Distributed Generation of Energy using Micro Gas Turbines: Polygeneration Systems and Fuel Flexibility

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Abstract. The use of micro gas turbines (MGT) for on-site small-scale energy production offers a great opportunity for primary energy saving and reduction of pollutant and greenhouse gas emissions. These benefits mainly come from the possibility to locally recover waste heat from exhaust gas especially for air conditioning thermally activated technologies and also for their capability to use low heating value gases such digester gas.

This paper summarises the potential of micro gas turbines in distributed generation systems to simultaneously produce power, heat and chilled water for air conditioning. Different configurations for coupling micro gas turbines and sorption systems will be presented from the conventional hot water driven to the directly exhaust gas driven configurations. The main advantage of these systems is the consumption of waste heat for refrigeration and air conditioning instead of high cost electricity.

On the other hand the use of digester and landfill gas in micro gas turbines is very attractive from many points of view: reduced electrical bill, higher energy efficiency due to on-site heat recovery, reduction of odours and lower greenhouse emissions. The processing of pig manure to produce biogas is of high interest in geographic areas with a surplus of manure that can not be naturally absorbed and limits the growth of farm sites. In this paper it is presented a summary of the state of the art for the use of biogas in microturbine based cogeneration systems along with a brief description of the different types of fuels that can also be used in microturbines.

Key words

Distributed generation, micro gas turbine, thermally activated refrigeration, biogas.

1. Introduction

The accelerated need for new energy generation systems and distribution lines to cope with the increase in electricity demands in recent years is causing supply problems and high emissions of pollutants. Cooling demand is increasing dramatically, and peak demand for power in several countries now is in summer, not winter. Distributed generation systems using micro gas turbines (MGT) are already available in the market. Their deployment will not only help to produce the required electricity but also for combined heat and power applications will contribute significantly to reduction of CO_2 emissions due to their higher global efficiency in comparison with conventional power stations. Another important benefit is the security of supply.

This paper summarises the potential of micro gas turbines in distributed generation systems to simultaneously produce electricity, heat and chilled water for air conditioning. Different configurations for coupling micro gas turbines and sorption systems will be presented from the conventional hot water driven applications to the directly exhaust gas driven configurations. The main advantage of these systems is the use of waste heat for refrigeration and air conditioning instead of high cost electricity.

On the other hand the use of digester and landfill gas in micro gas turbines is very attractive from many points of view: reduced electrical bill, higher energy efficiency due to on-site heat recovery, reduction of odours and lower greenhouse emissions. The processing of pig manure to produce biogas is of high interest in geographic areas with a surplus of manure that can not be naturally absorbed and limits the growth of farm sites. In this paper it is presented a summary of the state of the art for the use of biogas in microturbine based cogeneration systems along with a brief description of the different types of fuels that can also be used in microturbines.

In the next section it will be introduced the main features of micro gas turbine technology prior to the presentation of the microturbine and thermally activated technologies coupling (section 3) and the different types of fuel that can be used in microturbines (section 4).

2. Micro Gas Turbine Technology

Although there is not a clear definition of the size of microturbines, micro gas turbines can be defined as small high-speed turbo-alternators of up to 200 kW, operating as a Brayton cycle which consist of a centrifugal compressor, a radial turbine and a permanent magnet alternator rotor. Their main feature is that the high speed generator is directly coupled to the turbine rotor and that they use power electronics instead of a gearbox and a conventional generator to adapt the power produced to the grid power quality [1, 2]. Other mini gas turbines of

higher electrical capacities will not be considered in this study.
In a typical MGT regenerative system (figure 1) the incoming atmospheric air is compressed and then passes through the regenerator where it is preheated with the hot gases leaving the turbine before it enters the combustion chamber. This reduces the amount of fuel used to reach the operating temperature. In the combustion chamber, compressed fuel is burned with excess compressed air to produce hot gas at high temperature and pressure. This is then expanded through a turbine, which extracts energy and uses it to drive the compressor and the alternator. The turbine exhaust gases are then fed through the recuperator and finally through a boiler, a directly driven absorption chiller, a drying process or any other process that can benefit from high temperature gases.
Microturbines usually use a single shaft. This configuration has a lower production cost than the double shaft configuration and the generator can also be mounted opposite the gas exhaust, so the gases leave the turbine with a lower pressure loss. This increases the net power and reduces the fuel consumption. Another way to decrease the fuel consumption is to use regenerators to preheat the inlet air. This doubles the electricity efficiency, but reduces the waste heat that can be recovered from the exhaust gas. So in some microturbines the regenerator can be completely or partially bypassed if required. A simple cycle configuration, that is, a non regenerative cycle, is a valid option when the main purpose of the plant is to produce heat at very high temperature to obtain greater overall efficiency rather than greater electrical efficiency.
Microturbine turbomachinery is currently based on single-stage radial flow compressors and turbines. Radial flow turbomachinery handles the small volumetric flows with reasonably high component efficiency. The economic cost is also lower than that of axial components. The main drawback of radial compressors and turbines is that they are less efficient. So axial turbines are preferred for gas turbines of higher capacities.

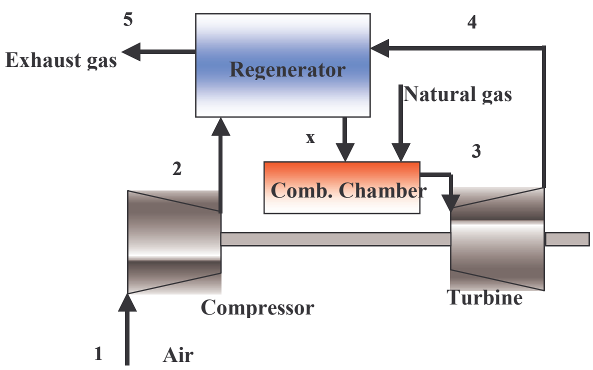

Figure 1. Schematic of a regenerative micro gas turbine

All the above features mean that microturbines have some advantages over other competing technologies such as natural gas reciprocating engines. These advantages are:

- They are lightweight and very compact systems.
- They produce low noise levels and are vibration free.
- Their exhaust gas emissions are lower than those of competing technologies, with the only exception of fuel cells [3].
- Like other gas turbines, the heat recovery system is less complex than that of engines.
- They require less maintenance, specially the oil free microturbines that use air bearings instead of oil lubrication. All the MTG electronics are also cooled by air.

A complete micro turbine system consist of different elements linked as shown in figure 2. These elements are:

- Fuel system. For the conditioning of the fuel supply to the required fuel inlet conditions.
- Micro gas turbine. The microturbine with all the elements (compressor, combustion chamber, recuperator, etc) including the electric generator.
- Heat recovery boiler. To recover waste heat in the form of hot water.
- Power conditioner. For the conditioning of the generated power to the required power characteristics.
- Battery controller. To add black start capability and transient load capacity.
- Communications and control. For the regulation and control of the whole system.
- User Interface. To configure and access the system parameters on-site or remotely.

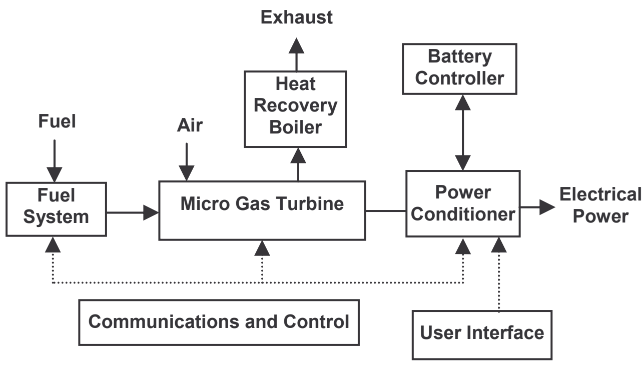

Figure 2. Bloc diagram of a microturbine CHP system.

Microturbines can be operated as:

- Stand-Alone systems
- Grid Connected systems
- Dual Mode systems with automatic transition between stand-alone and grid operation modes.
- Multipac systems. This system consists in the interconnection of many microturbines in parallel to produce a higher electrical output and working together as a single system.

The electrical efficiency of current MGTs, which are also characterised by low-pressure ratios and modest turbine inlet temperatures, is between 25-30%, depending on the size of the MGT.
One of the critical components in low-compression ratio microturbines is the recuperator. Recuperators are heat

exchangers that recover some of the waste heat from the exhaust stream and transfer it to the incoming air stream. The preheated incoming air is then used for combustion because less fuel is required to raise its temperature to the required level at the turbine inlet. Most of today's compact recuperators are manufactured using 300 series stainless steels which are used at exhaust-gas temperatures below about 650ºC.

It is clear that significant increases in microturbine efficiency can only be achieved with increases in engine operating temperatures, but because most of the current microturbine designs utilise metallic components without air cooling, higher operating temperatures without any improvements in materials performance would result in shortened lifetimes. Therefore improvements in microturbine efficiency can only be realised through the use of advanced metallic alloys and ceramics for high-temperature components [4, 5].

There are basically two major types of packaging solutions for the recuperator in a microturbine. The first one is an annular shaped recuperator wrap-around the microturbine. Their main advantage is that the good aerodynamic gas flow path produces low pressure losses, there is no need for external ducts and also the noise level is lower. The other option is the conventional "cube-shaped" recuperator installed behind and in line with the rotating machinery. The main advantage in this case is the possibility to by pass partially the hot exhaust gas to obtain a higher temperature for the heat recovery applications that require high temperature.

3. Integration of Microturbines and Refrigeration Systems

In warm climate areas the major concern is air conditioning rather than simply heating. In this situation, thermally activated sorption technologies are a key technology because they make it possible to transform waste heat into cooling. At the same time it can reduce the site electrical requirements, increase the gas turbine capacity by inlet air-cooling and provide the necessary air conditioning load. The considered technologies for the analysis shown in this paper are:

- Absorption chillers: single and double effect water/LiBr absorption chillers
- Adsorption chillers: commercial silica gel/water systems
- Desiccant cooling systems

For reasons of space the fundamentals and characteristics of these systems will be covered just to show the capabilities of their coupling with microturbines. For a detailed description the reader can refer to the specialised literature on each technology. In absorption machines, the refrigerant fluid is first absorbed in a liquid solution before being pressurised in liquid form. The pressurisation of a liquid requires much less energy than for a gas. Absorption systems therefore consume very little electrical energy to drive the liquid pump. The main energy requirement is for thermal energy from fuel, waste heat (e.g. cooling water or exhaust gases of motor engines) or solar heat, for separating the liquid refrigerant from the solution by boiling. There are two commercially available working pairs (refrigerant/absorbent): water/LiBr and ammonia/water. Most absorption chillers are directly gas fired, thus hindering the use of waste or solar thermal heat. Single-effect absorption chillers operate with a single evaporator, condenser, absorber and generator requiring a driving temperature as low as 90ºC. A higher efficiency can be achieved by adding a second generator/condenser combination. Such cycles are known as double-effect. A system using a double-effect cycle can exhibit a COP of up to 1.3, whilst a typical single-effect system has a COP of 0.7, although a double-effect chiller require a higher temperature input, around 140ºC or more. A COP of up to 1.6 is possible with triple-effect systems. Currently, there are no triple-effect absorption chillers commercially available although it is under development by a number of world wide absorption manufacturers.

Another concept, which has been developed to improve energy efficiency, is the ammonia/water GAX (Generator-Absorber heat eXchange) cycle, whereby heat is recovered from the absorber and used in the generator.

In the power range below 20 kW there are currently no absorption technologies available on the market, which can be indirectly heated. From about 30 kW to several MW single and double effect absorption machines are available.

As an alternative for low temperature driving heat sources, adsorption chillers can be used. In adsorption chillers a solid medium is used as absorbent instead of a liquid as in absorption systems. Desiccant cooling units with air as the cooling agent can be used for applications with high air exchange rates. There is a very limited experience available in Europe to couple such machines with waste heat or solar thermal energy.

Next the following coupling configurations will be discussed:

- MGT / Single-effect hot water driven water/LiBr absorption chiller
- MGT / Double-effect exhaust gas driven water/LiBr absorption chiller
- MGT / Exhaust gas driven Ammonia/water absorption chiller
- MGT / Adsorption chiller
- MGT / Desiccant cooling system

3.1 MGT / Single-effect hot water driven water/LiBr absorption chiller

Nowadays the only commercially mature technology that produces cooling using absorption refrigeration for small power applications in combination with an MGT is an intermediate gas/water heat exchanger that produces hot water to drive the absorption system. As MGTs usually have a regenerative cycle configuration, the gas exhaust temperatures are only appropriate for the production of hot water at relatively low temperatures. At these temperatures only single-effect chillers can be used. This is considered the most conventional system among MGT/absorption chillers configurations.

Below we report the performance of conventional MGT/hot water driven absorption chillers. The considered MGT sizes are appropriate for light commercial building applications. The results were obtained by modelling the system with programme Equation Engineering Software (EES). The single-effect chiller was set to provide chilled water at 7ºC and driven by hot water at 90ºC. As can be seen in figure 3, the maximum cooling capacity that can be obtained with each of the four MGTs considered in this study ranges from 36 kW, for the MGT with the smallest capacity, to 90 kW for the biggest. It is important to notice that only a few commercial chillers are available in this capacity range. Figure 1 also shows the hot water production capacity, which corresponds to the heating power required to drive the absorption chiller.

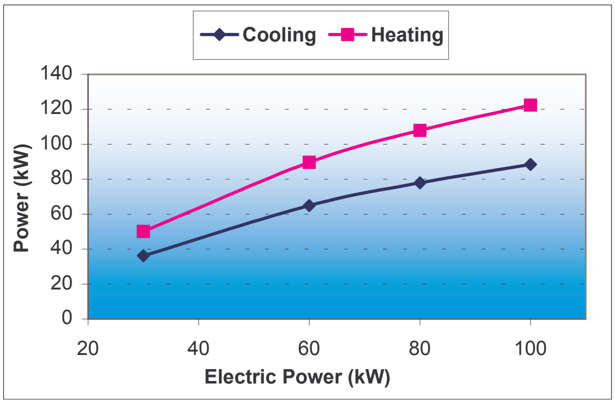

Figure 3. Production of cooling and heating power as a function of MGT electric power

The consumption of primary energy for a MGT of 30 kW_e and an absorption chiller with a *COP* of 0.7 and a cooling capacity of 36 kW, is 116 kW. This is a 10% lower than the consumption of primary energy with a conventional system producing the same amount of energy and considering an electrical grid efficiency of 33%, an electrical transport and distribution efficiency of 95% and a *COP* for the compression system of 3.5.

3.2 MGT / Double-effect exhaust gas driven water/LiBr absorption chiller

The performance of existing MGT/single-effect absorption systems is too limited: their COPs are low, the range of chilling capacities is too restricted, the electricity and cooling capacity depend on each other completely, etc. Therefore, it is very interesting to analyse the possibility of using the exhaust gas in direct fired absorption machines with the option of natural gas post-combustion. Direct-fired chillers are more efficient and better positioned in the refrigeration market than their hot water driven counterparts. In these systems the MGT exhaust gas can be used as heating medium to drive the chiller. There is the possibility to use the MGT exhaust gas, which contains a high concentration of O_2, as combustion air in a direct-fired absorption chiller (figure 4). In this case, not only the cooling capacity can be increased but also as the chiller still uses its own burner, it can run independently from the MGT. So in this way the refrigeration and electric production are decoupled. Some of the single and double effect water/LiBr systems can work as a chiller/heater system producing chilled water and hot domestic or heating water in some cases simultaneously increasing the flexibility of the integrated MGT/absorption system. In the Engineering Analysis Center in Pico Rivera (California, USA) there is a demonstration facility with this configuration.

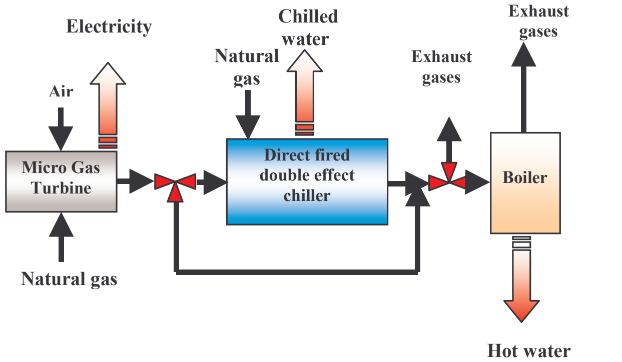

Figure 4. Diagram of a directly coupled MGT and absorption chiller

Next it is presented the performance of several MGT/direct-fired absorption chillers with post-combustion but without fresh air. The oxygen necessary for the combustion reaction is taken from the MGT exhaust gas stream. In this case, as no additional air is used, the MGT hot exhaust gases are not diluted and the temperatures achieved with the same amount of post-combustion are higher than those obtained with additional air. So the gas temperature reached in the post-combustion process limits the maximum amount of natural gas used for post-combustion. The material's resistance to high temperatures sets this maximum temperature. Even though no fresh air is added there is no limitation because of the quantity of oxygen available. The system reaches its maximum temperature long before the oxygen available is exhausted. Figure 5 shows the maximum cooling capacity for each MGT with post-combustion and without adding fresh air.

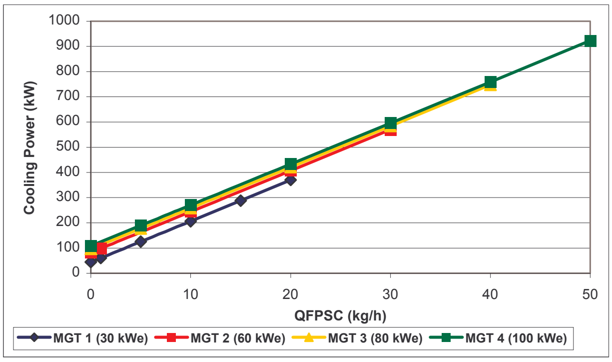

Figure 5. Cooling capacity of a double effect absorption chiller directly coupled to different MGTs without additional fresh air as a function of postcombustion natural gas consumption

3.3 MGT / Exhaust gas driven Ammonia/water absorption chiller

The ammonia/water chillers are designed primarily for industrial refrigeration applications, such as freezing food or process refrigeration, with evaporator temperatures as low as -55ºC. However, there are also some air cooled small capacity ammonia/water units (>18 kW) based primarily on advanced single effect cycles known as GAX (Generator-Absorber heat eXchange) cycles, whereby heat is recovered from the absorber and used in the generator. The main benefits of these systems are the possibility of using hot exhaust gases to directly drive them and also that using the ammonia /water pair there is no need for a cooling tower to dissipate the heat at medium temperature released by the chiller. Southern California Gas Co. in Downey (California, USA) built a test facility with this configuration.

Cerezo et al. [6] studied a combined system that consists of a regenerative microturbine cycle of 28 kW_e of maximum electrical capacity, an air cooled ammonia-water GAX absorption system and a water waste heat boiler. In this chiller, the generator and absorber are split into sections so that internal energy integration is greater and external heating and cooling requirements are lower in the generator and the absorber, respectively.

3.4 MGT / Adsorption chiller

In adsorption chillers a solid medium is used as absorbent instead of a liquid as is the case for absorption systems. Adsorption cooling units are attractive since they can be operated at temperature levels where liquid absorption systems cannot work, that is, at very low generator and ambiance heat sink temperatures.

The process of adsorption involves separation of a substance from one phase accompanied by its accumulation or concentration at the surface from another. The adsorbing phase is the adsorbent, and the material concentrated or adsorbed at the surface of that phase is the adsorbate. Adsorption is thus different from absorption, a process in which material transferred from one phase to another (e.g. liquid) interprenetrates the second phase to form a "solution". The term sorption is a general expression encompassing both processes. Adsorbent substances can be restored to original conditions by a desorption process usually involving the application of heat. Adsorbents are characterised by surface properties: specific surface area, polarity and pore size distribution.

The system is built up with a condenser, a throttle valve, and an evaporator and the adsorbent bed. Adsorbent beds that are used to create the pressure changes needed to drive a condensation /evaporation replace the mechanical compressor.
This is by nature a discontinuous process. To obtain continuous cooling a multiple bed system is used, typically two adsorbent beds out of phase. The length of the cycle is a very important parameter strongly affecting the operation of gas-solid systems.

Different working pairs can be used although the silica gel-water based system is the selected adsorbent for the existing commercial chillers because it is possible to use heat sources below 100ºC.

The available absorption chillers for air conditioning applications can not be driven by hot water temperatures below 90ºC. As an alternative for low temperature heat sources, adsorption chillers can be obtained commercially from Japan (Mycom, Nishiyodo). There is very limited experience available in Europe to couple such machines with waste heat or solar thermal energy.

The research activities in adsorption are still increasing to solve the crucial points that make these systems not yet ready to compete with the well-known vapour compression system.

3.5 MGT / Desiccant cooling system

Desiccant cooling systems take air from outside or from the building, dehumidify it with a solid or liquid desiccant, cool it by exchange of sensible heat, and then evaporatively cool it to the desired state. The desiccant is regenerated with heat [7].

Rotatory solid desiccant systems are the most common for continuous removal of moisture from the air. The principle of operation of a typical system is indicated in figure 6. The process followed at the points from 1 to 9 of figure 6 is traced on the psychrometric chart of figure 7. Ambient air is heated and dried by a dehumidifier from point 1 to point 2. The desiccant wheel rotates through two separate air streams. regeneratively cooled by exhaust air from 2 to 3, evaporatively cooled from 3 to 4 and introduced into the building. Exhaust air from the building is evaporatively cooled from 5 to 6, heated to 7 by the energy removed from the supply air in the regenerator, heated by the MGT/Chiller exhaust gas [8] or other source such as solar energy to 8 and then passed through the dehumidifier where it regenerates the desiccant. The selection of the adsorbing agent depends on the size of the moisture load and the application.
In liquid desiccant systems the drying agent is a liquid, such as triethylene glycol, and waste heat can be used to regenerate the glycol.

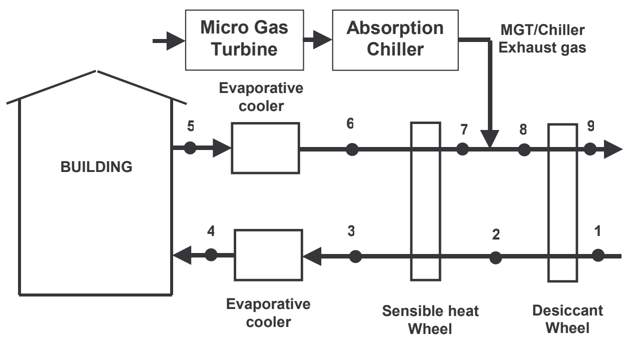

Figure 6. Schematic of a MGT/desiccant cooling system

4. Use of Different Types of Fuels

In this section it is presented a summary of the state of the art for the use of biogas in microturbine based cogeneration systems along with a brief description of the different types of fuels that can also be used in microturbines.

4.1 Natural Gas

This is by far the most common fuel used with MGT. Two type of natural gas systems are in use:

Low-pressure systems: A gas compressor is required to boost the fuel pressure up to the combustion chamber pressure. In some models the compressor is integrated in the same package containing the microturbine or as a separate unit. The electric consumption for the natural gas compression reduces the net electric power of the micro turbine.

High-pressure systems: In this case a fuel regulation valve substitute the fuel compressor.

4.2 Propane

Microturbines can run also with gaseous propane. The microturbine test facility of CREVER-Universitat Rovira i Virgili in Tarragona [3] has already driven a 30 kW_e microturbine using commercial propane in order to acquire experience with this type of fuel and characterised its performance using it. It is a high-pressure system feed directly from propane bottles thus the original low-pressure natural gas microturbine system was temporarily converted to operate with a high-pressure fuel system.

4.3 Digester and Landfill gas

The digester and landfill gas are referred by the generic name of biogas for some authors, although due to their special features it may be convenient for some applications to distinguish between them separately and named them digester gas and landfill gas. The common sources for biogas are:

- Landfill gas
- Waste water treatment plants
- Farm manure digesters
- Food processing waste digesters
- Gasified woody biomass, or other sources of organic waste

Microturbines features enable them to compete against reciprocating engines using biogas particularly at smaller sites [9]. The use of digester and landfill gas in micro gas turbines is very attractive from many points of view: reduced electrical bill, higher energy efficiency due to on-site heat recovery, reduction of odours and lower greenhouse emissions. Methane contributes more to the greenhouse effect than the CO_2.
The processing of pig manure to produce biogas is of high interest in geographic areas with a surplus of manure that can not be naturally absorbed and limits the growth of farm sites.

In the production of biogas, the organic wate (e.g. manure) is put into the digester where it is heated to accelerate anaerobic digestion. Anaerobic refers to a process that occurs in the absence of oxygen. Digestion refers to a biological process performed by microbes or bacteria, which accomplishes the digestion of organic waste materials.
The anaerobic decomposition of organic materials under the action of bacteria and following different processes (hydrolysis, acidification and methanisation) produces a fermentation gas, mainly methane and CO_2 and other minor gas components (H_2O, H_2, H_2S, ammonia, CO, N_2, O_2 and traces of organic compounds: aromatics, VOC, siloxanes). The temperature and pH of the process are controlled to optimise the digestion reactions and the health of the microbes/bacteria. Figure 7 shows a block diagram for a typical biogas MGT facility.

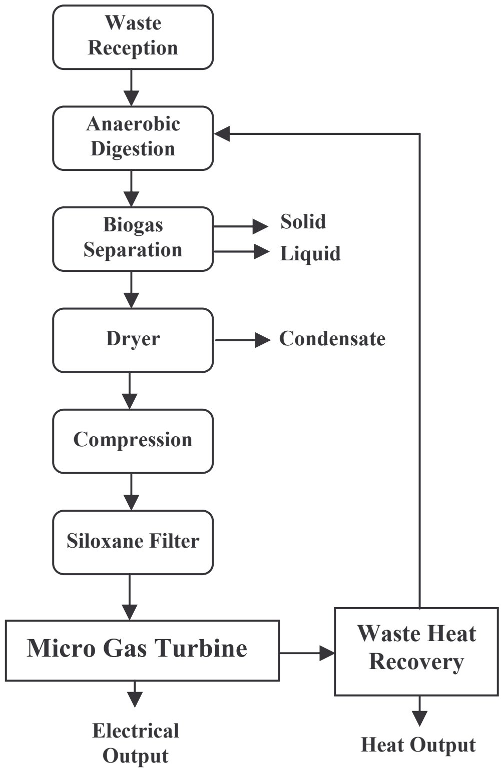

Figure 7. Typical block diagram of a biogas treatment plant for a micro gas turbine

Onsite generation of electric and hot water can be an important element in making an anaerobic digester installation economically feasible. Also the microturbine can eliminate excess odours while producing lower emissions than a reciprocating engine. Odours associated with concentrated animal waste are not only a nuissance but also a risk for health. Presence of hydrogen sulphide and ammonia in the air cause neurological damage to community residents.

Reciprocating engines can use also biogas. Engines adapted for landfill gas with capacities less than a few

hundred kilowatts are harder to find [9]. Besides smaller landfill sites and old, closed sites, microturbines are also appropriate at landfill sites in drier climates where the methane content is lower (organic matter decays more slowly in drier climates.) Some models accept digester gas at atmospheric pressure; others require compression of the gas. It is a mature technology with a relatively low capital cost especially for units higher than 500 kW but their use is limited by higher operating costs and mainly by the methane content of the biogas. Below a content of 45% of CH_4, the stops are frequent and below 40% the engines do not work. Often reciprocating engines can require blending with purchased natural gas or propane when the methane content is too low.
However, using biogas in microturbines it is possible to work with a CH_4 concentration as low as 30-32 %. Table 1 gives an overview of typical biogas compositions depending on their origin [10].
Several factors influence the amount and heat content of the biogas produced [11]:

- Type of digester technology
- Specific digester design details, such as, residence time, temperature and mixing
- Type and quality of animal feed
- Scraping method
- Type of bedding

Table 1. Typical compositions for different sources of biogas [10].

Component	Agricultural waste	Waste water	Industrial waste	Landfill gas
CH_4	50-80%	50-80%	50-70%	45-65%
CO_2	20-50%	20-50%	30-50%	34-55%
H_2O	Saturated	Saturated	Saturated	Saturated
H_2	0-2%	0-5%	0-2%	0-1%
H_2S	100-700 ppm	0-1%	0-8%	0.5-100 ppm
NH_3	Traces	Traces	Traces	Traces
CO	0-1%	0-1%	0-1%	Traces
N_2	0-1%	0-3%	0-1%	
O_2	0-1%	0-1%	0-1%	0-5%
Organic compounds	Traces	Traces	Traces	5 ppm

According to the diagram of figure 7 the required auxiliary systems are:

Filtration of siloxanes: Siloxanes in sewage sludge digester gas and landfill gas convert to silica (ash) during combustion. This problem does not exist in agricultural digesters. Different species of siloxanes are found in landfill gas because it is a chemical used extensively in industrial products such as lubricants and in personal care products like cosmetics, hair spray and deodorants. The combustion of gas containing siloxanes is responsible for the presence of silica deposits. Silica causes abrasive wear and settings that reduce also efficiency due to their isolation properties. The filtration of biogas with graphite media is the usual procedure to reduce the presence of siloxanes in biogas. Some companies offer turnkey solutions for the removal of siloxanes. It is recommended to reduce the concentration of siloxanes to <5 ppb.

Compression system: Microturbines require digester gas to be compressed to the combsution chamber feed pressure.

Dehumidification/gas cooling: Drying of compressed digester gas is very important. Otherwise, compounds in the condensate foul the microturbine fuel control valves and fuel injectors. Also cavitation problems of expanding water drops can occur. Refrigerated dryers have proven to be the more reliable. Some compressor failures have also been caused by condensate. Gas/liquid separation is also important.

Biologic desulphuration and dechloration if required

Digestion eliminates odour problems that arise from storing manure in a lagoon, and prevents groundwater pollution. Uses of heat in farms:

- Digester heating
- Heating of home, offices and other facilities onsite
- Absorption chilling (air conditioning and refrigeration)
- Thermal drying and pelletizing of biosolids for sale or land use

On-farm generation supports voltage levels on rural parts of their distribution network, potentially offsetting grid reinforcement costs.

The vast majority of biogas-fuelled microturbines are installed in the United States and Canada, with a handful of units in Europe, Japan and elsewhere.
The projects that have encountered problems were caused by the fuel conditioning system and worked successfully after replacing or reworking the fuel conditioning equipment. The materials of construction must address the corrosive properties of digester gas. Stainless steel is the best option. When clean, dry fuel is supplied reliably to the microturbines, the systems operate continuously, with no attention required for the plant personnel.
Capstone Turbine Co. produces microturbines of 30 kW to run with landfill and digester gas and flare gas. The required fuel heat contain has to be comprised between 13.04 and 42.1 MJ/m^3. For the 60 kW$_e$ model the acceptable range for the fuel heating value is 36.14 to 42.1 MJ/m^3. Natural gas can be added if required. The lowest the heating value of the fuel the highest the feed pressure has to be. The microturbine can work as a grid connected system with a minimum capacity of 15 kW$_e$. It is not possible to work as an stand alone system. The fuel temperature has to be comprised between 50 and -20ºC or 10ºC over the fuel dew point.
The microturbine of 100 kW$_e$ originally manufactured by Turbec has started the firsts field tests to run with biogas and digester gas. Ingersoll-rand also has some units of its microturbine of 70 kW$_e$ running with biogas.

Microturbines require a lot of gas pretreatment at the front end, but as a result they require far less ongoing maintenance than reciprocating engines and provide significant cost savings particularly where state, local, and utility grants are available to promote the use of biogas.

4.4 Flare gas

Oil extraction platforms produce non-recuperated gases. Usually these gases are flared to prevent pressure build-ups and explosions. This flare gas produces harmful air emissions and wastes potentially valuable energy.
Microturbines can reduce the amount of flare gas in oil platforms with the corresponding increase in oil production due to the reduction of backpressure, reduction of emissions and economic benefit coming from the generated electricity. These flare gas, which contains a high percentage of hydrogen sulphide, can create especially caustic and harmful emissions. The use of microturbines can deal with these flare gas emissions. There is a considerable experience with this type of application using microturbines of 30 kW_e.

4.5 Liquid Fuels

The available microturbines for liquid fuels use diesel and kerosene. There is one experience with a palm oil fuel in Malaysia. The only commercially available microturbines sizes for liquid fuels have a capacity of 30 and 80 kW_e, one of 100 kW_e is coming soon. The net electrical power is a little reduced by the fuel pump. As it is logic the NOx emissions are higher than those obtained with gaseous fuels.

5. Conclusions

Micro gas turbines offer new possibilities for the operation of the electric system. They offer the advantages of gas turbines at small-scale capacities closer to the load and can be used in combination with multiple advanced and efficient thermal driven sorption systems to provide HVAC and refrigeration. The result is an increase in the efficiency of the energy production system and significantly lower greenhouse gas and pollutants emissions.

There are different configurations for coupling micro gas turbines and sorption systems. From the conventional hot water driven applications to the directly exhaust gas driven configurations. The main advantage is the consumption of waste heat for refrigeration and air conditioning instead of high cost electricity. The direct use of microturbine exhaust gas in absorption chillers is more efficient than hot water driven systems because no intermediate heat exchanger to produce hot water is required and higher driving temperatures are available. Also there is the possibility to burn additional fuel as postcombustion fuel so there is a decoupling between the required electricity and refrigeration loads.

On the other hand the use of digester and landfill gas in micro gas turbines is very attractive from many points of view: reduced electrical bill, higher energy efficiency due to on-site heat recovery, reduction of odours and lower greenhouse emissions. The processing of pig manure to produce biogas is of high interest in geographic areas with a surplus of manure that can not be naturally absorbed and limits the growth of farm sites.

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