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Waste heat usage

Jim Swithenbank [a], Karen N. Finney [a,*], Qun Chen [a], Yao Bin Yang [a], Andy Nolan [b], Vida N. Sharifi [a]

[a] Sheffield University Waste Incineration Centre (SUWIC), Department of Chemical and Biological Engineering, University of Sheffield, Mappin Street, Sheffield, S1 3JD, UK
[b] Sheffield City Council, Town Hall, Surrey Street, Sheffield, S1 2HH, UK

HIGHLIGHTS

- ► The UK has few district heating schemes but there is much potential for development.
- ► GIS mapping can identify heat sources/sinks to aid infrastructure deployment.
- ► Innovative CHP systems for cities need to be small-scale and high-efficiency.
- ► Numerical modelling of heat transfer can help optimise combustor designs.
- ► Energy storage can mitigate the erratic supply of non-fossil fuel energy sources.

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ABSTRACT

This paper presents an overview of heat transfer issues arising from the current national situation regarding energy sustainability and global warming. An important concern addressed is the inefficiency of present fuel usage in the UK – namely large-scale, fossil-fuelled power stations and energy-from-waste plants that discharge huge quantities of low-grade heat to the atmosphere. Other countries recover this thermal energy and use it to supply heating and hot water to nearby domestic, commercial and industrial buildings. Such district heating schemes can provide cost-effective and low-carbon energy to local populations. Although the amount of district heating in the UK is small, Sheffield currently has an award-winning city-wide district energy network that incorporates a combined-heat-and-power energy-from-waste facility, providing electricity and district heating; this scheme is explored herein, with the purpose of identifying potential expansions through heat mapping. Heat transfer will clearly need to play a major part in one or more of the various power generation technologies proposed to meet the demands of the developing energy situation – these comprise high-efficiency systems using high-temperature regenerators or high-pressure combustion and energy storage utilising supercritical steam accumulators, which are all considered in this paper.

1. Introduction

The 2009 UK Low Carbon Transition Plan highlighted two major goals for national energy policy: tackle climate change by reducing CO_2 emissions and ensure secure, clean and affordable energy as we become increasingly dependent on imported fuel. Many current scientific papers [e.g Refs. [1–4].] start by drawing attention to the global problems of climate change, fuel poverty and energy sustainability; therefore, it is assumed herein that these topics are already familiar to engineers/scientists, hence the focus of this paper will be 'what can/should we do about the situation'.

A key feature of the approach used is based on recognising the fact that the UK does not use a large fraction of the energy in the fuels consumed. The chemical energy of a fossil fuel is predominantly released via combustion at flame temperatures >1000 °C. Conventional thermodynamics tell us that maximising the efficiency of mechanical/electrical power production depends on using high top and low bottom temperatures for the thermodynamic cycle. Since power is generally more valuable than heat, it is important that we exploit the fuel energy by utilising high flame temperatures whenever practicable. We use about one third of all the fossil fuels consumed in the UK to produce low-grade heat for buildings – this is clearly not an ideal. Fortunately, many industrial

Abbreviations: ASU, air separation unit; CCS, carbon capture and storage/sequestration; CFD, computational fluid dynamics; CHP, combined heat and power; CV, calorific value; EfW, energy-from-waste; ERF, energy recovery facility; GIS, geographical information systems; HHV, higher heating value; LHV, lower heating value; MSW, municipal solid waste; NO_x, oxides of nitrogen; SO_x, oxides of sulphur.

* Corresponding author. Tel.: +44 114 2227563; fax: +44 114 2227501.
E-mail address: K.Finney@sheffield.ac.uk (K.N. Finney).

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facilities, such as power stations that produce electricity reject low-grade heat at temperatures suitable for heating buildings. As a consequence, the well-known concept of combined-heat-and-power (CHP) is a naturally available resource. Many cities in Europe, such as Vienna (Fig. 1), use CHP by distributing the low-grade heat from power stations at the edge of the city through a district heating pipe network.

The reason why CHP is not generally used in the UK is probably due to the fact that the government set up the Central Electricity Generating Board in 1937 to generate electrical power as cheaply as possible, rather than with a responsibility to use fuels efficiently. Most process plants obey the 0.6 power scaling law, which means the capital costs of plants does not increase linearly with scale. The result was that electrical generation plants were built as large as practicable and hence are located far from cities that could use the waste heat for district heating. Many of these plants are now approaching the end of their life and could be replaced by smaller plants located near towns where they could be connected to a district heating scheme, increasing their overall efficiency from 40–45% ('electricity-only' generation) to regularly exceeding 70–85% for CHP.

2. Principles of district heating

District/community heating can have a range of benefits. Firstly, the technologies utilised, such as co-/tri-generation, make use of 'waste' process heat. They operate at higher efficiencies so more energy can be recovered; this in turn decreases both fuel consumption and pollutant generation for the same energy output, consequently helping achieve CO_2 reductions and aiding resource conservation. This is particularly true if renewable/sustainable fuels, like biomass or wastes are used. Secondly, CHP-based systems can provide cost-effective energy to local populations, in terms of electricity, space heating/cooling and hot/cold water. Due to the higher efficiencies, often lower environmental impacts and benefits to consumers, increasing the amount of heat from distributed energy can be both a sustainable and secure means of meeting future energy demands. There are however disadvantages: the main contentious issue is that a heat distribution network is needed to dispense energy from the source to the end-users. Installations can be expensive and difficult to retrofit into existing homes/buildings. Nevertheless, power stations already need a large investment that is only recovered over many years; CHP has a similar need for long-term investment in the pipe network.

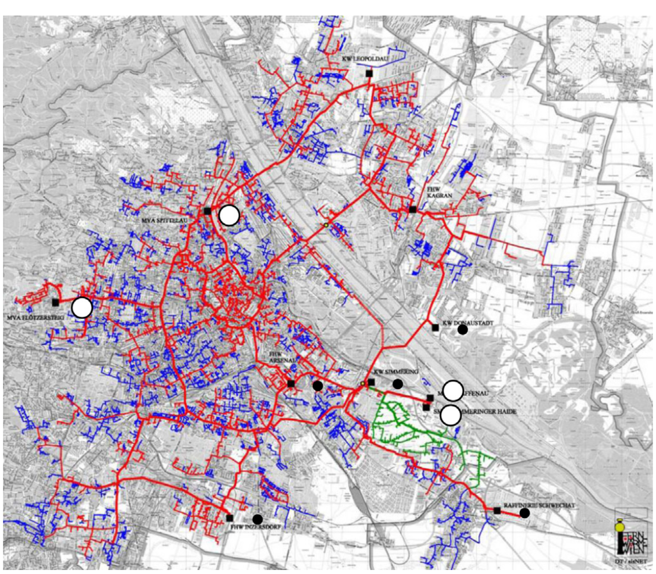

Fig. 1. An overview of the Vienna waste-to-energy district heating system. This annually distributes 5580 GW h of heat around the city, via 1100 km of pipelines to 5800 major customers, including 285,000 domestic environments in the city. The heat input comes from four incinerators ○ (burning waste and sewage sludge) and five power stations ●, as well as six other sites. Source Ref. [5].

Most district heating systems supply the heating water at ~150 °C and return it at ~70 °C to match currently installed radiators and pipe designs. However, overall system efficiencies could be increased through using a 'condensing' boiler principle. This allows the latent heat of the moisture in the flue gas to be recovered and requires that the return water temperature from the district heating system is below the dew point of the flue gases (~65 °C). A return temperature of 30 °C is appropriate to satisfy the corresponding heat exchanger approach temperature requirement. Clearly, this would necessitate a significant change in the design of central heating systems. Increasing the size of radiators is probably not appropriate, thus two alternatives are proposed. The first is the use of fan-assisted multi-cell radiators, such as the 'Agavector', which provide a compact wall mounted unit. The second is the use of under-floor heating that operates at ~30 °C; this limits the floor temperature by circulating water through a mixing valve. Clearly, the latter is more suitable for new buildings, since pipes can be installed during construction.

3. Modelling heat and energy

3.1. GIS modelling for expanding district heating networks

3.1.1. The existing district energy network in Sheffield

Sheffield already has an extensive district energy system, incorporating community heating and electricity production, where the primary energy generation facility is located near the city centre. Although this provides a number of benefits, the expansion of this network could further ensure that future energy demands in Sheffield are met from low-carbon, renewable/sustainable energy sources [6]. The award-winning network here consists of an energy recovery facility (ERF) that operates on the CHP principle, combusting ~225,000 t of local municipal solid waste (MSW) annually. This generates 60 MW of thermal energy for district heating and 21 MW of electricity, which is fed into the National Grid [7]. The ERF is connected to a 44 km underground pipeline network, which distributes the heat for heating buildings and hot water. There are over 140 buildings served by this, including shops, offices, health facilities and both universities, in addition to almost 3000 residences. Around 120,000 MW h of heat is delivered each year, which results in annual CO_2 savings of ~21,000 t. Established in 1988, this district energy network is not only the largest in the UK, but also the most successful [7]. The pipeline network, connected buildings and stand-by/peaking energy stations are outlined on Fig. 2.

There are four main benefits of district heating in general: (i) heat is generated in proximity to where it is used; (ii) renewable heat technologies currently require a distributed approach; (iii) district heating can provide reasonably-priced heat – critical to the fuel poverty agenda; and (iv) heat can easily be stored [8]. Environmental advantages are also often apparent; there are several reasons why this is less carbon-intensive than traditional large-scale, centralised power facilities that combust fossil fuels, like coal. The system in Sheffield burns residual (non-recyclable) MSW; often more than two thirds of the carbon in this energy source is greenhouse gas-neutral (in some cases, 85% of the CO_2 is bio-derived), thus much lower amounts of net CO_2 are emitted [9]. This can aid the achievement of national carbon emission reduction targets. Other pollutants, such as CO, particulates and acid gases like NO_x and SO_x (oxides of nitrogen and sulphur), are minimised/removed by gas cleaning