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Techno-economic survey and design of a pilot test rig for a trilateral flash cycle system in a steel production plant

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Abstract

In recent years the interest in recovering rejected low-grade heat within industry has intensified. Around 30% of global primary energy consumption is attributed to the industrial sector and a significant portion of this is rejected as heat. The majority of this wasted energy is available at temperatures below 100°C and as such conventional waste heat to power conversion systems cannot economically recover the energy, producing simple pay backs that are unacceptable to industry. The Trilateral Flash Cycle (TFC) is however a promising technology with the ability to harness the rejected heat found in these low grade waste streams. The current research work presents a techno-economic assessment of the installation potential for a low grade heat to power conversion system using a TFC system. In particular, thermodynamic modelling is utilised to estimate the expected energy recovery and, in turn, the potential savings achievable through the TFC solution. The survey investigated three diverse and challenging heat sources at steel production plants. Annual energy recovery from the chosen heat source is expected to be 782 MWh. Prior to the upscaling of the system to the 2MW waste thermal power, a pilot test rig was designed and built. Preliminary tests showed a net electrical power output up to 6.2 kW and an overall efficiency of 4.3%.

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Keywords: trilateral flash cycle; waste heat recovery; steel production; industrial energy recovery

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Nomenclature

c_p	Specific heat at constant pressure [J/(kg K)]
h	Specific enthalpy [J/kg]
$\dot{m}$	Mass flow rate [kg/s]
T	Temperature [°C]
η	Efficiency [-]

1. Introduction

Recovery of heat for conversion to power is of growing importance in today's industrial sector; energy demands and prices are continuing to rise in the global market, and there is increasing scrutiny of industrial environmental impact. Studies find the potential of theoretical global waste heat to be 68.2 TWh, and that 63% of this potential occurs at temperatures below 100°C [1]. As such, low temperature waste streams are once again being examined as potential power sources [2]. These can be found in numerous manufacturing industries in the form of thermal streams and despite containing a significant amount of energy, this energy is often rejected to atmosphere or requires additional energy input to cool. Waste heat from industrial processes, hot flue gasses from gas turbine generators, and heat rejected from nuclear reactors are just some of the sources available [3]. Recovering this energy will help to reduce thermal pollution and generating electricity will play a key role in decreasing overall plant operating costs [4]. Utilising waste heat for production of electricity is therefore increasingly important.

The total heat recovery opportunity for the industrial sector is estimated to lie in the region of 36-71PJ (10-20TWh) [5]. The Iron and steel sector counts for almost half of this potential, which is unsurprising since it is the largest industrial heat user, with an annual energy demand of 213PJ. There are several key processes involved in the making of steel, but by far the largest energy consumer of any integrated plant is the blast furnace. This facility has low exhaust temperatures around 150°C, which puts the recovery of this energy firmly into low-temperature waste heat potential. In fact the iron and steel industry has the highest potential for recovery of low grade heat (below 250°C) of all industrial sectors [5].

The growing interest in technologies for conversion of heat to power is not only limited to the steel industry. In fact, applied research on the topic of waste heat recovery is extensive and has been completed for several different sectors including: ceramics [6], paper and pulp [7], metallurgical [8], oceanic [9], and solar thermal [10]. In particular, there is a wealth of literature around conventional heat recovery cycles used in existing power plants, such as organic Rankine cycle and Kalina cycle [4,11]. The Trilateral Flash Cycle (TFC) is however still largely unexploited. Literature for the TFC is noted by Ian Smith et al. at City University London, where a cycle conceived especially to optimize power recovery from heat resources less than 250°C, is presented [12,14]. Included is detailed technical analysis which shows that the gross power output from the TFC exceeds that of any simple organic Rankine cycle over the entire low-temperature range [13].

The present paper describes the methodology required to develop a TFC system for low grade heat to power conversion applications, with reference to the working fluids at the state of the art. Waste heat recovery opportunities in Iron and Steel have made Tata steel an ideal demonstration partner for this TFC system. As such, three opportunities for demonstration sites at Tata Steel locations are reviewed from technical and economic perspectives, and the complexities considered when designing the pilot-test rig are discussed. Preliminary experimental results are eventually presented.

2. TFC fundamentals and Thermodynamic modelling

In a TFC system, heat gain is achieved without phase change of the organic working fluid, and the expansion process therefore starts from the saturated liquid state rather than a vapour phase. With reference to the plant layout and T-s diagram displayed in Figures 1 and 2, the working fluid is pressurized adiabatically, heated at constant pressure to its saturation point, expanded adiabatically as a two-phase mixture and eventually condensed at constant pressure.