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# Environmental performance assessment of the application of high temperature phase change materials in waste-to-energy plants

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## Abstract

The constantly growing worldwide population is leading to a constant increment of waste production. In most developing and developed countries an ongoing key challenge is to collect, recycle, treat and dispose consistent quantities of solid waste. In this context, Waste-to-Energy (WtE) plants play a crucial role as they convert waste into energy. Among the different technical issues, temperature fluctuations of the flue gas and high temperature corrosion represent two of the main limitations to the plant efficiency. A possible solution consists of using a refractory brick containing a Phase Change Material (PCM) to enable the installation of additional superheaters in the combustion chamber in order to increase the temperature of the superheated steam without provoking corrosion, which allows the overall electrical efficiency to be increased. This study assesses the environmental impact originated by the employment of the aforementioned technology by means of Life Cycle Assessment (LCA). In particular, an LCA comparison study between a "standard" WtE plant configuration and a PCM-equipped plant is carried out. The comparison aims to highlight the environmental burdens generated by the employment of an additional quantity of refractory material, as well as the adoption of PCM and the modifications applied at system level (e.g. heat exchanger surfaces). On the contrary, such negative contribution should be mitigated by the increment in the electric efficiency of the plant which, given a definite amount of solid waste input to handle would return a higher amount of electric energy as output.


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## 1. Introduction

Emission of pollutants from Waste-to-Energy (WtE) plants is one of the key issue addressed by researcher and plant manufacturer in the last decades; lower emission of pollutant has been achieved by using costly flue gas treatment units. To counterbalance this cost increase, the research is now focused on improving the energy efficiency of WtE plants. Steam boiler operating with higher steam parameters (temperature and pressure) is one of the main technical solutions that can be adopted to achieve this aim. Nevertheless, higher steam parameters increase the corrosion risk and the associated cost for plant downtime and repair. Many solutions, such as SiC concrete [1] and rear-ventilated tiles [2], are currently available for overcoming the corrosion limits of the steam superheater. Recently, the use of refractory brick based on phase change material (PCM) for corrosion protection of the radiant superheaters has been proposed in [3].

In this study, Life Cycle Assessment (LCA) is used to compare a traditional WtE plant with a WtE employing the PCM-based brick technology. In particular, the focus is to understand whether the introduction of the PCM-based brick technology has an overall positive effect from the environmental point of view on a lifecycle perspective.

LCA is a widely known tool to compare products, technologies and services in terms of environmental performance on a wide perspective. The main aim of the tool is to quantify environmental impacts over the full life cycle, the so called ''cradle-to-grave'' approach. Such approach allows the burden shifting among different life stages to be avoided and enables a fair comparison between products, processes and services [4–6]. The utilization of LCA to evaluate energy systems, with particular reference to WtE plants, is currently being explored in the scientific community with relevant results. Particularly, detailed LCA studies have been exploited to assess the influence of a change in waste composition on the environmental performance of a WtE plant [7]. LCA of existing WtE plants has been carried out by using either commercially available software tools (e.g. Simapro) and ad-hoc tools (e.g. EASEWASTE [8]) in order to find out the importance of the accuracy and robustness available dataset to perform LCA studies [9].

The correctness of life cycle datasets plays a key role in scientific community debates as it limits the applicability of the LCA methodology [8]. Power substitution is used to estimate the benefits coming from alternative power production such as waste incineration which, in the modelling scenario, would replace the production of electricity with other sources. Due to the extensive life span of an incineration plant, such "substitution" becomes an important and decisive step, therefore the choice of the replaced power mix (generally is a country mix), must be carried out with consciousness.

In section 2, the problem statement and the proposed solution are explained. In section 3, the LCA methodology is introduced together with the LCA models as well as the environmental results. In section 4 insights and comments on the results are discussed, while in section 5 conclusions are given.

## 2. Problem statement

In current WtE plants, steam boilers composed by radiant evaporators, evaporators, economizers and superheaters are used to recover the heat released by waste combustion. Figure 1a shows a typical configuration of a steam boiler used in a traditional WtE plant; the energy efficiency for this type of steam boiler is mainly limited by the corrosion occurring at high metal surface temperature (i.e. superheater tube surface) and the significant fluctuations in the thermal power of the flue gas due to the inhomogeneous nature of the solid waste (i.e. variation in the calorific value associated with it). The unpredictable variation of the calorific value of the waste leads to uncontrollable temperature fluctuation in the combustion chamber of the WtE plant; such temperature fluctuations make the installation of steam superheaters in the combustion chamber (which is a technical solution for improving the energy efficiency) very risky due to the high risk of tube failure caused by unpredictable overheating. One of the best available technologies has been tested in the WtE plant in Rosenheim (Germany), where rear-ventilated tiles has been used to protect radiant superheaters located in the upper combustion chamber area [2]. The limit of this particular technology regards the maximum achieved steam temperature (i.e. 480 °C) and the increased plant complexity, which requires additional skills and competence for plant design, process control and operation. In addition to this, it has to be considered that