DECENTRALISED ENERGY FROM WASTE PLANTS BASED ON ORGANIC RANKINE CYCLE TECHNOLOGY

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ABSTRACT

Waste to Energy sector is looking continuously at the development and implementation of new solutions aimed to reduce CO_2 emissions, improve its energy efficiency and lower environmental footprint. Within this framework, the selection of the right corrective actions and the proper technologies in support of such actions is crucial. Among the various options available, the conversion to small/medium decentralized Energy from Waste plants (plants with an annual capacity <100,000 tons) represents an effective and profitable solution to hit the target of sustainability.

Organic Rankine Cycle (ORC) is a state-of-the-art technology that allows converting efficiently waste heat into electricity, showing major advantages over alternative technologies. Thanks to the use of organic working fluids, ORC systems result in simple power plants with no water consumption, extremely low operation and maintenance costs, high availability and simplicity of operation, where the automatic functioning does not require dedicated personnel neither in standard operating conditions nor in off-design conditions (partial loads, start-and-stop procedures etc.). All these features make the ORC technology very appealing in heat recovery applications from industrial process and explain why these systems are becoming more and more popular, especially in steel and cement industries. Upon these experiences, also the Waste to Energy industry could benefit of this technology, considering its implementation in small / medium Energy form Waste plants.

This paper brings to light the advantages offered by decentralized small/medium Energy from Waste plants compared to big traditional Energy from Waste. Medium Energy from Waste plants allows to minimize logistics costs and has a higher community consent. Small Energy from Waste plants are the best options for remote locations, which are typically off-grid, suffer from high diesel generation costs, and have poor waste management practices as the small waste volume does not justify a recycling plant.

ORC technology for power generation offers significant advantages in terms of high performances, dependability and lower OPEX comparing to traditional Rankine Cycle technology; especially for such small/medium Energy from Waste plants where the operational costs should be minimized.

Keywords: decentralized Waste To Energy, Organic Rankine Cycle, incineration, Energy From Waste

1. INTRODUCTION

ORC technology is widespread in the world for low-enthalpy geothermal applications. Yet in the last decades an important market has developed for ORC medium-high-enthalpy applications, especially for plants fuelled by combustion of solid biomass or for industrial heat recovery plants.

Further to these recent developments, ORC technology has been successfully applied even in WtE applications. Up to day three different ways to use ORC turbogenerators in WtE plants have been implemented:

· Recovery of heat streams in existing heat-only waste incinerators;

· Heat recovery from landfill gas engines' exhausts;

· Decentralized small/medium scale waste incinerators or waste gasifiers.

Those ways of using ORC turbogenerators in WtE will be described in this paper, showing few examples of recent projects and discussing over the main pro and cons compared to traditional bigger central EfW plants.

2. THE ORC TECHNOLOGY

The principle of electricity generation by means of an ORC process corresponds with the conventional Rankine process. The substantial difference lies in the fact that an organic working medium with favourable thermodynamic properties [1, 2, 3] is used instead of water. The working principle and the different components of the ORC process are shown in Figure 1. The ORC process is connected with the thermal source via thermal oil, pressurized water or saturated steam loop. The ORC unit itself operates as a completely closed process utilizing a suitable organic fluid (such as silicon oils, refrigerants or hydrocarbons) as working medium. This pressurised organic working medium is vaporised and slightly superheated in the evaporator and then expanded in an axial turbine which is connected to an electric generator. Subsequently, the expanded organic working fluid passes through a regenerator (in which in-cycle heat recuperation takes place) before it enters the condenser.

The condensation of the working medium takes place in a direct air condenser at a temperature level as close as possible to the ambient temperature or, especially in Cogeneration Heat and Power (CHP) applications, by means of a water condenser. In this second scenario the condensation occurs at a temperature level which allows to use the recovered heat as district or process heat. Then, the liquid working medium passes the feed pumps to achieve again the appropriate pressure level of the hot end of the cycle. In order to obtain a high electric efficiency (defined as the net electric power produced / thermal power input) of the ORC unit itself, it is necessary to keep the back-pressure of the turbine as low as possible, according to the needs of the thermal users (district heating or process heat) in case of CHP application.

Thanks to the thermodynamic characteristics of the organic media used as working fluid in the ORC systems, the typical enthalpy drop across the ORC turbines employed in medium-high-enthalpy applications is in the range 100 – 250 kJ/kg. This thermodynamic characteristic leads to a rather low fluid speed in the turbine (thanks to the high molecular weight of the organic media the speed of sound is relatively low) and to a relatively low rotational speed of the turbine itself (which is typically about 3.000 rpm). One of the result is that ORC plants are relatively silent: the highest noise emissions occur at the generator and amount to about 88-90 dB(A) (SPL at a distance of 1 m).

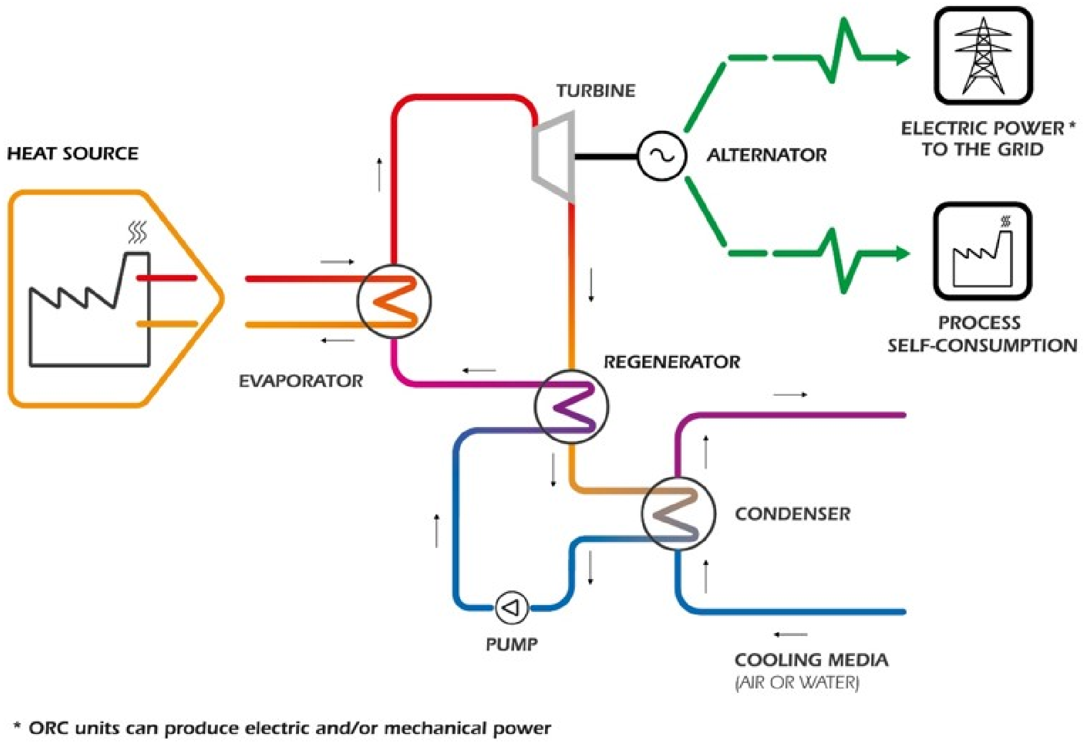

Figure 1: ORC working principles and main components

Another consequence, considering also the lubricant-like behaviour of the organic fluids (and the fact that they are not corrosive nor erosive) and that the ORC process is closed loop (no losses of the working medium take place), is that the operating and maintenance costs of the ORC systems are low.

The usual lifetime of ORC units amounts to more than twenty-five years, as proven by geothermal and biomass applications. The organic fluids used as working medium have the same lifetime as the ORC since they do not undergo any relevant ageing.

Compared to competing technologies, in the range from 0.2 to 15 MWe, the main advantages obtained with the ORC solution are the following:

· High cycle efficiency (especially if used in cogeneration plants);

· Very high turbine efficiency (up to 90%);

· Low mechanical stress of the turbine, thanks to the low peripheral speed;

· Low RPM of the turbine, allowing the direct drive of the electric generator without reduction gear;

· No erosion of the turbine blades, due to the absence of moisture in the vapour nozzles;

· Very long operational life of the machine due to the characteristics of the working fluid that unlike steam is non eroding and non-corroding for valve seats tubing and turbine blades;

· No water treatment system is necessary.

There are also other advantages, such as simple start-stop procedures, quiet operation, minimum maintenance requirements and good partial load performance [4].

3. DECENTRALIZED SMALL SCALE WASTE INCINERATORS OR WASTE GASIFIERS

The Waste Framework Directive 2008/98/EC (WFD) defines an energy efficiency criterion, often referred to as the "R1 criterion" or the "R1 formula", which sets the condition for a municipal solid waste incineration facility to be considered as a Recovery operation or as a Disposal operation.

The main objective of the R1 formula is to promote the efficient use of energy from waste in WtE plants. It takes into account the plant's effectiveness in recovering the energy contained in waste but also the effective uses of energy as electricity, heating and cooling or processing steam for industry.

According to [5] and [6], when looking at trendiness of R1 values and at the size of plant, it can be noticed that the R1 value of a WtE plant tends to increase with size. More in detail, in the case of the CHP plant, when looking at the trend line, the R1 value is almost constant, with a loose dependency on the size, while in case of heat-only and electricity-only plants the R1 value increases more clearly with the increase of plant capacity.

The data show a clear dependence of the R1 factor on the plant size for electricity-only and heat-only plants, while this dependence is loose for CHP plants.

The use of ORC technology can help to reach higher efficiency even in small-medium scale WtE electricity-only or CHP plants.

3.1 Case study: Small-medium scale WtE plants with ORC turbogenerators

Currently most of the high-enthalpy ORC projects in Europe are in the field of the cogeneration of heat and power from wood biomass. Standard ORC units for CHP or electricity-only applications in the range from 0.2 to 15 MWe are available in the market. These ORC turbogenerators can be easily integrated in small-scale solid waste incinerators or waste gasifiers. Here in the table 1 below a list of Turboden references in Waste to Energy plants.

Project	Order year	Country	Waste treatment technology	ORC gross power (MW)
Agrivis S.p.A.	2003	Italy	Industrial waste incineration plant	0,5
MIROM Roeselare	2007	Belgium	MSW incineration plant	3,0
E&S Energy S.p.A.	2009	Italy	Landfill gas engines	0,5
Albany County	2010	USA	Waste incineration plant	1,0
HSY	2010	Finland	Landfill gas engines	1,3
ITC	2011	Turkey	Industrial waste gasifier	5,3
Alcea,Groupe Seche	2013	France	MSW incineration plant	2,7
ITC	2013	Turkey	Industrial waste gasifier	5,3
VEOLIA Rhin-Rhône	2014	France	MSW incinerator	0,7
Kantor Energy	2015	UK	RDF incineration	6,5
Ortadoğu Enerji	2016	Turkey	Landfill gas engines	2,3
Ortadoğu Enerji	2016	Turkey	Landfill gas engines	4,6
City of London	2017	Canada	Industrial waste incinerator	0,6
SABA	2017	Poland	Industrial - medical waste incineration	1,0
undisclosed	2016	Japan	Sewage sludge incineration	1,0
Suez	2018	Romania	Sewage sludge incineration	1,2
YFY	2018	HK	RDF incineration	10
TRV	2018	Italy	RDF incineration	1,5

Table 1. Turboden ORC references in WTE plants

Two representative examples are the 11 MWe plant of ITC in Turkey and the 1 MWe plant of SABA in Poland.
The former is located in Mamak, Ankara province, and is operated by ITC-KA Enerji Uretim Sanayi VE Ticaret A.S.. As described in the Figure 2 below, the plant is based on a rotary gasifier that treats about 320÷350 tons per day of non-pre-treated industrial and medical waste. The syngas produced is burned in combustion chambers and the hot gasses generated feed two thermal oil heat recovery units of 20 MW thermal capacity each. In the thermal oil heat recovery boilers the sensible heat in the hot flue gas is transferred to two ORC turbogenerators *55 HRS*, with nominal capacity of 5.5 MWe gross each. Being an electricity-only plant (no heat used), the condensing heat is dissipated through cooling towers and the gross electrical efficiency of the Turboden ORC is as high as 27%.

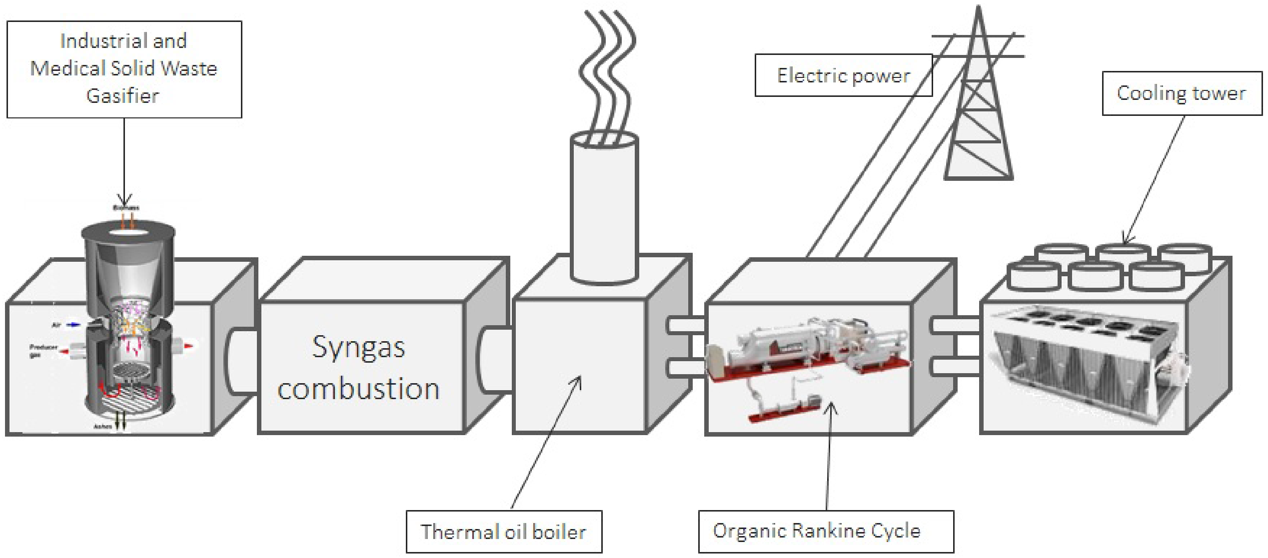

*Figure **2**. Basic scheme of the ITC waste gasification plant*

The latter case, the SABA project, it is a hospital waste incinerator located in Poland own by Saba Sp. z o.o.. Saba is a Polish manufacturer of adhesive and packaging. They had already an incinerator plant for the disposal of plastic to generate power for self-consumption and heat for their production processes. Saba decided in 2017 to invest in a second incinerator plant connected to an ORC turbine for electricity generation only. The incinerator gets waste from a hospital nearby and the electricity generated is sold to the grid.
The SABA plant was supplied by Promont, with oil heat exchanger to feed an ORC turbogenerator generating hot oil at 310°C. The ORC unit is a dissipative one with air coolers for power generation of 1 MWe, exported to the electric grid. The working fluid being used is a silicon compound for an electrical efficiency of about 24%.

4. DRIVERS AND BARRIERS OF SMALL SCALE EFW PLANTS

Waste is mainly an urban challenge, which means it is an increasing problem as world urban populations are growing. Therefore, large EfW (waste quantity > 500.000 ton/year) facilities have tended to be developed in proximity to major urban areas. However, when the volume of waste (< 100.000 ton/year), transportation costs or public opposition rule out large-scale mass-burn EfW, small-scale technologies can offer smaller communities in rural, semi-urban or remote areas a sustainable alternative to landfill. The challenge for small scale systems is to effectively meet emissions limits and regulations while dealing with the higher specific capital costs.

It is recognised that the costs, both operational and capital, are higher for small scale EfW facilities in comparison to larger plants, but that despite this, there are often other drivers which take precedence over economics alone. Whilst it may be challenging in some cases to demonstrate value for money, other benefits support a case for small scale EfW.

Small scale EfW plants are not uncommon; however, the presence of small scale EfW plants varies significantly between different countries. There are clear policy drivers which are influencing EfW development in general, but the decision to develop facilities on a small scale are more relevant to local communities and politics that might welcome the presence of plants sized to dispose their own waste production rather than a much larger amount..

Geography can be a driving factor for small scale EfW, but in many cases there are additional drivers.

Security of supply is a factor to consider. A larger plant might benefit of the economy of scale, but uncertainties in the supply will affect the economic risk assessment and might thus make it harder to initially finance the investment.

The advantages offered by small scale EfW, such as the treatment of waste close to the point of generation, the generation of jobs in the local community, and lower transport distances and others, all serve to increase the public acceptance of such facilities. With their smaller footprint, smaller scale EfW facilities can be more easily integrated in to existing industrial areas.

4.1 Policy and legislation

One of the main drivers for the establishment of EfW facilities has been the need to divert waste from landfill in order to treat waste higher up in the waste hierarchy. In Europe, the main policy drivers originate from EU Directives, such as the Landfill Directive (1999/31/EC), the Industrial Emission Directive (2010/75/EU)(IED) and the Renewable Energy Directive (2009/28/EC) (RED), all of which have encouraged the development of EfW infrastructure.

In response to these Directives, EU Member States have adopted a wide range of fiscal and regulatory measures in order to encourage EfW development, including imposing taxes and disincentives to landfill. These measures have made all other waste treatment operations more competitive. In some cases there has also been incentives and subsidies to specifically increase the uptake of EfW as well as taxes on energy or fossil carbon emissions.

Another aspect of policy and legislation is the effort for the plant to keep up to date with the changes in the legislation. In larger plants there might be dedicated people working with those specific questions, while in a small scale plant, this have to be integrated in the personnel’s ordinary work.

4.2 Economics

In addition to financial penalties such as landfill and carbon taxes, there are often financial incentives that make small scale facilities more attractive. Appropriate feed-in tariffs for electricity from waste as well as a certain period of time over which these tariffs are guaranteed are essential to drive market introduction of small-medium scale WtE plants forward.

In fact, the capital costs of an EfW facility do not tend to increase linearly with plant capacity. There are economies of scale that allows larger EfW plants to be more cost effective (the specific cost of the plant for waste disposal is lower for larger plants). For example, more efficient use of land, reduced unit costs, higher energy efficiency of some elements of the plant, and the fact that some costs such as access roads, weighbridges, development costs and engineering design typically do not increase in line with plant capacity. Some of the operational costs are also higher for a smaller plant: the costs for periodic measurements of emissions and the need for quality assurance and control of the instruments used in emission monitoring are examples that are not proportional with size of plant, but are related to the number of instruments and/or number of production lines in the plant and are disadvantageous for smaller plants.

4.3 Energy Demand

In general there is a demand for electricity especially from renewable energy sources. However, what is considered renewable from EfW plants and their priority in the grid differs between countries and this impacts the availability of incentives.

One of the drivers for small scale EfW plants can be the need for thermal and electric energy by a local small-medium user.

With regard to the electricity value, the fact of using the energy generated by the EfW plant to satisfy internal consumption (e.g. in a manufacturing plant) rather than exporting to the grid allows a much higher valorisation (especially in European countries where the electricity bought from the grid is charged with a high taxation to finance renewables).

Considering the heat valorisation, having a low cost energy source to fuel district heating networks provides a major beneficial economic impact to the project. The fact that the heat source needs to be within reasonably close proximity to the heat network becomes an obvious consequence, and distributed small-medium EfW plants may comply with this requirements much easier than larger EfW plants.

In countries where there is less demand for heat, or no established district heating infrastructure, small scale facilities may not be as attractive as the loss of economy of scale cannot be offset by the sale of heat.

4.4 Geography

Geography is a common factor influencing the decision to develop a small scale EfW facility. As an example, in remote locations transport of waste can be difficult and expensive; this might make a small scale plant more attractive.

This is the main driver of the development of small scale EfW facilities on islands, together with the lack of landfill capacity, especially for on smaller islands.

There might also be a desire to be self-sufficient in managing waste by developing an independent local solution for waste treatment and thereby avoiding transports of waste to other areas, also considering the opportunity for district heating.

Conversely, communities on islands or other remote locations may oppose EfW, even at a small scale, due to perceived negative impact to the environment and tourism.

4.5 Security of Supply

When considering the supply of combustible waste for an EfW facility, for a small scale facility this might be easier, making possible to secure the necessary amounts of waste with few suppliers and in in advance. This can be a crucial factor when obtaining financing for the plant, since a large part of the revenues are related to the gate-fee payed for incoming waste.

Larger plants generally have a greater area of uptake and are, in some cases, dependant on commercial and industrial waste as well as MSW from public procurement. Depending on the treatment capacity present in a region or nation, there might be a tight competition for the waste. This in turn might both lead to lower gate fees and insecurity of supply, both of which represent larger risks for the party financing the plant.

Considering the lower amount of waste a small-medium EfW plant need for its operation in comparison to larger plants, the former plants may be authorized, designed and developed for some specific types of waste fuels, not being flexible to accept many differ wastes. This would result in considerable advantages in the authorization process as well as on the economics, especially with regard to the investment and operational costs of the combustion and the flue gas treatment systems.

4.6 Public Acceptance

Public opposition of EfW differs significantly from country to country.

In countries where there is a good track record of government policy supporting EfW as part of an integrated waste management system, public opposition is generally low. The public ownership of plants through specific non-profit companies has also aided the public acceptance of EfW facilities and the guarantee of protection of public health.

Small scale distributed EfW plants may use positive levers when being described to the public, like high energy efficiency (especially in case the heat generated is used), low impact on road transport, local sourcing for the waste, and in general the circular economy principle applied to waste (the generated by a community is disposed in the same community extracting the maximum value from it, e.g. heat and electricity).

Small scale EfW can have an advantage, especially when creating a connection with the public and the waste that they generate. The small scale can be a benefit when selling the concept to stakeholders at a planning stage, and in subsequent public engagement. It may be also judged to be easier to obtain the relevant planning permits for a small scale plant than for a larger scale. There is often only a very small amount of local opposition during the planning, construction and operation of small facilities.

4.7 Technical issues

Technical issues are not deemed to be a specific barrier. Technologies deployed at small scale are established, and include conventional combustion facilities such as moving grate and oscillating kilns, and Advanced Conversion Technologies.

With regards to technology, there has not been any significant development in the technologies applied to small scale plants. The dominating conversion technology is combustion, which can be done in moving grate fired boilers, fluidized bed boilers, rotary and rocking furnaces or other technologies.

In some specific markets there have been increases in plants with alternative conversion technologies, such as gasification and pyrolysis.

In the future, with the increasing diffusion of distributed small-medium EfW plants the development of smaller scale EfW facilities using Advanced Conversion Technologies - which enable the flexibility in the outputs of the EfW - are likely to be developed at a smaller scale.

Most gasification and pyrolysis technologies are based on modular designs and are often smaller than conventional combustion facilities. These technologies ae often found and popular in small-medium EfW plants.

4.8 Financing

In terms of waste disposal capacity, large EfW plants might be 10-20 even 30 times larger than small-medium distributed plants. Even considering an economy of scale effect on the specific cost of the waste disposal capacity, a larger plant has a total cost that can be easily 10 times greater than a small distributed plant.

5. ORC ADVANTAGES IN FAVOR OF DECENTRALIZED WTE

Several technical-side constraints are of great importance for decentralised plants. The technology shall be robust and highly available, and plants shall be designed to run in unmanned operative conditions: a high level of process control and process automation is necessary. Other important factors are a good partial load behaviour and the ability to handle quick load changes. A high number of full load operation hours and high overall efficiency are crucial factors for the economic performance of the plant.

The ORC technology possesses all these features and thanks to its property of converting efficiently low-medium-enthalpy thermal sources into electrical energy, it proves to be the best solution for small-medium scale WtE plants.

Here below in figure 3 it is shown a comparison between traditional Rankine Cycle and Organic Rankine Cycle highlighting the main advantages of ORC technology which are relevant for decentralized WTE plants as mentioned above.

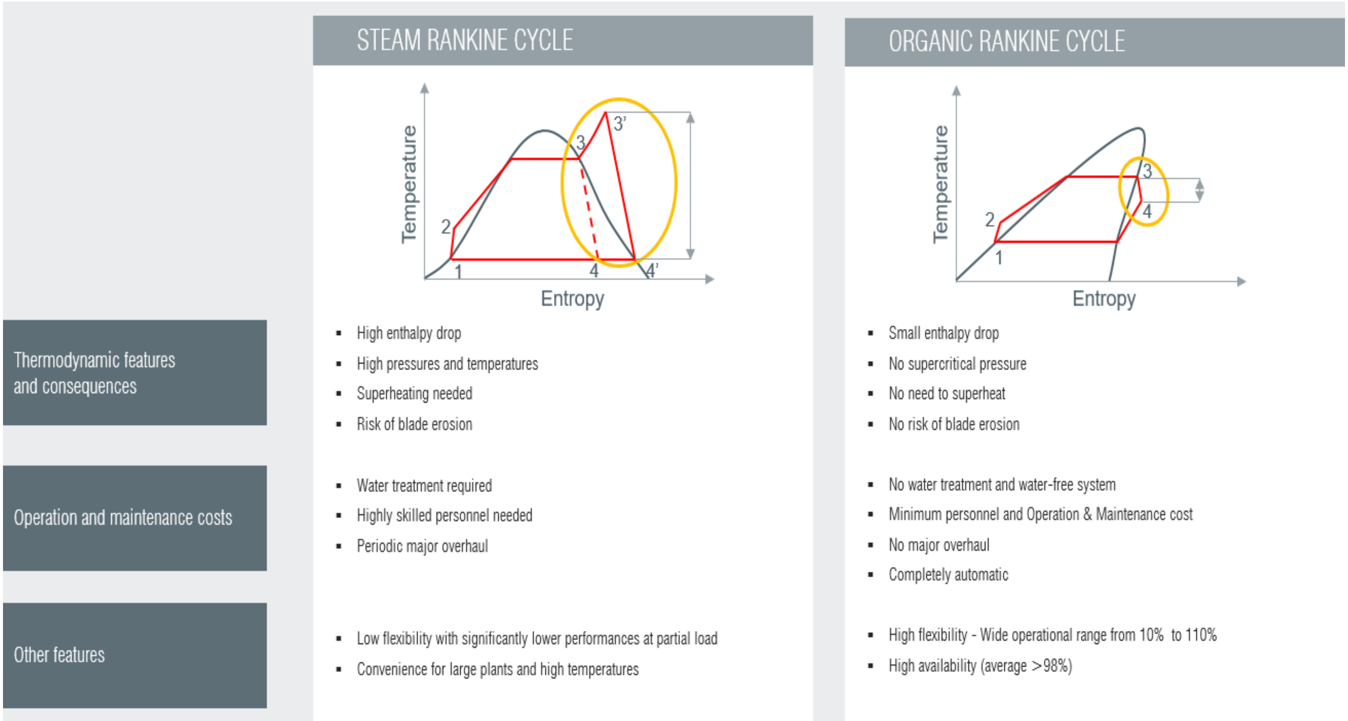

Figure 3: comparison of Steam Rankine Cycle (RC) and Organic Rankine Cycle (ORC)

The main advantages are due to the utilization of high molecular mass organic fluid allowing larger-diameter turbine with less stages and lower rotational speed. All those technical features translates to lower mechanical stress and blade erosions with benefits on both operation and maintenance requirements.

Some operational advantages are also simple start-stop procedures, automatic and continuous operation, no operator attendance needed, quite operation, high availability (typically 98%), partial load operation down to 10% of nominal load and high efficiency at partial load as it is shown in figure 4.

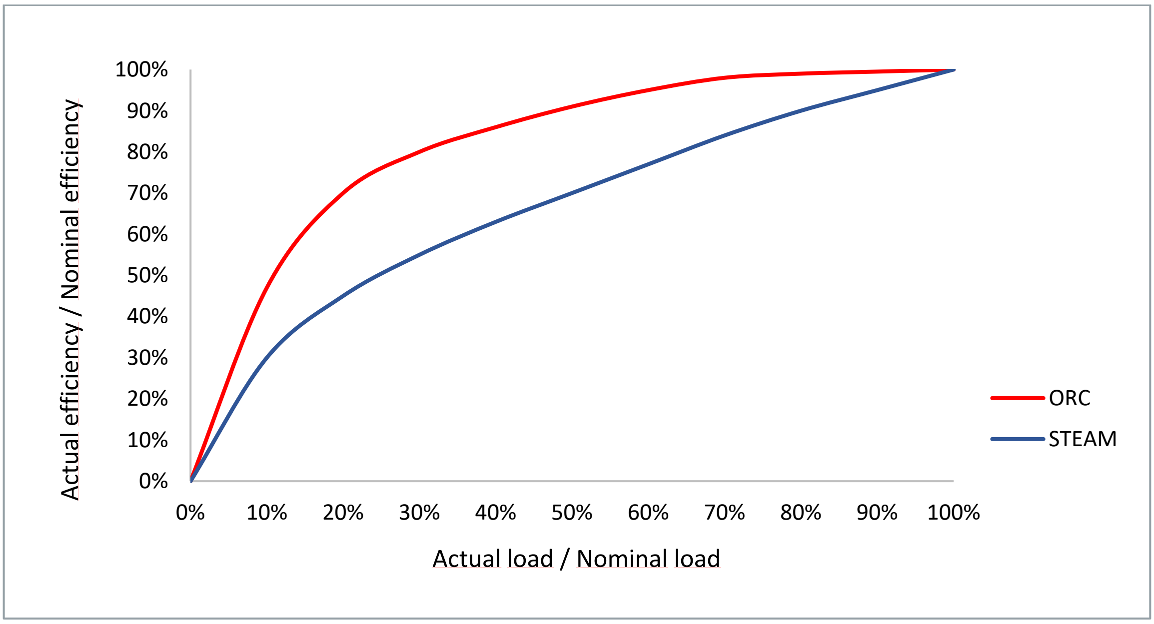

Figure 4: ORC – RC efficiency comparison at partial load

The figure 4 above shows how the electrical efficiency for ORC turbine stays above 90% of the nominal one even with 50% of the nominal load inlet the ORC. On the contrary steam turbine efficiency at partial load is much more penalized decreasing below 70% of the nominal figure. As known steam turbine suffers partial load operation due to the high risk of blade erosion.

6. CONCLUSIONS

A localized approach to waste management is beneficial as there is both expense and negative environmental impact associated with the long distance transfer of waste. In comparison to the traditional mass burn incinerators that are generally used at the moment, a small/medium incinerator (< 100,000 ton/y) with WHR and energy generation based on ORC technology has a very small footprint so it can be built in urban areas without looking out of place. As a result the problem of waste treatment can be addressed at a local level, close to the waste source, rather than spending huge amounts of the tax payer's money transporting waste around the country to landfill sites, an activity, in itself, that creates more traffic congestion and produces even more greenhouse gases.

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