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Reprint of “Desalination using low grade heat in the process industry: Challenges and perspectives”☆

Yasmine Ammar [a,*], Hanning Li [b], Conor Walsh [c], Patricia Thornley [c], Vida Sharifi [b], Anthony P. Roskilly [a]

[a] Sustainable Energy and Power Group, Newcastle Institute for Research on Sustainability, 2nd Floor Stephenson Building, Newcastle University, Newcastle upon Tyne NE1 7RU, United Kingdom
[b] Department of Chemical & Process Engineering, Sheffield University, Mappin Street, Sheffield S14DU, United Kingdom
[c] Tyndall Centre for Climate Change Research, School of Mechanical Aerospace and Civil Engineering, The University of Manchester, Pariser Building, Sackville Street, Manchester M13 9PL, United Kingdom

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ABSTRACT

This paper examines the use of low grade heat from process industries for thermal desalination processes as this is relevant not only to current energy conservation schemes but also may play a role in increasing the capacity to satisfy future water demands. The study focuses on low grade heat sources from a paper mill located on a British coastal area which presents a large quantity of recoverable waste heat at low temperature (<100 °C). Two scenarios are considered: (i) low grade heat is used directly to feed the desalination process, (ii) low grade heat is upgraded using a heat pump coupled with a desalination system.

In the first scenario, a Humidification Dehumidification process was identified as a suitable technology due to its low operating temperature. In the second scenario, the low grade heat temperature was upgraded using a hybrid absorption heat pump and subsequently used to feed a Multiple Effect Distillation desalination system. These two cases were compared in terms of performances and economics. For both cases, a payback period of less than 10 years could be obtained for water price equal to £2 per tonnes of water. This is comparable to the price of home water supply. Environmental aspects were also discussed from the results of a full Lifecycle assessment. Low grade heat utilisation in both cases reduced the Global Warming Potential in comparison with fossil fuel powered systems, but toxicological impacts appeared higher in comparison to a system using natural gas.

1. Introduction

At the beginning of the 21st century, industrial energy use (particularly the metal and chemical sectors) represented 25% of the total energy use in the UK [1]. Despite industry having invested in energy efficiency technologies for more than thirty years, a considerable amount of this energy is still wasted via gas, liquid or solid discharge. However heat from streams of low thermal quality cannot be economically recoverable within the processes themselves and is currently rejected into the environment. This is referred to as Low Grade Heat (LGH) according to Ammar et al. [2].

The market potential for surplus heat available from industrial processes in the UK was estimated in 2006, by the Carbon Trust to be 40 TWh [3] and more recently by the Government Office of Climate Change as 18 TWh [4] and 10–20 TW h by McKenna [5]. It is worth mentioning that it is difficult to obtain accurate estimates on waste heat at a national scale (this data often being confidential), so most of the results presented in the above investigations are extrapolated from industrial CO_2 emissions, probably due to the relative ease of obtaining emissions data. For instance, McKenna [5] developed a procedure to determine the quantity of thermal energy released into the environment, based on CO2 emission and energy consumed by industries. According to [6], a large amount of LGH was available in process industry as water from cooling towers with a temperature between 35 °C and 55 °C. Flue gas or vapour sources from stacks were equally abundant with a larger temperature range of between 30 °C and 250 °C. The temperature range for LGH sources reported in [7] is in accordance with the widely accepted threshold temperature for LGH which is around 250 °C with 75–85% of all process heat transfer applications operating below 200 °C [8].

LGH is available in large quantities but effective utilisation requires matching the sources with potential end-users in the

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* Corresponding author. Tel.: +44 1912223080.
E-mail address: Yasmine.ammar@ncl.ac.uk (Y. Ammar).

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Abbreviations

A	Absorber
BM	Board Machine
COP	Coefficient of performance
E	Evaporator
EV	Sub-Evaporator
ECOP	Electric COP
FH	Feed Heater
G	Generator
GOR	Gain Output Ratio
HAHP	Hybrid Absorption Heat Pump
HD	Humidification Dehumification
HEX	Heat Exchanger
LCA	Life Cycle Assessment
LGH	Low Grade Heat
MED	Multiple Effect Distillation
MSF	Multi Stage Flash
P	Pre-Heater
RO	Reverse Osmosis
TCOP	Thermal COP

surrounding of the plant. As industrial sites are often located in coastal areas and water shortage is likely to affect large urban zones even in developed cities such as London [2], a sustainable and efficient way to use LGH would be to desalinate seawater on or near the industrial site which acts as heat sources. As a substantial amount of energy is required to convert seawater into desalinated water, it is likely that the UK may face increased future energy demands for desalination plants.

Different methods can be coupled to LGH sources in order to desalinate seawater. They are shown in Fig. 1.

Muti Stage Flash (MSF) heats saline water to a high temperature and passes it through vessels of decreasing pressure leading to flash evaporation. The vapours are condensed back into water by being passed through the brine heater.

Compared with the commonly used MSF desalination process, The Multi Effect Distillation (MED) is becoming an attractive technology, mainly due to low corrosion rate, power consumption and capital cost [9]. The heat source to the MED is also provided by high temperature/pressure steam (>70 °C). But the coupling of MED with Absorption Heat Pump (AHP) renders the use of LGH at lower temperature possible and this is a technical solution retained in this paper. The working fluid in the AHP is chosen as a water-ammonia mixture. In order to increase the ammonia-vapour pressure and therefore allow a greater temperature at the absorber, a compressor driven by electricity is inserted in the AHP cycle. The resulting cycle is referred to as a Hybrid Absorption Heat Pump (HAHP).

Another low temperature desalination system is the Humidification – Dehumification (HD) process. In such a system, the heated water is sprayed into incoming air in the humidification chamber. This serves to humidify the air, which is then cooled down by the feed seawater in the dehumidification chamber, where the condensed moisture is collected. HD systems have proved efficient for small scale application with heat source temperature between 50 °C and 90 °C (cf [6].).

The adsorption desalination is an emerging technology developed for LGH thermal desalination. The process utilizes the adsorbent-adsorbate characteristics and produces fresh water at the condenser. The adsorbents are generally activated carbon, zeolite and silica gel. This technology is currently in R&D investigation. The advantage over conventional thermal desalination have been reviewed [10,11].

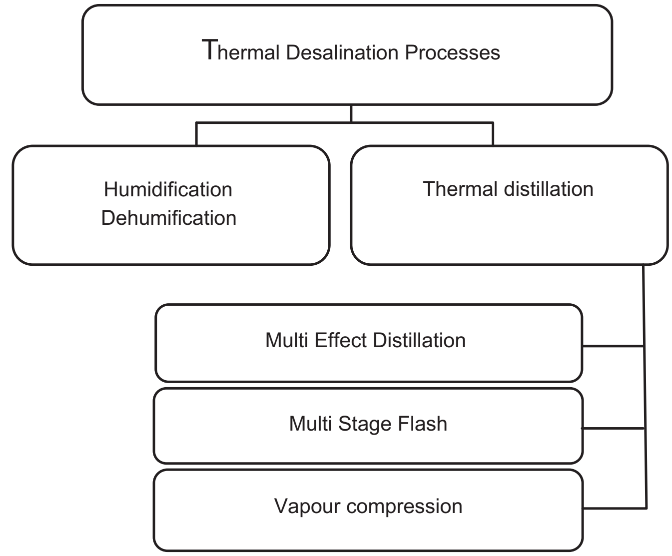

Fig. 1. Desalination thermal processes.

This paper will examine the techno-economic feasibility of the two options: (i) MED + HAHP process and (ii) HD at the industrial scale. The viability of using industrial heat at low temperatures for desalination application depends upon the thermal performance of the desalination process as well as the economic and environmental factors. After presenting the case study, both proposed technical solutions, namely MED + HAHP and HD processes, will be described and analysed, in terms of thermal performance and economics. The environmental impact of using low grade heat to desalinate seawater with the MED + HAHP process is then discussed from the outcome of a full Life Cycle Assessment (LCA).

2. Case study: a paper mill

In order to examine the feasibility of using LGH for the desalination of seawater, an integrated Pulp and board mill was chosen. It is equipped with a CHP plant which supplies the plant with all its steam and most of its electricity requirements. In Table 1 we characterize and classify the potentially recoverable LGH streams in the paper industry. The data have been communicated by the paper mill but the source must be kept confidential.

Based on Table 1, it is shown that more than 20 million litres of water at temperature in excess of 35 °C is discharged into the sea daily. There also exist large quantities of exhaust air leaving the roof at high temperatures without heat recovery. Most of the LGH available is given by the Board Machine (BM). Air and water streams identified

Table 1
Characterization and classification of potentially recoverable low grade heat gas streams in the paper industry.

Description	Location	Temperature (°C)	Mass flow rate (kg/s)	Moisture content
Size exhaust	Size exhaust - BM	56	21.800	0.046
Air exhaust 1	Pre-drying hood - BM	59	20.318	0.035
Air exhaust 7	After-drying hood – BM	61	15.115	0.061
Air exhaust 3	Pre-drying hood – BM	63	20.034	0.052
Air exhaust 5	After-drying hood – BM	109	18.613	0.054
Air exhaust 6	After-drying hood – BM	66	17.214	0.065
Air exhaust 4	Pre-drying hood – BM	50	20.983	0.075
Air exhaust 2	Pre-drying hood – BM	69	26.824	0.049
Air exhaust 0	MG hood BM	67	9.040	0.093
Water	Effluent and water treatment department / Heat exchanger-Pulpmill	47	86	N/A