21th International Conference on Renewable Energies and Power Quality (ICREPQ'23)
Madrid (Spain), 24th to 26th May 2023
Renewable Energy and Power Quality Journal (RE&PQJ)
ISSN 2172-038 X, Volume No.21, July 2023

Small-scale Waste Heat Recovery through incineration – a brief review

Bruno Eduardo Piske[1], Fernanda Lopes[1], Jonathan Utzig[1] and Vinicyus Rodolfo Wiggers[1]

[1] Department of Chemical Engineering
FURB, University of Blumenau
Rua São Paulo 3250, Blumenau, SC, 89030-000 (Brazil)
Phone: +55(47)3321-6052, e-mail: jutzig@furb.br and vwiggers@furb.br

Abstract.

This paper brings a brief discussion about small-scale waste to energy units, specifically using incineration. Solid waste treatment is an important issue around the world. Incineration has been applied successfully in developed countries. In the south hemisphere landfills and dumps are still predominant. This study aims to show that there is a lack of small-scale waste-to-energy (WtE) incineration plants and one of the reasons is associated with the high cost of the installations. The review performed showed that Organic Rankine Cycle (ORC) has been applied in small-scale plants as a tentative to reduce costs related to infrastructure required for electrical energy production. The air pollution control process also has a huge impact on this kind of installation. The lack of data and information about the operation of these plants turn difficult the study. Public policies to encourage small-scale waste energy recovery are required to improve these techniques, especially in developing countries.

Keywords. Solid waste, incineration, small scale, energy, refuse-derived fuel.

1. Introduction

The need to adopt renewable and environmentally conscious processes is ever-growing. Alongside this, due to population growth and economic development, solid waste management and disposal is a problem yet to be solved. In 2015, 2.01 billion tonnes of municipal solid waste (MSW) were generated and this number is estimated to grow to 3.40 billion tonnes by 2050, having its greatest increase in low-income countries [1]. Waste-to-energy technologies (WtE) are a potential solution to both challenges.

Among these, the generation of energy through incineration is a climate-neutral technology that has shown great success in developed countries with land restraints such as Japan and the European Union members, and processed 11 % of global waste in 2015 [1]. It has advantages such as greatly reducing waste mass and volume, destroying hazardous wastes, recycling metals, and small land requirements. Even though it is capable of processing virtually any type of waste, incineration facilities operate primarily on municipal and industrial wastes, having a smaller group dealing with hospital and commercial waste, sludge, and manure [2] [3].

Incineration is yet to be successfully applied in low to upper-middle-income countries in Latin America, South Asia, the Middle East, and North Africa [1], where waste management and disposal are done primarily in open dumps and landfills, which have large land requirements and offers no energy source generation.

The energy generated in incineration facilities is the result of the direct combustion of the waste stream, where the heat released is captured by a working fluid and used for thermal or electrical energy production. The process also has fly ash and bottom ash as by-products that must be properly treated and disposed of. The released gases are treated through proper unitary processes, referred to as air pollution control (APC) which controls its pollutant contents.

This paper aims to discuss about heat recovery through the incineration of waste, the overall operation of waste incineration plants, and infer ORC ease of installation and facilitating the implementation of this technology in the small waste stream by analysing some WtE incineration facilities.

2. WtE Incineration

The incineration process can be defined as controlled combustion to convert organic material to carbon dioxide and water vapor. A small number of other gases are also produced. Some aspects put WtE technologies ahead of other renewable energy processes. For instance, it requires much less land than wind and hydroelectric energies. It also greatly reduces residue volumes, can destroy dangerous compounds, and recycle precious metals. Landfills that were previously seen as mere dumps are now storage for energy and other materials. The waste heat recovery technologies are also the most versatile as it is suitable for a variety of wastes if it is suitable for combustion, which may be verified through Tanner's diagram [4]. Even though these technologies are versatile with their waste, the facilities which use them can deal with a specific type of waste input due to the innate high variety of existing wastes.

The combustion of solid wastes occurs in incinerators, where wastes and air are inputs, and combustion gasses and ashes are output. The commonly used incinerators employ moving grates, fluidized bed reactors, fixed bed gasification, bubbling and fluidized bed combustors, and rotatory kiln as technologies to promote combustion. The high temperature of the operation generates a huge toll on the equipment structure, which in turn requires specific materials and mechanics to withstand these conditions.

Before combustion, the waste goes through a drying stage in which its humidity is reduced to increase its calorific value. This operation is paramount to facilities operating on high water content waste such as manure and sludge.

The waste combustion might be carried out at a minimum of 850 °C to prevent the discharge of intermediary compounds in a high concentration such as dioxins, furans, PCBs, and aromatic and halogenated compounds. The operation requires an air injection ensuring oxygen presence in stoichiometric excess to cause complete oxidation of the comburent compounds in the waste stream. Fuel burners are commonly used for start-up scenarios and to maintain the process temperature when required.

The corrosive and high-temperature conditions of the combustion products require the use of castable refractory cement in the furnaces' construction. Commonly used castable refractory materials contain metal oxides such as aluminum, silicon, and chrome [5]. The presence of chlorine, nitrogen, and sulfur in the waste composition creates a non-negligible amount of hydrogen chloride, ammonia, nitrogen oxides, and sulfur dioxide in the gaseous output stream. Waste incineration deals with variations in moisture, calorific value, and composition causing instability of the combustion [6]. Corrosion is also an important issue.

A series of operations are realized to minimize pollution and control the composition of the gases emitted, the APC. This step consists commonly of adsorption, absorption, and filtration of the gaseous stream. The residue generated by this step is denominated in Air Pollution Control Residue (APCr). To reduce the formation of nitrogen oxides, gas injections of alkaline materials such as urea and hydrated lime solutions are carried out where the selective non-catalytic occurs, consuming nitrogen oxides and generating nitrogen and water. The hydrogen chlorine produced is removed from the stream via spray dryer absorption, where the component is captured by the liquid phase. The control of solid particles in the gas stream is done by adsorption of the material in adsorbent substances such as activated carbon or lignite coke. Finally, a filtration step removes the adsorbent and other solids with fabric filters.

Municipal solid waste and Industrial Solid Waste (ISW) have different classifications and destinations in Brazil. At this point, the variability of physical and chemical properties tends to be lower in waste from industries, which can lead to the more stable operation of incinerators [4].

Associating the proper disposal of waste with the generation of electricity is one of the positive aspects of incineration. To convert the heat generated through combustion, a Rankine cycle system is applied. In this way, conventional and organic Rankine cycles play an important role. The technology readiness level (TRL) methodology [7] can be applied to classify energy processes in terms of maturity and, according to Dovichi Filho et al. [8], conventional and organic Rankine cycles are technologies with the highest TRL.

3. Organic and Steam Rankine Cycle

The Rankine cycle, in its most simple form, requires a pump to circulate a working fluid, an evaporator where the fluid receives energy, and evaporates, an expander coupled with a generator, which transfers energy from the fluid to generate electrical energy, and a condenser where the fluid loses its heat and condenses. A pre-cooling and preheating step may be added to ensure a more efficient operation.

The energy carrier fluid commonly used is water, however, recent studies have shown that other fluids, such as Kalina, ammonia, and organic fluids may be more suitable for operations under specific conditions [9]. When the working fluid is organic, such as hydrocarbons and refrigerant fluids, the system is referred to as an Organic Rankine Cycle (ORC) (Figure 1), which requires a less robust infrastructure, reducing its capital expenses.

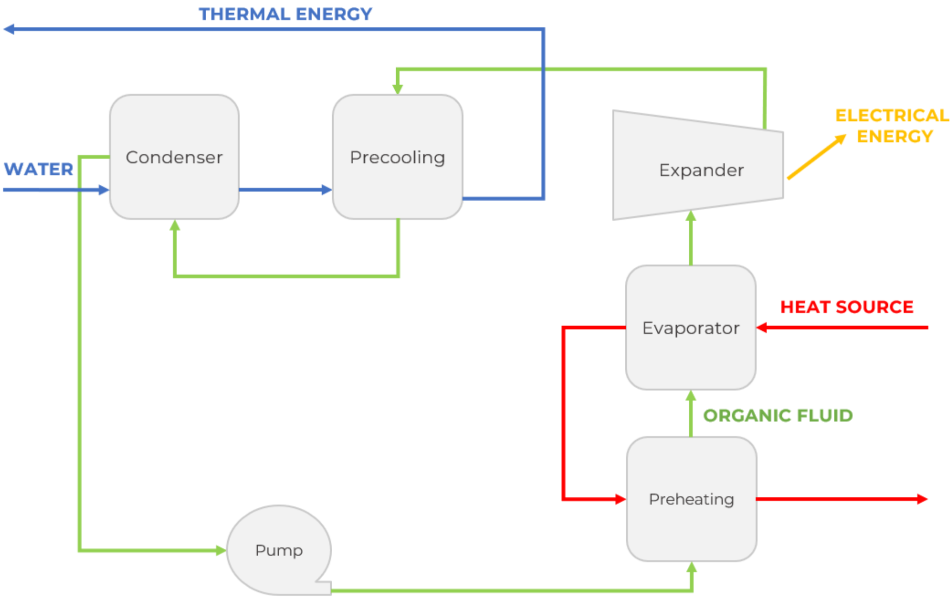

Fig. 1. General scheme of an ORC cycle using organic fluid precooling and preheating.

The organic fluids used are classified as dry and isentropic fluids, which have a positive or zero slope after the vapor saturation line. This property of some organic fluids eliminates the need for a superheating step before the vapor expansion since vapor quality is no longer a problem.

Figure 1 shows a diagram of an ORC system, which is very similar to the Steam Rankine Cycle (SRC) – not shown since it is well known. The main difference relies on that generally, ORC uses a thermal oil, heated in the thermal energy source to change energy with the organic working fluid used in the Rankine cycle. The organic working fluid operates in temperatures ranging from 150 to 350 °C.

To evaluate the facility's efficiency, the $Pe/\dot{m}$ variable is defined as the ratio of electrical energy generated and waste feeding capacity. It is also possible to broadly infer the waste calorific power as energy generated per waste mass.

ORC cycle might be more efficient when heat and electrical energy are produced. Therefore, it becomes attractive when coupled with industrial plants that can make use of this thermal energy, or close to cities that need district heating, usually in the form of hot water distribution [10].

Table 1 presents data from small-scale installations intended to convert waste into energy. One can note that installations with higher feed capacity generally use the steam Rankine cycle, while small ones choose the ORC.

Moving grates are the preferable combustion technology for bigger installations and when the wastes have a higher variation in composition, i.e., waste produced from municipal, commercial, and/or industrial activities. Fluidized beds and fixed beds are applied for more homogeneous feeding, especially when they come from a specific industrial activity. All these technologies are established, include conventional combustion furnaces, and do not present a barrier to the application of WtE plants worldwide.

Between the power plant installations related in Table 1, the one with higher $Pe/\dot{m}$ is the steam Rankine cycle system Newhaven Energy Recovery Facility, which manages 14 tons/h of municipal waste, producing 19.5 MWe. On the other hand, the one with the lower energy produced per fed waste ratio is an undisclosed ORC installation from Japan, that process 12.5 tons/h of dewatered sludge on a bubbling fluidized bed combustor, producing 1.0 MWe. Most of the installations with enough known data present $Pe/\dot{m}$ ratios of approximately 0.7. The case of an undisclosed ORC installation from Taiwan shows that even this type of cycle can work with a ratio greater than one, producing the higher electrical energy rate of the cycle category (9.0 MWe) and burning tires and refused-derived fuels. Except for this one, the other ORC installations produce from 0.6 up to 5.3 MWe, while the SRCs energy generation range from 7.0 up to 19.5 MWe.

Regarding the waste type, among the installations presented in Table 1, it is clear that municipal, commercial, and industrial wastes in general are used in the bigger installations the most. The availability, the recurrence, and the high amount of this type of waste are key features of the plant´s operation. Due to its flexibility and even small size compared to the SRCs, the Organic Cycle plants reviewed in this work deal with a wide range of wastes. Animal manure refused materials, and sludge from treatment stations are examples of fuels incinerated mainly in fluidized bed furnaces.

The flue gas derived from waste incineration, pyrolysis, or gasification is commonly cleaned using conventional operations such as scrubbing, adsorption, and filtration. Most of the small-scale WtE installations reviewed use lime and ammonia as absorption agents, whose slurry is sprayed in scrubbing towers to react with the incoming flue gas. Besides that, the use of activated carbon in adsorption devices allows for vapor phase contaminants removal, which can be produced in the early stage of the burning process. Finally, solid particles are removed from the gas stream using fabric, bag filters, or cyclone separators, depending on the allowed emission limit.

New trends in WtE installations require integration with advanced technologies, artificial intelligence, machine learning and to optimize waste sorting and collection.

Various forms of waste require the use of different thermochemical conversion processes like gasification and pyrolysis. These hybrid systems might provide a more stable and reliable energy supply promoting circular economy practices.

The interest in decentralized WtE installations is growing aiming to reduce costs with transportation, although quantifying this reduction is not easy.

The costs of ORC installations can be costly depending on the type and size of the installation and the location. Smaller ORC units tend to be less expensive than bigger ones. The long lifespan and reduced maintenance result in long-term savings. It is expected that the costs of ORC installation might reduce alongside the advance of technology and the demand for sustainable energy supply.

Table 1. - Overview of some small installations dedicated to waste energy recovery.

Name/Plant location	**Cycle**	**Waste Capacity (ton/h)**	**Energy Generated (MWe)**	**$Pe/\dot{m}$**	**Furnace type**	**Waste type**	**Flue Gas Cleaning**	**Ref.**
Sheffield Energy Recovery Facility, United Kingdom	SRC	28.00	19.0	0.679	Moving Grate	Municipal	Urea-activated carbon, lime, fabric filter	[11]
SUEZ Isle of Man, United Kingdom	SRC	7.42	7.0	0.943	Moving Grate	Municipal	Ammonia, lime, spray absorber,	[12]

							Activated carbon, Bag filters	
Leeds Recycling and Energy Recovery Facility, United Kingdom	SRC	20.50	11.0	0.537	Moving Grate	Commercial & Industrial	Urea, lime, activated carbon, bag filters	[13]
Bolton Thermal Recovery Facility, United Kingdom	SRC	16.00	11.4	0.713	Moving Grate	Commercial & Industrial	Ammonia, lime, activated carbon, cell bag filter	[14]
Integra North West Energy Recovery Facility, United Kingdom	SRC	12.60	9.0	0.714	Moving Grate	Commercial & Industrial	Lime, urea, bag filters, activated carbon	[15]
Integra South East Energy Recovery Facility, United Kingdom	SRC	24.00	15.0	0.625	Moving Grate	Commercial & Industrial	Lime, bag filter	[16]
Newhaven Energy Recovery Facility, United Kingdom	SRC	14.00	19.5	1.393	Moving Grate	Municipal	Ammonia, lime, activated carbon, bag filter	[17]
Medical Waste Incineration Plant Oncological Centre, Poland	ORC	-	1.2	-	Rotatory Kiln	Medical	Urea, bag filter, calcium hydroxide, activated carbon	[18], [19]
ITC-KA, Turkey	ORC	-	5.3	-	-	Industrial & Medical	-	[18]
MIROM Roeselare Incineration Plant, Belgium	ORC	-	3.0	-	Moving Grate	Municipal	Electrofilter, sodium bicarbonate, activated carbon, fabric filter, ammonia	[18], [20]
SABA Incinerator, Poland	ORC	-	1.2	-	Rotatory Kiln	Plastic & Hospital	-	[18]
Güres Tav. A.Ş., Turkey	ORC	16.67	2.3	0.138	Fluidized Bed Combustor	Chicken Manure	-	[18]
BGB EnerjiYatırımA.Ş., Turkey	ORC	4.16	2.3	0.553	Fixed Bed Gasification	Chicken Manure	-	[18]
Albany County Sewer District: Incineration Waste Heat Recovery, USA	ORC	1.50	1.0	0.667	-	Dried Sludge	-	[18]
Undisclosed, Japan	ORC	12.50	1.0	0.080	Bubbling Fluidized Bed Combustor	Dewatered Sludge	-	[18]
ENGIE, Romania	ORC	-	0.6	-	Fluidized Bed Combustor	Dewatered Sludge	-	[18]
Undisclosed, Taiwan	ORC	8.33	9.0	1.080	-	Refused- & Tires-derived fuel	-	[18]

Veolia Propreté Rhin-Rhôn, France	ORC	-	0.7	-	-	-	-	[18]
The Corporation of the City of London, Canada	ORC	-	0.6	-	Fluidized Bed Combustor	-	-	[18]
Terraverde, Italy	ORC	-	1.2	-	-	Refused-derived fuel	-	[18]

Mukherjee et al. [21] presented a review on the adoption of WtE technologies in the US, in which it was presented that only 13 % of MSW are incinerated and 53 % are landfilled. Lee et al. [22] provides a systematic overview of thermochemical hybrid WtE systems to understand possible configurations for waste processing.

Due to technological and sustainable development, more than 1,700 energy recovery incineration plants are currently in operation worldwide, located in countries such as Japan, France, Germany, and the United States and more than 200 incineration plants are currently under construction with prospects of being in operation by 2023 [23].

4. Conclusion

The use of landfills for the final disposal of waste still predominates in South America, mainly due to the availability of land and the simplicity of the process. Waste incineration as a strategy for energy recovery and final destination has advantages such as reducing mass, volume, and destruction of toxic and/or pathogenic substances. However, variables such as calorific value, water content, ash, and volatile material, as well as chlorine, sulfur, and metals have a direct impact on the cost of implementation and operation, as the necessary environmental control technologies have a high financial cost. Thus, for viability, the plants must have a large processing capacity, requiring large investments and resulting in a greater environmental impact in the vicinity. Thus, energy recovery from waste has faced difficulties in implementation in small municipalities. The Organic Rankine Cycle technology has the advantage of requiring less infrastructure for its installation and might lead to an easy implementation.

Distributed small-scale thermal plants have the advantage of offering a lower environmental impact, and lower transportation costs in addition to being able to be customized for certain types of waste, which can reduce costs and lead to a more stable operation. However, public policies are needed to encourage the use of small waste energy recovery plants.

Acknowledgment

The authors are grateful to the Universidade de Blumenau (FURB), to Brazil Recuperadora de Polímeros Ltda., to the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq, nº 403538/2020-3 and nº 304560/2020-0) for the financial support that made this article possible.

References

[1] S. Kaza, L. Yao, P. Bhada-Tata, and F. van Woerden, “What a Waste 2.0,” Washington, DC, (2018). doi: 10.1596/978-1-4648-1329-0.

[2] S. Kaza and P. Bhada-Tata, “Decision Maker’s Guides for Solid Waste Management Technologies,” 2018.

[3] W. Foster *et al.*, “Waste-to-energy conversion technologies in the UK: Processes and barriers – A review,” *Renewable and Sustainable Energy Reviews*, vol. 135. Elsevier Ltd, Jan. 01, (2021). doi: 10.1016/j.rser.2020.110226.

[4] C. Floriani, L. M. Chiarello, T. Gomes Porto, and R. Wiggers, “PHYSICAL AND CHEMICAL CHARACTERIZATION OF A REFUSE DERIVED FUEL FROM AN ISW IN A LANDFILL LOCATED OF SOUTHERN BRAZIL,” 2022.

[5] Â. Cristante, L. A. Nascimento, E. S. Neves, and F. Vernilli, “Study of the castable selection for blast furnace blowpipe,” *Ceram Int*, vol. 47, no. 14, pp. 19443–19454, Jul. 2021, doi: 10.1016/j.ceramint.2021.03.281.

[6] J. Zhuang et al., “Comprehensive review on mechanism analysis and numerical simulation of municipal solid waste incineration process based on mechanical grate”, Fuel, vol 320. Elsevier Ltd, July. 15, 2022. doi.org/10.1016/j.fuel.2022.123826.

[7] R. F. Beims, C. L. Simonato, and V. R. Wiggers, “Technology readiness level assessment of pyrolysis of triglyceride biomass to fuels and chemicals,” *Renewable and Sustainable Energy Reviews*, vol. 112. Elsevier Ltd, pp. 521–529, Sep. 01, 2019. doi: 10.1016/j.rser.2019.06.017.

[8] F. B. Dovichi Filho *et al.*, Evaluation of the maturity level of biomass electricity generation technologies using the technology readiness level criteria, Journal of Cleaner Production, vol. 295. Elsevier Ltd, May., 2021. doi.org/10.1016/j.jclepro.2021.126426.

[9] R. Loni *et al.*, “A review of solar-driven organic Rankine cycles: Recent challenges and future outlook,” *Renewable and Sustainable Energy Reviews*, vol. 150. Elsevier Ltd, Oct. 01, 2021. doi: 10.1016/j.rser.2021.111410.

[10] S. Quoilin Liège, “Sustainable Energy Conversion Through the Use of Organic Rankine Cycles for Waste Heat Recovery and Solar Applications,” 2011.

[11] Veolia Environmental Services Sheffield Ltd., 2012. Sheffield Energy Recovery Facility: Annual Performance, Report (2011).

[12] SITA (Isle of Man) Ltd., 2010. Isle of Man – Energy from Waste Facility: Annual Performance Report (2009).

[13] Veolia Environmental Services. Leeds Recycling and Energy Recovery Facility: Annual Performance, Report (2019).

[14] Viridor (Greater Manchester) Ltd., 2010. Bolton Thermal Recovery Facility: Annual Performance Report (2009).

[15] Veolia Environmental Services Hampshire Ltd., 2012a. Integra North Energy Recovery Facility: Annual Performance, Report (2011).

[16] Veolia Environmental Services Hampshire Ltd., 2012b. Integra South East Energy Recovery Facility: Annual Performance, Report (2011).

[17] Veolia Environmental Services Southdowns Ltd., 2011. Newhaven Energy Recovery Facility: Commissioning Report.

[18] TURBODEN ® Clean energy ahead, Turboden Waste To Energy. Turn your waste into useful power

[19] PROMONT GROUP Waste Management. (2015). https://www.promont.com/en/download/

[20] MIROM ROESELARE Verbrandisgsinstallatie. (n.d.) https://www.mirom.be/verbrandingsinstallatie

[21] Mukherjee, C., Denney, J., Mbonimpa, E. G., Slagley, J., & Bhowmik, R. (2020). A review on municipal solid waste-to-energy trends in the USA. In Renewable and Sustainable Energy Reviews (Vol. 119). Elsevier Ltd. https://doi.org/10.1016/j.rser.2019.109512

[22] Lee, J., Lin, K. Y. A., Jung, S., & Kwon, E. E. (2023). Hybrid renewable energy systems involving thermochemical conversion process for waste-to-energy strategy. In Chemical Engineering Journal (Vol. 452). Elsevier B.V. https://doi.org/10.1016/j.cej.2022.139218

[23] UNEP (2019). Waste-to-Energy: Considerations for Informed Decision-Making.