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Recycling waste heat energy using vapour absorption heat transformers: A review

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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

Vapour absorption heat transformers are thermodynamic cycles which are capable of upgrading the temperature of waste heat energy using only negligible quantities of electrical energy. Although marked as a future technology by the IEA (International Energy Agency), as being important for energy utilization in the 21st century, industrial applications of heat transformers are still very limited. This paper presents a comprehensive review of heat transformer research over the past two decades. Emphasis is placed upon optimisation studies, alternate cycle configurations, working fluids comparisons and industrial application case studies.

Contents

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1. Introduction

Future uncertainty regarding sources of energy supply, the cost of energy, and the need for reductions in carbon emissions means that reducing fuel requirements is a necessary proposition for many companies. Currently, vast quantities of heat energy are being dumped to atmosphere as waste on a daily basis. It is estimated that roughly 3×10^{13} kWh of heat energy is being lost as dissipative waste energy each year from US manufacturing alone [1]. Such figures correspond to approximately 50% of the energy input to this sector leaving in the form of exhaust gases, cooling water, heated products and from surfaces of hot equipment [2]. Although such figures represent large quantities of a valuable resource not many systems are currently employed in industry to combat this situation.

The principle reason that this energy is being discharged is due to its low temperature, as the plant cannot further utilise it in any heating operations. In order to allow recycling and reuse of this energy, its temperature must therefore be increased using a heat pump. The principle of a heat pump is to transfer thermal energy from a low temperature source to a high temperature sink. Many different configurations of heat pumps exist, however in general they may be divided into two main categories namely vapour compression heat pumps and absorption heat pumps [3]. Vapour compression heat pumps are simple in design and can achieve large gross temperature lifts (GTLs), however their main disadvantage for use in the energy recovery sector is that they require significant quantities of valuable high quality electrical energy. Absorption heat pumps (AHPs) are an alternative which reduce this electrical requirement. Such systems use a working fluid pair consisting of a refrigerant and an absorbent, and utilise high temperature heat energy (and negligible quantities of electricity) to achieve their heat pumping action [4]. The AHP's requirement of a high temperature heat source means that it is principally suited to refrigeration applications however, and is thus generally termed an absorption chiller.

The vapour absorption heat transformer (AHT) inverts the operation of an AHP however, enabling intermediate temperature waste heat energy to drive the cycle and to generate a high temperature heat source (Fig. 1). Thus while the AHP is suited to refrigeration applications, the AHT is of primary interest when attempting to recycle heat energy by increasing its temperature, converting it into a quantity of high temperature, high quality, usable energy [5]. Up to 50% of the waste heat may typically be recovered [6], and their operation requires only very small amounts of mechanical energy [3]. The remainder of the heat energy which is not recovered is discharged to a low temperature sink [5] (Fig. 1). It has been demonstrated that considerable energy savings and a reduction in fuel requirements may be achieved if installed in suitable facilities [7], and it is for these reasons that heat transformers have been called 'future technology which will be important for energy utilization in the 21st century' by the IEA [8].

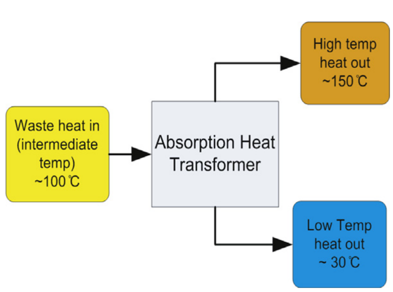

Fig. 1. Conceptual operation of an absorption heat transformer.

Although AHTs may enable significant energy savings at minimum operating costs [9], only very few of these systems are currently in industrial use [8]. The majority of studies which have been conducted to date focus primarily upon the thermodynamic performance of the system. Issues such as the practicality of physically operating an AHT in a plant or the economic issues affecting its financial performance require further analysis however in order to convince industrial investors to install these cycles in their plants. Table 1 lists some of the principle potential advantages and disadvantages of this technology. The conventional working fluid combinations used in AHTs have problems associated with significant levels of corrosivity, and therefore this issue is explored further in Section 4. The application of these cycles integrated into actual plants and processes, including detailed economic analyses, must also be conducted in order to determine their feasibility under different conditions. Such studies are discussed in Section 5.

The principle reason why heat transformers are not being utilised in industry is that they are still an unknown entity. The literature therefore needs to move away from treating AHTs as theoretical thermodynamic objects, and begin to address issues which may prevent industrial application (such as those listed in Table 1). This paper therefore attempts to enable such future work to proceed by combining and analysing the thermodynamic, working fluid and industrial case study results published to date, ensuring that future research can utilise such previous findings instead of duplicating them as has happened on numerous occasions in the past.

2. Single stage heat transformers (SSHT)

Single stage heat transformers can increase the temperature of approximately 50% of the waste heat energy by ~ 50 °C. They are the simplest and most commonly investigated heat transformer configuration. This section therefore summarises the principal findings emanating from thermodynamic studies which have been conducted on this type of system.

2.1. SSHT system description

This subsection describes the operation of a single stage heat transformer (SSHT). A single stage heat transformer is effectively a single effect absorption heat pump (or absorption chiller) working in reverse [10], and consists primarily of one condenser, one evaporator, one absorber and one generator (Fig. 2). The primary difference compared to the single stage absorption heat pump is that the absorber and evaporator now operate at high pressure and the condenser and generator at a lower pressure. A heat source supplied to the generator is used to separate the more volatile component, the refrigerant, from the absorbent (generally water and LiBr–H_2O solution) by evaporation at an intermediate temperature (~ 100 °C). The refrigerant vapour then flows to the