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Opportunities for low-grade heat recovery in the UK food processing industry

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ABSTRACT

Energy efficiency in the process industry is becoming an increasingly important issue due to the rising costs of both electricity and fossil fuel resources, as well as the tough targets for the reduction in greenhouse gas emissions outlined in the Climate Change Act 2008. Utilisation of waste heat sources is key to improving industrial energy efficiency, with an estimated 11.4 TWh of recoverable heat being wasted each year, a quarter of which is from the food and drinks processing sector.

This paper examines the low-grade waste heat sources common to the food and drinks processing sector and the various opportunities for the use of this heat. A review of the best available technologies for recovery of waste heat is provided, ranging from heat transfer between source and sink, to novel technologies for the generation of electricity and refrigeration.

Generally, the most economic option for waste heat recovery is heat exchange between nearby/same process source and sink, with a number of well-developed heat exchangers widely available for purchase. More novel options, such as the use of organic Rankine cycles for electricity generation prove to be less economical due to high capital outlays. However, with additional funding provision for demonstration of such projects and development of modular units, such technologies would become more common.

1. Introduction

Reducing industrial energy consumption is becoming an increasingly important issue in the UK processing industries because of various factors. The rising cost of both electricity and fossil fuel resources [1] provides an ever increasing monetary incentive while companies are also often keen to be viewed as sustainable in order to be more attractive in the eyes of key stakeholders, including the consumer.

However, the principal incentive for reduction in energy consumption is provided by the tough self-imposed UK government legislation outlined in the Climate Change Act 2008 [2]. This legislation targets an 80% reduction in greenhouse gas emissions by 2050 (based on 1990 levels), and an interim target of 34% by 2020. With UK industry contributing around 20% [3] of current emissions, it is expected that particular emphasis will be placed on the process industries to reduce emissions.

With the demand for industrial produce unlikely to drop, especially in the crucial food/beverages sector, the emphasis is on reducing energy consumption by increasing energy efficiency. A key way of doing-so is to recover energy from waste streams, i.e. streams of greater than ambient temperature that are currently emitted to the environment.

The estimated potential for waste heat recovery in the UK processing industry is significant at 11.4 TWh/year [4], around 5% of the total energy consumption, with 2.8 TWh/year of waste heat available in the food/beverages sector. Utilisation of this heat can be described as a *green*, carbon neutral, energy source as it is making use of what is essentially a waste product. Hence if this heat may be used in place of traditional fuels, the reduction in greenhouse gas emissions would be significant, as would cost savings.

For example, the predicted reductions in greenhouse gas emissions and operating costs for the best case theoretical scenario whereby all of the available waste heat is recovered to replace heating duties previously provided by natural gas is shown below in Table 1.

Table 1 shows that huge cost and emissions reductions are possible through the complete recovery of waste industrial heat in the UK. Overall, it is possible to save up to £285million and over 2 million tonnes of carbon by replacing previous gas heating duties by recovering waste heat. The food/beverages sector accounts for around 25% of this waste heat, with the potential to save £70million/year and over 500,000 tonnes of carbon dioxide/year, and will therefore be a key player in the recovery of industrial waste heat.

Although these are only our best estimates, (often there is a surplus of waste heat preventing the matching of waste heat

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Table 1
Potential cost and emissions savings per year due to recovery of industrial waste heat.

	Units of waste energy per year (kWh/year)	Cost per unit gas [5] (£/kWh)	Greenhouse gas emissions per unit of gas [6] (kg/kWh)	Potential cost savings per year (£m/year)	Potential emissions savings per year (tCO_2eq/year)
Industry total	11.4×10^9	0.025	0.1836	£285m	2093040
Food & drinks sector	2.8×10^9	0.025	0.1836	£70m	514080

sources with suitable heat sinks which leads to the need to explore further heat recovery options), they are useful in giving a picture of the overall magnitude of the potential for waste heat recovery in UK industry.

Heat recovery has been explored many times previously and the idea is not a new one: heat integration based on pinch analysis was first introduced in the 1970's for example [7]. However, various new technologies have emerged in recent years to enable the recovery of lower temperature heat streams, such as low temperature organic Rankine cycles with novel working fluids [8] and compact heat exchangers with low approach temperatures. As basic pinch technology is based around the shell and tube model of a heat exchanger [7], and the general rule is that low temperature streams are of little heat value, a lot of waste heat streams have been ignored and only now has the focus shifted to utilising this low-grade heat.

This paper concentrates on the potential for low-grade heat recovery in the UK food and drink processing industry and reviews the best available technologies for the utilisation of this heat. An assessment of common low-grade heat sources in the industry is provided along with a discussion of the merits of each technology in each situation.

In this sector there are several challenges in heat and mass transfer (some of which are unique), which must be considered if heat recovery is to be implemented. The various obstacles include the need for tight control of temperature and heat transfer rates, and the high levels of fouling and complex rheologies of many process streams. Also, any new equipment must comply with strict health and safety regulations outlined by government agencies. These difficult challenges must be overcome in order to achieve successful heat recovery.

2. The UK food and drinks processing industry

2.1. Definition of the industry

Food and drinks processing in the UK is a major industrial sector, employing 3.6 million people and amassing a profit of over £80billion/year [9]. It accounts for around 25% of industrial energy use (42 TWh/year).

The scope of the industry is any processing of foodstuff and drinks in the UK. The main sub-sectors are meat and fish production, processing and preservation of potatoes, vegetables and fruit, dairy produce, manufacture of edible oils and fats, grain mill products, bakery products, sugar production, brewing and distilleries, soft drink production, and tea/coffee production.

2.2. Energy use in the industry

As previously stated, this sector accounts for around 25% of industrial energy use in the UK, around 42 TWh/year. This energy use is broken down according to the various processes involved in Fig. 1 [4].

Low temperature processes (including cooking of food in ovens/fryers etc) dominate the energy usage in the industry, with the only other significant thermal shares belonging to drying/separation (which also often occurs at low temperatures) and refrigeration (both synonymous with the industry).

With limited accurate data available on the specific temperature grade of the waste heat available within the industry, assumptions must be made to predict this. As the industry uses the majority of its energy in running low temperature processes, a fair assumption is that most of waste heat available will be in the low temperature range. Hence a significant amount of low-grade waste heat is available for recovery. Furthermore, waste heat streams associated with refrigeration and drying generally fall into the category of low-grade, thus strengthening the assumption.

Also, these data suggest that uses for the low-grade heat will be abundant as the high degree of low temperature processes should provide a large number of potential heat sinks. This means that the savings in both running costs and greenhouse gas emissions should tend to the theoretical predictions in Table 1.

3. Sources of low-grade heat

3.1. Definition of low-grade heat source

Low-grade heat is defined to be in the temperature range of ambient up to around 260 °C [10]. Therefore a low-grade heat source is any process stream in this temperature range that is currently emitted to the environment via the stack or drain network. However, it is generally accepted that heat recovery in the range of ambient to 60 °C is extremely difficult [10], meaning novel heat recovery solutions are often required.

Generally, the most efficient and economically sound recovery of waste heat is to re-use it in the process from which it is emitted, or in a nearby process [10]. There is great scope for this as over 60% of the energy requirement in the sector is in the low temperature range (as described in Section 2).

3.2. Common heat sources in the food and drinks industry

Low-grade heat sources in the industry are from both generic industrial processes and sector specific processes. Generic industrial processes such as boilers, power plant, air compressors all lose

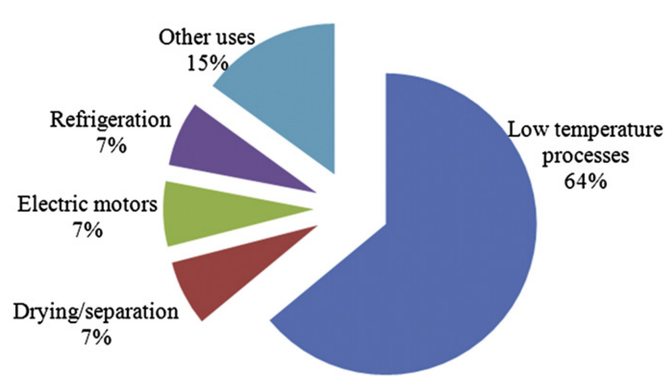

Fig. 1. Breakdown of sector energy usage.