speed of n = 1 500/1 800 min^{-1} (for 50/60 Hz) is optimal. For Otto engines modified from petrol (ex-vehicle) engines n = 3 000/3 600 min^{-1} may be a viable option also, especially as they often show poor performance at speeds lower than n = 2 000 min^{-1}. Life span however is shorter at higher speeds.

- Power: The electric power to be produced must be established from the

requirements of the anticipated electric consumers operating simultaneously (check operational schedule). Voltage U, current I and the cos £ value (for electric motors) are either known or can be measured from existing consumers. The electric power demand Pel

Of each piece of equipment can be calculated as follows:

phase apparent power (kVA)

2-phase Pel = U· I

3-phase Pel=U· I ·

$\sqrt{3}$

phase active power (kW)

2-phase Pel = U· I· cos φ

3-phase Pel = U · I

$\sqrt{3}$**·cos φ (Equ. 7.16)**

Resistors like heating, lighting, etc. have a cos φ value of 1, i.e. the active power drawn from the grid equals the apparent power. Electric motors with a cos φ value of 0.75 . . . 0.9 draw active power which is less than the apparent power resulting

from measurements with simple A/V meters. The actual cos φ is therefore required to specify the actual (active) power drawn from the grid or generator. Generator manufacturers, however, specify the generator's power output in kVA as the future type of consumption is unknown to them.

Modern generators can bear a short overload of about 2.5 times the specified current. The overload occurs during start-up of electric equipment, especially motors to overcome the break-away torque. To limit the overload for the generator, three-phase electric motors should have star/delta switches. Overdimensioning of gen-sets for start-up peak loads should not be necessary, especially as also the engine can usually produce more power for a short period.

For the selection of an adequate engine the generator's demand in mechanical power Pgen has to be established. The generator's efficiency ηg which considers losses like heat, bearing friction and the power consumption of its own cooling fan is defined as

$\eta_g = \frac{P_{el}}{P_{gen}} \leq 1$ **(Equ. 7.17)**

The generator efficiency is specified by the manufacturer and usually ranges at ηg = 0.82 . . .0.92. In case of belt transmission, the transmission efficiency needs to be considered also in a way that the total power demand of engine cum transmission required from the engine Peng, a is:

Peng,a = 1/ηg · 1/ηT · Pel (Equ. 7.18)

Before foal specification of the generator and engine according to the power

required by one's own equipment, the operational schedule or the power demand profile respectively has to be sufficiently studied as it also determines the power or power range of the gen-set.

The following example shall serve as a demonstration of the layout of a biogas-driven generator set.

Given situation:

-biogas production (potential)	V_{bg} = 180 m³/d = 7.5 m³/h
-mean specific biogas consumption	
of engine (estimated)	sfc=0.65 m³/kWh
-efficiency of generator	η_g=0.9
-transmission	direct, no losses
-voltage (country standard)	U=220/380 V
-frequency (country standard)	f=50 Hz
-daily electric power demand:	
- from 0 to 7hrs	P_{el}= 2 kW
- from 7 to 17hrs	P_{el}=12 kW
- from 17 to 24 hrs	P_{el}= 2 kW

Solution:

Step 1: Establish amount of biogas needed daily for the generation of the required electric power. Electric energy demand per day,
E_{el}:

$E_{el} = (14h \cdot 2kW) + (10h \cdot 12kW) = 148\ kWh/d$

Biogas demand for the gen-set per day, Vbg:

$V_{bg} = E_{el} \cdot 1/\eta_g \cdot sfc$

$V_{bg} = 148\ kWh/d \cdot 1/0.9 \cdot 0.65\ m^3/kWh = 107\ m^3/d$

The biogas production of 180 m³/d is more than sufficient for the generation of the power demand, but on a daily basis only.

Step 2:
Establish the mechanical/electric power directly available from the continuous biogas production rate and complete the daily supply/demand profile:

$$P_{el} = V_{bg} \cdot \frac{1}{sfc} \cdot \eta_G = 7.5 m^3/h \cdot \frac{1}{0.65 m^3/kWh} \cdot 0.9 = 10.4 kW$$

- **-from 0 to 7 furs: excess biogas available**
- **-from 7 to 17 furs: power demand is higher than related biogas production**
- **-from 17 to 24 furs: excess biogas available.**

The excess biogas produced during the low demand period provides the possibility for storage to be supplied to the gen-set during the high demand period. Furthermore other consumers like lighting, heating, baking, cooking can utilize the excess gas during that time.

Step 3:
Establish necessary biogas storage.

Biogas demand per hour

Vbg = Pel · 1/ηg · sfc

a) high demand period (7 to 17 furs)

Vbg = 12 kWel· 0.9 · 0.65 m³/kWh = 8.7 m³/h

b) low demand period (0 to 7 hrs and 17 to 24 hrs)

Vbg = 2 kWel · 1/0.9 · 0.65 m³/kWh = 1.44 m³/h

The gas storage capacity Vs needed for the high demand period (see Equ. 7.3):

Vs = 10 h (8.7 m³/h - 7.5 m³/h) = 12 m³

Note that a certain gas quantity is usually stored in the biogas digester itself. A certain volume is however necessary for the normal fluctuations in biogas production in most plants and possible fluctuations in power demand.

In the given situation it would be worthwhile to reconsider the operational schedule with the aim to better adapt biogas production and biogas consumption to each other:

> **-Lower the demand for electric power while the operational period is extended (e.g. Iess water pumped per hour during a longer operation time). The gas storage could be avoided.**
> **-Raise biogas production to Vbg = 8.7 m³/h to avoid the gas storage. At**

the same time secure a use for the excess gas produced during the low demand period.

- If no other gas use is available build a smaller biogas plant for a lower biogas production. The daily amount of biogas required to be sufficient for the generation of 148 kWh was 107 m³/d or 4.5 m³/h. A larger gas store is then necessary with Vs = 10 h (8.7 - 4.5) = 42 m³. For future extension - one may consider about a 25% increase in these figures.

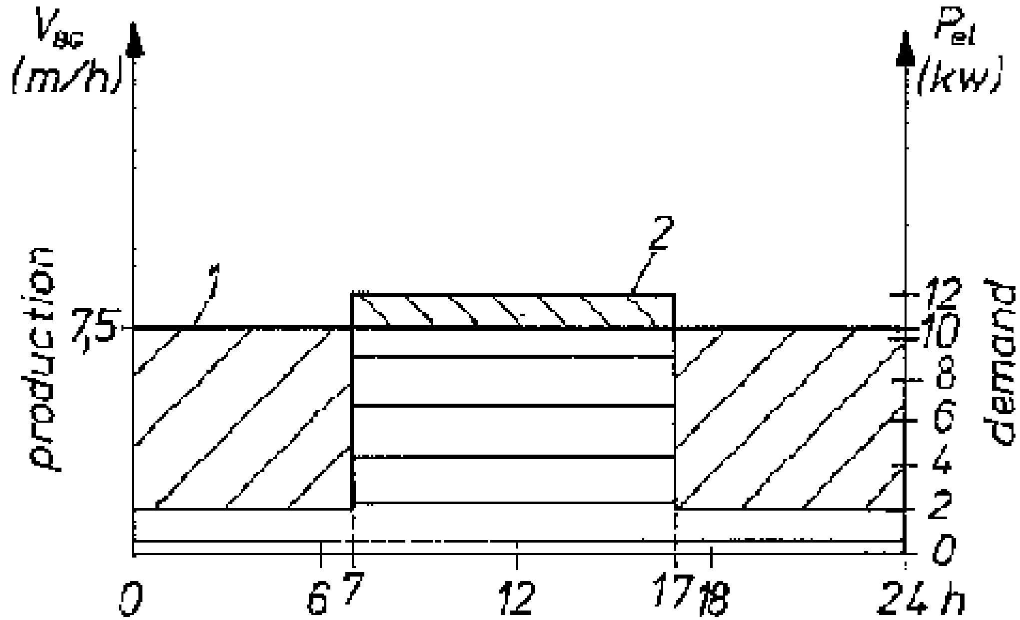


Fig. 7.14: Daily profiles: 1 biogas and potential power production, 2 electric power demand (refers to example)

Step 4:
Specify the generator:
Voltage: 380 V
Frequency: 50 Hz

Phase: 3-phase (unless all existing electric equipment is 2-phase)
Speed: 1500 1/min
Type:

- **asynchronous if net parallel operation is anticipated**
- **synchronous (brushless, self-exitating) if isolated grid operation is anticipated**

Power:

- **present maximum demand 12 kW**
- **provision for future extension 25%**
- **total electric power 15 kW**

Current: (necessary for specification of switchgear, cables. connections, etc.)

for 3-phase (cos φ assumed = 0.85)

$$I = \frac{P_{el}}{U \cdot \sqrt{3} \cdot \cos\varphi} = \frac{15kW}{380 \cdot \sqrt{3} \cdot 0.85} = 26.8A$$

Step 5:
Select engine

- **mechanical power demand from machine, i.e. generator:**

$$P_{mech} = \frac{1}{\eta_{G}} \cdot P_{el} = \frac{1}{0.9} \cdot 15kW = 16.7kW$$

The operational power of the engine is about 17 kW while the value of the rated or maximum power of the engine (Peng,r) to be selected for modification is higher (see Chapter 7.3.2).

a) Diesel engine to be modified for dual fuel

Peng,r = 1.56 · Pmach = 1.56 · 16.7 kW =25.1 kW

b) Otto engine (ex-petrol) to be modified for biogas

Peng,r = 1.95 Pmach = 1.95· 16.7 kW = 32.6 kW

- pilot fuel demand:

The diesel engine requires about 20% of its rated diesel fuel consumption for pilot ignition, i.e.

fc= 16.7 kW · 0.31/kWh · 0.2=1 l/h

- speed, transmission:

The generator speed is suitable for direct transmission by rubber-damped coupling or propeller shaft:

$n_{eng} = n_{mach} = 1\ 500\ min^{-1}$

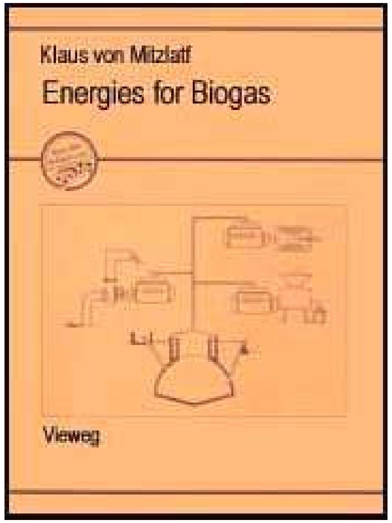
The direction of rotation is usually optional for generators and only related to the mode of cable connection.

The given demand profile allows operation of the engine at a good efficiency for 10 hours a day. During the low demand period the engine can only be operated at almost idling conditions. Its use in this case is hardly economic as the cost for service, maintenance, operating personnel and the depreciation process are dependent on the actual operation period irrespective of the actual power produced.

Some alternatives would be worth considering:

-Sell electric power to other consumers or public grid at a rate which allows the full utilization of the excess biogas.
- Buy the electric power needed during the low demand period and only switch over to self-generation during the high demand period.
-Consider renouncing the use of electricity during the low demand period, i.e. operate the engine in high demand period only.
-Use an additional smaller biogas-driven generator set (3 . . . 4 kW) for the low demand period; this however requires extra investment.

In the last three cases find a useful purpose for the excess gas produced during the low demand period or consider a smaller biogas plant cum appropriate gas storage (see step 3).



Engines for Biogas (GTZ, 1988, 133 p.)

8. Utilization of the engine's ''Waste'' heat

(Cogeneration)

8.1 Theoretical aspects

The degree of utilization of the energy content of engine fuels for power production alone is fairly low, i.e. between 25% and 35% only. Through cogeneration of power and heat the total utilization degree can be improved to about 85%. This provides an incentive to try and use both forms of energy simultaneously whenever possible.

Not only should the waste heat of an engine be utilized whenever power production is the initial issue. Especially in cases where biogas is considered for low temperature heat generation (about 100 °C) an engine should be introduced.

The thermodynamic validity of mechanical power is much higher than that of low temperature heat.
Any fuel suitable for utilization in engines has the potential to generate power.

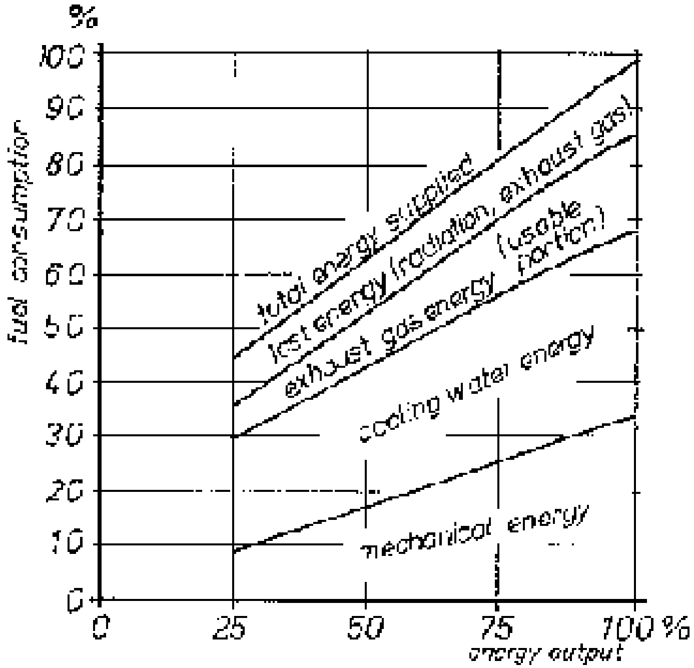


Fig. 8.1: Distribibition of fuel energy in an engine (schematic)

When low temperature heat is required, the degree of utilization (efficiency) of the combustion Process in a boiler is about 85%, hence similar to that of a cogeneration unit:

- low temperature heat demand:	Using the relations for establishment of the Q = 20 kW fuel consumption and considering power and	
- efficiency of boiler:	$\eta b = 0.085$	heat either separately or as a sum for cogeneration:

- mechanical power demand:	P = 10 kW	
- efficiency of engine:	ηeng = 0.3	fc =1/η *(P + Q) x 1/Hu x 3600
- efficiency of cogeneration:	ηc = 0.85	(see Equ. 4.11)
	separate generation of fuel and power	cogeneration
biogas needed for engine	fc,e = 6 m³ /h	-
biogas needed for boiler	fc,b = 4.2 m³ /h	-
total biogas needed	fc,tot = 10.2 m³/h	fc,tot = 6.4 m³/h

However the latter can transform one third of the fuel energy into power, a chance that is missed when using a boiler alone.

A simple example shall demonstrate this advantage of a cogeneration unit:

In the case of an optimal matching of heat and power demand in cogeneration the mechanical power of 10 kW is achieved with an additional fuel demand of only 6.4 - 4.2 = 2.2 m³/h. The same power requires 6 m³/h when being produced separately. In other words the efficiency of power production in cogeneration is increased from 30% in separate production to more than 80% in cogeneration. It is understood that demand and supply rarely match so perfectly. But as long as satisfying one type of demand, either power or heat, includes the free benefit of at

least partially satisfying the other, it is well worth being considered.

As, however, the demand profiles for power and heat have to be somewhat parallel, continuous operation of the whole system appears to be the most favorable condition for cogeneration in general.

8.2 Technical aspects

The potential of the engine's heat energy cannot be utilized fully for two reasons:

- **The exhaust gas must leave the heat ex- changer at temperatures above 180 °C. Lower temperatures would allow condensation of fuel impurities such as H2S which are corrosive with humidity.**
- **A certain part of the heat is emitted from the engine housing itself to the surroundings (can be useful to heat the machine room if required).**

The diagram in Fig. 8.1 helps to establish the actual quantities of the heat obtainable from the cooling water or air of the engine or the exhaust gas. The respective percentage is multiplied with the engine's total fuel energy consumption as calculated earlier in Chapter 4. As a rough estimation the following relation can also help to establish the total fuel energy input Ef in kJ/s:

Ef = 3 . . .4 x engine operating power (in kW) (Equ. 8.1)

Out of the total energy input the following portions can be utilized as heat (values differ with engine type, size, efficiency, etc. by ± 10%):

- **cooling water directly:**

35% at temperatures up to 80 °C,

- cooling air from fan:

35% at temperatures up to 50 °C,

- exhaust gas:

15% at temperatures up to 200 °C, so that the actual amount of heat obtainable becomes:

Q = proportion x Ef (Equ. 8.2)

whereby: Q = heat flow/transfer in kJ/s.

The temperatures to which the cold flow is actually heated depend on its flow rate. Smaller amounts of water flowing through an exhaust gas heat exchanger will be heated to higher temperatures than a larger water flow. This means that besides the temperatures of the two different media it is also their individual flow rates which determine the amount of heat transferred. The heat increase or decrease of a medium between inlet (1) and outlet (2) of a heat exchanger is given by

$Q = m \cdot cp \cdot \Delta t$ (in kJ/s) (Equ. 8.3)

whereby: Q = heat decrease/increase (in kJ/s), m = mass flow rate of medium (in

kg/s), cp = specific heat of medium (kJ/kg· K)2, $\Delta t = t_2 - t_1$, temperature difference of the medium between inlet and outlet of heat exchanger; positive value indicated heat absorption, negative value heat emission.

The heat exchanger surface A, i.e. the area of the material through which the heat is exchanged from the hot to the cold medium, is established using the heat flow to be utilized, e.g. the actual proportion of the total energy Q as found under Equ. 8.2:

$$A = \frac{Q}{k \cdot \Delta t_m}$$ **(Equ. 8.4)**

The heat transfer coefficient k depends on the types of media flowing on each side of the separation wall, the flow characteristics, and the wall material itself. Assuming that the wall material is metal (steel, brass, copper, aluminum) and the surfaces clean, the following mean k values can be used considering however that they can differ by + 50%:

- **liquid - metal wall - liquid:** $k = 2500 \frac{kJ}{m^2 \cdot h \cdot K}$
- **liquid-metal-gas: k = 150**
- **gas-metal-gas: k = 80**

The liquid is usually water; the gas can be air or exhaust gas.

The active mean temperature difference Δtm varies with the type of heat exchanger but can be established within acceptable tolerances by (see Fig. 8.2):

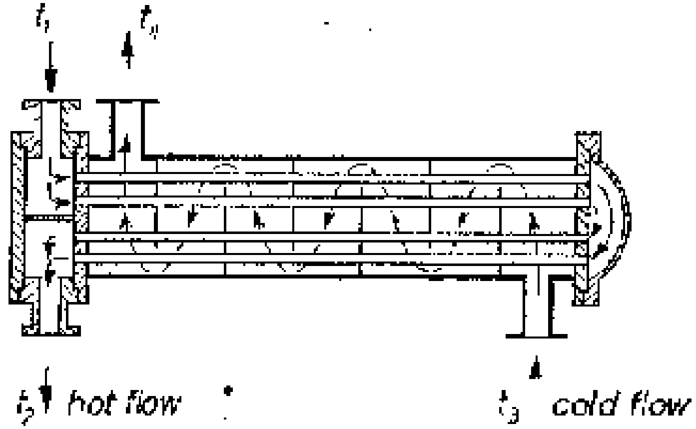


Fig. 8.2: Principial scheme of heat exchanger (mixed flow type)

Δtm =0.5/(t_1 + t_2) - (t_3-t_4)/ (Equ. 8.5)

Counterflow exchanges as in Fig. 8.2) have a higher Δt value, parallel flow a lower value and mixed flow/crossflow types (e.g. vehicle radiators) have roughly the value calculated in Equ. 8.5.

When using the cooling air from an aircooled engine or air emerging from a standard engine radiator, these airflows shall in no way be subjected to resistance in the following heat exchanger nor directly connected to equipment, e.g. dryer. The original blowers are normally too weak to overcome any extra resistance. The cooling of the engine can therefore become insufficient and the engine overheats.

For water heating from exhaust gas a heat exchanger design with two concentric tubes is recommended and is easy to manufacture. For water heating from cooling water a heat exchanger in the form of a coil within a larger vessel or tank is suitable. The coil or other heat exchanger shall not be too long, too narrow or otherwise impose too much resistance to the cooling water flow as the normal

water pump is not designed for much extra flow resistance. Here too the cooling of the engine may become insufficient. Larger heat exchangers should be insulated from outside as they emit heat to the surroundings which is lost for the initial purpose.

The operation of the heat exchanger, especially when using the engine's cooling air or water, needs a safety control to ensure that the cooling of the engine is always sufficient and the temperature of the cooling water returning to the engine is at around 50 °C with only minor fluctuations. The amount of heat conducted away from the engine has to match with the amount automatically produced in the engine according to its actual load. If more heat is produced than consumed, the control can be achieved using thermostats and a separate safety bypass cooler. If more heat is consumed from the cooling water than produced, the engine will gradually operate at too low temperatures which increases wear.

Taking too much heat from the exhaust gas reduces the final outlet temperatures and may lead to corrosion in the exhaust gas heat exchanger. The operation of the heat exchangers or heat users must therefore always consider that the heat production in the engine is linked directly to the mechanical power output, i.e. the driven machine's operation. Under the control aspect continuous operation of the whole system is therefore the best precondition for waste heat utilization.

The following example shall demonstrate the layout of a heat exchanger:

Given conditions:

- engine mechanical power: P = 15 kW

- engine efficiency: $\eta_{eng} = 0.32$
- cooling water temperatures:
from engine: 80 °C, back to engine: 50°C
- exhaust gas temperatures:
- from engine: 350 °C,
to surroundings: 180°C
- cold water temperature: tw = 20 °C

Problem: Supply of as much hot water at 60 °C as possible at constant rate.

Solution: Step 1:
Establish total fuel energy input:

$E_{tot} = \frac{1}{\eta_{eng}} \cdot P = 47kW = 47kJ/s$ **(see Equ. 3.9)**

Step 2:

Establish amount of heat to be obtained (see Equ. 8.2):

a) from cooling water
Qcw = 0.35 · 47 = 16.5 kJ/s

b) from exhaust gas
Qex = 0.15 · 47 = 7.1 kJ/s

Step 3:

Establish heat exchanger surface size (see Equ. 8.4):

a) cooling water heat exchanger

$$A_{cw} = \frac{Q_{cw}}{k \cdot \Delta t_m} = \frac{16.5 \cdot 3600^3}{2500 \cdot 25} = 0.95 m^2$$

with

-

$$k = 2500 \cdot \frac{kJ}{m^2 \cdot h \cdot K}$$

- Δtm = 0.5/(80 + 50) - (20 + 60)/ = 25 K[4]

b) exhaust gas heat exchanger

$$A_{ex} - \frac{Q_{ex}}{k \cdot \Delta t_m} - \frac{7.1 \cdot 3600}{150 \cdot 225} - 0.76 m^2$$

with

- -

$$k = 150 \cdot \frac{kJ}{m^2 \cdot h \cdot K}$$

- Δtm = 0.5/(350 + 180) - (20 + 60) /= 225 K

The exchanger areas can be materialized with a number of tubes in parallel to prevent excessively long exchangers.

Step 4:

Establish how much hot water is available (see Equ. 8.3):

a) from cooling water exchanger

$$m_{CW} = \frac{Q_{CW}}{c_p \cdot \Delta t} = \frac{16.5 \cdot 3600}{4.2 \cdot 40} = 354 kg$$

b) from exhaust gas

$$m_{ex} = \frac{Q_{ex}}{c_p \cdot \Delta t} = \frac{7.1 \cdot 3600}{4.2 \cdot 40} = 152 kg$$

with

c_p = 4.2 kj/(kg · k)

Δt= 60-20=40K
for the water circuit.

The two heat exchangers produce a total of 506 kg/in (or 1/h) of hot water. The parallel arrangement, i.e. cold water flows to both heat exchangers, allows for more flexibility in the water use:

- When water of higher temperature is wanted, the exhaust gas unit can supply it at a lower water flow rate.
- When less water is used the exhaust gas unit can be reduced to 0 l/h; only the final exhaust gas outlet temperature rises.
- When the warm water demand is further reduced, but the engine continues operation at the same load, part of the heated water from the engine's cooling water exchanger (not the cooling water itself) can be purged off to maintain engine cooling unless the cooling water cycle can be switched over to a bypass cycle with a standard engine radiator cum fan.

Ready-made cogeneration units for supply of heat and electricity are on the market in various sizes and versions. Heat exchangers can also be found in a large variety; some are even supplied for ready mounting to certain engine types. For both see Chapter 10.

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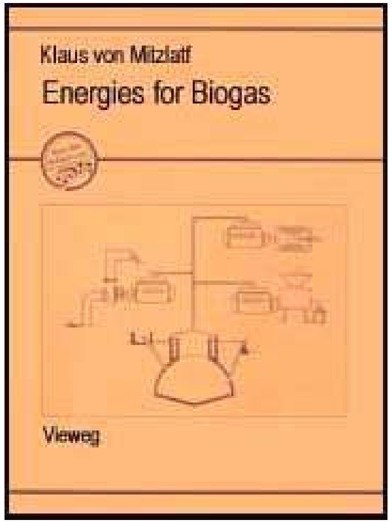

9. Biogas for vehicles

The utilization of biogas in vehicles requires a method of compact storage to facilitate the independent movement of the vehicle for a reasonable time. Larger quantities of biogas can only be stored at small volumes under high pressure, e.g. 200 . . .300 bar, or purified as methane in a liquid form at cryogenic conditions, i.e. -161 °C and ambient pressure. The processing, storage and handling of compressed or liquified biogas demand special and costly efforts.

Compression is done in reciprocating gas compressors after filtering of H_2S. At a

medium pressure of about l5 bar the CO_2 content can be "washed out" with water to reduce the final storage volume. Intermediate cooling and removal of the humidity in molecular sieve filters are essential as the storage containers should not be subjected to corrosion from inside. The storage cylinders, similar to oxygen cylinders known from gas welding units, can be used on the vehicle as "energy tank" and in larger numbers as refilling store.

One cylinder of 50 l volume can store at a pressure of 200 bar approximately

- 15 m³ unpurified biogas (CH_4 = 65% Vol) with an energy equivalent of 98 kWh or 101 diesel fuel, or
- 13 m³ purified biogas (CH_4 = 95% Vol) with an energy equivalent of 125 kWh or 12.51 diesel fuel.

The storage volume thus required on the vehicle is still five times more than is required for diesel fuel. Purification of biogas to CH_4 increases the storage efficiency by 25 . . . 30% but involves an extra gas washing column in the process.

Purified biogas, i.e. methane, has different combustion features than biogas because of the lack of the CO_2 content. It combusts faster and at higher temperatures; this requires different adjustments of ignition timing. Dual fuel methane engines are prone to increased problems with injector nozzle overheating and have to operate on higher portions of diesel fuel (about 40%) to effect sufficient cooling of the jets.

Liquification of biogas requires drying and purification to almost 100% CH_4 in one

process and an additional cryogenic process to cool the CH_4 down to -161 °C where it condenses into its liquid form.

Storage is optimal at these conditions as the volume reduction is remarkable, i.e. 0.6 m^3n with an energy content of 6 kWh condense to one lifer of liquid with an energy equivalent of 0.61 diesel fuel. The required tank volume is only 1.7 times the volume needed for diesel fuel.

This advantage is opposed by a more sophisticated multistage process, the handling of the liquid in specially designed cryo-tanks with vacuum insulation and the fact that for longer storage it has to be kept at its required low temperature in order to prevent evaporation. This requires additional energy and equipment. The practicability of such systems is still being researched with commuter bus traffic in Sao Paulo, Brazil. Data on the economic viability are not yet available.

The use of biogas as a fuel for tractors on farms has been elaborately researched. The processing of the gas does not only require about 10% of the energy content of the gas, mainly for compression, but also involves considerable investment. The tractor itself needs to carry four gas cylinders at least for a reasonable movement radius. A 40-kW tractor can then operate for about six to seven hours at mixed/medium load. The modification of the tractor has to include a three-stage pressure reduction system as the fuel gas is fed to the mixer at low pressure, i.e. about 50 mbar.

Modification into an Otto gas engine includes the risk of non-availability of the tractor at biogas shortage. It therefore needs LPG as spare fuel or another diesel tractor standby. Dual fuel tractor engines, on the other hand, are difficult to

control, especially because of their frequent speed and load changes during operation in the field.

Biogas for road service has become an issue in Brazil lately. It must however be seen in connection with the specific situation in this country. The main issue is to utilize the large natural gas resources for substitution of diesel fuel which is scarce. Purified biogas is therefore integrated into a larger "methane program", for which the government may decide to give specific economic preferences because of energy-political reasons. The biogas will furthermore be obtained and processed in larger units, e.g. municipal sewage plants and sugar factories which reduces the cost per m³ considerably.

With the current (political) price of fuel in industrialized countries the equivalent price for "vehicle biogas" is about two or three times higher than for diesel fuel. It is therefore presently not economic though technically feasible to use biogas in vehicles on a larger scale. The infrastructure for processing and filling however must also be developed accordingly.

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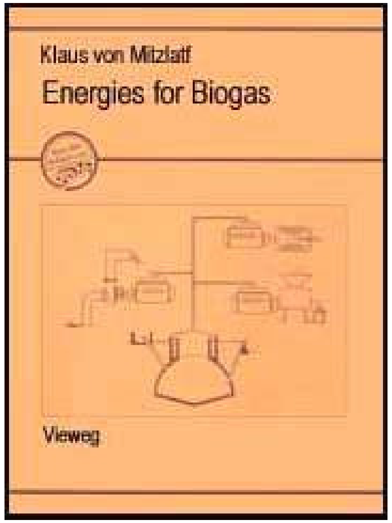
Engines for Biogas (GTZ, 1988, 133 p.)
10. Overview of Commercially Available Systems
10.1 Engines
10.2 Engine modification kits, other accessories



10.3 Other equipment

Engines for Biogas (GTZ, 1988, 133 p.)

10. Overview of Commercially Available Systems

10.1 Engines

Some manufacturers offer engines for the use of biogas, either diesel gas (dual fuel) or Otto types. Some manufacturers are listed below with specifications of their engines (as far as they were made available to the author) as well as some general comments.

In cases where more detailed specifications were given they will be reproduced in the appendix. Citation of manufacturers' names and specifications has only informative character and should not be regarded as advertising for any of the manufacturers.

(Data as per January 1987)

10.1.1 Smaller Engines up to 15 kW

10.1.1.1 Hirloskar Diesel Gas Engines, India

The Indian diesel engine manufacturers offer some of their standard diesel engines as diesel gas engines also.

> **- Basic engine type: 4-stroke diesel engine with direct injection.**
> **- Type of modification: Addition of simple hand-controlled mixing chamber. Mounted directly to the inlet manifold. As no other modification is undertaken, the engine remains a fully functioning diesel engine with the option to utilize biogas for up to about 80% of its fuel requirements.**
> **- Type of control: The control mechanism for diesel fuel operation is fully maintained. The biogas is manually controlled with a hand-operated valve at the biogas inlet to the mixing chamber.**

Rough control of power and speed is achieved by setting the required speed at the governor lever and then opening the biogas valve to admit the allowable amount of biogas to the mixing chamber. Fine control, if not done manually by an operator, can be taken over by variations of the diesel fuel amount through the governor/ injector.

The amount of biogas admitted must however be less than the maximum possible 80% (see Chapter 5.1.4).

According to information of the company the diesel fuel control is equipped with a minimum fuel adjustment to ensure that sufficient pilot fuel is always supplied. Problems with injector nozzle overheating are said to be unknown.

Engine specification of type TV I G

(Information on other types is available from the manufacturer.)

Bore (mm)	87.5
Stroke (mm)	110
Max. speed (rpm)	2000
Min. idle speed (rpm)	750
Min. operating speed (rpm)	1200
Cooling system	water-cooled

B.H.P. (at 2000 rpm)	
B.S. 649: 1958 continuous	8.7
S.F.C. at full load when fully on diesel(g/bhp-h)	176.00
S.F.C. at full load of ignition diesel when on-dual fuel (g/bhp-h)	30
Biogas requirement for dual fuel (m^3/bhp-h) (15 cubic feet/bhp-h)	0.425

Biogas specification: The data are based on biogas with

- **methane content: 60% Vol**
- **pressure: 100 mbar (± 50 mbar)**
- **H_2S content: no data but a value of 0.2% Vol should not be exceeded.**

Engine/machine units readily available:

- **engines cum electric generator, various types**

- engines cum water pumps, various types.

Comments: Kirloskar diesel engines, some of which are based on models of other international manufacturers under license, are widespread in India where they apparently enjoy a goodreputation and a considerable share in the market.

Manufacturer's address:
Kirloskar Oil Engines Ltd.
Luxmanrao Kirloskar Rd.
Khadki, Pune 411003
India

10.1.1.2 Shanghai Bioenergy Engineering Co., China

The Chinese company offers a biogas Otto engine obviously modified from a standard single-cylinder diesel engine.

- Basic engine type: 4-stroke, single-cylinder Otto engine.
- Type of modification: Basic diesel singlecylinder engine modified and equipped with gas mixer (venturi), spark ignition, alternator, etc. (see Chapter 5.3).
- Type of control: no direct information available but obviously mechanical governor acting on venturi throttle valve as engine is designed to work with a generator at constant speed.

Engine specifications (as far as given in manufacturer's leaflet)

-model: S 195 DZ

-type: 4-stroke, horizontal, watercooled

- number of cylinder(s):	1
- displaced volume(l):	0.82
- speed (1/min):	2000
- power (kW): approx	6

Biogas specifications:

- methane content min.: 70% Vol
- hydrogen content max.: 5% Vol

Engine/machine units readily available:
- engine cum electric generator with Pel = 5 kW

U=220/380V, F=50 Hz
Comments: no further information available.

Manufacturer's address:
Shanghai Bioenergy Engineering Co.
P.O. Box
Shanghai
People's Republic of China

10.1.1.3 Montgomery/Yanmar, Brazil

The Brazilian manufacturer offers smaller Otto engines for generators, pumps, etc.

They are built for various fuels such as petrol, alcohol, kerosene and biogas.

- Basic engine type: 4-stroke, single-cylinder Otto engine with standing valves
- Type of modification: The housing of the original carburetor for petrol/alcohol is used to form a venturi type of mixing chamber.

Biogas is introduced through a nozzle pointing into the core of the venturi bottleneck. Timing of valves, ignition and the compression ratio remain unchanged from the basic petrol version and this
version is therefore not optimal for biogas operation.

-Type of control: mechanical speed governor with possibility for manual setting, acts on carburetor throttle valve.

Engine specifications:

- models:	R-137	R-320	R-480
-type:	4-strocke, vertical,	air-cooled	(for all models)
- number of cylinder(s):	1	1	1
- displaced volume (1):	0.14	0.32	0.48
- speed range:	n=1800.3600 1/min	(for all models)	
- power (kW at n = 3 600 1/min):			
(approximately)	1.5	4.0	6.5

Biogas specifications:

- methane content: 60 . . .70% Vol
- pressure: 120 . . . 180 mbar

Engine/machine units readily available:

- Engine types R-137 and R-320 with electric generators 0.9 kW and 2.5 kW respectively
- engine types R-137 and R-320 with centrifugal pumps
- engine types R-320 and R-480 with self-priming pumps

Comments: the company has so far only sold about 300 units for biogas, mainly in Brazil. According to the company's own statement the experience is not always positive and some further developments would be required. The engine as such is of an outdated design (standing valves, excentric compression chamber), the compression ratio (about 7: 1) very low for biogas. The reliability of the magnetic ignition system could be improved. The engines, as they are designed presently, do not appear to be recommendable for continuous service but might be useful for occasional operation.

Manufacturer's address:
Cia. Yanmar
Av. Dr. Gastao Vidigal, 2001
Cx. Postal 542
Sao Paulo Bazil

In principle other small direct injection diesel engines can be used with simple modification (mixing chamber) for biogas dual fuel operation even though other

manufacturers do not specifically offer biogas versions. The same is true for small Otto engines as long as they can operate on unleaded petrol. They require either a modification of their carburetor, or an adapted venturi/mixing valve. Their performance with biogas will however be significantly (up to 40%) lower than with petrol.

10.1.2 Larger Engines

10.1.2.1 C.A.S./Henkelhause-Deutz, Federal Republic of Germany

The German company specializes in the commercial modification of standard "Deutz" diesel engines into Otto gas engines for natural gas and biogases. Their air-cooled engine series range from 15 kW to 144 kW. The water-cooled series from 122 kW to 500 kW are not included here; specifcations may be obtained from the company.

> **-Basic engine type: 4-stroke Otto gas engine in "Deutz" module design, air-cooled. Type of modification:**
> **-Engine block cum cylinders, crank- and camshaft, cooling and lubrication system are retained from the diesel engine version.**
> **-Low compression (e = 11.5) pistons, cylinder heads with provision for spark plugs are mounted in exchange for the original parts of the diesel version.**
> **-Ignition system with distributor connected via angular gear to the drive for the obsolete injector pump, ignition coil and 24-V alternator cum batteries are added.**
> **-A suction-pressure-controlled air/gas mixing valve with butterfly throttle**

for the control is connected to the original air inlet manifold.
-A gas inlet control system with filter, shut-off solenoid valve, constant pressure regulation valve and suction gas pressure manometer is added.
-A separate large lubrication oil tank for extended oil exchange intervals is added.

Type of control: The company offers two types of control according to the future operation of the engine:

-mechanical control, using the original governor for the diesel injector pump. The motion of the control rack is passed on to the butterfly throttle of the gas mixing valve. The precision ("droop") is about 5 . . . 8% of the speed set at the governor lever. The mechanical control is sufficient for less sensitive isolated grids and for the drive of pumps or other machines;
- electronic control, using a magnetic pick-up to sense the engine speed from the flywheel ring gear. The speed pulse signal is transmitted to the electronic control box where the actual and the desired speeds are compared. The correcting pulse is given to the actuator which via a linkage moves the throttle in the gas mixing valve. The precision ("droop") of this unit is less than 1%, hence considerably better than the mechanical unit. The control system is made by Barber Colman, USA.

Safety devices like cut-out at overspeed, low oil pressure, low gas pressure and at too high a temperature are part of the system.

Engine and biogas specifications of naturally aspirated 4-cylinder engine (F 4 L 912): (Information on other types is available from the manufacturer.)

Rated power for continuous operation (10% overload, DIN 6271, 27 °C, 100 m above sea level,

60% ref. Humidity)	28 kW
Speed	1500 rpm
No. of cylinders	4
Cylinder arrangement in line	
Bore/stroke	100/120 mm
Swept volume	3.77 l
Mean effective pressure at rated power	5.90 bar
Mean piston speed 6.00 m/s	
Fuel consumption at full load:	
- natural gas	8.8 Nm^3/h
- biogas	12.6 Nm^3/h
Gas pressure	13-20 mbar
Max. Permissible mm H_2S 0.15%	
Lube oil consumption 60 g/h	
Lube oil capacity	10.1 l
Direction of engine rotation anticlockwise	
Heat quantities:	
- radiation heat of engine 4.0kW	
- heat quantity to be dissipated in cooling air	31.1 kW

- heat quantity to be dissipated	
in exhaust gas	23.5 kW
Exhaust quantity (referred to 20 °C)	160 m³/h
Exhaust temperature	460 °C
Air requirement/hour for	
- cooling air	1810 m³/h
- combustion air (20 °C) 133 m³/h	
Quantity of used air (70 °C) 2234 m³/h	
Engine dimensions:	
- length	813 mm
- width	661 mm
- height	803 mm
Weight	300 kg
Noise (measured at 1-m distance)	91 dB(A)
Power when using	
- refuse dump gas	26 kW
-lean gas	24 kW

Engine machine units readily available:

- engines cum electric generator in accordance with customer's planned operation and specification.

Comments Henkelhausen/Deutz gas Otto engines enjoy a good reputation for

reliability and a high service factor. Over two hundred machines are in the field, the majority for electricity generation, hence in continuous service. Biogases from waste water treatment plants, waste disposal fields and producer gas are used in about 60% of the engines; natural gas is used in about 40%.

Manufacturer's address:
G.A.S., Henkelhausen/Deutz
Hafenstrasse 5 1
D-4150 Krefeld 12
Federal Republic of Germany

10.1.2.2 Deutz MWM, Federal Republic of Germany

After the recent merger of the two large diesel and gas engine manufacturers Deutz and MWM the group offers a large range of gas engines in diesel gas (dual fuel) and gas Otto versions, from about 20 kW to 3 000 kW. The gas engines are based on standard stationary diesel engines. Specifications for the larger series with a power of more than 100 kW are not included here but can be obtained from the manufacturers.

- Basic engine type: 4-stroke Otto gas engine, vertical in line and V-type, watercooled.
- Type of modification: basically as described in Chapter 10.1.2.1 above.
- Type of control: electronic control, similar to the system described for 10.1.2.1. Manufacturer of the control system is Bosch, Federal Republic of Germany.

Engine specifications:

-models:G 227-3 G 227-4 G 227-6 G 232 V6 G 232 V8

- types:4-stroke Otto gas engines, water-cooled (for all models)

	vertical in line			V-type	
-number of cylinders:	3	4	6	6	8
- displaced volume (1):	2.83	3.77	5.65	8.8	11.8
-compression ratio:	11.6:1 (for all models)				
-speed(1/min):	1500/1800 (for all models)				
- power (Pel in kW):	18/21	24/28	36/43	65/77	87/103

Biogas specifications:

- methane content min.: 65% Vol
- H_2S content max.: 0.1%Vol

Engine/machine units readily available:

- engine cum electric generator and heat cogeneration according to specifications of the customer
- engine cum pump or blower (for aeration ponds in waste water treatment plants)

Comments: The company has sold several thousand gas engines for natural gases and biogases worldwide. Their engines have a good reputation for reliability and a high service factor. The majority of the driven machines are electric generators, furthermore blowers, pumps and heat pumps, all in continuous service. The greater part of the group's activities lies however in the larger power range.

Manufacturer's address:
MWM Motorenwerke Mannheim
Carl-Benz-Str.
D-6800 Mannheim
Federal Republic of Germany

KHD Klckner Humboldt Deutz A.G.
P.O. Box 800 509
D-5000 Kln-Deutz
Federal Republic of Germany

10.1.2.3 Volkswagen (VW) do Brasil, Brazil

The Brazilian VW affiliate has developed Otto engines based on standard vehicle engines for operation with alcohol as a consequence of the Brazilian national alcohol program. Due to the increased compression ratio (e = 12) these engines are suitable for biogas operation. About 50 engines are running in vehicles with purified and compressed biogas; a few others produce electricity in stationary application.

- Basic engine type: 4-stroke Oto gas engines, vertical in line, V-type and

opposed arrangement ("boxer") type.
-Type of modification: increase of compression ratio to about 12: 1 with smaller variations according to the engine type. Exchange of (alcohol) carburetor for venturi gas mixer or addition of a simple venturi onto the existing carburetor with possibility of switching back to liquid fuel.

Type of control:

- in vehicles: butterfly throttle is connected to driver's pedal as common in vehicles;
- mechanical: a separate mechanical governor (Franker) is driven by the normal V-belt and acts on the throttle valve of the gas mixer/carburetor. Precision is said to be ± 5% of set speed.

Engine specification:

- models:	318-3F	1600 (boxer)	1600 (in line)
- types: 4-stroke Otto gas engine	V-type	boxer type	in-line type
- number of cylinders:	8	4	4
- displaced volume (1):	5.2	1.6	1.6
- compression ratio:	9.5: 1	10:1	10: 1
- speed, max. (1/min):	4 000	4 000	4 000
- power, max., short term (kW):	100	30	40

Biogas specification: purified biogas or natural gas with methane content between

90% and 100% and a calorific value between 32 400 and 36 000 kJ/Nm³; H2S content about zero because of intensive filtering.

Engine/machine units readily available:

- **small pick-up vehicle ("Saveiro" type) with 1.6-1 engine,**
- **light truck (Type 6 - 140) with 5.2-1 engine,**
- **combi with 1.6-1 boxer engine.**

Comments: The basic engines are taken from standard Otto engine series and are of proven quality. The versions for methane/ purified biogas have only recently been developed but have performed satisfactorily so far. As the engines are mainly projected for use in vehicles the speed and power output are relatively high while engine life will be around 3 000 hours. For continuous service and longer engine life speed and power will have to be reduced to 50% which the company decided to do in one larger stationary application. Engine versions for direct use of untreated biogas are so far not offered by the company but one might consider using them on an individual basis. The power will of course be further lowered according to the actual calorific value of the untreated biogas.

Manufacturer's address:
Volkswagen do Brasil S.A.
09700 Sao Bernardo do Campo
Sao Paulo
Brazil

10.1.2.4 Ford Motor Company, Federal Republic of Germany

The German Ford affiliate offers Otto gas engines based on their standard vehicle engines.

> **- Basic engine type: 4-stroke Otto gas engines, vertical in-line type, water-cooled**
> **- Type of modification: increase of compression ratio to 11: 1 for natural gases and biogas. (For LPG compression ratio remains at 8: 1 as for petrol versions.) Exchange of carburetor against gas mixing valve (Impco).**

Type of control:

> **- mechanical: a separately mounted governor acting onto the butterfly throttle of the mixing valve;**
> **- electronic: as described earlier under 10.1.2.1.**

Engine specifications:

-models:	2274 HC	Dovergas S.1.4	Dovergas S.1.6
-type: 4-stroke vertical in-line Otto gas engine (for all models)			
- number of cylinders:	4	4	6
- displaced volume (1):	1.6	4.15	6.22
-compression ratio (natural gas/LPG):	11:1/8:1 (for all models)		
-speed(min^{-1}):	1500/3000	1500	1500
-power (Pel in kW):	12/24	33	50

(Bio)gas specification:

- **standard LPG, natural gas (CH_4 > 90%)**
- **for biogas no data available.**

Engine/machine units readily available: The manufacturer supplies the engine alone while other engineering companies use the Ford engines to offer engines cum electric generators and heat cogeneration.

Comments: The basic engines are taken from standard mass production series and are of proven quality' also for stationary purposes. The majority of the engines delivered so far work on LPG and natural gas; for the use of biogas the power data given will have to be reduced by about 30%.

Manufacturer's address:
Ford Werke A.G.
Edsel Ford-Strasse
D-5000 Cologne 71
Federal Republic of Germany

In other countries refer to the local Ford representative.

10.1.2.5 Peugeot, France

The French automobile manufacturers offer gas versions of their standard vehicle engines.

- **Basic engine type: 4-stroke Otto gas engine, vertical in-line and V-type,**

water-cooled.
-Type of modification: increase of compression ratio, exchange of carburetor against gas mixing valve.
-Type of control: electronic, similar to system described under 10.1.2.1.

Engine specifications:

-models:	2 E 1A	X N 1 P	ZN 175
-type:	4-stroke	Otto in line	4-stroke Otto V-type
-number of cylinders:	4	4	6
-displaced volume (1):	1.1	2.0	2.8
-compression ratio:	9.6:1	8.8:1	9.5:1
-speed (1/min):	3000 3000	3000	
-power (Pel in kW):	20	32	48

(Bio)gas specifications:

- standard LPG and natural gas
- biogas, methane content min.: 60% Vol H_2S content max.: 0.5% Vol

Engine/machine units readily available:

- engine cum electric generator with cogeneration using the engine's waste heat.

Comments: The basic engines are taken from standard mass production series and

are of proven quality. The relatively low compression ratios, while suitable for LPG, will result in a higher fuel consumption for methane gases compared to higher compressed engines. Power data given may have to be reduced by about 30% for operation with biogas.

**Supplier's address (in the Federal Republic of Germany): Peugeot Motoren GmbH
Bonner Ring 17
D-5042 Erftstadt-Lechenich
Federal Republic of-Germany**

In other countries refer to the local Peugeot representative.

10.2 Engine modification kits, other accessories

10.2.1 Impco Gas/Air Mixing Valves, USA

The US company has long been offering carburetion kits for the modification of Otto petrol engines into Otto gas engines. Such kits include suction pressure-controlled mixing valves with butterfly throttles, constant pressure reduction valves, adapters for manifolds and other ancillaries. Elaborate equipment for alternative dual fuel (gas/ petrol, not diesel) is available but is rather geared to vehicle use.

Originally designed for the use of LPG in vehicles, the equipment also functions for natural gas with a calorific value of not less than 37 000 kJ/m³. For gases with lower calorific values, such as biogas, special valve types can be supplied.

The gas mixing valves are offered in a variety for engines from about 10 kW up to

about 500 kW. The normal gas pressure at inlet to the mixer should range from 20 . . . 50 mbar which in some cases is too high for Gobar gas-type biogas plants.

Comments: The standard Impco mixer types for high calorific value gases may produce a mixture with biogas which is too lean (λ 1.3) for satisfactory performance even at fully opened gas adjustment throttle. A compensation by throttling the airflow externally before the mixer may result in a better excess air ratio value but lowers the performance and efficiency of the Otto engine because of extra reduced filling. It therefore appears recommendable to only utilize the specifically designed digester gas ("DG") types for biogases with a methane content of 60 . . . 90%. A self-modification of the valve cone in the mixing zone of the valve is not recommended.

Manufacturer's address:
Impco Carburetion Inc.
16916 Gridley Place
Cerritos, CA. 90701
USA

10.2.2 Rodagas,Brazil

The Brazilian company has developed modification kits for vehicle and stationary engines, both for Otto gas and diesel gas (dual fuel) engines. The equipment is based on kits for LPG but was also further adapted to the use of purified biogas and natural gas. The mixers are based on the venturi principle which allows adaptation to the actual calorific value of the gas more easily than in mixing ,valves as explained earlier. Other equipment like constant pressure reduction

valves and ancillaries for the modification of diesel engines (dual fuel) are also available. The company participates in the Brazilian research program for the extended use of methane gases in small and large vehicles.

The various kits offered include modifi- cation kits for existing carburetors, mixers to be mounted onto carburetors, mixers with butterfly throttles in exchange for carburetors and all necessary control and safety accessories.

Comments: Even though the equipment is mainly designed for the use of compressed methane in vehicles the mixers are well suited for direct use of biogas in stationary engines also. An existing gas adjustment throttle and the possibility of exchanging or modifying the separate venturi ring (widen holes) offer the possibility to adapt the mixers to low calorific biogases.

Manufacturer's address:
Rodags
Rua Campante 713/721
(04224 Ipiranga)
Sao Paulo
Brazil

10.2.3 Kromschrder Gas Handling Accessories, Federal Republic of Germany

The company supplies a variety of equipment for handling of different types of gases. In the field of biogas as a fuel for engines the following selection from their program is particularly useful:

Filters, gas governors, ball valves, safety valves, butterfly valves, magnetic relief valves, pressure switches, flow meters, pressure gauges, fittings and others.

The equipment meets DIN and other international standards. Most of the equipment is resistant to H_2S corrosion, but a gas specification should be sent with enquiries.

Comments: Many suppliers of biogas engines use Kromschrder equipment for their gas preparation and control and have expressed their satisfaction with the quality of the products.

Manufacturer's address:
Kromschrder A.G.
P.O. Box 2809
D-4500 Osnabrck
Federal Republic of Germany

10.3 Other equipment

10.3.1 Barber Colman Electronic Control System, USA

The company offers complete electronic control systems with speed pick-up, electronic control box and actuator. Speed precision is very high, with tolerances as low as 0%. The control system is suitable for grid parallel operation of engine-generator sets.

Comments: The system is widely used in cases where electricity generation with a high degree of frequency stability is required. Under difficult conditions in terms of

service and spare part availability, however, a mechanical governor should be preferred if the operation allows slight engine speed fluctuations.

Manufacturer's address:
Barber Colman Company
Precision Dynamics Division
1354, Clifford Ave.
P.O.Box 2940
Loves Park, IL.61132-2940
USA

10.3.2 Fiat Totem, Italy

The company supplies compact cogeneratior units in a standard module version for 15 kW electric power and a heat supply of about 30 kW. The unit is equipped with automatic control and suitable for isolated and grid parallel operation. The cost of the system (about US$ 1 500) is only justified when heat and power are fully utilized. The engine i based on a standard Fiat (127) Otto vehicle type engine. The company has supplied unit for natural gas and biogas. The system can be supplied through the local Fiat representative.

10.3.3 Communa Metall, Federal Republic of Germany

The company supplies cogeneration units in standard module versions in a range from 6 . . . 65 kW electric power combined with 15 . . . 90 kW of heat. The units are equipped with automatic control for isolated and grid parallel operation. The engines are Ford standard types, modified for natural gas and biogas. A high

degree of utilization of both power and heat is necessary for economic operation.

Manufacturer's address:
Communa Metall Uhlandstr. 17
D-4900 Herford I Federal
Republic of Germany

10.3.4 Sauer und Sohn, Federal Republic of Germany

The company supplies heat pump and cogeneration units driven by gas engines, based on Ford standard engines as described earlier. It also offers ready-made heat exchangers for waste heat utilization of engines, some of which are designed for straight application to the Ford engine model series 2270, 2700, 2710, 2720.

Manufacturer's address:
Sauer und Sohn
P.O. Box 1240
D-6110 Dieburg
Federal Republic of Germany

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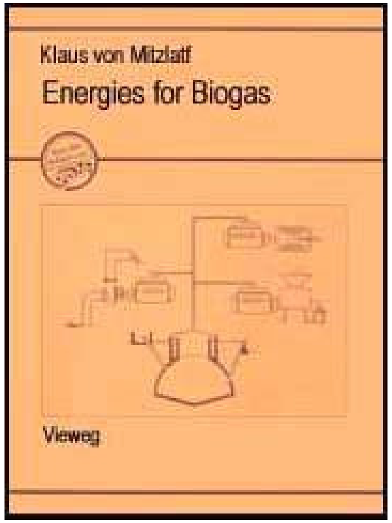


Literature

[1] Energy for Rural Development, USAID/National Academy of Sciences, Washington D.C., USA, 1976

[2] Appropriate Technology Sourcebook, by K. Darrow and R. Dam, Volunteers in Asia Inc., Stanford California, USA, 1976

[3] Biogas Plants, by L. Sasse, GATE/Vieweg, Braunschweig, FRG, 1984

[4] Biogas Handbuch, by G. Eggeling et al., BORDA/GTZ, Bremen, FRG, 1979 (in German)

[5] Praktischer Leitfaden fr Biogasanlagen in der Tierproduktion, by U. Werner et al., Oekotop/GATE, Eschborn, FRG, 1986 (in German)

[6] Production and Utilization of Biogas in Rural Areas of Industrialized and Developing Countries, by J. Hohlfield, L. Sasse et al., GTZ, Eschborn, FRG,1986

[7] Energy for Development in Eastern and Southern Africa, by M. Mwandosya, S. Lwakabamba, S.R. Nkonoki, Vols. I, II, Arusha, Tanzania, 1983

[8] Kirloskar Dual Fuel Biogas Engines, by M.K. Kulkarni, publ. Commonwealth Regional(Asia/Pacific) Rural Technology Programme, Bombay, India, 1980

[9] Application of Biogas on Farm Internal Combustion Engine, by Cao Zexi, Provincial Agricultural Machinery Research Institute of Sichuan, P.R. of China, Nov. 1982

[10] Diesel Engine Modification to operate on Biogas, by J. Ortiz Canavate

et al., Transactions of the ASAE, 1981

[11] Use of Biogas as an Alternative Fuel in Stationary Diesel Engines, by K. v. Mitzlaff and M.H. Mkumbwa, Res. Rep. University of Dar-es-Salaam, Tanzania, 1985

[12] Studie ber die Eignung von Biogas als Treibstoff fr Landwirtschaftstraktoren, by J. Fankhauser and A. Moser, FAT Publications No. 18, Tnikon, Switzerland, 1983 (in German)

[13] Traktor mit Biogasantrieb - Umrstung und erste Einsatzerfahrungen, by S. Bttner and K. Mauser, Landtechnik Nr.6,KTBL, Darmstadt, FRG, June 1982 (in German)

[14] Encontro de Biogs Automotivo pare Empresa Rural, 1. Londrina-PR, Embrater, Brazilia, Brazil, 1983/84 (m Portuguese)

[15] Verbrennungsmotoren, by A.W. Hussmann, University manuscript, Technical University of Munich FRG, 1971 (in German)

[16] Thermodynamik, by H.D. Baehr, Springer Verlag, Berlin, FRG, 1962 (in German)

[17] Engineering Thermodynamics, Work and Heat Transfer, by G.F.C. Rogers and Y.R. Mayhew Longman Publishers, London, U.K., 1983

[18] Economic Issues of Renewable Energy Systems - A Guide to Project

Planning, by G. Oehlert et al., GTZ Publication, Eschborn, FRG, 1985

Publications of Manufacturers/Suppliers

[19] MWM Gasmotorenhandbuch (Gas Engine Handbook) and MWM Gasmotoren-Information (Gas Engine Information), Motorenwerke Mannheim, FRG (both in German)

[20] Gas Engines, KHD Deutz, Kln (Cologne), FRG, 1985

[21] Kraftfahrtechnisches Taschenbuch (Automotive Handbook) and Diesel-Einspritzausrstung (Diesel Injection Equipment), R. Bosch GmbH, Stuttgart, FRG, 1976 (both in German)

[22] Impco Carburetion (Gas Carburetors, Kits), Handbook, Catalogue, Service Manual, Cerritos, California, USA, 1985

[23] Rodagas, Auto Methane (Gas Carburetors, Kits), Handbook, Catalogue, Sao Paulo, Brazil, 1985

Other Manuscripts/Papers

[24] Reinigung von Biogas (Biogas Cleaning), by H. Muche and H. Zimmermann, GATE/Vieweg, Braunschweig, FRG, 1984 (in German)

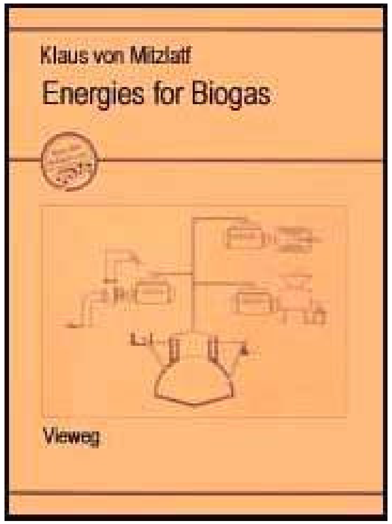
[25] Bericht ber H2S-Untersuchungen (Report on investigations on H2S reduction in biogas), by R. Henning and C. Andres, Oekotop GmbH and GATE/GTZ, Berlin, FRG, 1986 (in German)

[26] Biogas Engine, by E. Dohne, KTBL, Darmstadt, Proceedings of 4th International Symposium on Anaerobic Digestion, Guangchou, P.R. of China, 1985

[27] Mechanical and Electrical Power from Biogas in Developing Countries (Draft), by D.B. Mahin, International Energy Projects, Virginia, USA, 1984

[28] Modification of a Single-Cylinder Diesel Engine for Natural Gas, by S. Mahnewald et al., Engineering thesis, University of Kassel, FRG, 1979 (in German)

Home"" """"> ar.cn.de.en.es.fr.id.it.ph.po.ru.sw



Appendix I

Symbols and abreviation		
Symbol	**Name**	**Unit**
A	Ampere (unit for current)	
A	area	m², mm²
Ag	cross-sectional area of gas supply pipe	m², mm²
Av	cross-sectional area of venturi contractor ("bottleneck")	m², mm²
a	angle, crank angle	°
a_i	crank angle at ignition	° before TDC
AC	alternating current	
bar	pressure unit	

bar	pressure unit	
BDC	bottom dead center, piston's lowest position	
BG, bg	biogas	
c	velocity	m/s
c_i	intake velocity	m/s
c_v	velocity at venturi bottleneck	m/s
c_g	velocity through gas nozzle	m/s
°C	degree Celsius (temperature unit)	
c_p	specific heat at constant pressure	kJ/(kg K)
c_v	specific heat at constant volume	kJ/(kg K)
D, d	diameter	m, mm
D_{eng}	diameter of engine pulley	m, mm
D_{mach}	diameter of machine pulley	m, mm
d	day (time unit)	
d;	inlet diameter	mm
dg	gas nozzle diameter	mm
dv	venturi contraction diameter	mm
Ap	pressure difference	mbar
ΔV	volume to be added	cm³
DC	direct current	
E	energy	J, kJ, kWh

E	energy flow	flow J/s, kJ/s, kW
E_f	fuel energy	J, kJ, kWh
E_f	fuel energy flow	J/s, kJ/s, kW
η	efficiency	
ηb	boiler efficiency	
ηc	cogeneration efficiency	
ηeng	engine efficiency	
ηg	generator efficiency	
ηmach	driven machine's efficiency	
ηmech	mechanical efficiency	
ηp	pump efficiency	
ηt	transmission efficiency	
f	frequency	l/s, Hz
f_c	fuel consumption	1/h, m^3/s, m^3/h
f_{cd}	Diesel fuel consumption	l/h
g	gram (unit for mass)	
g	gravity constant	9.81 m/s2
γ	isentropic exponent (= cp/cv)	
h	hour (time unit)	

H	height, water head	m
HCV	hand-controlled valve	
I	current	A
i	number of cylinders	
J	Joule (energy unit)	
k	heat transfer coefficient	$kJ/(m^2 \cdot h \cdot K)$
K	Kelvin (temperature unit)	
kg	kilogram (unit for mass)	
kJ	kilojoule (energy unit)	
kW	kilowatt (power unit, energy flow unit)	
I	liter (volume unit)	
λ	excess air ratio in air/fuel mixture	
m, mm	meter, millimeter (length unit)	
m	mass	kg
m	mass flow	kg/s, kg/in
m_f	mass flow of fuel	kg/s, kg/in
m^3 n	cubic meter at standard conditions	
mbar	milibar (pressure unit)	
min	minute (time unit)	
n	polytropic exponent	
n	shaft (rotational) speed	min^{-1}

n	shaft (rotational) speed	min^{-1}
n_r	rated shaft speed	min^{-1}
n_{eng}	speed of engine	min^{-1}
n_{mach}	speed of driven machine	min^{-1}
P	power	kW
P_{el}	electric power	kW, kVA
P_{gen}	power of generator	kW
P_{mach}	power demand of driven machine	kW
P_{mech}	mechanical power	kW
P_p	number of pole pairs	
p	pressure	bar, Pa, mm WH
P_a	ambient pressure	bar, mbar
P_c	pressure after compression	bar
p_p	biogas plant pressure	bar; mbar
p_s	section pressure	bar
P_a	Pascal (pressure unit)	
ppm	parts per million (volume unit)	
Δp	pressure difference	bar
Q	heat	kJ
Q	heat flow, heat transferred	kW, kJ/s

Q	pump capacity (volume flow rate)	m³/s, m³/h
R	specific gas constant	kJ/(kg K)
r	"rated" (design conditions)	
ρ	density	kg/m³, kg/1
ρ_w	density of water	1000 kg/m³
s	second (time unit)	
sfc	specific fuel consumption m³/kWh,I/kWh,kWh/kWh	
sgp	specific gas production	m³ga/(d* Vp)
t	Celsius temperature	°C
Δ t	temperature difference	°C, K
Δtm	mean temperature difference	°C, K
T	absolute temperature	- K
T_c	absolute temperature after compression	K
T_s	suction temperature	K
TDC	top dead center, highest position of piston	
t_o	time of operation	h
U	voltage	V
V	Volt (unit for "tension", voltage)	
V	volume	m³, 1, cm³
V_c	compression volume	1 cm³
V_{dc}	displaced volume of one cylinder	1 cm³

V_{dc}	displaced volume of one cylinder	l cm
V_{de}	displaced volume of engine	1, cm^3
V_p	volume of biogas plant	m^3
V_{prev}	previous volume of compression chamber	cm^3
V_{new}	new volume of compression chamber	cm^3
V_s	storage volume for biogas	m^3
V_{tot}	total volume of cylinder	l, cm^3
V	volume flow rate	m^3/s, m^3/h, 1/h
V_{bg}	biogas volume flow rate	m^3/s, m^3/h
V_w	water volume flow rate	m^3/s, m^3/h
ΔV	volume to be added	cm^3
WH	water head	m

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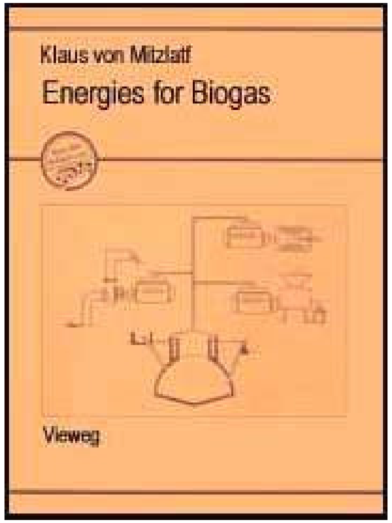

Appendix II

Tables, Conversion Factors

Properties of various fuels

fuel	density	calorific	ignitability	ignition	stoichiometric	methane

		value (kJ/kg)		**temperature in air (°C)**	**air/fuel ratio (kg/kg)**	**no.**
			(Vol % gas in air)			
methane	0.72	50000	5.0...15.0	650	17.2	100
	kg/m³n					
LPG	0.54 kg/l	46 000	2.0 . . .9.0	400	15.5	30
propane	2.02	46 300	2.0. . .9.5	470	15.6	35
	kg/m³ n					
butane	2.70	45 600	1.5 . . .8.5	365	15.6	10
	kg/m³ n					
petrol	0.75 kg/1	43 000	0.6 . . .8.0	220	14.8	-
diesel	0.85 kg/1	42500	0.6 . . .8.5	220	14.5	-
natural	0.83	57500	5.0 . . . 17.0	600	17.0	80
gas	kg/m³ n					
	1.2	18000	5.0. . . 15.0	650	10.2	130
biomas1	kg/m³					

(60% CH_4)	kg/m³ n					

1) H_2S content should be at 0.15 Vol % (1500 ppm), but never more than 0.5 Vol % (5000 ppm).

Other useful correlations

- Calorific value of biogas by methane content
100% CH_4: Hu = 36 000 kJ/m³ n = 10 kWh/m³ n
each 10% of CH_4 content in biogas: Hu = 3600 kJ/m³ n = 1 kWh/m³ n

Example:
65% CH_4: Hu = 23 400 kJ/m³n = 6.5 kWh/m³n

- Energy equivalents of biogas

1 kWh biogas =0.1 l diesel fuel =0.11 l petrol
1 m³ n biogas =0.6 l diesel fuel =0.67 l petrol
1 m³ n biogas = 1.5 kWh mechanical energy= 1.3 kWh electrical energy

- Pilot fuel requirement for diesel gas engine (at 20% of consumption in diesel fuel mode): 0.06 1/kWh
- Change (decrease) of engine performance with ambient conditions
- location altitude approx. 1% each 100 m above sea level
- pressure approx. 1% each 10 mbar below design conditions

- temperature approx. 1% each 5 °C above 20 °C
- rel. humidity approx. 2% each 10% above 65%
- Change of ambient pressure with location altitude approx. 10 mbar each 100 m

Metric conversion table:

Energy				
	kcal	**kWh**	**kJ**	**kNm**
kcal	1	$1.163*10^{-3}$	4.187	4.187
kWh	860	1	3600	3600
kJ	0.239	0.278	1	1
kNm	0.239	0.278	1	1

Pressure				
	PA	**bar**	**m WG**	**N/m²**
PA	1	10^{-5}	10_{-4}	1
bar	10^{5}	1	10	10^{5}
mWG	10^{4}	0.1		10^{4}
N/m²	1	10_{-5}	10^{-4}	1

Power				
	kcal/h	**kW**	**kJ/h**	**HP***

	kcal/h	kW	kJ/h	HP
kcal/h	1	$1.163*10^{-3}$	4.187	$1.6*10^{-3}$
kW	860	1	$3.6*10^{3}$	1.36
kJ/h	0.239	$0.27*10^{-3}$	1	$0.38*10^{-3}$
HP*	633	$2.65*10^{3}$	0.736	1
* 1 HP = 745.70 W, HP metric = 735.49875 W				

Factor	**Unit**	**Equivalents**
Length:	**m**	**1 m= 0.001 km**
	= 100 cm = 1000 mm	
Volume:	m³	1 m³= 1000 l
Time:	s	1 min= 60 s,
	1 h = 3600 s,	
	1 d= 24 h,	
	1a=365 d	
Temperature: K	0 ºC = 273 K	
	T [K] = 273 [K] + °C	

Conversion of Sl units into British/American units

Combined measures can be converted by inserting the appropriate conversion factors into the original expression, e.g.:

BTU/h ft^2 F = 1055/(3600*0.0929*5/9) = 5 678 W/m² K

SI (metric) to Brit./Amer.		**Brit./Amer. to SI (metric)**	
Length			
1 cm	= 0.3937 in (inch)	1in	= 2.5400 cm
1 m	= 3.2808 ft	1ft	=12in= 0.3048 m
	= 1.0936 yards	1 yard	= 3ft= 0.9144 m
1 km	= 0.6214 mile (statute)	1 mile (statute)	= 1.60934 km
Area			
1 cm²	= 0.1550 sq in	1 sq in	= 6.4516 cm²
1 m²	= 10.7639 sq ft		= 0.000645 m²
	= 1.1960 sq yards	1 sq ft	= 0.0929 m²
1 ha	= 2.471 acres	1 sq yard	= 9 sq ft = 0.836 m²
	= 10000 m²	1 sq mile	= 2.590 km²
		1acre	= 0.4047 ha
Volume			
1 cm³	= 0.06102 cu in	1 cu in	= 16.3870 cm³
1 dm³	= 61.024 cu in		= 0.01639 dm³
1 l	= 0.03531 cu ft	1 cu ft	= 28.317 dm³
	= 61.026 cu in	1 cu yard	= 0.7646 m³
	= 0.21998 gal (Brit.)	1 gal (Brit.)	= 4.546 l

	= 0.26428 gal (Am.)	1 gal (Am.)	= 3.785 l
1 m^3	= 35.315 cu ft	1 quarter (Brit.)	= 64 gal
	= 1.308 cu yards	.	= 290.9 l
	= 6.299 Petr. barrels	1 Petr. barrel	= 0.15876 m^3
			=42gal
1 quart (Am.)	= 2 pints		
			= 0.946 dm^3
1 bushel (Am.)	= 35.2421		
1 bushel (Brit.)	= 36.37 1 = 8 gal		
1 Nm^3	= 37.97 cu ft	1 cu ft	= 0.02635 Nm^3
	(60°F, 30 in moist)	(60°F, 30 in moist)	
1 Nm^3	= 37.22 cu ft	1 cu ft	= 0.02687 Nm^3
	(60°F, 30 in dry)	(60°F, 30 in dry)	
Weight, mass, density			
1 g	= 0.03527 oz (av)*	1 grain	= 0.0648 g
	= 15.432 grain	1 oz (av)*	= 28.35 g
1 kg	= 2.2046 lb (av)*	1 lb (av)*	= 16 oz
	= 0.0787 quarter (Brit.)		0.4536 kg
			= 7 000 grains
1 t	= 0.984 long tons	1 quarter (Brit.)	= 28 lb = 12.701 kg
	= 1.102 short tons	1 long ton (Brit.)	= 1016 kg

1 kg/m³	= 0.06243 Ib/cu ft	1 short ton (Am.)	= 2000 Ib = 907.2 kg
		1 Ib/cu ft	= 16.0185 kg/m³
1 g/kg	= 7.0 grain/lb	1 grain/lb	= 0.1426 g/kg
I g/m³	= 0.437 grain/cu ft	1 grain/cu ft	= 2.2884 g/m³
1 g/m³	= 2.855 ton/sq mile	1 ton/sq mile	= 0.3503 g/m³
1 m³/hm³	= 0.0547 cbf/sq ft	1 cfm/sq ft	= 18.3 m³/hm³

*** Avoirdupois (av), the generally accepted series of weight units based on a pound of 16 ounces and an ounce of 16 drams, as opposed to the troy system based on a pound of 12 ounces and an ounce of 20 pennyweights or 480 grains.**

Velocity and flow			
1 m/s	= 196.85 ft/min	1 ft/min	= 0.508 cm/s
1 km/in	= 0.6214 mph	I mph	= 1.60934 km/in
1 Kn	= 1.852 km/in	1 km/h	= 0.54 Kn
	= 0.514m/s		= 0.278m/s
1 m³/h	= 4.403 gal/min (Am.)	1 gal/min (Am.)	= 0.227 m³/h
	= 3.666 gal/min (Brit.)	1 gal/min (Brit.)	= 0.273 m³/h
1 m³/h	= 0.5886 cu ft/min	1 cu ft/min	= 28 317 1/min
		= 1.700 m³/h	
1 kg/in	= 0.0367 Ib/min	1 Ib/min	= 27.216 kg/in
Power			
1 W (Watt)	= 3.412 BTU/h	1 BTU/h	= 0.2931 W

1 kW	= 3412 BTU/h	1 HP	= 0.7457 kW
Enthalpy and entropy			
1 kJ/m³	= 0.02684 BTU/ft3	1 BTU/ft3	= 37.26 kJ/m³
1 kJ/kg	= 0.43021 BTU/lb	1 BTU/lb	= 2.3244 kJ/kg
1 kJ/K	=0.5266 BTU/F	1 BTU/F	= 1.899 kJ/K
Pressure and force			
1 N (Newton)	= 0.2248 lb (f)	1 lb (force)	= 4.448 N
1 N/m²	= 0.0209 Ib/ft2	1 Ib/in (psi)	= 6895 N/in2
(Pascal)			= 68.95 mbar
			= 703.1 mm H_2O
1 bar	= 14.504 psi	1 Ib/ft2	= 47.88 N/m²
	= 29.530 in Hg		= 0.4788 mbar
	= 0.987 atm		= 0.0470 mm H_2O
1 mbar	= 0.0145 psi	1 in H_2O	= 249.08 N/m²
	= 0.0295 in Hg		= 2.4908 mbar
	= 0.4019 in H_2O		= 25.4 mm H_2O
	= 2.089 lb/ft2	1 in Hg	= 33.864 mbar
1 mm H_2O	= 0.0394 in H_2O	1 ft H_2O	= 29.89 mbar
1 atm	= 14.696 psi	1 atm	= 1.013 bar

1 mm H_2O/m	= 1.1993 in H_2O/100 ft	1 ft H_2O/100 ft	= 98.10 N/m²*m
1 N/m² m	= 0.1223 in H_2O/100 ft	1 in H_2O/100 ft	= 8.176 N/m²*m
1 mbar/m	= 0.442 psi/100 ft	1 psi/100 ft	= 2.262 mbar/m
Energy			
1 J (Joule)	= 0.948 10-3 BTU	1 BTU	= 1.055 kJ
1 kJ	= 0.948 BTU	1 ft lb (force)	= 1.356 J
1 kWh	= 3414.5 BTU	1 HPh	= 2685 kJ
1 MWh	= 34.1297 therms	1 therm	= 0.1055 GJ
		(100 000 BTU)	(29.288 kWh)
Specific heat			
1 kJ/kgK	= 0.2388 BTU/lb F	1 BTU/lb F	= 4.187 kJ/kgK
1 kJ/m³K	= 0.0149 BTU/ft3 F	1 BTU/ft3 F	= 67.070 kJ/m³K
Heat			
1 kJ/m².	= 0.0881 BTU/ft2	1 BTU/ft2	= 11.357 kJ/m²
1 W/m²	= 0.3170 BTU/h ft2	1 BTU/h ft2	= 3.155 W/m²
1 W/m²K	= 0.1761 BTU/h ft2 F	1 BTU/f ft2 F	= 5.678 W/m²K
1 W/mK	= 0.578 BTU/h ft F	1 BTU/h ft F	= 1.7296 W/mK
	= 6.9348 BTU in/h ft F	1 BTU in/in ft2 F	= 0.1442 W/mK
1 m²K/W	= 5.6786 h ft2 F/BTU	1 h ft2 F/BTU	= 0.1761 m²K/W
1 mK/W	= 1.7296 h ft F/BTU	1 h ft F/BTU	= 0.5782 mK/W
	= 0.1442 BTU in/in ft2 F	1 h ft f/BTU*in	= 6.934 mK/W

Refrigeration			
1 kW	= 0.2843 tons of refrigeration	1 ton of refrigeration	= 3.517 kW
Heating			
1 kW	= 0.1019 HP (boiler)	1 HP (boiler)	= 9.809 kW
			= (33 475 BTU)
1 kW	= 14.22 EDR (steam)	1 EDR (equivalent	
	= 22.74 EDR (water)	direct radiation)	= 70.34 W
	= 3412 BTU/h water	steam	= 43.97 W

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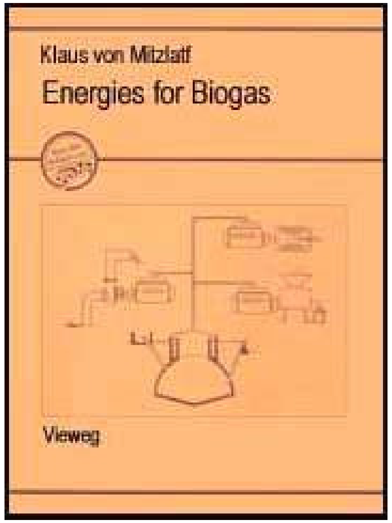

Appendix III

Comparative Summary of Engine Features

Feature	Diesel	Otto	
1. Design data			
- compression ratio e	15 . . . 21	6 . . . 9.5 petrol	
			6 .. .12 alcohol
- pressure			

after compression			
without ignition	35 . . . 60 bar	15 . . . 20 bar	
- temperature after compres-			
sion without ignition	600. . . 900 °C	400 . . .600 °C	
-excess air ratio l	1.3 . . . 4.0	0.7 . . .1.2	
-efficiency	0.3 . . . 0.4	0.2. . . 0.35	
-specific fuel consumption	230 . . . 350 g/kWh	300 . . .400 g/kWh	
-volumetric efficiency	0.7 . . . 0.9	0.3 . . . 0.9 (low values for	
			partially closed throttle)
-exhaust gas temperature	400 . . . 600 °C	500 . . . 900 °C	
- speed ratio			

- stationary	1,300 . . . 2,500	1,300 . . . 2,500 (gas)	
	- vehicle	1,300 . . .5,000	1,300 . . . 7,000
	- ignition type	self-ignition by injection of fuel into hot compressed air shortly before piston reaches TDC	spark ignition by spark plug
	2. Control principle	variation of amount of fuel injected by the injector pump. Airflow is not controlled, i.e. full compression is always achieved. The variation of amount of fuel is done by the centrifugal mechanism of the governor with the aim to maintain the speed chosen and set by the control lever position.	variation of admission of ready air/fuel mixture by throttle valve between mixing device (carburetor, venturi, mixing valve) and engine inlet. Throttling reduces actual suction pressure of engme, hence absolute compression and efficiency.
	- manual	by setting the governor control lever to the required speed which remains constant within small limits, irrespective of the actual power demand. Speed changes can be achieved by setting the lever to a different position.	by setting the lever of the butterfly valve (throttle) in the carburetori load/speed variations require an appropriate regulation of the throttle.
	- automatic	using the same mechanism as above.	- using a separately mounted mechanical governor to operate the throttle.

			- using an electronic speed sensor with control unit and actuator to operate the throttle.

Features of Biogas Engines
(only where different from unmodified engines)

Feature	Gas diesel	Gas Otto
1. Design data		
-compression ratio e	15 . . .18	10. . . 12
-excess air ratio	1.3 . . . 4.0	0.9 . . . 1.3
-specific fuel consumption	0.55 . . . 0.75 m³/kWh	0.65 . . .1.0 m³/kWh
	(+ pilot fuel)	
-exhaust gas temperature	500 . . . 700 °C	500 . . . 900 °C
- ignition type	self-ignition of pilot fuel inject- ed into a hot compressed mix ture of air and gas which is ignited by the pilot fuel sub sequently.	as in other Otto engines
2. Control principle	A small amount of diesel fuel is injected to facilitate ignition. Variation of the amount of fuel gas supplied to the mixing de vice is	as in other Otto engines

	used for variation of power output. The airflow is not con trolled to maintain a high pres sure and ignition temperature. mode	
- manual	The governor/injector system is fixed at supplying the pilot fuel amount only. The gas valve at the mixing chamber is set to achieve the required speed/power output.	as in other Otto engines. Carburetor is replaced by venturi mixer or gas mixing valves.
- automatic	Using the same mechanism as above. The gas valve is however operated by a governor or an actuator of an electronic control system.	as in other Otto engines.

Overview of Mode of Operation, Control and Mixing Device

Mode of operation	**Type of control**	**Type of mixing device**
speed: constant load: constant (e.g. pump with constant head and capacity; electric generator with constant load and frequency)	- manual	
	Otto: fixed setting of gas and air or throttle in the case of a venturi	Otto: - simple mixing chamber with manually operated control valve for air

		and for gas, or
		- venturi-type mixer with manu diesel:
	fixed setting of gas	- simple mixing chamber with manually operated control valve
		- automatic not necessary as long as load remains constant
speed: constant load: varying (e.g. electric generator with constant frequency and varying electricity demand; pump with varying capacity and head)	- manual	
	Otto: adjustment of gas/air valves or throttle (venturi) whenever load changes. Not recommended with frequent load changes.	Otto:
		- venturi mixer with manually operated throttle (Simple

		mixing chamber with two valves is impracticable for readjustments.)
		- mixing valve with manually operated butterfly throttle diesel:
	diesel:	
	adjustment of gas valve whenever load changes. Without adjustment load variations are compensated by variations in diesel fuel supply automatic ally. Substitution of diesel fuel by biogas is however reduced.	- simple mixing chamber with manually operated gas valve
	- automatic	
	Otto:	Otto:
	speed governor or electronic control system operating the butterfly throttle of mixing device diesel: fixed setting of pilot fuel injection. Electronic control or governor operating the gas valve of the mixing chamber.	- venturi mixer, or
		- mixing valve with butterfly valve

		operated by control system
		diesel:
		- simple mixing chamber with gas valve operated by control system
speed: varying load: varying (e.g. drive of different machinery)	- manual	
	Otto: adjustment of throttle valve in accordance with required load/speed	Otto: - venturi mixer, or - gas mixing valve with manually operated butterfly
	diesel:	diesel:
	adjustment of gas valve in accordance with required load/speed	- simple mixing chamber with manually operated gas valve
	- automatic	
	Otto:	Otto:
	mechanical governor or electronic control system with practicable mode of set point adjustment	- venturi mixer, or - gas mixing valve with butterfly valve

		operated by control system
	diesel:	diesel:
	fixed setting of pilot fuel injection. Electronic control system or (separate) speed governor with	- simple mixing chamber with gas valve operated by control system practicable mode of set point adjustment.

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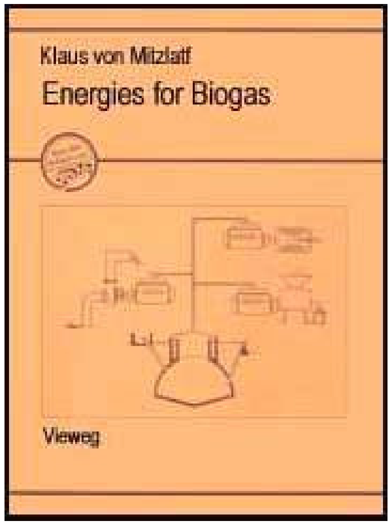


Appendix IV

Design Drawings of a Venturi Mixer for Self-Manufacture (Example)

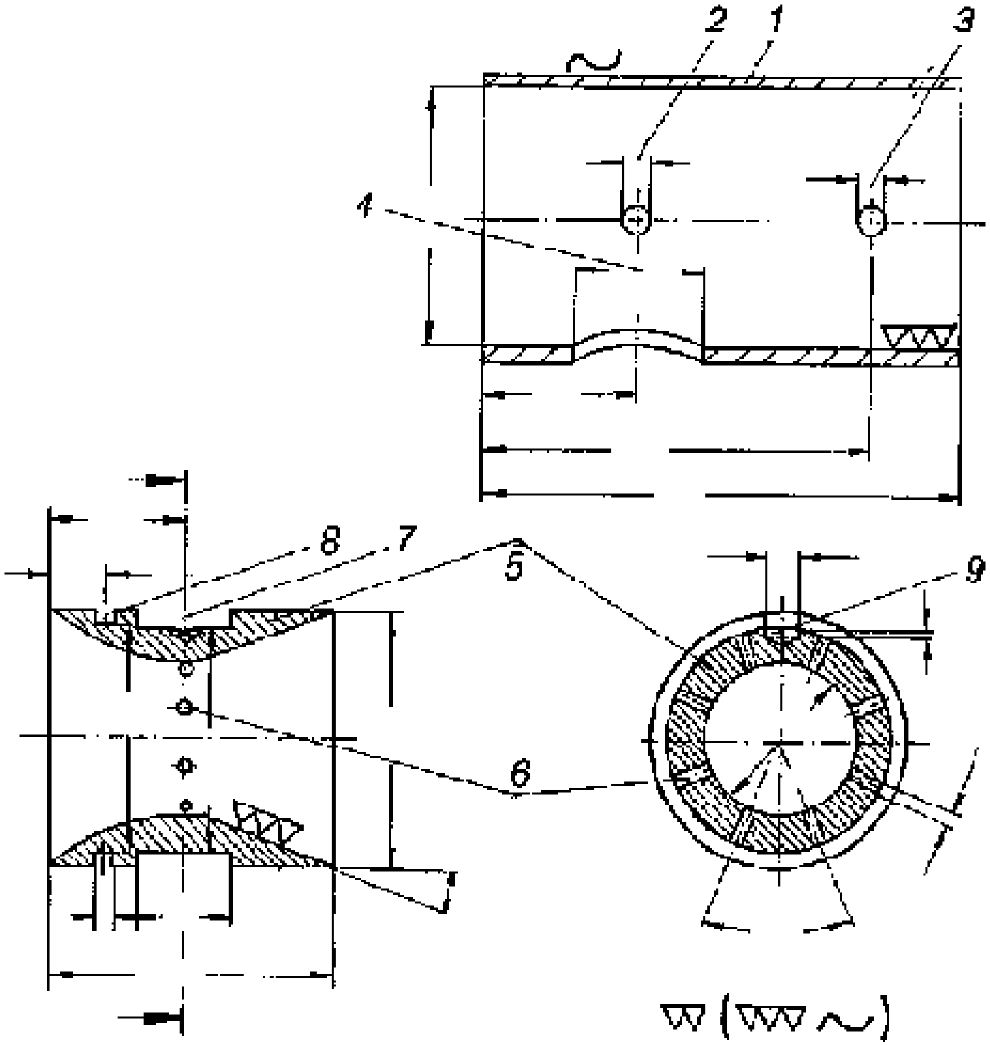


Fig. 1: Venturi mixer parts 1 Mixer body (tube), 2 Bore for venturi ring holder bolt, 3 Bore for butterfly valve shaft, 4 Bore for gas supply pipe connection (brazed, welded), 5 Venturi ring, 6 Calibrated bores for gas inlet, 7 Gas supply ring channel, 8 Groove for seal ring (O-ring), 9 Bore for venturi ring holder bolt; all dimensions according to calculations and engine inlet size (refer to Chapter 6).

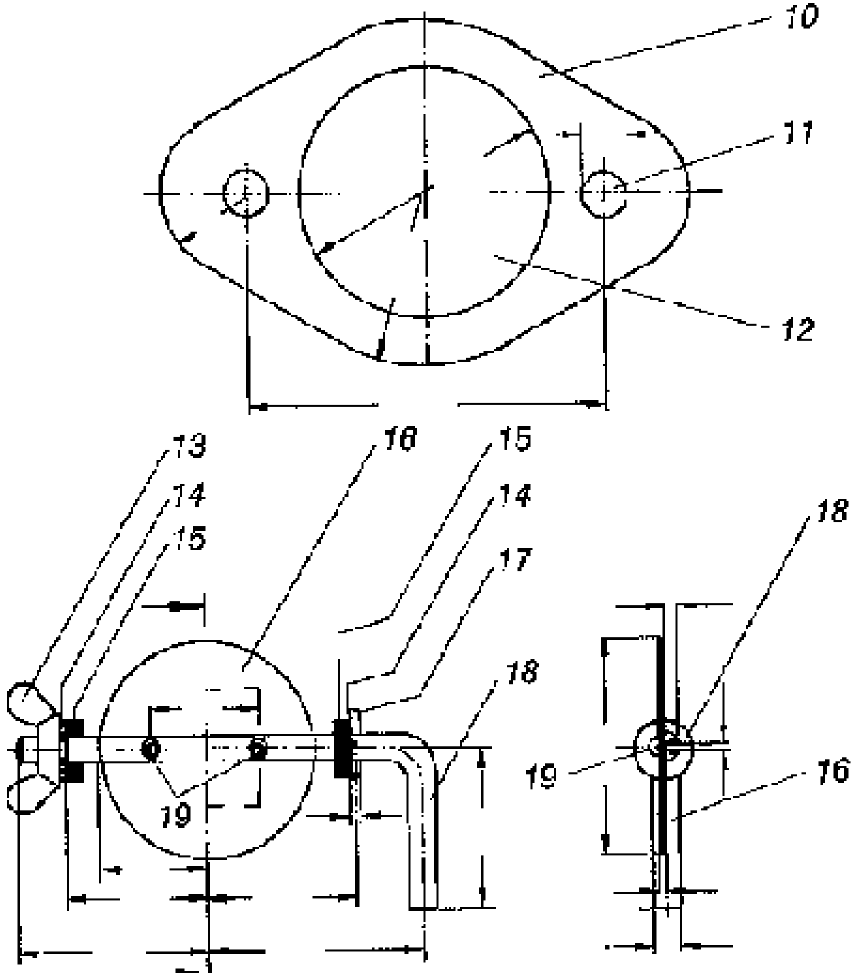


Fig. 2: Venturi mixer parts, continued. 10 Connection flange, 11 Bore for connection bolts to engine and air filter, 12 Bore for connection of mixer body (brazed, welded), 13 Wing nut for fixing the butterfly valve shaft, 14 Washer, 15 Rubber/plastic seal ring, 16 Butterfly valve, 17 Washer fixed to butterfly valve shaft, 18 Butterfly valve shaft cum control lever, 19 Small bolts for fixing butterfly to shaft.

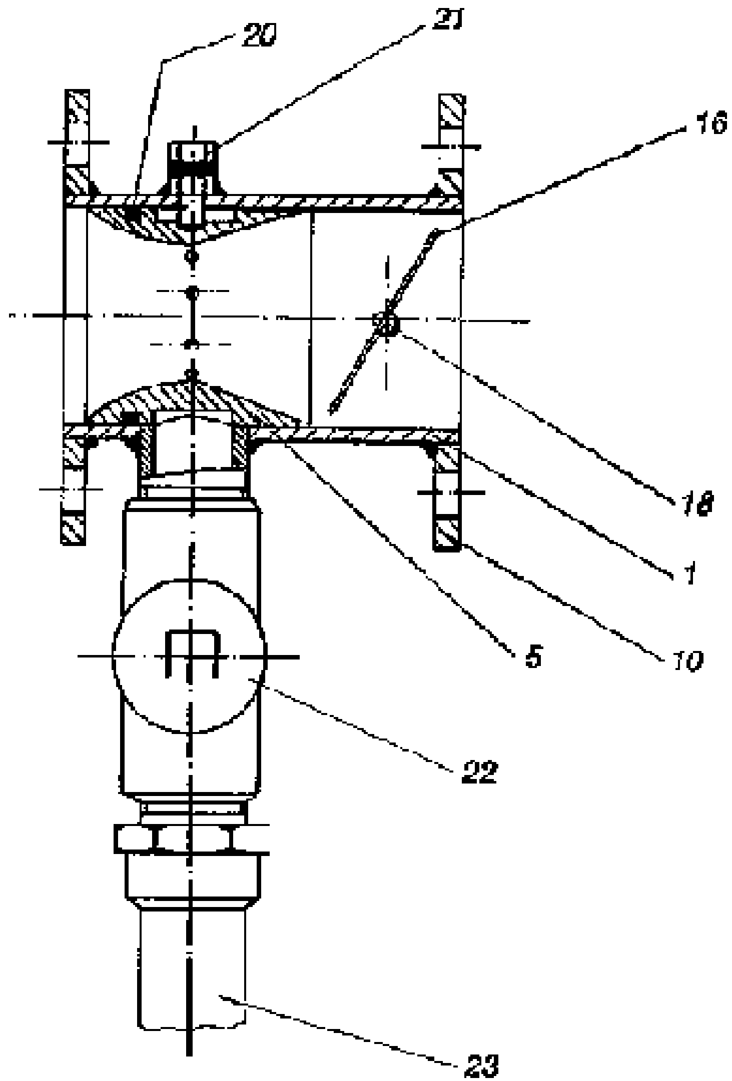
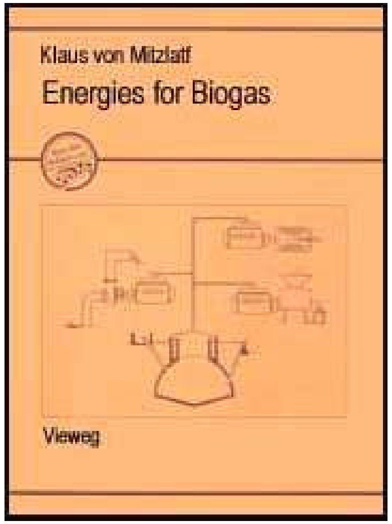


Fig. 3: Venturi mixer assembly

20 Venturi seal ring (0-ring), 21 Venturi holder bolt and nut, 22 Gas inlet valve, 23 Gas supply pipe


Klaus von Mitzlaff
Energies for Biogas
Vieweg

Appendix V

Planning Scheme for the Lay Out of a Biogas Plant (1

Step 1: establish gas requirement
Guide values for gas consumption

Cooking: 0.25 m³ (8 cu ft) per person per day
Lighting: 0.12-0.15 m³ (4-5 cu ft) per hour per lamp
Driving engines: 0.75 m³ (17 cu ft) per kW per hour

Gas requirement per unit x No. of units = Total gas requirement

Example: 0.25 m³ per person and per day X _4_ persons =__1.0__m³

Gas requirement for cooking: 0.25 m³ per person per day X __________persons =___________m³
Gas requirement for lighting: 0.15 m³ per lamp per hour X ____________lamps =____________m³
Gas consumption of engines: 0.75 m³ per kW per hour X _________operating hours = _______m³

Gas requirements for other processes: __________X___________=___________m³

- **Refrigeration __________X___________=___________m³**
- **Drying plant __________X___________=___________m³**
- **Production ___________m³**

Total gas requirement per day

Is this gas requirement likely to satisfy needs in 5 years?

Z Additional gas requirement __________X___________=___________m³

Total gas requirement ______________m³

Step 2: establish gas production
Gas generation - guide values

Type	Manure (moist) per day	Gas per kg per day	Gas yield per animal
1 head of cattle	10 kg	361(1.3 cu ft)	3601(13 cu ft)
1 water buffalo	15 kg	361(1.3 cu ft)	5401(19.5 cu ft)
1 pig (approx. 50 kg)	2.25 kg	781(2.8 cu ft)	1801(6.3 cu ft)
1 chicken (approx. 2 kg)	0.18 kg	62 1(2.2 cu ft)	11.21 (0.4 cu ft)
Adult human excrete	0.4 kg	701(2.5 cu ft)	281(1 cu ft)

Gas yields refer to material with its natural moisture content.

For the final design of a biogas plant the use of specific literature e.g. 131, [4], [5], [6] is recommended, likewise the consultation of a biogas expert if available.

Actual production
Fertilizer production Gas production
Number X volume per unit = volume per day Number X volume per unit = gas per

day

Example: 2 buffalo X 15 kg/day = 30 kg/day 2 x 0.540 m³/day = 1. 08 m³/day

Buffalo	X 15 kg/day	=	kg/day X 0.540 m³/day = m³/day
Cows	X 10 kg/day	=	kg/day X 0.360 m³/day = m³/day
Calves	X 5 kg/day	=	kg/day X 0.200 m³/day = m³/day
Pigs (50 kg)	X 2 kg/day	=	kg/day X 0.180 m³/day = m³/day
Horses	X 10 kg/day	=	kg|day X 0.350 m³/day = m³/day
Sheep	X 2 kg/day	=	kg/day X 0.100 m³/day = m³/day
Chickens	X 0.18 kg/day	=	kg/day X 0.011 m³/day = m³/day
Toilets	X 0.4 kg/day	=	kg/day X 0.030 m³/day = m³/day
Green material	kg/day X 0.200 m³/day = m³/day		

Gas and manure production per day kg/day m³/day
Does this correspond with livestock
in 5 years?
Increased
level X kg/day = kg/day m³/day = m³/day

Gas and manure production
potential kg/day m³/day:

Step 3: Comparison between gas volume needed and gas generation potential

Does potential gas production match   If so, the chosen size of plant is correct, and the

requirements?	next step can begin.
Is production greater than required?	It may be a good idea to build this plant nonetheless and to ask a neighbor if he alsorequires biogas; if not, build a smaller plant.
Is consumption higher than potential gas production? Check the following possible measures:	- Can consumption be lowered (calculate gas requirements again)?
	- Can more organic material be acquired as fuel (calculate gas production again)?
	- Can a plant be constructed jointly with a neighbor?

Step 4: Calculating influencing factors on the biogas plant

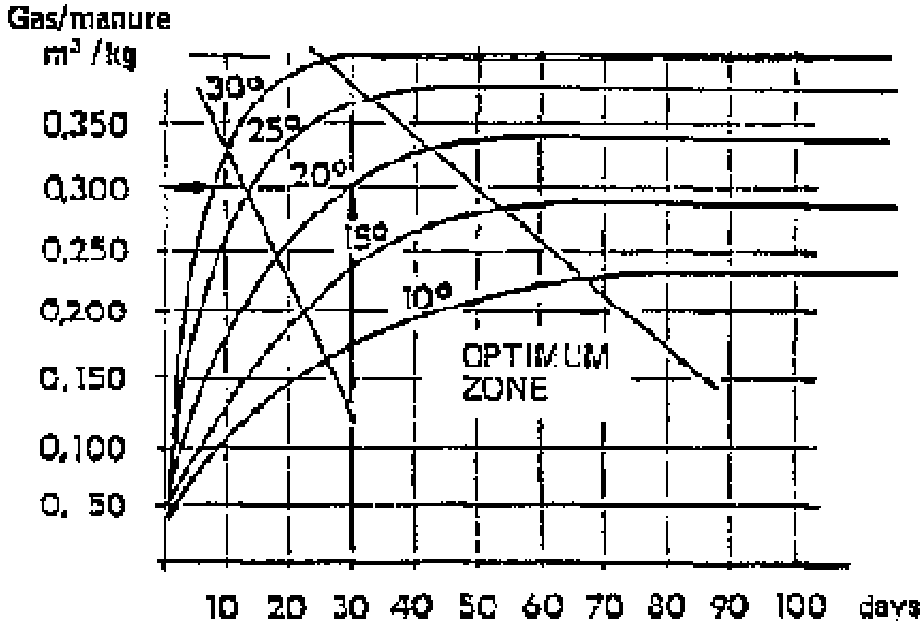
Temperature - fermentation period in digester

The fermentation time is an important factor in determining the size of the biogas plant and epends on the temperature in the digester. The fermentation period is defined as the time taken for material to flow through the plant from input to output. The following guide values apply to the regions stated:

30 - 40 days	Hot, tropical plains climate: e. g. Sudan, Cameroon, Sri Lanka, Indonesia, Venezuela,Central America
40 - 60 days	Hot regions which cool down only slightly in winter: e. g. India, Thailand, Philippines, Kenya, Ethiopia60 - 90 days More temperate climate with distinct drop in temperature during winter: e. g. China,Korea, Turkey

The table below shows the relationship between material fermentation time, temperature and gas output.

In regions with a distinct winter season or severe differences between daytime and nighttime, temperatures (mountainous regions) assume a temperature 5 °C lower for calculation purposes.



Digester pit temperature °C

Fermentation period days

Quantity of material added

The material must be added in the form of a free-flowing liquid, or else blockages will occur, However, if it is diluted too much, gas production will be reduced.

Generally speaking, the solid material must be mixed with at least the same volume of water.

An accurate calculation depends on the analysis of the material and should be based on the list shown below.

Typical mixing ratios

Cow dung, fresh: water	1:0.5
Cow dung, superficially dry: water	1:1
Horse and sheep's dung: water	1:1
Green refuse: water	1:0.5 to 1:2

Quantity of material added per day:

Type of manure/material	Quantity (kg = 1)	Water (kg = 1)	Liters
Cow dung	+	=	
Pig dung	+	=	
Other animal faeces	+	=	
Human excrete from toilets	+	=	
Agricultural refuse	+	=	

Volume added per day liters

note: in case of concrete stable floor the collected urine is sufficient for dilation, no water needs to be added

Step 5: Establishing the dimensions of the biogas plant

Establishing the dimensions of the biogas plant
The volume of the digester pit is determined from the volume of material added per day multiplied by the fermentation time.
Volume of material added per day X fermentation time =

kg/day X days =
(1000 l = 1 m³)

Gas volume from plant per day: m³/day
Size of gas holder = approx. 1/2 of daily gas production = m³

About

With the steady increase in demand for the useful exploitation of renewable energy resources the transformation of biogas into shaft - or electrical power appears as one of the sensible options for biogas utilization.

This book wants to provide a source of information not only for the various technical aspects of modification of internal combustion engines, both Diesel- and Gasoline (Otto-)engines, to operate on biogas-fuel but also for planning and economic operation of these engines in a system comprising of the fuel generating biogas plant and the power consuming driven equipment.

The reader, who is assumed to have basic technical interest and understanding, will furthermore find information on the use of the engine's waste heat and a

commented list of manufacturers of biogas engines and available equipment for the self-modification of engines.

Deutsches Zentrum fr Entwicklungstechnologien
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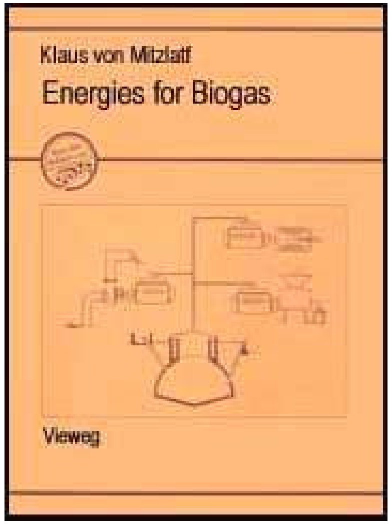

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Deutsches Zentrum fr Entwicklungstechnologien - GATE

Deutsches Zentrum fr Entwicklungstechnologien - GATE - stands for German Appropriate Technology Exchange. It was founded in 1978 as a special division of the Deutsche Gesellschaft fr Technische Zusammenarbeit (GTZ) GmbH. GATE is a centre for the dissemination and promotion of appropriate technologies for developing countries. GATE defines "Appropriate technologies" as those which are suitable and acceptable in the light of economic social and cultural criteria. They should contribute to socio-economic development whilst ensuring optimal utilization of resources and minimal detriment to the environment. Depending on the case at hand a traditional, intermediate or highly-developed can be the "appropriate" one. GATE focusses its work on three key areas:

- Dissemination of Appropriate Technologies: Collecting, processing and disseminating information on technologies appropriate to the needs of the developing countries; ascertaining the technological requirements of Third World countries; support in the form of personnel material and equipment to promote

the development and adaptation of technologies for developing countries.

- Research and Development: Conducting and/or promoting research and development work in appropriate technologies.

- Environmental Protection: The growing importance of ecology and environmental protection require better coordination and harmonization of projects. In order to tackle these tasks more effectively, a coordination center was set up within GATE in 1985.

GATE has entered into cooperation agreements with a number of technology centres in Third World countries.

GATE offers a free information service on appropriate technologies for all public and private development institutions in developing countries, dealing with the development, adaptation, introduction and application of technologies.

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The government-owned GTZ operates in the field of Technical Cooperation. 2200 German experts are working together with partners from about 100 countries of Africa, Asia and Latin America in projects covering practically every sector of agriculture, forestry, economic development, social services and institutional and material infrastructure.

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- appraisal, technical planning, control and supervision of technical cooperation projects commissioned by the Government of the Federal Republic or by other authorities
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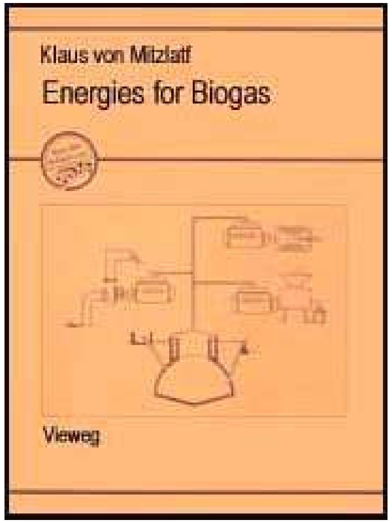


Engines for Biogas (GTZ, 1988, 133 p.)

Preface

The world's energy situation, whether in developing or industrialized countries, is an issue frequently discussed under economic, technical and political aspects. While it has meanwhile become common knowledge that today's main resources of energy such as coal, crude oil, natural gas and even nuclear energy will become scarce within the next generation the renewable sources such as hydro-, wind- solar- and bioenergy are gaining more and more importance in terms of research and development as well as implemented systems. A common feature of renewable energies is that they are mainly available through a decentralized, sometimes even individual approach. This generates a chance of having energy at one's own disposal but creates a problem of management and network when large energy quantities are required.

Some developing countries find themselves under considerable energy constraints. While the growing demand for household energy decreases the fuelwood reserves and increases desertification, their foreign exchange earnings do not allow for sufficient importation of energy. Their potential for other renewable energies may be large but is not sufficiently exploited for reasons like lack of capital and expertise. Industrialized countries, though still in a position to import energy, are feeling the burden of ever-increasing energy cost while their renewable energy potential is not tapped for, amongst others, political reasons.

The issue "biogas" tends to initiate adverse reactions, ranging from blind enthusiasm and belief via critical openmindedness or sympathy to total rejection. Critical sympathy appears to be a good precondition for coming to terms with biogas issues and for a successful development of biogas-related projects.

The biogas technology has been steadily developed within the last fifty years from

small individually designed units to industrial plants with sophisticated boundary technology. The development, however, has largely taken place on the side of biogas production and anaerobic waste treatment. The utilization of the gas has only recently been given more attention as larger and more sophisticated biogas systems require or depend on a sensible utilization of the larger gas quantities. Transforming the energy from biogas into the thermodynamically higher valued mechanical energy marks one of the sensible options wherever appropriate.

The aim of this publication is to build a bridge between the elaborate literature and information on the biogas production side and the existing technical and scientific know-how on the side of internal combustion engines. An engine fuelled by biogas shall become understandable as a core module in a system of energy supply, energy transformation and a demand of energy for a useful purpose. This publication attempts to provide a source of essential information for decision-making, planning, modification and operation of biogas engines within this system.

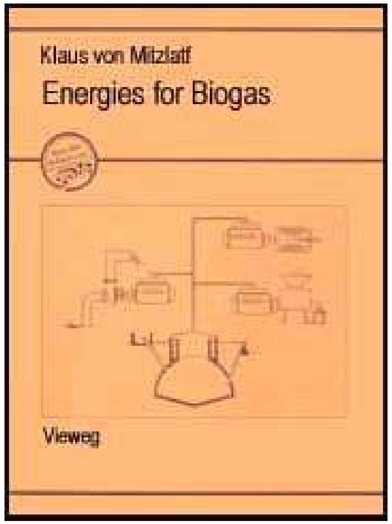
The author hopes to contribute to the better understanding and the further development of the utilization of biogas for motive power. As this book is written while a large number of experts are working on and further developing similar issues in the field as well as in the laboratories, the author wishes to encourage the readers of this book to come forward with discussions, criticism and suggestions for further improvement on its contents and the form of presentation.

I wish to express my sincere gratitude to the GTZ and GATE for graciously helping to produce this publication. The cooperation with the corresponding department, especially with Dr. P. Pluschke, Mr. M. Homola and Ms. H. Mende, was agreeable,

stimulating end marked by mutual understanding. Likewise the author is indebted to suppliers and manufacturers of engines, biogas ancillaries and modification equipment who provided data and specifications of their products as well as much useful discussion. Many thanks go to Ms. K. Pfeiffer who drew most of the figures and diagrams. For the tedious job of processing a partly difficult to handle manuscript and for useful assistance in editing Mr. B. v. Mitzlaff deserves the author's special thanks.

Gttingen, September 1986

Klaus v. Mitzlaff



1. Scope of this publication

It is the aim of this book to provide a source for the basic understanding, the planning and the execution of issues and ventures in relation to biogas engines. The scope therefore needs to comprise a range of information from the theory of internal combustion engines to the actual way. of modification and to a guide on the parameters influencing a useful and economic operation of biogas engines.

The readers of this book are likely to come from various fields with a non-uniform background of specific experience and knowledge of the matter. On the basis of experience gained in a number of biogas programs and activities within the last ten years the publishers (GATE) and the author came to the understanding that a certain minimum of technical knowledge on the reader's part shall be taken for

granted. The very basics, e.g. of the way an internal combustion engine functions or of workshop technology, are therefore not elaborately explained. The book is mainly addressed to readers with some technical background and those who are eager to further-embark on biogas engine matters. Some will find it useful as a handbook and reminder while others may realize that there are more parameters to be considered for a successful implementation than just buying an engine.

Parts of the contents, especially the chapters on the essential theory of internal combustion engines and on the operation of an engine together with a driven machine, are naturally not only biogas-engine-specific. It was however felt that in many cases people are only coming into contact with engine and machine operation issues in connection with a possible use of biogas for mechanical/ electric power. Sufficient knowledge or expertise on engines and their operation can therefore not always be assumed.

Furthermore there is an additional quality in using an engine fuelled by biogas. Here the whole fuel generation and supply side becomes an integral part of the system. There is a direct interdependence between the management and operation of the biogas plant, its size and gas storage facilities and the size and operations of the engine cum driven machine. It was therefore considered essential to elaborate on the system character of an issue comprising the generation of fuel energy, its transformation into mechanical energy and the consumption of the energy in a useful and economic way. Biogasfuelled engines easily turn out to be less practical and economic than other alternatives or solutions if the system aspect is undervalued.

Two chapters, one on the utilization of the engine's waste heat and one on the use

of biogas in vehicle engines, have been added. The use of waste heat plays an essential part in making an energy system economic which utilizes only about 30 % of the fuel energy but has the potential of exploiting a total of about 80 % of the biogas energy if a useful purpose for the heat energy can be found.

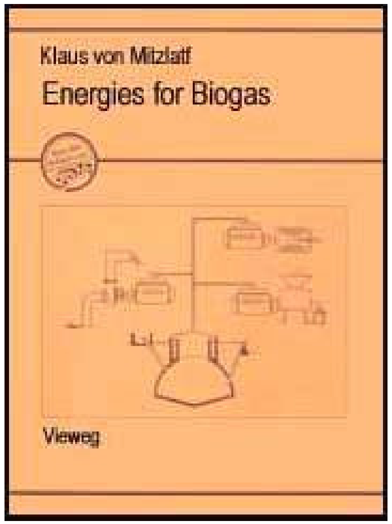
Utilization of biogas in a processed form, i.e. almost pure methane CH4, is becoming more and more important in vehicle applications. While an effort in plant investment and process energy is necessary, a specific fuel situation may well provide economic incentives to use biogas in tractos, lorries and smaller vehicles. Institutions in Brazil are presently running elaborate research and development programs on this issue.

The type and size of engine considered in this book were limited by two factors. One is the conception that the modification of the engines should be possible with "local" means and expertise, i.e. without sophisticated laboratory-type methods. The other factor is that the basic engines used for modification should be standard engine types from larger series for reasons of availability and the. access to spares and service. The idea of self-handling of engines and modification also limits the engine's size. From the experience of a larger number of biogas projects a power range of about 50 kW was found to be a good compromise. While the theory is valid for the larger engines also, they often incorporate more sophisticated technology such as turbocharging.

This publication cannot and does not attempt to meet the claim of a recipe book for all possible cases. It rather wants to explain and make understandable the various design, economic and other influential parameters and their function in biogas engine issues.

The given examples therefore provide proposals on how to use the given information in a specific situation in order to arrive at a meaningful solution. Proposing standard solutions or final answers does not appear to be appropriate in dealing with an energy system with too many variables which are situation-specific and not always primarily technical ones. A change of only one variable can easily result in a totally different solution.

Positively speaking there is sufficient room and incentive for the reader's own engineering which he will hopefully enjoy after having worked his way through the following chapters. There is after all a better chance of planning, implementing and running a successful project with a broader understanding of the issues concerned.



2. Review of existing literature

Literature with relevance to the topic of this book comes from different fields. One naturally is the standard literature on internal combustion engines which is elaborate to an extent that it would go far beyond the framework of this book to give a complete list[1]. The first Otto engines at the turn of the century were gas-fuelled engines. They are well covered in the standard literature on engines.

Another field is the literature on biogas, dealing mainly with issues concerning the biofermentation and the various plant designs for different biomaterials, plant sizes, etc. The greater portion of the literature was written within the last ten to fifteen years while the awareness of the role and potential of biogas as an energy

gradually increased. In a standard sourcebook for renewable energies for developing countries from 1976 biogas did not yet receive any attention [1]².

Others, however, quoted biogas but mainly as an alternative energy for household use [2]. From the mid-seventies onwards a large number of papers in conferences and journals signalized the growing importance of biogas, not only for small-scale use in households but as a product of municipal and industrial waste treatment with anaerobic fermentation. To name only a few there is L. Sasse's standard book on biogas plants for rural applications [3], BORDA's Biogas Handbook [4] and more recent publications like Oekotop's "Biogas" on the more practical and implementation issues in developing countries [5] and the GTZ's "Production and Utilization of Biogas in Rural Areas of Industrialized and Developing Countries" [6].

The importance given to biogas in the developing countries themselves is documented in numerous publications and seminar proceedings like "Energy for Development in Eastern and Southern Africa" [7] and many others especially from India and China where the small-scale biogas technology development had gained momentum one generation before it became an international development issue.

With the increase in biogas production towards larger quantities the technical utilization like the transformation into mechanical energy became an issue to be researched on. While larger engines specifically designed for gas were on the market, smaller engines modified from standard Otto or diesel engines were seen to fill the gap for small to medium and decentralized applications. Indian [8] and Chinese [9] publications mainly dealt with the modification of small stationary diesel engines for dual fuel operation. Others went on to modify medium-sized

diesel engines including their governors [10], or researched the performance paramters of dual fuel biogas engines in more detail [1 1].

Biogas as a fuel for vehicles has been an issue since the 1950's. While in Europe the use in tractors seems to be the issue [12, 13], in Brazil the aim is to substitute petrol and diesel fuel in the automotive sector using purified and compressed biogas or natural gas [14].

Much useful material and information have been contributed in recent years by publications of manufacturers of gas engines and modified engines or suppliers of equipment and modification kits for standard Otto and diesel engines. Some of their publications are named in the Literature Reference List.