Advanced Waste-to-Energy plant design for the enhanced production of electricity

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Keywords: waste-to-energy, efficiency, steam cycle, reheating, gas quench.
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Waste-to-Energy (WtE) is a fundamental practice for the sustainable waste management of every country (Porteous, 2005). Its environmental outcome can be correctly evaluated only based on rigorous Life Cycle Assessments (LCA), as suggested also by normative (EC, 2008). In this perspective, the environmental outcome of WtE is determined as balance between caused and avoided / substituted emissions. Such a balance is heavily influenced by the energy efficiency of WtE, which directly determines the amounts of substituted useful effects (typically the net electricity and heat productions) and, hence, the associated avoided emissions.

Modern WtE plants are designed to maximise, in different ways, energy efficiency, abiding by several technical and economic constraints.

In colder regions, like Central and Northern Europe, energy efficiency is maximised in terms of heat recovery, since the significant heat demand of the highly developed district heating networks of such regions. Achieving high heat recovery rates in WtE plants does not represent a challenge from the technical standpoint, and the economics are also favoured.

In warmer regions, like Southern Europe, the entire Mediterranean area, the Middle-East and so on, besides very peculiar cases, the sole possibility of maximising energy efficiency is through high rates of electricity production. Achieving high electric efficiency in WtE plants is much more challenging than getting high heat recovery. This handicap of WtE operations in warmer regions is recognised also by the European normative, which had introduced a climate correction factor in the “R1 energy efficiency formula” (EU, 2015).

This article deals with an innovative approach in seeking the maximisation of electric efficiency in WtE plants while respecting all the technical and economic constraints set by the state-of-the-art technologies. Energy and economic performances of two large-size WtE plants are compared: one plant is based on a conventional design, the other adopts the innovative concept of “flue gas quench”, allowing for a reheated steam cycle.

Steam reheating in WtE power cycles is typically avoided, since current technologies do not warrant adequate reliability of such a configuration. The “flue gas quench” concept is explained in Figure 1, whereas its implementation in a WtE plant is depicted in Figure 2. It allows respecting all the technical constraints set by material resistance even in the case of a reheated steam cycle.

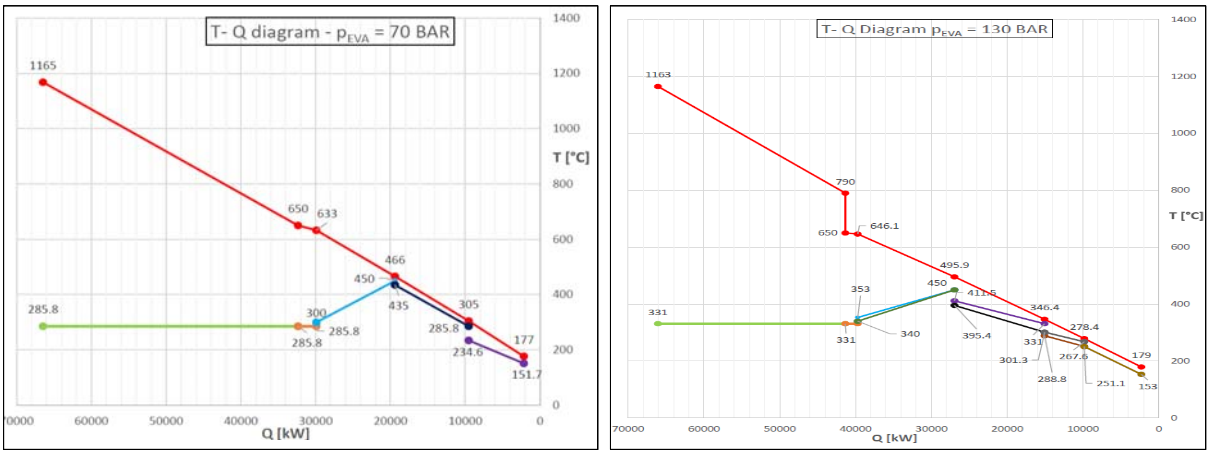

Figure 1. Heat exchange diagrams of two WtE boilers with the same power input and: (a) a conventional, state-of-the-art steam cycle; (b) a reheated steam cycle and “flue gas quench”.

The introduction of reheating causes other modifications in the shape of the steam cycle, the first of which is the increase in evaporating pressure. In comparison with the conventional WtE steam cycle, the advanced configuration features lower steam flowrate, significantly reduced heat duties for water evaporation and steam superheating, slightly increased heat duty for water economisation and the additional heat duty for steam reheating.

If the radiant section of the boiler is used only for water evaporation, as assumed in the diagrams in Figure 1, the reduction of the associated heat duty due to the introduction of steam reheat causes the flue gas exiting such a boiler section at a higher temperature with respect to the conventional case. To abide by the technical constraints posed by material corrosion, the advanced design applies the “flue gas quench” concept, by means of a second flue gas recirculation in between the radiant and the convective sections of the boiler. In this way, flue gas temperature is reduced before entering the convective section of the boiler, controlling the problem of corrosion.

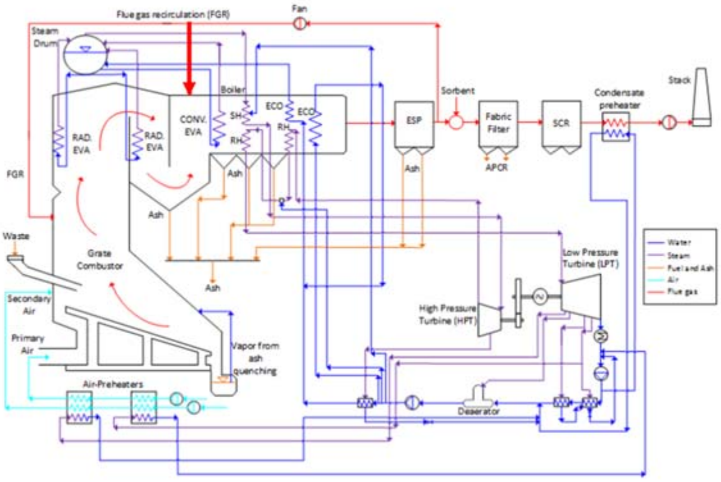

Figure 2. Implementation of the “flue gas quench” concept in a large-scale WtE plant, by means of a second flue gas recirculation (highlighted) in between the radiant and the convective sections of the boiler.

The two WtE configurations have been simulated by means of the Thermoflex® software package, under both on-design and off-design conditions to define a feasible sizing of the various components. A preliminary economic evaluation of both investment and operational costs has been carried out by means of both the capabilities of the simulation program and some inputs from a boiler manufacturer.

The advanced WtE plant, thanks to the reheated steam cycle, achieves net electric efficiency almost three percentage points higher than that of the conventional plant. Moreover, the reduction in the heat duty for evaporation originates a significant smaller radiant section of the boiler, which results cheaper although the higher evaporating pressure. The economic savings in the radiant part of the boiler are overcompensated by the higher cost of the convective section (that features a larger cross-sectional area due to the increased flowrate of flue gas). However, the reduced flowrate of steam, originates some savings also on other components, the first of which are the steam turbine and the condenser. Therefore, the overall investment costs of the two plants are very similar, with the advanced one featuring also lower operational cost, due to the higher efficiency.

In conclusion, the advanced plant is more efficient, implies an investment like that for the conventional plant, and allows for a lower gate fee. Table 1 summarises the main data and performances of the two plants.

Table 1. Main data and performances of the two WtE plants compared.

	Conventional plant	Advanced plant
Combustion power input – single line, MW_{LHV}	66.7	66.7
Number of lines	3	3
Evaporating pressure, bar(a)	70.0	130.0
Superheating / reheating temperature, °C	450 / -	450 / 450
Reheating pressure, bar(a)	-	25
Condensing pressure, bar(a)	0.08	0.08
Flowrate of steam at HP turbine inlet, t/h	253.8	217.1
Gross electric efficiency, $\%_{LHV}$	33.0	36.0
Net electric efficiency, $\%_{LHV}$	29.8	32.5
Assumed value of electricity, €/MWh	50.0	50.0
Assumed Capital Charge Ratio (CCR), %	15.0	15.0
Corresponding gate fee, €/t	76.0	71.5

References

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