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A hierarchical approach for evaluating and selecting waste heat utilization opportunities

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A R T I C L E I N F O

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A B S T R A C T

This paper presents a ranking criterion for evaluating opportunities that utilize recovered energy from the available waste heat in process sites. The ranking criterion takes into account the energy performance of waste heat recovery technologies associated with each opportunity, their potential to reduce greenhouse gas emissions (namely CO_2) and the economics (costs and benefits). Mathematical modelling of the opportunities using the ranking criterion is developed to allow for systematic evaluation of opportunities, for example within an optimization framework. A methodology using the ranking criterion to design site waste heat recovery systems is also proposed.

The methodology is applied to a case study of a petroleum refinery. Hierarchy and performance of waste heat utilization opportunities depends on the temperature of the heat available, amongst other factors. The site operating cost and CO_2 emissions reduce by 26% and 18% respectively when opportunities to use the recovered energy from waste heat within and outside the process site boundaries are explored. Sensitivity of the ranking to energy prices is studied, to explore the outlook for waste heat utilization in the future. The methodology can be applied to the process industries and other facilities producing waste heat.

1. Introduction

The process industries are responsible for 45% of global carbon dioxide emissions (the majority of which are from combustion of fuel to produce heat and electricity) [1]. Carbon dioxide emissions also account for the largest share of global greenhouse gas emissions [1]. Greenhouse gases are the major precursors of global warming, effects of global warming include: rise in sea levels, increase in global temperature, change in precipitation patterns, loss of habitat and treat to food security. There are three major ways to reduce industrial carbon dioxide emissions: (1) a shift to renewable energy, (2) carbon capture and storage, (3) improving energy efficiency. Energy efficiency has been identified as the most cost effective measure for carbon dioxide mitigation especially in the short and medium term.

As part of an energy efficiency measure, recovery of waste heat in the process industries has been identified as an effective way of improving the energy efficiency of process sites, reducing operating costs and reducing CO_2 emissions [2]. Utilization of waste heat is also described as a green, carbon neutral energy source [3]. Waste heat is defined as the residual heat after heat recovery within a process, heat recovery between several processing units on a site, and residual heat rejected to cooling water and air from a site utility system [4]. This waste heat is produced from multiple sources and occurs over a wide temperature range.

Mature and commercialised technologies exist to recover useful energy (electrical power, chilling and heating) from industrial waste heat. Examples include ORC (organic Rankine cycles) for electrical power generation, absorption chillers for chilling provision, heat exchangers and economisers. Organic Rankine cycles produces shaft work from low to medium temperature heat sources (50–220 °C [5]) using pure and mixed organic fluids [6]. The schematic of a basic cycle is shown in Fig. 1; waste heat vaporizes the working fluid in the evaporator, which expands to generate electricity. In absorption chillers, waste heat provides energy to desorb the absorption liquid in the generator which is condensed, flows through an expansion valve to the evaporator, where it is evaporated hence producing a refrigeration effect. A schematic is shown in Fig. 2. Heat exchangers (schematic shown in Fig. 3) are useful for heat transfer from a hot fluid i.e. heat source which could

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Nomenclature

Abbreviations

ACC	annualised capital cost (£/y)
AHT	after heat recovery
CEPCI	Chemical engineering plant cost index
CO_2E	site CO_2 emissions
CO_2R	CO_2 emissions reduced (kg/y)
EEx	electrical power exported (kW)
FB	financial benefits (kW)
HExN	heat exported to new buildings (kW)
HExE	heat exported to existing buildings (kW)
MC	maintenance cost (£/y)
OC	operating cost (£/y)
P	profit (£/y)
Q	quantity of energy (kW)
RC	ranking criterion
SOC	site operating costs (£/y)
T	temperature (°C)
TAC	total annualised cost (£/y)
TEC	total electricity cost (£/y)
TFC	total fuel cost (£/y)
UER	useful energy recovered (kW)
y	year

Subscripts

i	index for temperature interval
j	waste heat recovery technology
Δ	change

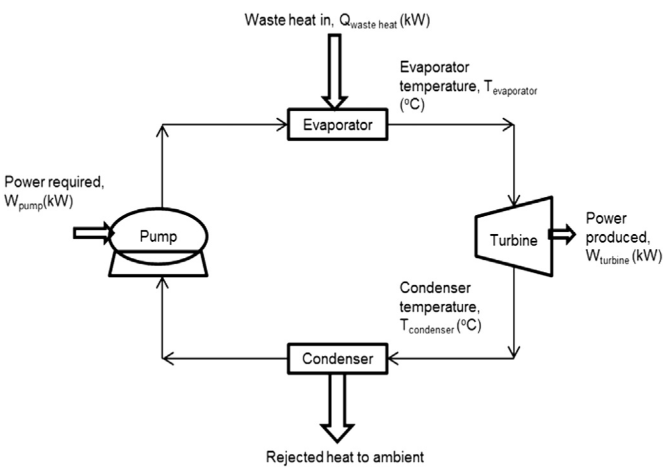

Fig. 1. Organic Rankine cycle schematic [4].

be waste heat to a cold fluid i.e. a heat sink, which could be for generating hot water. Economisers are gas–liquid tubular heat exchangers in which the hot gas (usually waste heat gas streams) flow over finned tubes containing a liquid to be heated up (for example boiler feed water) [3].

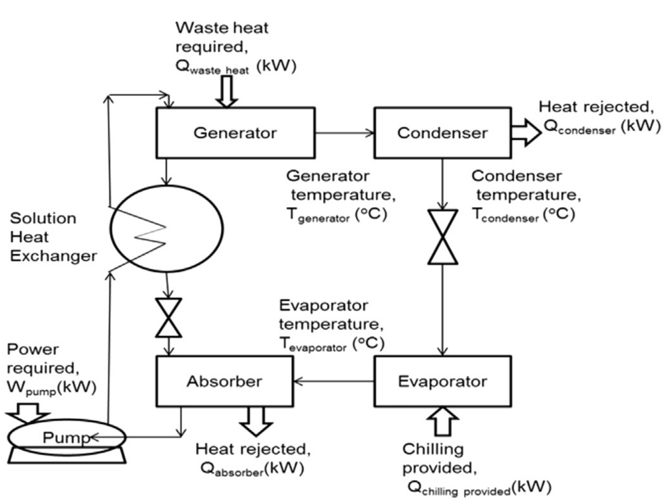

Fig. 2. Absorption chiller schematic [4].

In Hammond and Norman [8], the potential in waste heat is evaluated for the UK process industries. Technologies considered include Rankine cycles for power generation, heat exchangers for on-site waste heat recovery, mechanical heat pumps for heat upgrade, absorption chillers for chilling provision and heat transport off-site. The potential is evaluated based on primary energy saved and greenhouse gas emission saved. The economics (i.e. cost and benefits) associated with the use of recovered energy is neglected and waste heat sources are assumed to be at a single temperature. Opportunities for using waste heat in the UK food and drink industry was evaluated in Law et al. [3], the economic evaluation was limited to the cost of the technologies neglecting the value to which the recovered energy is put and the available waste heat is assumed to be at the same temperature.

For electrical power generation from industrial waste heat, Meinel et al. [9] investigated the performance and economics of an organic Rankine cycle, the economic analysis is based on total costs of operating the technology neglecting the value from using the electricity generated and the potential to reduce emissions. Song et al. [10] performed thermodynamic and economic analysis of an organic Rankine cycle for electrical power generation using five waste heat sources at different temperature levels; design was done at the same target temperature for all the heat sources. In this work, the economic criterion used is a ratio of net power output to total heat transfer area, neglecting the financial benefits associated with the use of the electricity generated and the potential to reduce CO_2 emissions. A technical, economic and market review of organic Rankine cycles was conducted in Velez et al. [11], the economic review is limited to investments in the technology also neglecting the financial benefits associated with the use of the generated electrical power, and the potential to reduce emissions.

Kapil et al. [12] considered different opportunities for using recovered energy from the available waste heat in a process site (a

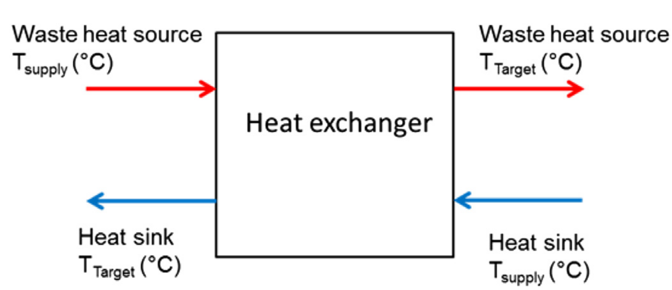

Fig. 3. Heat exchanger schematic.