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Review of Gas Microturbine Application in Industry

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Constant pressure is put on energy consumers to decrease their demands. A special focus is on primary energy sources, its maximum efficiency, and the best possible utilisation of produced energy. Another critical question nowadays is the environmental impact. With strict emission limits, it is important to aim for the cleanest source possible. A cogeneration unit seems to be a very promising solution thanks to its high efficiency and good acquaintance. This paper focuses on gas microturbines which are still considered progressive technology. A gas microturbine can obtain the combined heat and power efficiency of up to 90 % with low pollutant flue gas. With such parameters, gas microturbine ought to be considered a promising source of energy, especially for industrial operations with high heat demand. This paper provides essential gas microturbine characteristics, its advantages and disadvantages, and a comparison with other types of combined heat and power units (e.g., organic Rankine cycle units, solid oxide fuel cells units). The study is based on recent papers published in a wide range of journals. Review of the literature shows that gas microturbine is suitable for coupling with other technologies, especially for combined cooling, heat and power units. However, about 50 % of the examined paper used gas microturbine only for power generation. There is still space for complex and more rigorous gas microturbine integration into industrial operations, especially the use of exhaust gases for direct drying.

1. Introduction

Due to continually increasing consumption of primary sources it is necessary to ensure their maximal utilisation with high efficiency. On a long-term basis, there is pressure on decreasing fossil fuels use and preference to use renewable sources in a sustainable and environmentally-friendly way. Finally, the decentralized energy generation concept is enforced. It brings better stability and load demands of the grid, lower CO_2 emission, enlargement of energy reserves and independence for plants in a crisis, such as power failure (Kanchev et al., 2011).

One of the possible answers to these issues is the cogeneration unit (CHP). Primary fuel is utilised to generate electricity and heat, with the overall efficiency of up to 85 %. According to Isa et al. (2018), CHP systems can help to achieve goals of smart grid integration. CHP systems can be improved with cool generation, known as combined cooling, heat and power production systems (CCHP).

CHP unit can be part of the energy grid or can work independently. It can provide energy only for the most demanding part of the day and peak loads, or it can be a regular primary energy source with continuous operation. These properties make the cogeneration unit highly variable source for a different type of application. Into this category, steam turbines, combustion engines, fuel cells and microturbines up to 500 kW, can be included.

Although the development of gas microturbines (GMT) started in the 1950s, this technology is still very progressive. This well-known technology gives a wide range of opportunities for application. Easy integration, low maintenance requirements, and high combined efficiency of 80–90 % (Nelson et al., 2018) make GMTs usable for both commercial and industrial sites.

Review of the literature has shown that GMTs are still a discussed topic, especially in combination with other technologies for higher energy efficiency of CHP/CCHP systems. This paper gives an overview of chosen types of CHP/CCHP technologies and characteristics of the GMT. The main focus is on a selected research paper about GMT application in industry.

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2. Cogeneration units

CHP units are defined as systems with a combined generation of heat and electricity using just one type of fuel, and high efficiency of energy production is reached. Depending on whether the priority is given to the production of electricity or thermal energy, units are distinguished into the topping cycle and bottoming cycle respectively (Al Moussawi et al., 2017). Here is a listing of prime movers for CHP units:

- steam turbine,
- gas turbine,
- microturbine,
- internal combustion engine (ICE),
- organic Rankine cycle (ORC),
- Stirling engine,
- fuel cell.

All of these technologies are well-known, reliable, and stable movers widely used in real applications both in the industry and commercial sector, turbines and combustion engines especially. However, this paper focuses on more modern and progressive technologies, i.e., GMT, ORC and fuel cells. Also, these movers are frequently combined into complex CHP/CCHP systems, and they are described in detail in the following sections of the paper.

2.1 Gas microturbine

The GMT is a well-known technology with power output in a range of 30 – 350 kW (Al Moussawi, 2017). It can be connected to create parallel systems with power output in the order of units and tens of MWs. GMT is divided into single-shaft and double-shaft. The main advantage of the single-shaft design is less moving parts because the generator is on the same shaft as the turbine. The double-shaft turbine has an additional gearbox to connect the turbine and the generator on different shafts. The GMT works on the principle of the Brayton cycle. Ambient air is compressed and combusted with fuel in the combustion chamber. Hot gases expand through the turbine that produces power for the generator. The recuperator preheats the inlet air before compression (Gillette, 2010). A GMT can work with different types of fuels – natural gas, biogas, landfill gas, propane gas etc. The strength of the GMT is its lower sensitivity to fuel composition and impurities in it (Bruno et al., 2009). Because of these, the GMT is very variable in applications.

One of the most significant GMT advantages is high purity of exhaust gases which can be further utilised. A GMT has very low NOx emissions due to continuous combustion. So there is no need for an additional device for flue gas treatment to meet emission limits. The outlet temperature of exhaust gas is around 275 °C, which can be a quality heat source for another usage – hot water heating, cold production, direct drying, preheating of process fluids etc. In this way, a GMT is a prospective source for CHP and CCHP units.

In comparison with other CHP technologies, a GMT has low weight and compact size (considering the power output), low maintenance demands, low noise level and vibration, long lifetime, quick response and high overall efficiency (Isa et al., 2018), Al Moussawi et al. (2017) highlights the variability of gaseous and liquid fuels. Specific parameters of the Capstone C30 microturbine are in Table 1. The C30 type is chosen because of its use in several examined case studies.

Table 1: Gas microturbine performance specification (Capstone, 2017)

Capstone C30	
Power Output	30 kW
Combined Efficiency	Up to 90 %
Electrical Efficiency	26 %
Exhaust Temperature	275 °C
Exhaust Gas Flow	0.31 kg/s
Acoustic Emissions	65 dBA
Weight	405 kg

On the other hand, a GMT has a higher investment cost about 1,300 – 1,800 $/kW (Ferreira et al., 2014). Also, it is sensitive to ambient conditions, mainly to ambient temperature. A GMT is possible to use as part of complex systems for power generation (Kalantar and Mousavi, 2010), backup sources (Ismail et al., 2013) or for an island and offshore operations.

2.2 Organic Rankine cycle unit

An ORC unit is the possibility to effectively utilise different types of waste heat for electrical power production. This unit is based on a closed cycle with an organic working fluid which is preheated and evaporated using waste heat. The evaporated gas expands through the turbine connected to the generator. For condensation of the gas, there is water- or air-cooling unit. The liquid condensate is transported back to the evaporator. The turbine is not in direct contact with the waste heat stream, and no erosion of turbine blades occurs (Vescovo, 2009). The ORC cycle works with several types of working fluids with various critical temperature. However, some of the fluids can cause an ecological load, and it is necessary to consider its future legislative restriction (Schuster et al., 2009).

The energy efficiency of the cycle is about 85 % (Schuster et al., 2009). Consequently, the ORC cycle is characterised by low mechanical wear, easy maintenance and long lifetime (Vescovo, 2009). From an economic point of view, the specific investment cost of ORC units is around 2,300 – 4,500 $/kW (Lemmens, 2016). However, Al Moussawi et al. (2017) give the upper price cap up to 8,400 $/kW.

2.3 Fuel cells

Fuel cells are a modern and developing technology using direct chemical reaction energy to produce electricity. The process uses an electrochemical reaction, such as electrolysis. Different types of electrolyte are suitable for various applications. Solid Oxide Fuel Cells (SOFC) are often combined with GMTs to increase electricity production and overall efficiency. These cells need two gas streams to operate – hydrogen and oxygen. They are suitable for high heat operations with a temperature of 1,000 °C. Their efficiency of electricity generation is about 50 % (Massardo et al., 2002) and as in the case of GMTs, fuel cells units can be connected to increase power capacity.

Fuel cells are useful sources of energy with low emissions because of the direct chemical conversion into energy. However, they are sensitive to pollutants in fuel. Therefore, there is a need to use a fuel pre-treatment unit, especially for biogas fuel (Trendewicz and Braun, 2013). Also, fuel cells, as modern developing technology, still have a higher investment cost up to 4,000 $/kW (Velumani et al., 2010).

3. Application of gas microturbine

As it was mentioned in the previous section, the GMT is a variable and effective mechanism to produce both electricity and heat. With other technologies, it is possible to create more complex systems with higher efficiency and supply facilities or apparatuses according to their special requests and demands. In this section, chosen research papers and case studies on the GMT coupled with other units are analysed. These studies were selected for their relation to industry and the utilisation of forward-looking technologies, such as GMT or SOFC. As can be seen in Table 2, the most frequent configuration is CHP units, and about 50 % of studies focus on the power generation field. All examined studies are listed in Table 2 below, with the main characteristics and specifications.

3.1 Gas microturbine and CHP applications

CHP applications are common due to their easy implementation with a heat exchanger (HE) or direct use of exhaust gases. In this section selected approaches to CHP units with GMTs are presented.

Caresana et al. (2011) gave a comparison of 716 kW_e ICEs and six 100 kW_e GMTs for landfill biogas fuel. The process was evaluated for economic viability which depends on the purchase cost of produced electricity and heat, subsidies and operational cost. The same result comes out of the study of Vera et al. (2012) for a GMT and a biomass gasifier for olive oil production.

Heat recovery for a coffee roasting facility was examined by Pantaleo et al. (2018). The authors compared scenarios for an ORC unit and two GMT configurations; for this particular facility, neither of these options was suitable because of the low number of working hours (6 h per day). To make one of the options favourable, the working hours need to increase to a minimum of 12 h per day.

Coupling of ORC and GMT units was presented by Invernizzi et al. (2007), where exhaust gases from 100 kW GMT were used for a smaller 40 kW ORC turbine. With this set-up, another 45 kW of electricity was produced and the efficiency of electrical power generation increased by 10 %. Small ORC units are promising for waste heat, but their cost is still rather high.

MosayebNezhad et al. (2018) connected a GMT with the modern technology of SOFC to utilise biogas as the primary source in the wastewater treatment plant. The heat from GMT exhaust was used for sludge pre-heating. In case of biogas lack, the GMT operates on natural gas and provides heat for the process. Ability to use both types of fuel makes the system very stable and reliable in various situations.

Table 2: Overview of examined case studies and papers

Authors	GMT output [kW]	CHP	CCHP	Branch	Specification
Bruno et al., 2009	30		x	sewage treatment	biogas fuel, absorption chiller
Buck and Friedmann, 2007	100		x	power generation	solar tower, HE, absorption chiller
Caresana et al., 2011	6x100	x		landfill	landfill biogas fuel
Ferreira et al., 2015	30, 65	x		manufacturing	direct use of GMT exhaust
Ge et al., 2013	80		x	food retail	CO_2 refrigeration
Huicochea et al., 2011	28		x	power generation	double effect absorption chiller
Invernizzi et al., 2007	100	x		power generation	Micro Rankine cycle
Kalantar and Mousavi, 2010	230			power generation	wind turbine, solar, battery, GMT
Massardo et al., 2002	50	x		power generation	SOFC, GMT
Máša et al., 2017	30	x		laundry treatment	direct use of GMT exhaust
MosayebNezhad et al., 2018	30, 65	x		wastewater treatment	SOFC, GMT
Nelson et al., 2018	100	x		power generation	solarized GMT
Pantaleo et al., 2013	100	x		power generation	biomass and natural gas
Pantaleo et al., 2018	100	x		coffee roasting	Comparison with ORC unit
Tassou et al., 2007	80		x	food retail	HE, absorption chiller
Velumani et al., 2009	30		x	power generation	SOFC, GMT, absorption chiller
Vera et al., 2012	30	x		olive oil production	gasifier of biomass

Very promising utilisation of waste heat in GMT exhaust gases was found by Ferreira et al. (2015). In this study, GMT was integrated into the process of metal part heat treatment. Such technological operations are very energy demanding. Ferreira et al. (2015) used the C30 GMT type as the best solution that covers heat consumption of rinsing bath and dryers. Potential heat excess was used for pre-heating of annealing furnaces. In this case, the consumption of primary fuel decreased by 17 %, and the overall electricity consumption of the facility also decreased. Máša et al. (2017) presented the possibility of laundry drying also using the flue gas directly from the same GMT type. Their study also dealt with different factors for technical-economic analysis, such as operational hours, fuel and energy purchase costs, energy production income and location, to get optimal payback time.

It is evident that CHP units using GMTs can be favourable and smart solutions for various branches. However, it is necessary to consider the particular demands and needs of each process and provide a precise and detailed economic evaluation to achieve good results with GMT integration. The most influencing factors are investment cost, energy purchase price, working hours, subsidies, natural gas to electricity cost ratio and ambient conditions.

3.2 Gas microturbine and CCHP applications

CCHP systems are also very frequent for GMT integration. Together with electricity and heat, cold is produced, which covers the main demands of almost every industry or commercial operation. A typical device for cold production coupling with a GMT is an absorption chiller. Chillers can be divided by the number of stages and by absorption mixture – H_2O/NH_3 or $H_2O/LiBr$ (Hwang, 2004). As in the previous section, selected studies on the CCHP system with the GMT are analysed.

Bruno et al. (2009) presented the concept of the GMT with an absorption chiller for a sewage treatment plant. The primary fuel was biogas (eventually natural gas), the exhaust gas was used in the chiller, and the produced cold water was utilised for biogas pre-treatment unit and cooling of combustion air for the GMT. In this study, Bruno et al. (2009) compared twelve scenarios. Coupling the C30 GMT type and a one-stage absorption chiller covered all energy demands. With only 5 years payback time, it is a feasible possibility in an economical point of view. Velumani et al. (2010), added an SOFC unit; the overall power capacity of the system was then 230 kW_e with a 55 kW_t cooling unit. The efficiency of such a system is estimated to be more than 70 %.

With a heat exchanger, the CCHP system can be further improved by heating water for domestic use. Tassou et al. (2007) demonstrated this system in the food retail industry. This solution appears promising for this application. However, to make it cost-effective with a short payback time, the natural gas to electricity cost ratio needs to be examined.

Another CCHP model also for food retail industry was proposed by Ge et al. (2013) who used an 80 kW_e GMT with CO_2 refrigeration cascade instead of an absorption chiller. This configuration covered 90 % of overall electricity demand but with higher consumption of natural gas and with an excess amount of heat. A more complex CCHP system was presented by Buck and Friedmann (2007). The authors paired a solar source, a GMT and a heat recovery unit (consisting of an absorption chiller and heat exchanger) for locations with high solar irradiation.

Research of papers on the topic of CCHP proves that systems with GMTs are very stable and efficient sources of electricity, heat and cold. With various apparatuses, it is possible to create a CCHP unit for each facility with specific requirements. However, as in previous CHP applications, the proper technical and economical balance sheet needs to be done.

4. Conclusion

The gas microturbine is still developing, and modern technology which is enforced in CHP and CCHP use. This paper has introduced the main characteristics and principle of operation. Also, other CHP technologies often connected with GMTs have been presented, such as ORCs and fuel cells. Review of the literature showed that the CHP is a frequent application for GMTs with easy implementation. Direct exhaust use is one possibility of utilising the waste heat; another option is the integration of heat exchanger for water heating. The latter application of the GMT is a CCHP system that covers the basic demands of most processes – electrical power, heat and cold. For these purposes, the GMT is connected with an absorption chiller.

According to the research, about 50 % of examined papers focused on power generation field. All papers agree on the GMT being a very promising source of energy with high efficiency, whether it is a stand-alone configuration or a combination with other technologies. However, for the optimal choice and implementation of the GMT to the process, it is necessary to execute a complex and rigorous technical-economic analysis considering all the influencing factors. The primary parameter, of course, is the payback period and these points need to be met to make it as short as possible:

- effective integration of GMT to the process,
- maximal GMT operating time,
- favourable cost ratio for natural gas and electricity (the lower price of natural gas than electricity),
- high purchase prices for heat and electricity,
- subsidies.

This review has given a general knowledge of GMT integration based on recent scientific publications. It is evident; there is still space for GMT use in industrial processes. Notably, the use of GMT exhaust gases for the direct drying, is still a rare possibility for GMT integration. The future work will focus on the real process applications of the GMT and the development of a new integration tool for GMT in industrial operation.

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