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Evaluation of low grade heat transport in the process industry using absorption processes

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HIGHLIGHTS

► Review of low grade heat potential in process industries.
► Identification of suitable low grade heat sources from a papermill case study.
► Technical and economical evaluation of Humidification Dehumidification desalination.
► Technical and economical evaluation of Multiple Effect Distillation coupled with heat pump.
► Full Life cycle assessment and comparison to a system using natural gas.

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ABSTRACT

This paper looks at a long distance heat transportation system based on an absorption process using a mixture of water and ammonia as a working fluid in order to use low grade heat available in the process industry. This paper aims at establishing the potential of using this method for economically transferring low grade heat from process industries to domestic heat sinks. To do so, the efficiency of transporting low grade heat sources identified in the process industries was examined. The economic distance was defined as the limit for economically transferring low grade heat from the source to the domestic heat sink. Based on a 10 year payback period, it was shown that heat could reach as far as 30–40 km for low grade heat sources at temperature as low as 80 °C. Finally, the economic distance was expressed as a function of the amount of fuel equivalent associated with low grade heat recovery savings and the economics of the transportation solution was discussed with regards to the expected changes of the heating and steel price over time.

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1. Introduction

In 2001, industrial energy use represented 25% of the total energy use in the UK [1]. The chemical, food and drink, steel and iron and pulp and paper sectors of the process industries were substantial users and represented more than 50% of the industrial energy usage. Despite industry having invested in energy efficiency technologies for more than thirty years, a considerable amount of this energy is still wasted in gas, liquid or solid form. There is still scope for significant efficiency improvement but part of this surplus heat cannot be economically recoverable within the processes and is currently rejected to the environment. This is referred to as low grade heat according to Ammar et al. [2].

According to Ref. [3], a large amount of low grade heat was available in process industry as water from cooling towers with temperature between 35 °C and 55 °C and 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 low grade heat sources reported in Ref. [4] is in accordance with the widely accepted threshold temperature for low grade heat which is around 250 °C. Also, according to Ref. [5], 75–85% of all process heating, cooling and inter-process heat transfer applications take place in the temperature range from ambient up to approximately 200 °C.

Low grade heat is available in large quantity but in order to harness the potential of the low grade heat identified in process industry, there is a need for matching the sources with potential end-users in the surrounding of the plant. The review by Ammar et al. [2] have identified that one of the most important challenges

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Nomenclature

Abbreviation

COP	coefficient of performance
PP	cash flow
P_{an}	annual profit
PPA	payback period
Re	Reynolds number
TCOP	thermal COP

Latin symbols

C_c	installed factor
D	diameter
H	enthalpy
L	distance
$\dot{m}$	mass flow rate
P	pressure
P_c	construction cost
P_s	system price
P_h	heating price
Q	heat
R	radius
T	temperature
V	velocity
W	power consumption
X	ammonia mass fraction
Y	ammonia mole fraction

Greek symbols

ε	absolute roughness
μ	viscosity
ρ	density
λ	coefficient of friction

Subscripts:

a	ammonia
A	absorber
c	cooling
C	condenser
ex	heat exchanger
E	evaporator
G	generator
H	heating
In	inner
out	outer
P	pump
r	rich solution
R	rectifier
v	ammonia vapour
w	weak solution

is to harness the potential of the waste water streams abundantly available at lower temperatures (typically lower than 100 °C). Space heating/cooling can be an interesting alternative for low temperature heat sources. Typically, offices, schools, hospitals are large heat consumers. Cooling is for instance required in large quantity for industrial storage space, supermarket, data centre or for air conditioning in hot summer conditions.

The viability of a low grade heat recovery depends on whether the heat available can economically be transferred from the source to an identified heat or cooling sink. Large thermal energy consumers are often concentrated in urban areas while large heat emitters are located on the coast or suburban zones, typically tens of kilometres away from the cities. Therefore, to recover industrial heat for domestic applications, it is necessary to develop long distance low grade heat transportation which enables the economical transfer of heat over tens of kilometres. So far, however, there has been little discussion about the economic distance for heat transport from the source to the domestic heat sink. Industrial heat is usually transported via water or steam. According to the report by Terra Infirma [6], steam with a temperature of 120–250 °C can be transported over approximately 3–5 km while water with a temperature of 90–175 °C can be transported over 30 km. Other sources cited in that same report mentioned that 9 miles (around 15 km) is the economic limit for low-grade heat. In fact, how far heat can be transported depends on several factors. If heat is assumed to be transported via a pipe, the heat loss factor, which is defined as the ratio between heat loss and the quantity of heat supplied by the source, depends on the pipe material and the efficiency of its insulation, pipe diameter and the temperature of the fluid circulating in the pipe. The profitability of any heat recovery project will also depend upon the cost invested in heat transportation, the total cost being the sum of the pipeline installation, heat losses and pumping cost [7].

For long distances (typically over 1 km), sorption processes are efficient heat transportation systems [8]. The Industrial low grade Heat Long Distance Transportation (HLDT) system was first introduced by Kang et al. [9]. It differs from an absorption heat pump in that the generator and the condenser are located at the heat source site, and the evaporator and the absorber at the user's site. As shown in Fig. 1, three pipelines transporting the strong solution, the weak solution and the condensed working fluid link the source to the user site. Therefore, the system can absorb low grade heat sources from the generator and it can provide cooling at the evaporator and heat at the absorber. $LiBr–H_2O$ and $NH_3–H_2O$ are the usual working pairs of absorption system [9]. $NH_3–H_2O$ appears as a better choice for an absorption working pair. In particular, NH_3 is much cheaper (about one fifth of LiBr cost). There exists no risk of crystallisation for liquid ammonia; ammonia absorption cycle operating at positive pressure, there is only little impact on performance in the event of a leak; and ammonia is not harmful for environment although precautions should be taken with ammonia usage as short-term exposure to high ammonia concentrations air could be fatal [10].

Recently, Lin et al. [11] investigated the performance and the economics of a 500 MW heat transportation system over 50 km, with the heat coming from a nuclear plant. They showed a payback period of 3 years and 8 months for the whole system. Less waste heat is available for free from the process industries and therefore the feasibility and economics of the low grade heat recovery project need to be revised accordingly. There is nevertheless evidence of a potentially economic method based on absorption process to transport low grade heat.

The economic distance refers here to the distance threshold above which low grade heat cannot be economically transferred from the source to the domestic heat sink. It will depend upon the payback period considered. In this study, ten year payback period is assumed to be representative as the cost of construction and particularly the cost of burying pipes is likely to be high in the UK. This paper aims at establishing the potential of using the absorption process system for economically transferring low grade heat from industrial sources to domestic heat sinks. To do so, the system is designed to economically transport the low grade heat sources

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