

The Potential for Decarbonisation of Heat Using Heat Recovery Technology

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Abstract:

The paper aims to address the importance and demand for the technological development of waste heat recovery technologies for decarbonisation of heat. Increasing attention has been focusing on the decarbonisation of heat due to the concerns on environmental problems by burning fossil fuels for heating and the demand for highly efficient energy system. Energy-intensive industry sites contain a large amount of wasted heat, which have not been fully recovered and commonly dumped to the environment. The efficiently and effectively reuse the industry wasted heat is in high demand as one of the zero-emission heating solutions. The heat transport solutions including district heat networks and Mobilised Thermal Energy Storage System could be potential solutions to recover and reuse industry waste heat for either on-site or off-site application. The innovative technologies using thermochemical fluid to form a loss-free district heat network and integrating thermal energy storage system with heat to power technology-organic Rankine cycle are expected to be the future mainstream solutions as highly efficient integrated energy systems.

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1. INTRODUCTION

Increasing attention is focusing on the environmental problems caused by burning fossil fuels, which produce greenhouse gases, primarily CO₂. For example, the UK has set a target to cut its greenhouse gas emissions by at least 80% by 2050, relative to 1990 levels [1]. To achieve this target, a dramatical reduction in energy consumption will be required, and therefore significant improvements in energy efficiency are necessary. Energy recovery from industrial waste heat sources is considered to offer a significant contribution to improving overall energy efficiency in the energy-intensive industrial sectors. On 7th July 2018 Department for Business, Energy and Industrial Strategy (BEIS) launched the Industrial Heat Recovery Support Programme (IHRSP) aiming to overcome the barriers to the recovery and re-use of waste heat from industrial processes. BEIS believe that, over its lifetime, IHRSP has the potential to reduce total industrial energy bills by over £500 million, which will bring industrial competitiveness and productivity gains, and help to insulate the industry from future energy price fluctuations [2].

The energy-intensive industrial processes as well as in IC engines from the transport sector contain large quantities of waste heat. The effective and efficient use of waste heat adopting waste heat recovery technology is an enormous opportunity to increase the energy efficiency of various sectors and reduce emissions of primary sources. The waste heat recovery methods can be classified as follows [3, 4] (a.) reuse through heat exchanger for on-site heat recovery in industry and directly transport application [5] (b.) upgrade the heat source temperature from heat pump technology [6] (c.) convert the waste heat to cooling using absorption or adsorption heat pumps [7, 8] (d.) recover the waste heat to electricity or mechanical power with heat driven power generation technologies such as the Organic Rankine cycle [9, 10] (e.) store and transport the heat for the off-site demand use [11-13].

2. SOLUTIONS FOR DECARBONISATION OF HEAT

Heat is one of the most difficult sectors to decarbonise in the energy system [14]. The International Energy Agency reports that 50% of final energy consumption globally is used for the

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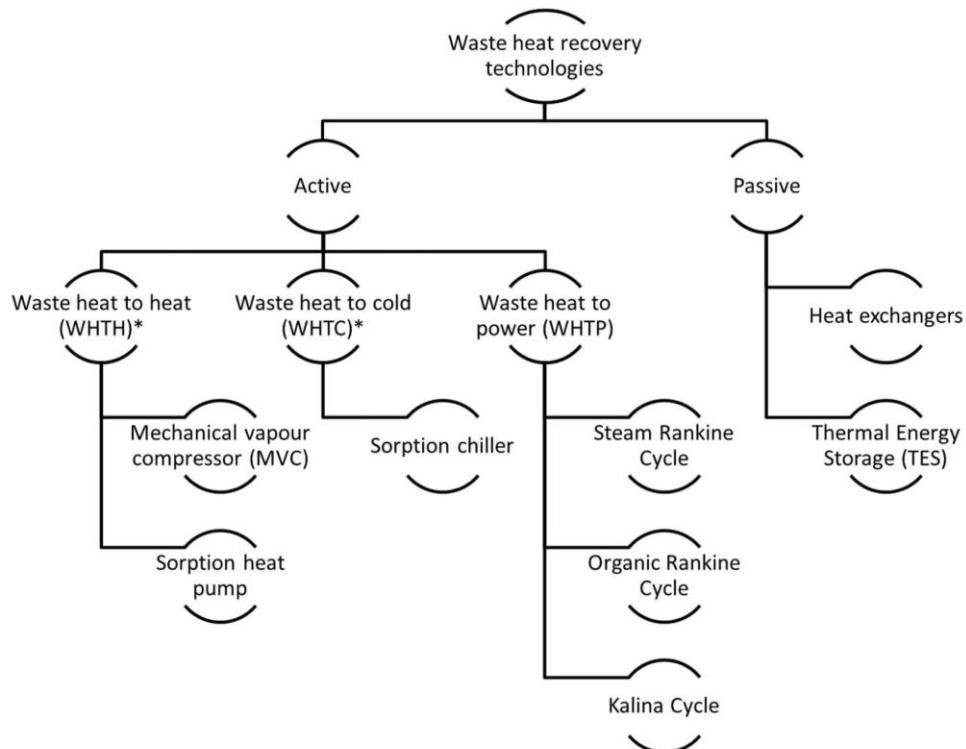


Fig. (1). Classification of waste heat recovery technologies [4].

generation of heat [15]. In the UK, heat is the single biggest use of energy accounting almost half (46%) of the final energy consumption [14]. Half of the final energy consumption in the EU can be contributed to heating and cooling applications [16]. Nowadays, the heat demands are primarily provided through the following three methods gas boilers burning natural gas, electric heaters and district heat networks. Although electricity can be recognised as a zero-emission energy resource, the life cycle of electricity is not actually zero-emission because the majority of the electricity generating from the power generation systems is through burning fossil fuels. The fact is fossil fuels provide around 75% of heat energy, which means heat is responsible for a significant proportion of greenhouse gas emissions [16]. It can be expected that tackling the decarbonisation of heat is essential and critical to fulfilling the climate obligations for many nations including the US, EU nations, and China.

Recovering heat from the energy-intensive industry processes is recognised as one of the most potential solutions [17]. One of the most important technical and economic barriers that limit the implementation of the WHR system is the fluctuating and/or intermittent nature of the waste heat sources [18]. These fluctuations occur inherently in industrial processes due to factors such as non-uniform production rates of batch processes [19]; in vehicle engines, they are due to changes in the engine load during driving or cruising conditions [9]. Thermal Energy Storage (TES) system has the potential to solve the intermittent and discontinuous waste heat sources stabilised generating a lower temperature output as shown in Fig. (2). The TES can be operated as either on-site or off-site mode. The on-site reuse and recovery of industrial waste heat

is an enormous opportunity to reduce the energy intensity of the plant resulting to the reduction of energy costs and the costs derived from the CO₂ emissions [20]. The on-site heat recovery can be classified into three types: 1). Directly used by the on-site equipment, which requires preheat function such as a regenerative burner 2). Stored in the TES system providing hot water or for industrial space heating 3). Recovered to generate steam to drive an expansion device for power generation. These three methods can be solely, jointly or all adopted for the on-site heat recovery based on the demand of the industry.

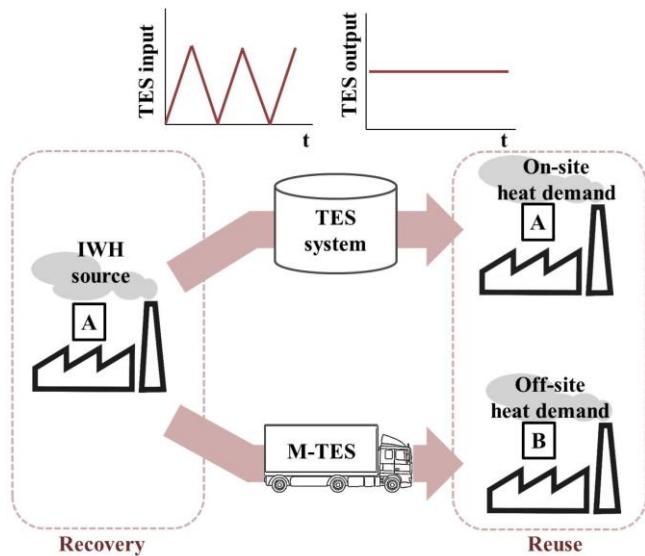


Fig. (2). Schematic of on-site and off-site reuse of industrial waste heat [20].

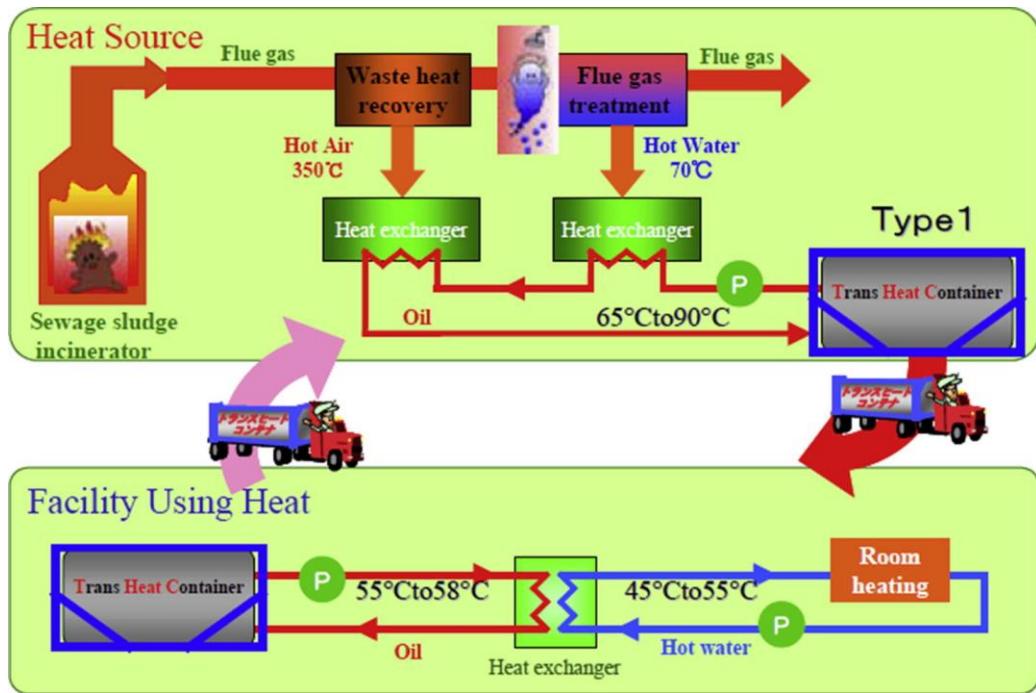


Fig. (3). Flow diagram of a mobilised thermal energy storage system [23].

The definition of the off-site heat recovery is to reuse and transport the wasted heat somewhere has the heat demand. The thermal energy of the industrial waste heat can either be directly connected to the district heat network or indirectly by integrating the TES system with district heat network [21]. The Mobilized Thermal Energy Storage System (M-TES) is an alternative method to reuse industrial waste heat [22]. Such a system as illustrated in Fig. (3) recover the industrial waste heat through heat exchangers transferring the heat to the heat storage container. The thermal energy storage materials can either use Phase Change Materials (PCM) or Thermochemical Materials. The M-TES system developed by the Sewerage Bureau of Tokyo Metropolitan Government adopted PCM as the thermal energy storage material recover the waste heat sources with the temperature ranging from 70 to 350 oC [23]. The system can be operated to produce room heating for hospital, offices, hotels and sports centre using Type 1 PCM with the melting point at 58 oC in the winter time. Moreover, the system can also be used to generate room cooling when the Type 2 PCM with the melting point at 118 oC driven an adsorption chiller as a system reported by the authors [7]. Results indicated the M-TES system can potentially reduce the overall energy consumption between 68% and 95% and achieve the reduction of CO₂ emissions between 71% and 93% [23]. The M-TES can be a potential solution when the overall cost of the district heating and cooling system is higher.

The heat transport is more speculative than other technologies because the transportation distance and the overall efficiency of the heat transfer and transport processes are facing considerable uncertainties [3]. Heat networks is a favourable solution. Linking the industrial waste heat to district heat networks not only can potentially reuse the surplus heat for the on-site space heating but also for commercial and domestic users. The most successful district heat networks are currently

in Denmark providing 70% of heat demands through the system [24]. The cost of heat pipelines, the uncertainty of heat supply from the industry plant for example a disruption in production or closure of one site, relatively low energy density of heat transfer media-water and the inescapable heat losses during the heat transport process using latent heat transfer media are the main barriers of the installation and application of heat networks.

Nowadays, increasing interest has been focusing on the technological development of integrated energy systems considering the economic, environmental and energy security benefits of heat networks. Researchers reported the definition of the 4th generation district heat and the concept of integrating smart thermal grids into future sustainable energy systems [25], which pointed out the importance of use and development of integrated smart electricity, gas, thermal grids and other energy systems. Raine et al. from Sheffield University investigated the potential of recovery intermittent industry waste heat from three steel making industries in the UK using a thermal energy steam accumulator as TES system, which is an on-site district heating network [26]. The feasibility study indicated such integrated system has the potential of an estimated annual 22,482 tCO₂ saving [26]. Geyer et al from KU Leuven [27] proposed to use hybrid thermochemical district networks for district heating, cooling and drying functions with the potential of no heat loss due to thermal chemical reactions during heat charging-discharging process, which can replace the current latent heat transfer media-water with thermo-chemical fluids. The preliminary study suggested the theoretical energy consumption can be reduced up to 85% [27]. A schematic diagram of the concept of thermo-chemical district networks is illustrated in Fig. (4) [28]. The proposed thermochemical district networks can also be integrated with heat pump, TES system and other heat recovery technologies to improve the overall energy efficiency and produce multi energies.

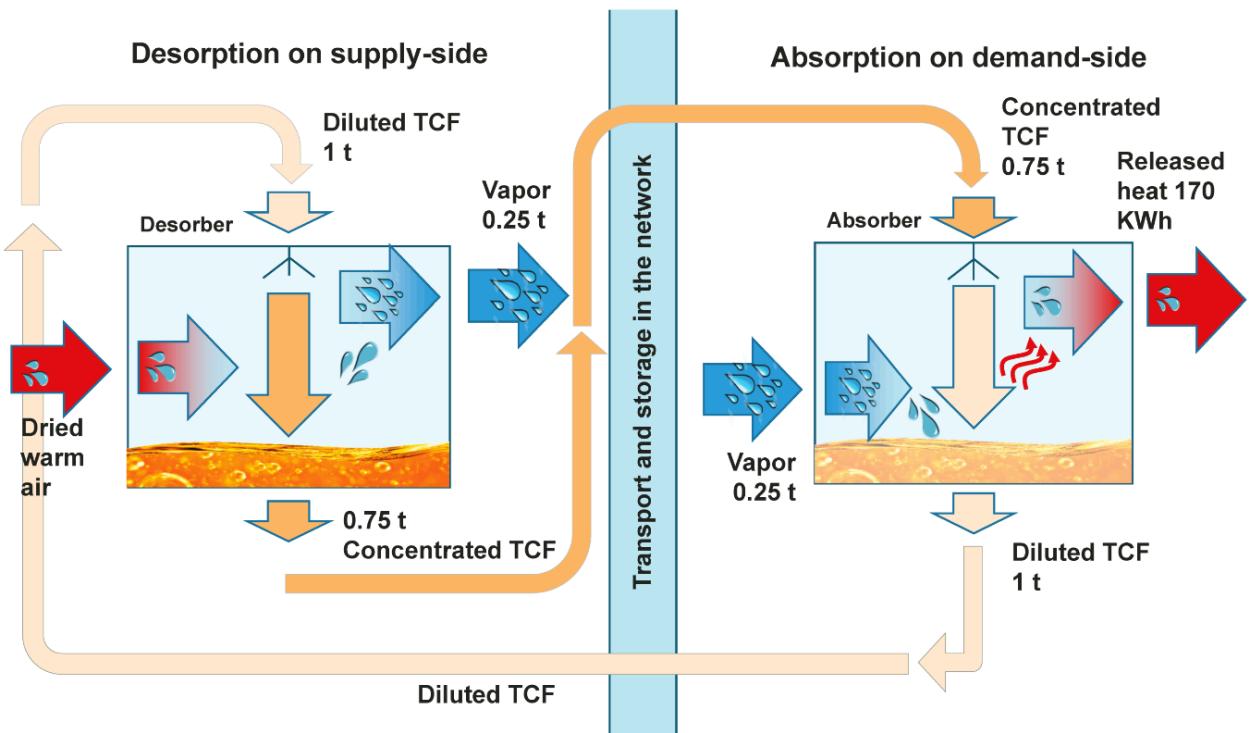


Fig. (4). Schematic diagram and working principle of the thermo-chemical district network [28].

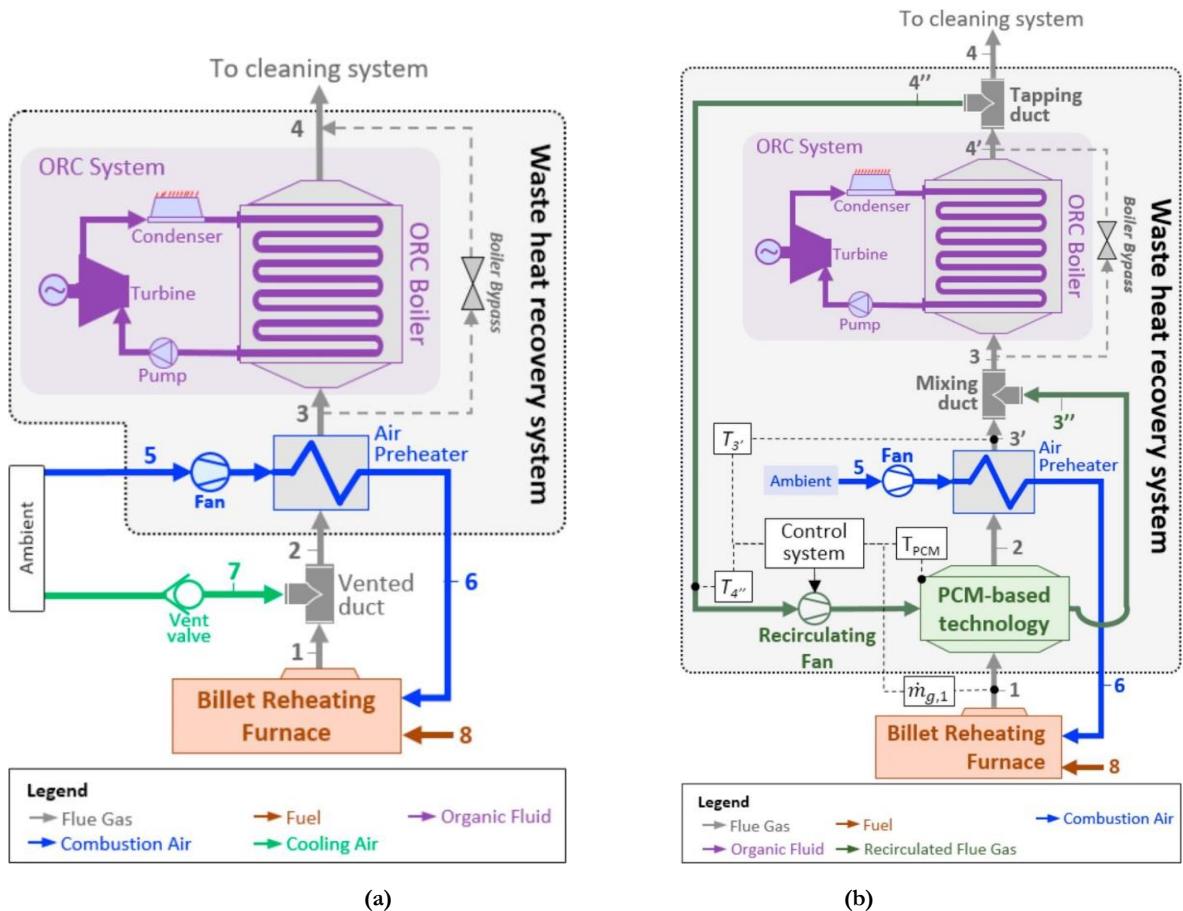


Fig. (5). Schematic diagram of heat to power Waste heat recovery system [18].

(a) conventional system, (b) system integrated with TES system using PCM-based technology.

The technology to decarbonisation of heat can also be integrated with heat to power system and TES system generating space heating, electricity and storing the thermal energy with the advantages of balancing the demands and optimising the system performance. A conventional heat to power waste heat recovery technology recovering industry waste heat is illustrated in Fig. (5a) [18]. A large amount of condensation heat demand from the organic Rankine cycle requires to be rejected to the environment, which is normally through a cooling tower. The condensation heat can be directly reused and consumed by the District Heat Networks for space heating if such system can be available close by. TES system can also be integrated with the heat to power system to balance the intermittent and fluctuating industry thermal sources with the benefit of maintaining the heat to power system within the designed conditions and the excess heat stored in the TES system can also be used for heating. It can be expected that the integrated energy system with the function of thermal energy storage will be the key research topic for Industry Waste Heat Recovery and a potential solution for decarbonisation of heat.

CONCLUSION

Heat is one of the most difficult sectors to decarbonise in the energy system and has been usually considered as a less important energy vector. The energy-intensive sectors especially the industry sector consume most energy sources in the world, which therefore attribute to the majority of greenhouse emissions. Using heat recovery technology to reuse waste heat from industry can be a potential solution to generate zero CO₂ emission heat and improve the energy efficiency of industrial plants. One of the technological and financial barriers using the waste heat recovery technology is the intermittent and fluctuating nature of the industrial thermal sources. Thermal energy storage system using phase change materials or thermochemical materials is desirable and generally recommended for the industrial waste heat recovery. District heat networks and M-TES are two main technologies for heat transport from the industry to the demand users. The main concern to apply M-TES system is the economic feasibility of the technology. The development of innovative integration systems such as using thermochemical fluid replacing water to form a loss-free district heat network and integrating TES system with heat to power system and district heat network is expected to be the future research tendency in the area. A combination of these technologies to form a highly efficient and energy saving heat network system with the capability of thermal storage and power generation can potentially open opportunities for recovering heat from industrial sites.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest

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