State-of-the-art experiences in power generation from furnace flue gas: start-up of three WHR systems based on ORC technology in container and float glass industries

Alessandro Monteforte, Francesco Zatti

Area Impianti SpA, Albignasego (PD), Italy

INTRODUCTION ABOUT WASTE HEAT RECOVERY WITH ORC

A good energy management is becoming a must in the modern glass industry, considering the increasing OPEX reduction demand. Efficient and reliable Waste Heat Recovery (WHR) with power or combined heat and power (CHP) generation is therefore a potential long term source of increased competitiveness for a glass factory today, container, float, or other.
ORC (Organic Rankine Cycle) technology is considered to be the most suitable for this application, thanks to its flexibility, reliability and simple operation.
This technology uses a heat transfer fluid, thermal oil; this is heated by the flue gases and brings the thermal power to the ORC module where an organic fluid is used to produce electricity. Several possible solutions are available to integrate in this system also cogeneration of hot water or steam.

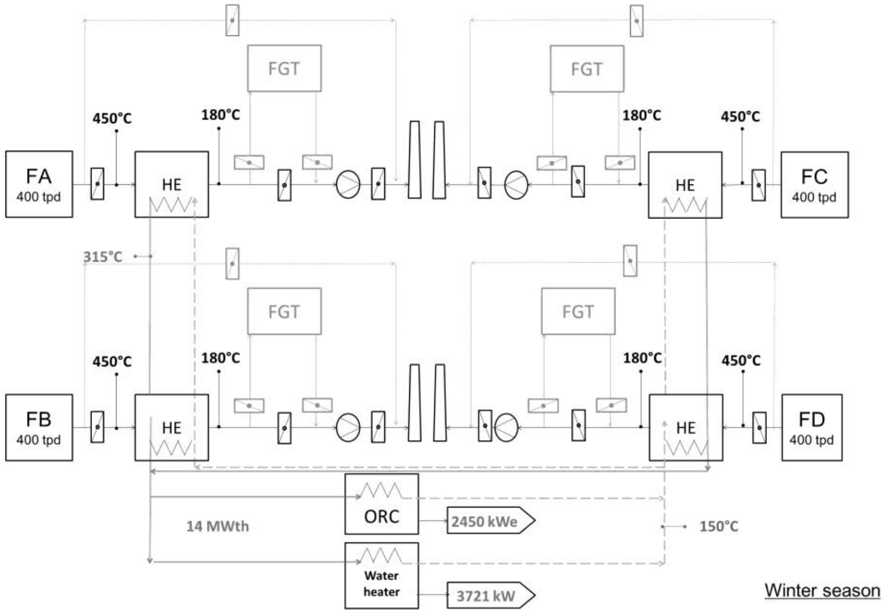
Recently, three new state-of-the-art WHR systems have been built in different plants, two float and one container, using ORC technology.

THE THREE NEW PLANTS

1 – FOUR CONTAINER FURNACES, RECOVERY UPSTREAM FUTURE FLUE GAS TREATMENT

This container plant has four furnaces, 400 tpd each. Furnaces being quite far one from the other, with independent stack, a flue gas / oil heat exchanger is installed in every furnace separately.
Oil is heated from 150°C to 315°C while flue gases are cooled down from 450°C to 180°C. A total of approximately 14 MWth are recovered. An ID fan ensures a stable pressure control at the regulation valve.
A provision for a future flue gas cleaning system using bag filter and low-T SCR deNOx is prepared downstream the heat exchanger, with big advantages in terms of investment.
Oil coming from the four heat exchangers is then collected in a single loop, reaching a diverter; from one side, with priority, oil is sent to a hot water generator with load variable according to the season from 1,4 to 3,7 MWth; all the remaining oil is sent to the ORC module, where power is produced in the range of 2,5 – 3 MWe. Open loop cooling towers are used for organic fluid condensation.
Subtracting all internal consumption of the system (ID fan, pumps etc.), the net power production ranges between 1,9 and 2,5 MWe, with a net power production efficiency between 18,8% and 19,8%. This also shows how the ORC efficiency is stable also with big load variation.

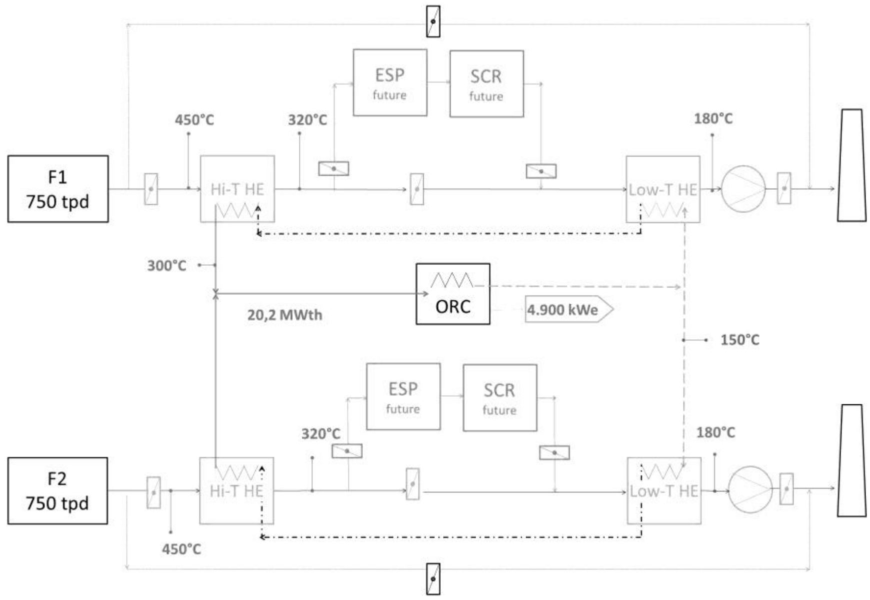
A basic system flow diagram is shown here below



2 – TWO FLOAT FURNACES, RECOVERY UPSTREAM AND DOWNSTREAM FUTURE FLUE GAS TREATMENT

This float plant has two furnaces, 750 tpd each. A flue gas / oil heat exchanger is installed in every furnace separately. Heat exchanger is conceived in two modules in order to allow, in the future, to insert a complete flue gas cleaning system (ESP + SCR deNOx) between the two modules.
Oil is heated from 150°C to 300°C while flue gases are cooled down from 450°C to about 320°C in the first module and then to 180°C in the second one. A total of approximately 20,2 MWth are recovered at nominal conditions. An ID fan ensures a stable pressure control at the regulation valve.
Oil coming from the two heat exchangers is then collected in a single loop and sent to the ORC module, where there is a nominal produced of 4,9 MWe. Open loop cooling towers are used for organic fluid condensation.
Subtracting all internal consumption of the system (ID fan, pumps etc.), the net power production at nominal conditions is 4,1 MWe, with a net power production efficiency between of 20,2%.

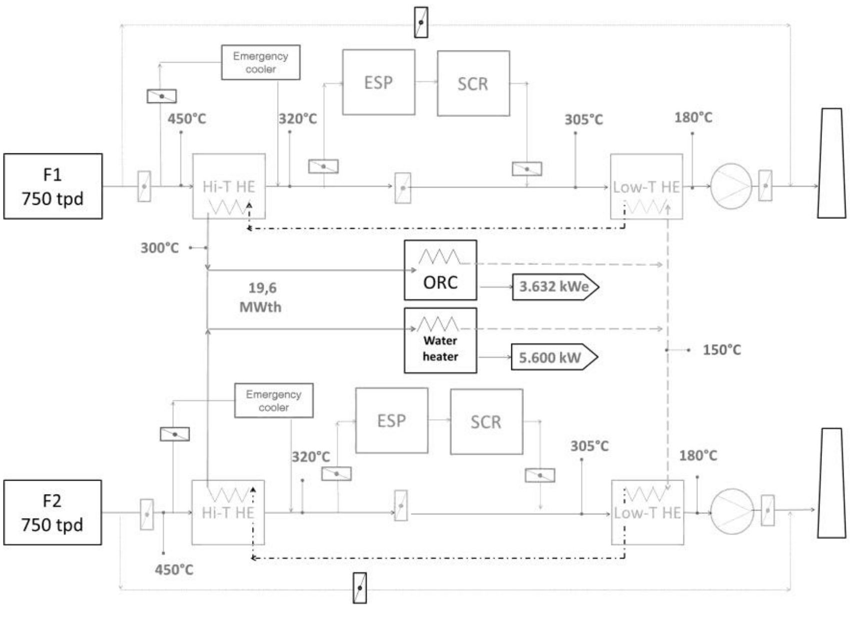
A basic system flow diagram is shown here below



3 – TWO FLOAT FURNACES, RECOVERY UPSTREAM AND DOWNSTREAM EXISTING FLUE GAS TREATMENT

This float plant has two furnaces, 750 tpd each. It is in the UE. A flue gas / oil heat exchanger is installed in every furnace separately. Heat exchanger is conceived in two separate modules one upstream and the other downstream an existing flue gas cleaning system (ESP + SCR deNOx). A cooler, previously used to reduce the temperature of the flue gases before the ESP, is by-passed during the WHR system operation and acts as an on-line back-up. Oil is heated from 150°C to 300°C while flue gases are cooled down from 450°C to about 320°C in the first module before ESP; they are recovered at 305°C after the SCR and cooled down to 180°C by the second module of heat recovery. A total of approximately 19,6 MWth are recovered at nominal conditions. The existing ID fan is re-used.
Oil coming from the heat exchangers of the two lines is then collected in a single loop, reaching a diverter; from one side, with priority, oil is sent to a hot water generator with load variable according to the season from 1,1 to 5,6 MWth; all the remaining oil is sent to the ORC module where power is produced in the range of 3,1 – 4,3 MWe. Air cooled condenser is used for direct organic fluid condensation.
Subtracting all internal consumption of the added system (pumps etc.), the net power production ranges between 2,7 and 3,65 MWe, with a net power production efficiency between 19,2% and 19,7%, with a quite steady efficiency of the ORC also with big load variation.

A basic system flow diagram is shown here below



TECHNICAL SOLUTIONS APPLIED

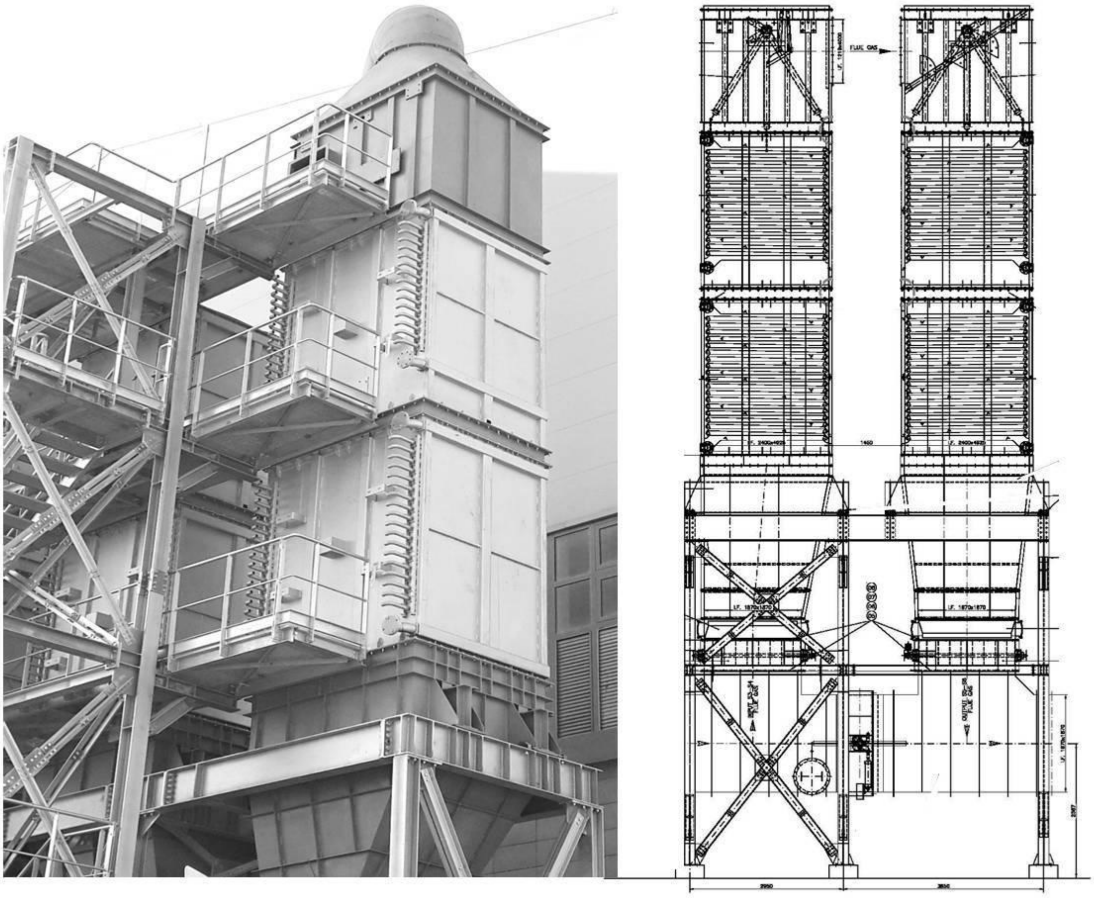
While describing technical solutions and showing drawing and pictures, we will focus on plant n°3, being the more complex and complete.
The key elements of the installed plant are the flue gas / oil heat exchanger and the ORC turbine chosen.

Heat exchangers are probably the most important part because their reliability is strictly affecting overall plant availability and the pressure drop of the line; they work on a dirty, polluted environment and they represent the connection between what happens into the furnace and the energy recovery; this means they don't have to create variable pressure drop to avoid problems to the glass production. For this reason, their technology is based on previous similar experiences of Area Impianti in heavy duty heat exchangers, applied in the glass industry since 1992. They are equipped with three automatic cleaning systems, based on very simple and tough technical solutions:

- Cleaning between vertical bundles of oil pipes, achieved with swinging chain cleaning
- Cleaning between horizontal pipes inside the bundles, achieved with compressed air periodical pulse jet
- Cleaning in the inversion hopper, using a drum slowly rotating, made of metallic discs and chains

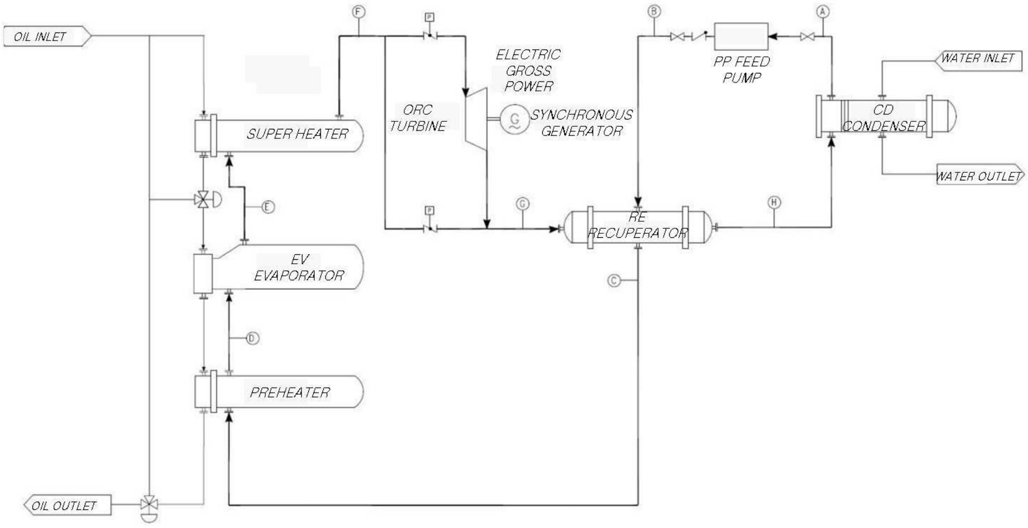
The heat exchangers are so resistant to dust load that the injection of reagent (lime) is performed upstream, so to have the reagent working at high temperature and using the residence time inside the heat exchangers to improve the reaction efficiency.

Heat exchanger, lay-out and picture



ORC used belong to the last generation. It uses a combined radial or radial-axial high efficiency turbine. The organic fluid used is cyclopenthane, having thermodynamic properties optimal to achieve the best efficiencies using thermal oil in the range of 300°C. This fluid also allows a direct condensation in air cooled condensers, being the best choice for the plant location; actually in this specific place water is only partially available and ambient temperatures are typically continental.

ORC, lay-out and picture



FIRST START-UP INFORMATION AND CONCLUSIONS

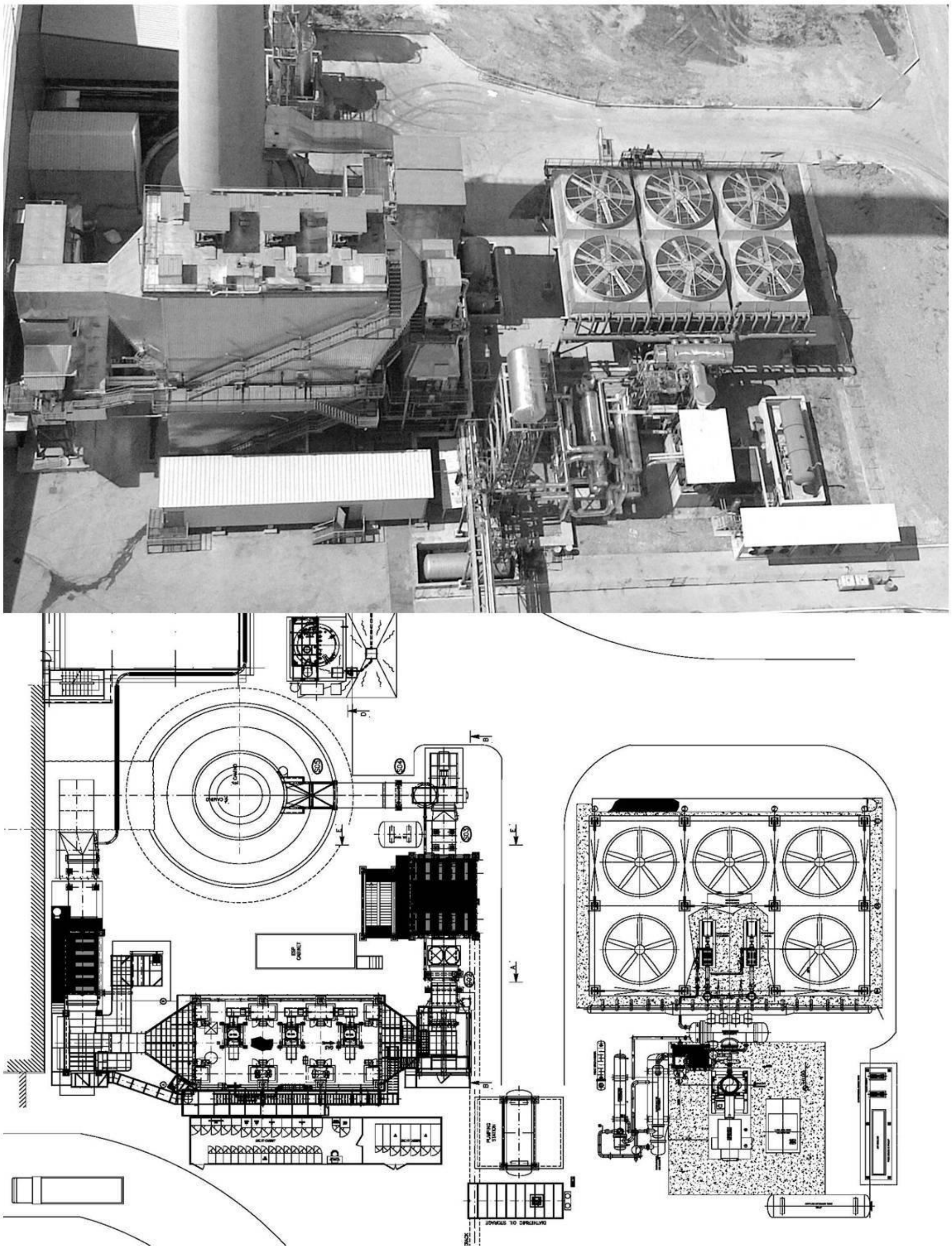
Plant n°3 has started-up only few weeks before this article was written. Here preliminary test results are shared, but it must be considered that furnace pull during first tests was much lower than nominal case, because of production reasons. Temperatures at heat recovery inlet were not far from nominal conditions, while flow rates were much lower. Ambient temperature was around 30°C.

Pressure drop test on the heat exchangers shows a global pressure drop of approx. 500 Pa per furnace. This value is much lower than expected, since, recalculating backward with actual flow rate passing through the heat exchangers, it should have been 750 Pa. ID fan speed was decreased from 49% to 44% after inserting the waste heat recovery system and by-passing the cooler before ESP. The additional pressure drop of the oil heat exchanger is compensated by the reduced flue gas temperature at the ID fan. This temperature was automatically controlled at 180 ± 2°C in order to avoid risk of acid condensation at stack.

Environmental performances were controlled by on-line continuous measurement at stack, and they were perfectly kept below emission limits during the whole test period.

Heat recovery performances at reduced load: thermal oil was heated from 170 to 297°C in one furnace and 294°C in the other; total heat recovered was 10,4 MWth, that means that plant was operating at 53% of its load; gross power output from turbine was 1946 kW (18,7% gross efficiency); subtracting internal system consumption, gives a net power output of 1597 kW, i.e. a net efficiency of 15,3%.

The plant n°3: lay-out and aerial picture



The preliminary results and the commissioning of the plant have been evaluated **very good** and plant shows a **flexibility** even much higher than expected, with very low efficiency drop despite the low thermal input due to low furnace pull.
Plant is expected to reach a steady nominal operation in the very next future, and we end this article with the promise of sharing complete performance tests in a future press article as soon as available.

Alessandro Monteforte

Area Impianti SpA
Via Leonino da Zara 3/a
35126 Albignasego (PD), Italy

E-mail: alessandro.monteforte@areaimpianti.it
Website: www.areaimpianti.it

Tel. +39.049.8626426
Mob. +39.335.7803639