Leveraging waste heat potential in the glass industry

Sara Milanesi and Andrea De Finis* discuss how Organic Rankine Cycle (ORC) waste heat recovery systems can enhance the sustainability and competitiveness of glass manufacturing factories, as well as providing a case study of their use at a Sisecam glass plant.

In today's energy-intensive industries, Waste Heat Recovery (WHR) systems have become a popular solution aimed at boosting energy efficiency.

The increasing demand for WHR systems stems from companies' ESG commitment and governmental directives targeted to reduce energy consumption and CO_2 emissions to tackle climate change.

Among the available technologies, Organic Rankine Cycle (ORC) stands out as an option for converting waste heat from industrial operations, such as that of glass melting furnaces, into electricity.

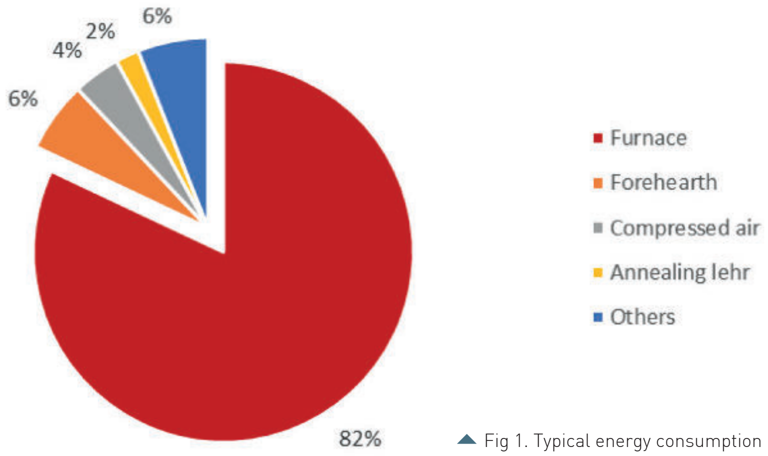
The glass industry exhibits diversity, evident in the wide array of products manufactured and the various techniques used in production.

However, a consistent feature across this diversity is the reliance on high temperatures ranging from 1200 to 1500°C and the substantial demand for melting sand and other raw materials.

This characteristic categorises the glass industry as highly energy-intensive. Heat generation within glass manufacturing processes typically occurs through direct combustion of fossil fuels, electrical heating methods, or a combination of both approaches.

Selecting the energy source, heating method and heat recovery approach shape furnace design. These decisions are pivotal in determining the environmental impact and energy efficiency of the melting process.

Additionally, the choice of energy source is influenced by the specific energy strategies and policies implemented by each state. For instance, states may prioritise the use of fossil fuels over nuclear power or offer incentives such as feed-in tariffs to encourage renewable energy production.



▲ Fig 1. Typical energy consumption by process.

These factors play a crucial role in shaping the overall sustainability and operational efficiency of the melting operation.

Typically, melting glass demands more than 75% of the total energy consumed in glass manufacturing. Additional notable energy-consuming areas include forehearths, the forming process, annealing, factory heating and general services (***Fig 1***).

Because glassmaking is such an energy intensive process there is a high potential for heat loss.

The high-temperature waste heat derived from furnace exhaust gases offers versatile applications, including:

1. Power generation through either the Steam Rankine process or Organic Rankine Cycle.
2. Internal use within the plant, such as steam generation for hot water heating, building heating, or external applications like district heating, particularly beneficial for low heat flows.
3. Cooling of buildings using absorption or adsorption chillers.
4. Implementation of thermo-chemical recuperator systems, using the recovered heat for hot synthesis gas production.
5. Preheating of oxygen and natural gas.
6. Preheating of combustion air using regenerators.
7. Integration into the manufacturing process, such as preheating materials loaded into the furnace.

In a glass manufacturing plant, all the above WHR recovery options can potentially reduce the energy operating costs and increase the overall efficiency of the plant.

Waste Heat Recovery with Organic Rankine Cycle systems

Waste Heat Recovery (WHR) systems frequently employed within the glass industry use both the steam Rankine cycle and the Organic Rankine Cycle (ORC).

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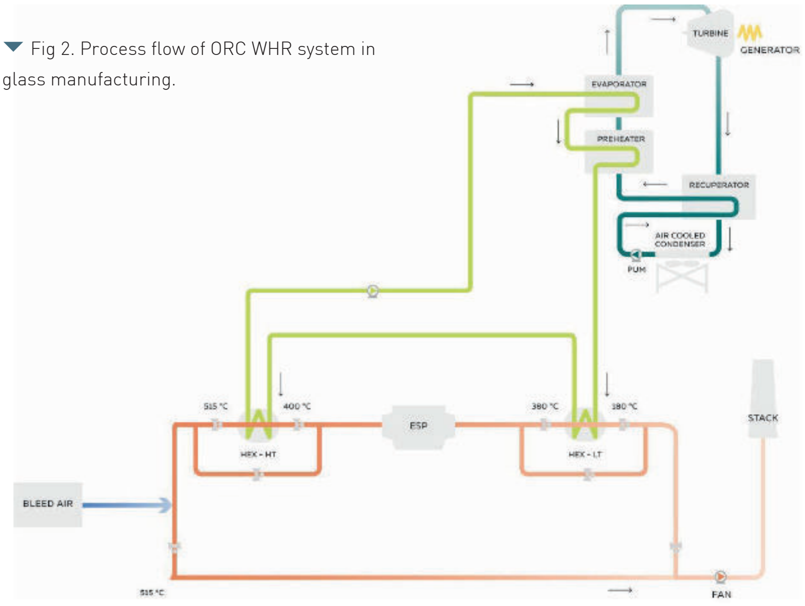
Fig 2. Process flow of ORC WHR system in glass manufacturing.



The ORC operates by employing organic fluids chosen based on thermodynamic considerations and techno-economic assessments. In this cycle, an intermediate circuit extracts heat from the thermal source, causing the working fluid to evaporate within a heat exchanger. Subsequently, the expanded organic fluid drives a turbine, generating electrical energy.

Following turbine expansion, the fluid undergoes liquefaction, releasing heat to a cold medium, such as air or water, before being pumped back to the maximum cycle pressure (***Fig 2***).

When the working fluid keeps high temperatures at the turbine outlet, incorporating a recuperator to preheat the liquid can enhance overall system efficiency. This approach is typically adopted for sources with higher temperatures, leveraging the recuperator to optimise energy use.

The choice of the working fluid primarily relies on the application and the fundamental characteristics of the energy source. Incorporating organic fluids such as refrigerants or hydrocarbons allows for the implementation of efficient and economically viable solutions, offering several advantages including:

- Retrograde saturation curve that brings to super-heated steam at turbine outlet.
- Possibility to choose fluids in a range of critical temperatures and pressures to optimise the heat exchange process with the hot and cold source.
- Possibility to choose fluids that can be non-flammable or non-toxic for particular hazard restrictions.

The main restrictions related to the working fluids are:

- Environmental limits like global warming potential or ozone depletion potential.
- The high flammable nature of hydrocarbons (Seveso Directive for EU).
- The high cost for some organic fluids (especially refrigerants).

The expertise in turbine operation and cycle design, coupled with careful fluid selection, enables the creation of an optimised plant design capable of achieving high levels of efficiency.

Typical applications use hydrocarbons due to their flexibility and affordability. However, their high flammability necessitates meticulous design and implementation of security systems within the plant.

Pentanes and butanes are prevalent hydrocarbons used in ORC modules, with fluid selection typically contingent upon the source temperature.

But, when the use of hydrocarbons is forbidden, refrigerants represent an excellent substitute. Their non-flammable nature makes them suitable for indoor installations or environments with stringent safety requirements. However, refrigerants are associated with higher costs per ton, thus affecting the overall cost.

The main components of an ORC system are:

- *The turbine:* it's the key component of the entire plant. It expands the working fluid producing mechanical energy that is converted into electricity by a generator directly coupled with the turbine shaft.
- *The heat exchangers:* the working fluid flows through the heat exchangers, extracting the heat from the intermediate thermal fluid. Shell and tube heat exchangers are usually applied but they can vary geometry and configuration depending on the energy source and the total thermal input.
- *The feed pump* brings the organic fluid from the condensation pressure to the maximum pressure of the cycle. The pump can be horizontal or vertical driven by an electric motor at variable rotating speed.
- *The condenser:* with the direct air to fluid heat exchanger, the organic fluid is cooled and liquefied before entering the pump. The use of air eliminates the requirement for water treatment and make up. It is possible to use also a water-cooled condenser.

Innovations

In 2010, Exergy International launched a turbine technology applied to ORC systems. Designed and patented by Exergy, the Exergy's Radial Outflow Turbine (ROT) represents a technological advancement, being the first turbine of its kind integrated into an ORC system.

Diverging from traditional axial and radial inflow configurations, the ROT excels in converting the energy contained in the fluid into mechanical power with unmatched efficiency, outperforming competing technologies available in the market.

In ROT, the fluid enters axially and is deviated by 90 degrees with a nose cone. The fluid expands radially through a series of stages arranged on a single disk. At the end, the fluid is discharged in a radial diffuser to recover the kinetic energy and then is conveyed to the recuperator or the condenser.

The ROT boasts advantages:

1. Inherently higher efficiency compared to an axial turbine, resulting in the potential for up to 20% more power. This enhanced performance is attributed to:
    - Incorporation of up to six stages on a single disk, thereby reducing the turbine's size and length compared to an axial turbine.

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Customer	Şişecam
Date of implementation	2015
Line capacity	700 t/d
Thermal Oil Flow rate	200 t/h
Thermal Oil Inlet Temperature	300°C
Thermal Oil Outlet Temperature	150°C
Gross Electrical Power	4.5 MWe
Condensing system	ACC
Installation	Outdoor

▲ Fig 3. Sisecam Targovishte ORC power plant in Bulgaria.

- Reduced tip leakage and disk friction losses.
- Minimal 3D effect due to the low blade height and minimal variation in blade height.

2. Elimination of the need for a gearbox, thanks to the low rotational speed (3000 or 3600 -1500 or 1800 rpm), allowing direct coupling with a generator equipped with two or four poles, enhancing overall system reliability.

3. Fewer limitations on cycle pressure and blade manufacturing: technological and manufacturing constraints related to the minimum blade height of the initial turbine stage and the maximum blade height of the final stage can be overcome with the ROT. Consequently, Exergy ROT permits the design of cycles with lower condensation pressures and higher evaporating pressures, expanding the range of applications.

4. An increase in volumetric flow achieved without requiring extreme changes in blade height. The stages are arranged radially instead of axially, facilitating accommodation of volumetric flow through increased fluid flow area.

5. Simpler construction technology: In contrast to the twisted blades of axial turbines, the straight blades of the ROT remain unchanged, as the fluid velocity across the stage experiences minimal modification in values and direction.

6. Reduced vibrations, resulting in prolonged bearing life.

7. Easy and cost-effective maintenance: The mechanical group (a module containing bearings, oil lubrication system, and seals) of the turbine can be easily removed without draining all organic fluid from the cycle.

By simply sliding back and locking the rotor disk towards the cage, downtime of the plant is dramatically reduced. The mechanical group can be removed and bearings replaced within six hours, compared to one week downtime for axial turbines and competing technologies.

$$PBT = \frac{CAPEX}{Revenues - Opex}$$

where *Reveneus* = P_{net} * *Electricity price* * *hours of operation*.

▲ Fig 4. Equation for the payback time (PBT).

Sisecam Targovište case study

Exergy, through an Italian EPC company, supplied Sisecam - an industrial group with a dominant presence across various sectors of the glass industry - with three ORC units for heat recovery from its glass furnaces (two units in Turkey and one in Bulgaria).

Sisecam aimed to enhance the energy efficiency of their facilities and decrease the environmental footprint of its industrial operations.

Exergy supplied three ORC systems using the ROT. The ORC technology applied to the float glass mill in Targovishte, Bulgaria, exploits the hot fumes generated to produce 5 MWel.

The heat is recovered through an intermediate thermal oil loop and a boiler. The thermal oil transmit the heat from the flue gases to the ORC working fluid. The intermediate loop circulates 120t/h of oil with a maximum temperature of 300°C and a return temperature from the ORC heat exchangers of 15°C.

The solution operates with direct air-cooled condensers; this means that no water is needed to operate the plant.

The ORC module is able to produce 4.7 MW of net electrical power with an efficiency equal to 22.6%.

Considering total revenues calculated on 8000 hours of plant operation and a price of the electricity for industrial customer equal to 0.22 €/kWh and a feed in tariff equal to 0.08€/kWh (at the time of the installation), the payback time of the solution installed could be calculated in first approximation (see ***Fig 4***).

Based on this method the assumed payback time for this plant could be equal to four years.

The Targovishte plant has been in operation since 2015 and produces electricity with zero extra emissions saving 20,000 tons of CO_2 and 7,500 tons of oil equivalent per year.

The high efficiency of the ORC system reduces the plant's energy consumption and carbon footprint contributing positively to the environment (***Fig 3***).

Conclusion

In conclusion, ORC waste heat recovery systems represent a viable solution for enhancing the sustainability and competitiveness of glass manufacturing factories.

By capturing waste heat from glass furnaces and converting it into usable clean energy, these systems contribute to increased energy efficiency, reduced environmental impact and cost savings.

Their implementation not only aligns with sustainability goals but also helps factories maintain competitiveness in the market by minimising reliance on external energy sources and reducing operational expenses.

Overall, ORC systems offer a promising avenue for driving forward the industry towards more sustainable and efficient production processes. ■

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