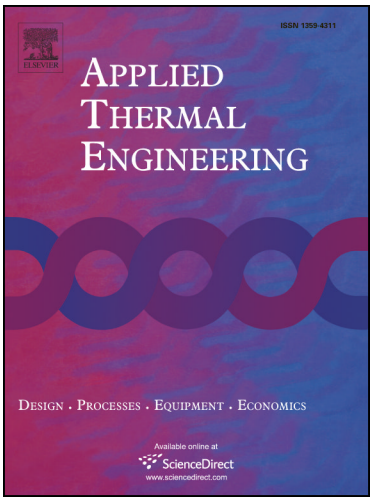

Thermal power fluctuations in waste heat to power systems: an overview on the challenges and current solutions

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Thermal power fluctuations in waste heat to power systems: an overview on the challenges and current solutions

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Abstract
Waste Heat to Power (WHP) represents an enormous opportunity to increase energy efficiency of various industry sectors and to reduce emissions and waste of primary sources. However, thermal power fluctuations are often present in waste heat from industrial processes and transport sectors. These fluctuations negatively affect the operation and economic feasibility of heat recovery power systems such as Steam and/or Organic Rankine Cycle. Due to the lack of literature in this topic, the current paper presents an overview of thermal power fluctuations in waste heat, the related issues affecting the recovery power systems and the available solutions for the problem. Different measures to compensate the fluctuations of different waste heat sources are reviewed, including stream control and intermediary storage units such as the standard sensible heat thermal oil loops systems and more sophisticated latent heat storage technologies based on phase-change materials. The economic considerations required for the WHP systems operating under fluctuating sources are also discussed.

Keywords: Energy efficiency; Waste Heat Recovery; Thermal Energy Storage, Organic Rankine Cycle

1 Introduction
One of the most pressing needs in the world now is the efficient use of the energy resources. Thermal energy conversion processes always require the disposal of some excess heat. In many cases, some of this excess heat still contains a significant amount of exergy that can be recovered and reutilized. Waste heat is present in large quantities in several sectors, such as the manufacturing industry, commercial and residential buildings, power plants and transportation systems. Waste Heat Recovery (WHR) systems basically transfer waste energy to a heat carrier or storage system. This waste heat can be subsequently utilized directly as thermal energy, or used in heat conversion technologies or power generation devices. Power generation from waste heat, however, is usually economically and technically feasible when the temperature of the heat source is higher than 150°C [1]. For this reason, energy-intensive industries (i.e. steelmaking [2], cement [3] and glass production [4]) and systems based on Internal Combustion (IC) engines [5] are suitable processes for Waste Heat to Power (WHP) systems.

Among the available technologies for power production, those based on the conventional Rankine cycle are the most widespread in WHP. Other thermodynamic cycles with potentially higher efficiency, such as Kalina cycles, are scarcely used because of their complexity [5]. Thermo-Electric Generators (TEG) represents an alternative to the technologies based on thermodynamic cycles [6], but the adoption of this technology is still hindered by its high capital cost and low efficiency. For this reason, the current paper focuses on Rankine-cycle-based WHP systems.

One of the most important technical and economic barriers that limit the implementation of WHP is the fluctuating and/or intermittent nature of the waste heat source [7]. These fluctuations occur inherently in industrial processes due to factors such as non-uniform production rates or batch processes; in vehicle engines, they are due to changes in the engine load during driving or cruising conditions.

WHP systems are designed for a nominal operating point (i.e. *design-point)*, which usually corresponds to the highest thermal power available from the waste heat source [8]. At design-point the conversion efficiency of the WHP system is maximum because all components work at rated conditions; however when fluctuations of the thermal power occurs, the WHP system is forced to operate at *off-design* conditions which causes an important drop in the conversion efficiency [9]. In addition to this, when subjected to very large thermal power fluctuations, the WHP systems may have to be completely by-passed due to their extreme off-design conditions. All these aspects lead to an overall low heat recovery which increases the pay-back time and affects the economic feasibility for the implementation of WHP systems. In order to reduce the detrimental effect of the thermal power fluctuations on the WHP systems, different approaches can be considered. These can be classified in two categories, those focusing on stream control and those using Thermal Energy Storage (TES) as a buffer of the fluctuations.

Despite being well-known, the issues associated with thermal power fluctuation on WHP systems, have not been systematically considered in the literature. Furthermore, there is no work to date that comprehensively examines the options to manage the fluctuations by providing technical and economic assessments. Therefore, this paper aims to provide analyses of the technical challenges that thermal power fluctuations impose on WHP systems, as well as review and classify the current efforts to manage these challenges, and the implications they carry on the economic feasibility