OPERATIONAL EXPERIENCE ON ORC USE FOR WASTE HEAT VALORIZATION IN BIOGAS POWER PLANT

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ABSTRACT

In the overall market of ORC, even though there is a lack of offer in the smaller power ranges (less than 100kW electrical), the potential markets and applications remain very significant. That is why the company ENOGIA was founded in 2009 by four French engineers, which purpose was to develop its own micro-turbine/alternator technology instead of the more classic “modified refrigeration screw or scroll compressor”.

The development of the ENOGIA turbo-expander took several years in order to bring an efficient, reliable and affordable expander, as well as the complete ORC system. The development path of these will be presented, as well as the many prototypes built and tested.

The current target market of ENOGIA is biogas power plant efficiency enhancement, and in order to bring efficient and cost efficient solutions for this market, we aim to improve our products with experience from real on-site demonstrators. Different ORC layouts for biogas plants enhancement were identified and will be presented. The two main approaches used are: The hot loop can use water from the biogas engine jacket, which provides low input temperatures, and can be coupled to an exhaust gas exchanger. In order to obtain higher input temperatures, it is possible to design the ORC in “direct evaporation” configuration using directly the exhaust gases. With this layout, higher condensing temperatures can be achieved and heat can therefore be used for customer applications.

In order to show return of experience on the proposed ORC for biogas plant layouts, operational perspectives from significant references of ENOGIA will be presented. Eventually those were positive experiences and ENOGIA is currently developing the product range for future projects.

1. INTRODUCTION

In the overall market of ORC, although there is a lack of commercial offer in the smaller power ranges (less than 100kW electrical), there are very significant potential markets and numerous applications, from waste heat valorization to biomass or geothermal renewable electricity production. This is the reason the company ENOGIA was founded in 2009 by four French engineers. The purpose of ENOGIA was to develop its own micro turbine expander / generator module instead of the more classic approach of “modified refrigeration screw or scroll compressor”, because it allows much more design flexibility of the ORC system.

The development of the ENOGIA turbo-expander started in 2009 and took several years in order to bring an efficient, reliable and affordable expander, as well as the complete ORC system. Hereunder is presented the development path of these, as well as the many prototypes built and tested.

2. TURBINE EXPANDER DEVELOPMENT

The first turbine was a small 3kW demonstrator with a very short lifetime of the bearing system. It was meant to be a proof of concept of the high speed close coupled turbine generator, in a hermetic housing. Thanks to this prototype, size of stators and rotors, shape of bladings, were adjusted and tested in both design and off design conditions. Even if this prototype showed significant weaknesses in the bearing system and the sealing system, the main purpose remained showing that the ENOGIA turbine is technically feasible before focusing on its lifetime in order to minimize maintenance costs.

Figure 1: First turbine prototype and bladings

The second version represented the first prototype for a 10kW unit. The expander bearing system was significantly improved with an active oil lubrication system in order to have a better long-term holding. Thanks to adapted components, we succeeded in having a very satisfying fluid-tightness. However this second version met the limitations of the electric generator, which had unsatisfying thermal transfer from the windings to the water cooling system.

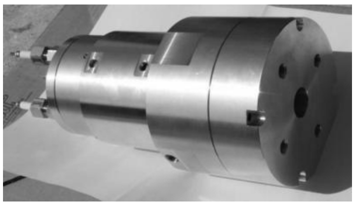

Figure 2: Second turbine prototype

A third version used a different permanent magnet generator type, with direct contact between the steel laminations of the stator and the cooling system, and proved to be very reliable and thermally efficient, with reasonable temperature levels in the windings, even at full power or even higher than maximum specified power.

Figure 3: Third turbine prototype

An important difference between the first turbine prototypes and the operational ORC modules for biogas units are the temperatures reached at the evaporator of the ORC unit. Indeed the first tests were made in regenerative cycle with relatively high temperatures, when the biogas genset gives to the ORC warm water at 90°C, sometimes even less. Because of this, ENOGIA had to adapt its technology for biogas applications, especially the working fluid and associated rotors and stators. The company is now able to produce the two products in standardize version: low temperatures without regeneration and medium temperatures with HFE fluid and regenerative cycle.

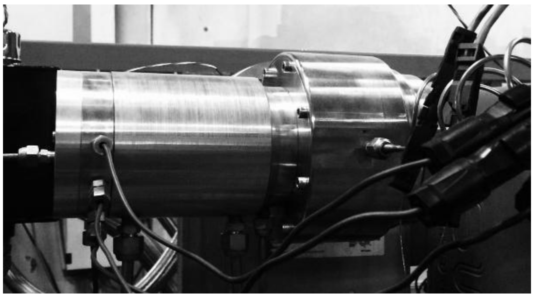

Figure 4: Commercial ENOGIA 10LT-V6 turbine in operation

One of the next steps was the improvement of the fluidic part including some modifications in the overall architecture to minimize pressure losses. The machining was also optimized to obtain the smoothest lines as possible. Moreover, the made-to-measure electric generator and shaft were another required stage to guarantee the turbine performance and reliability. The last changes were related to maintenance, making disassembly easier. ENOGIA is now following an optimization policy concerning mechanical parts in order to reduce production costs.

2. ORC FOR FARM BIOGAS

The current target market of ENOGIA is biogas power plant efficiency enhancement, and in order to bring efficient and cost efficient solutions for this market, the company aims to improve the products with experience from real on-site demonstrators.

3.1 System architecture

Different ORC layouts for biogas were identified and the two main approaches used are:

- The hot loop can use water from the biogas engine jacket, which provides low input temperatures, generally at 90°C. It can be coupled to an exhaust gas exchanger in order to recover a maximum of waste heat. In this configuration, the cold loop temperatures are around 30°C which is often too low and more complicated to reuse than higher temperatures. Sometimes, farmers can use this output heat to dry cereals, to dry straw, to heat greenhouses or to have pre-heat water for cattle. Nevertheless, given the low temperatures, the ORC is usually used only to generate more electricity.

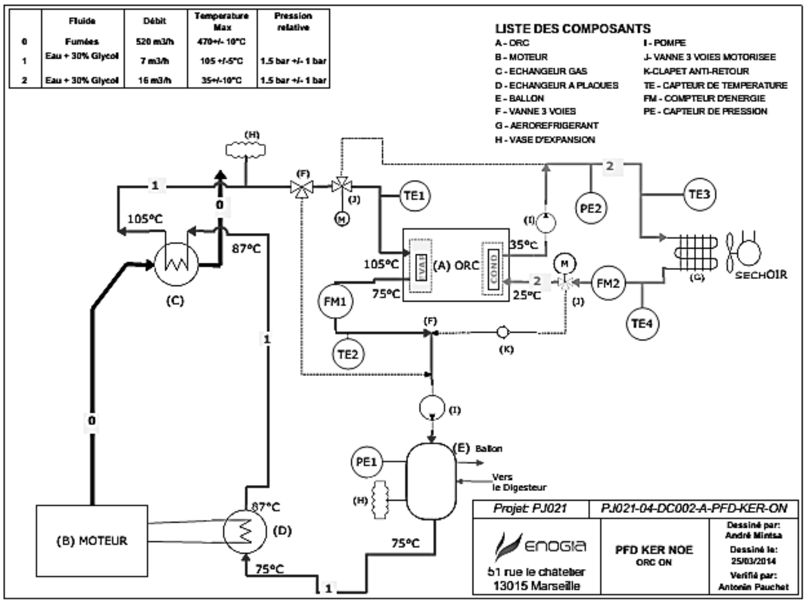

Figure 5: hot water ORC layout (Ker Noé, France)

- In order to obtain higher input temperatures, it is possible to design the ORC in "direct evaporation" configuration using directly the exhaust gases. With this layout, higher condensing temperatures can be achieved and heat can therefore be used for further customer applications especially domestic hot water. The first testing session on this technology with an ENOGIA prototype ORC unit was successfully achieved and the results are really promising.

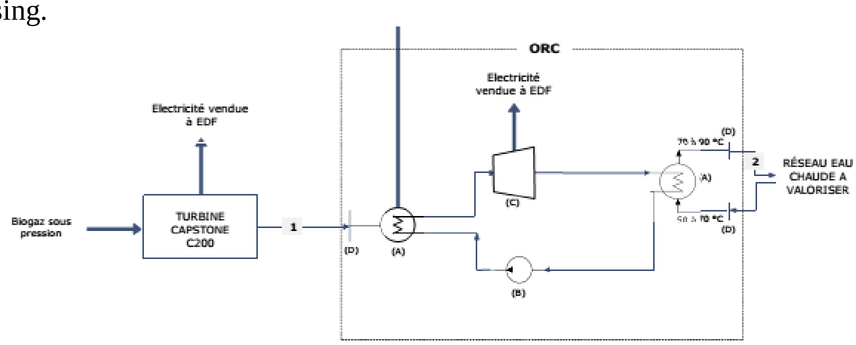

Figure 6: Exhaust gas ORC layout

3.2 Operational experience

In order to show return of experience on the proposed ORC for biogas plant layouts, operational perspectives from significant references of ENOGIA will be presented.

The first reference is the Treviso project in Italy. The ORC is a standard 10 kW unit using low temperatures: 90-70°C for hot loop with a thermal power of about 65kW and cooling ground water around 10-15°C. The main issue was the configuration of the existing plant. The exchanger of the biogas engine was too far from the ORC and piping not enough isolated, resulting in a huge loss of thermal power before the exchanger. The cooling ground water lead to working parameters quite specific (very low condensing pressures) when almost all projects use dry coolers. Thanks to this project, ENOGIA could learn and improve its technology especially concerning pump cavitation, efficiency, lubrication and vibrations besides the biogas engine.

Figure 7: Treviso ORC container with exhaust heat recovery

The second significant reference is the Ker-Noé project in France. It is the same configuration than the unit in Italy, except the cooling loop working with dry coolers. The owner uses the extra heat to dry cereals so that there is a minimum of waste heat in his biogas plant. The main feedback of this project was that theoretical pressure ratios were different from the operational ones so that ENOGIA could redesign the turbo-generator injectors. After almost a year of working, performances of the ORC were analyzed with data from tele-monitoring. The theoretical power production was about 7 kW_e with a thermal power input of $121kW_{th}$.

Although the engine thermal power was lower than predicted (about $20kW_{th}$ less), the ORC produces more than $6kW_e$ with the best adapted cooling. Finally, the power delivered corresponds to 90% of what ENOGIA expected.

At full load, the isentropic efficiency of the ORC expander reaches 70% no matter the cooling temperatures are, with a generator estimated efficiency of 80%. Except little changes in the regulation law to improve it, the other theoretical parameters were adapted to the existing installation. After these improvements, efficiencies attained 5 to 7 percent range with the very low grade heat available (90/70°C CHP water loop).

Figure 8: Ker Noé ORC unit

As it was said hereinabove, ENOGIA was working on another configuration since 2013, using directly exhaust gases. The issue of “direct evaporation“ was to design an adapted gas-fluid exchanger.

This technology was tested for a special non-stationary demand with the help of IFP Energies Nouvelles (also called IFPEN), a major research and innovation center, trusted partner of ENOGIA. The tests made during 2014 and 2015 were very successful and prove the high performance of this technology, which attained approximately 10% gross efficiency.

What makes the ORC unit more efficient is also the regenerative cycle used in conjunction with a novel working fluid, a HFE fluid from 3M; indeed it improves about 30% the overall performance. Another strong point of this technology is the capability to operate with higher condensing temperatures, in the 70°C range, allowing using the ORC unit as a real CHP.

On another side, ENOGIA had been forecast the necessity of security components in the conception phase, knowing what high temperatures imply. During testing, the by-pass on the exhaust gases had been engaged several times. A unit has been recently delivered for an installer of biogas solutions and the hope will be to include an ORC on each of its installation as the technology seems really efficient.

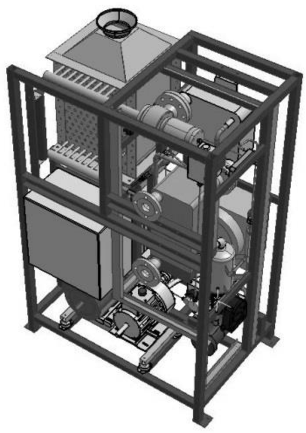

Figure 9: 10kW “Direct Evaporation” ORC unit

3. CONCLUSION

Since 2009, several ORC turbines were engineered and tested for small ORC applications, resulting in a commercial product that is available from ENOGIA, the ENO-10LT 10 kW low temperature ORC module.

This product has been tested at several customer premises in France and in Italy. Eventually those were positive experiences and ENOGIA is currently developing the product range for future projects. The company has developed a wider range of power and has already built 20kW, 40kW and 100kW units, although the last one uses a technology of turbine completely different given the higher power. Current prices go from 1800 to 3000 € per kW, depending on size and features, for ENOGIA's small ORC product range.

ENOGIA R&D team currently develops products with a direct gases evaporator, which will be available for farm biogas, and which first unit will be installed on the exhaust of a Capstone C65 turbine in a farm biogas plant in France. A key advantage of this technology will be that it will also produce hot water, improving the electrical efficiency of the biogas plant, but with very few loss of heating power as well.

ACKNOWLEDGEMENT

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