Andrea Burrato, GE Oil & Gas

DOWNSTREAM TECHNOLOGY SOLUTIONS | PRODUCTS & SERVICES

Development and Applications of ORegen* Waste Heat Recovery Cycle

Abstract

Because of the link between CO_2 and global warming, nations increasingly are searching for CO_2-neutral energy supply solutions. Hydrocarbon combustion in power generation is the process that has the highest impact on CO_2 and NO_x emissions, and CO_2 generation is directly tied to the efficiency of energy conversion from hydrocarbons.

One of the most effective ways to increase the efficiency of energy conversion is waste heat recovery. GE has developed the Organic Rankine Cycle (ORC), or ORegen system, which is able to operate at variable loads from 50 percent up to 100 percent in gas turbine power generation applications. Additionally, it can be located in areas where water is absent or scarce. The system's thermodynamic configuration allows modern plants to exceed 50 percent efficiency, even though the gas turbine simple cycle ranges from 30 percent to 40 percent.

Introduction

The rising concern about the role of CO_2 emissions in global warming, combined with the increase in energy demand spurred by developing nations that is foreseen over the next 15 years, has turned attention to potential CO_2-neutral energy supply solutions.

Gas turbine technology has been used in industrial applications for powering plant infrastructure and gas transportation since the early '50s. Many units built several decades ago are still running and still providing service. Improvements in turbomachinery technology have led to improved performance and cleaner and more reliable equipment.

GE Oil & Gas is constantly working to develop new solutions that better meet customer needs, and power generation units represent an important opportunity for efficiency improvements and emission reductions.

One of the most effective ways to increase the efficiency of energy conversion is waste heat recovery, and modern plants designed for baseload power generation and equipped with gas turbines typically employ a bottoming cycle. The standard bottoming cycle is the Rankine Cycle (RC), which recovers the heat from the gas turbine exhaust. The combination of the two is referred to as a combined cycle.

GE's Organic Rankine Cycle (ORC), referred to as ORegen, is a system for waste heat recovery from gas turbines. It operates at variable loads from 50 percent up to 100 percent in power generation applications and can be located in areas where water is absent or scarce, overcoming the limitations of the traditional water/steam Rankine Cycle when applied to gas turbines. The thermodynamic configuration allows modern plants to exceed 50 percent efficiency, even though the gas turbine simple cycle ranges from 30 percent to 40 percent.

How the ORC works

The ORC is a thermodynamic cycle based on the Rankine Cycle principle in which the working fluid is an organic, high-molecular weight fluid with a liquid-vapour phase change at ambient pressure, occurring at a lower temperature than that of water. The cycle permits the conversion of the heat source energy into useful mechanical energy, which can in turn be converted into electricity using an electric generator.

Figure 1 shows the ORC working principle process in a Temperature/Entropy diagram.

1. The working fluid (WF) is pumped into a series of heat exchangers where it is heated, vaporized and slightly super-heated (Pump and Heaters).
2. The WF passes through a turbine (Expander), where its pressure and temperature decreases and the useful work is extracted.
3. Since the WF temperature at the expander discharge is considerably higher than the condensation temperature, the WF passes through a regenerative heat exchanger that reduces the condenser load and preheats the WF before it enters the heat exchangers (Recuperator).
4. Finally, the WF is re-condensed (Condenser).

In the ideal cycle, the expansion is isentropic and the evaporation and condensation processes are isobaric. In the real cycle, the presence of irreversible processes lowers the cycle efficiency. Those irreversible situations mainly occur:

- During the expansion: Only a part of the energy recoverable from the pressure difference is transformed into useful work. The other part is converted into heat and is lost. The efficiency of the expander is defined by comparison with an isentropic expansion (Expander).
- In the heat exchangers: The WF path ensures effective heat transfer but causes pressure drops that lower the amount of power recoverable from the cycle (Heater).

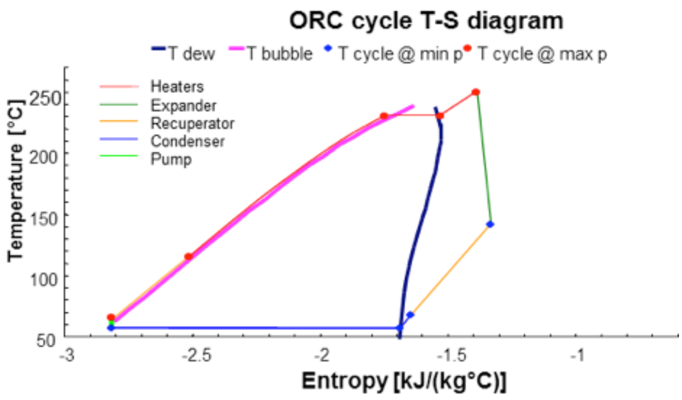


FIGURE 1 ORC T-S diagram

The TS curve presents a characteristic feature, where the vapor saturation line has a positive slope, while the same curve for water/steam has a negative slope everywhere. This fact, called retrograde behavior, has major implications for RC. In fact, fluids like water require considerable superheat to avoid excessive moisture at the turbine exhaust. But retrograde fluids allow expansion from the saturated vapor line into the superheated region, avoiding any moisture during the expansion process. The retrograde behavior also allows recuperating thermal energy from the hot vapor at the discharge of the expander, thus increasing overall cycle efficiency.

Using working fluids with boiling temperatures lower than that of water allows the use of ORC technology in several applications, and the recovery waste heat sources at low/medium temperatures where it is difficult to use traditional water/steam technology.

ORegen

The Organic Rankine Cycle developed by GE, ORegen was designed to recover waste heat energy from a variety of thermal sources (ranging from diesel and gas combustion engines to gas turbines to industrial processes with sufficiently high discharge temperature) and convert it into electric energy. The second loop is a thermodynamic cycle based on the Rankine Cycle principle, as described above.

When the first intermediate loop is used, the heating source and the working fluid are not in direct contact. Thermal oil, with high temperature characteristics, is used as the thermal vector. The diathermic oil and the organic fluid allow low temperature heat sources to be exploited efficiently to produce electricity over a wide range of power output, from a few MW up to 17 MW per unit. Figure 2 represents the ORegen process schematically.

The selection of the WF used for gas turbine waste heat recovery is a key factor in the system's design. GE Global Research in Munich, Germany, made a selection of the WF during the initial development stage of the arrangement. The study took into account several parameters:

1. Ideal vapor pressure
2. High critical pressure that allows greater expansion after boiling
3. High molecular weight that reduces the turbine size
4. An organic material with condensation temperature close to ambient temperature and high critical pressure
5. Vertical saturated vapor line in the T-S diagram, to avoid the presence of liquids at the end of the expansion
6. Environmental effect: low Global Warming Potential (GWP) and no corrosion issue, so that it is possible to use standard materials for piping

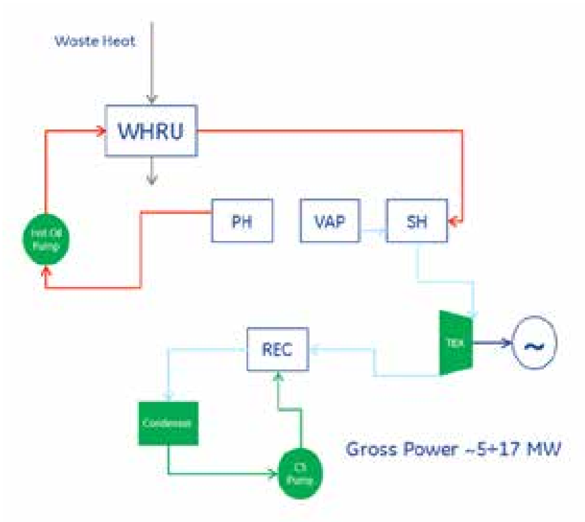


FIGURE 2 Schematic of the ORegen process

The analysis highlighted cyclopentane (C5H10) as the most suitable "compromise" fluid for this type of application, giving fair or high performance in all categories. The advantage of cyclopentane is that it provides very good efficiency over a broad waste heat temperature interval ranging from about 400°C to more than 500°C.

The purpose of the intermediate fluid (diathermic oil) is to transfer heat from the gas turbine exhaust gases to the working fluid. The hot oil also is used to increase system safety, avoiding direct heat transfer from the exhaust gases to the cyclopentane.

The selection criteria for the hot oil take into account the parameters of minimum pumpability temperature (TMIN) and operability range. Low minimum pumpability temperature also allows the use of hot oil in very cold climates, limiting winterization activities to the minimum. Features of the diathermic oil are:

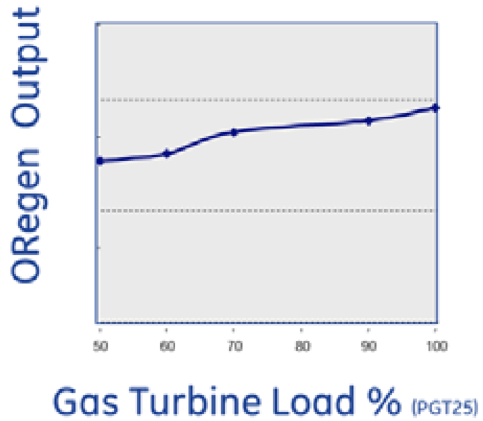
- Low freezing point and high temperature stability, which allow higher cycle temperature and higher efficiency
- High heat of vaporization and density
- Low environmental impact
- No additional EHS considerations
- Read availability at low cost

The selection of the diathermic oil and the working fluid is critical for the product development. Possible ORegen applications extend to every climate, from extreme cold locations, with minimum ambient temperature well below -20°C, to the extreme hot conditions of tropical and desert locations. The use of a suitable diathermic oil and cyclopentane as the working fluid allows the application of ORegen in every location.

The main advantages of the ORegen and ORC cycles are the facts that water is not required, the cycles can be remotely controlled, and there is layout flexibility, due to the presence of the intermediate hot oil loop.

The first fact makes ORegen technology a perfect fit for dry areas, locations where water is scarce or very cold places, so there is no need to install devices to protect equipment against freezing water. Water is becoming an increasingly precious resource in many places and it may be difficult and expensive to supply the quantity of demi water required by combined cycle. The second point makes ORegen technology a good fit for remote locations, which avoids the requirement to always have operators at the site. The layout flexibility is important for an installation on an existing unit, where the space close to the machine often is very crowded with balance-of-plant (BOP) equipment. The waste heat recovery unit on the gas turbine exhaust is the only equipment to be installed close to the gas turbine; all other equipment can be installed far from the gas turbine. The only interconnections are the oil piping, which also can be accommodated easily in a crowded plant.

When the gas turbine is not operated at full load, as in mechanical drive application, the Organic Rankine Cycles have better performance than the steam cycles, whose operability is difficult. In a case study with a PGT25 turbine, it was demonstrated that when the gas turbine load is reduced to 50 percent, the ORegen system can recover 80 percent of the maximum power.



Along with ORegen technology for power generation applications, an ORegen drive application in which the ORegen turboexpander drives a centrifugal compressor also is being developed. In this application, a new compressor is used in tandem with the existing one, either to increase the station flow without burning additional gas, or to keep the station flow constant, which reduces the load of the gas turbine-driven compressors. The application is meant for oil and gas customers who aren't interested in generating electrical power, or who have plants in very remote areas that are difficult to connect to the electrical grid, but nevertheless want to improve the efficiency of their plants.

ORegen applications

The basic scope of supply of ORegen includes the following:

- Diathermic oil system with waste heat recovery unit and oil pumping system
- Organic fluid system with pumping system
- Turboexpander generator set
- Piping and BOP components
- Air or water organic fluid condenser

The system can handle the recovery of waste heat from the exhaust of small- to medium-size gas turbines in simple cycle.

ORegen development also includes waste heat recovery from multiple gas turbines, combining the oil production from each gas turbine. This feature, called Parallel Oil configuration, is important for plants with multiple gas turbines installed – a very common occurrence in the gas compression stations – because only one ORegen system is installed for the plant instead of one system being installed for each gas turbine.

The term Direct Oil is used when referring to the configuration that connects one gas turbine to one ORegen system. All of the first ORegen systems sold are in Parallel Oil configuration.

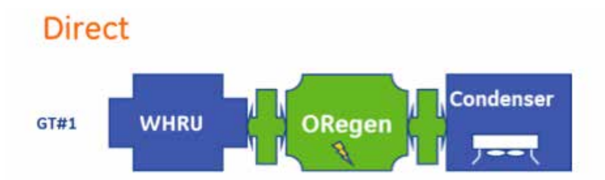


FIGURE 3 ORegen Direct Oil configuration

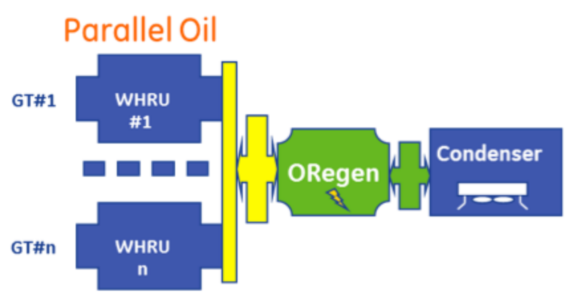


FIGURE 4 ORegen Parallel Oil configuration

GT Model	GT Power	Exhaust Flow	Exhaust Temp	GT Efficiency	ORC Output	System Efficiency
	(KW)	(Kg/sec)	(°C)	(%)	(MWe)	(%)
PGT25(*)	23 261	68.9	525	37.7%	6.9	48.9%
PGT25+ (*)	31 364	84.3	500	41.1%	7.9	51.5%
PGT25+ G4 (*)	33 973	89.0	510	41.1%	8.6	51.5%
MS5001 (*)	26 830	125.2	483	28.4%	11.3	40.4%
MS5002B (*)	26 100	121.6	491	28.8%	10.8	40.7%
MS5002C (*)	28 340	124.3	517	28.8%	12.4	41.4%
MS5002D (*)	32 580	141.4	509	29.4%	13.8	41.9%
MS5002E (*)	32 000	101.0	510	35.2%	9.8	47.2%
MS6001B (*)	43 530	145.1	544	33.3%	15.6	45.2%
MS7001E (*)	87 300	302.0	535	33.1%	31.1	44.9%
LM6000 (**)	43 397	125.6	454	41.7%	9.7	51.1%
LMS100 (**)	100 700	216.8	423	43.8%	15.7	50.8%

The first system sold in Canada recovers the waste heat from the exhaust of three gas turbines in a gas compression station, generating approximately 16.5 MW at the generator terminals. Two of the three gas turbines will always be running, while the remaining one will be on standby. The second application in Brunei recovers the waste heat from the exhaust of four gas turbines (three running and one standby) in a power generation station, generating approximately 16.5 MW at the generator terminals. The third application in Thailand recovers the waste heat from the exhaust of three gas turbines (two running and one standby) in a power generation station, generating approximately 12 MW at the generator terminals.

The table above shows the power that can be recovered from each of the GE Oil & Gas gas turbines coupled in direct configuration with one Oregen system.

Conclusion

GE Oil & Gas continues development in the waste heat recovery sector. ORegen, a waste heat recovery system, is capable of recovering waste heat from the exhaust of gas turbines operating at variable loads of 50 percent to 100 percent in mechanical drive or power generation applications and/or located in areas with limited water availability.

Imagination at work

GE Oil & Gas - Global Headquarters
The Ark - 201 Talgarth Road, Hammersmith - London, W6 8BJ, UK
T +44 207 302 6000
customer.service.center@ge.com

Nuovo Pignone S.p.A. - Nuovo Pignone S.r.l
Via Felice Matteucci, 2 - 50127 Florence, Italy
T +39 055 423 211
F +39 055 423 2800

Downstream Technology Solutions
4424 West Sam Houston Parkway North - Houston, TX 77041-8200, US

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GEA31935 (07/2015)