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Power generation from waste heat in a food processing application

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ABSTRACT

In this paper, the potential of recovering waste heat from the fryer section and exhaust stream sent to the stack of a typical potato crisps or chips manufacturing plant and using the heat to drive an Organic Rankine Cycle (ORC) system for power generation has been presented. Five different ORC system Options (A, B, C, D and E) were considered. The first two options (A and B) make use of the waste heat from the foul gas and exhaust to stack respectively for power generation using a single ORC system each while the third option (option C) makes use of a novel dual heat source single ORC system where the low temperature waste heat from the foul gas is used to provide preheating and the high temperature waste from the exhaust to the stack used to provide the evaporation. Option D also shows a dual heat source ORC system where the high temperature waste heat to the exhaust stack is used to provide the preheating while the lower temperature foul gas is used for the evaporation (reverse of option C in terms of waste heat usage) while option E makes use of a reheat cycle where the waste heat from the foul gas is used to provide the reheating of the working fluid exiting the turbine. In terms of waste heat usage, the combination of options A and B can be compared with options C, D and E.

The simulation result shows that in terms of net power generation, cooling water requirement, and working fluid (R245fa) requirement, the combination of Options A and B gives the best power generation result and this is similar as the result produced by Option C. Following option C is option E which gave a better result than option D. The entropy generation analysis showed that the entropy generation is inversely proportional to the power output.

It was also observed that the net power generation for the ORC configuration adopted in this paper (option C) meets the average daily power requirement of the crisps manufacturing process as well as 98.58% of the daily peak power requirement.

1. Introduction

The present work concerns the thermodynamic design of an Organic Rankine Cycle (ORC) system for power generation using the waste heat from the fryer section and exhaust stack of a potato crisps or chips manufacturing plant.

Commercial crisps manufacturing is a well established market which involves a series of recipes in order to transform the raw potato from the farm to the finished desired product. The sequential processes involved in crisps production includes de-stoning, washing, peeling, drum washing and inspection, slicing, cold washing, hot washing, de-washing, frying, and inspection, flavouring and packing.

In 2005, crisps consumption in the UK was estimated to be as high as 10^5 packets which represents more than half of the crisps sold in the European Union [1]. Despite many campaigns by some health organisations, crisps consumption has always been on the increase.

Associated with the increase in crisps consumption is an increase in energy consumption during crisps manufacturing. Crisps manufacturing is an energy intensive process [2]. Processes like the hot washing and peeling requires hot water and steam respectively while the packing hall requires to be heated. Space heating accounts for about 20% of the total energy and are produced using boilers which makes use of boiler fuels [2]. The frying operation is the most energy consuming unit operation and consumes more than 65% of the total energy use (in form of electrical energy). This comprises of the electrical energy used in driving the conveyor systems, foul gas fan, pumps and other auxiliaries. Fig. 1 shows a typical day hourly electrical energy

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Nomenclature

Φ	Entropy generation rate, kJ/s-K
$\Delta\dot{S}_{cv}$	Rate of change of entropy, kJ/s-K
$\dot{m}$	Mass flow rate, kg/s
$\dot{Q}$	Heat transfer rate (kJ/s)
s	Specific entropy, kJ/kg-K
T	Temperature, (K)

Subscripts

cin	Cold Fluid Inlet
con	Condenser
cout	Cold Fluid Outlet
eva	Evaporator
exp	Expander
hex	Heat Exchanger
hin	Hot Fluid Inlet
hout	Hot Fluid Outlet
in	Inlet
out	Outlet
p	Pump
pre	Preheater
tot	Total

consumption in a crisp manufacturing plant [3]. This shows an average hourly electricity usage of 65.90 kW up to the fryer and 124.40 kW in the fryer. Thus giving rise to a total daily average electricity usage of 190.30 kW.

Crisps frying involve passing the crisps through hot cooking oil. The oil is heated using heat from the combustion chamber. After heating the oil, the heat is emitted from the process through the industrial exhaust stack. Also during the cooking operation, some hot polluted air (foul gas) is emitted from the fryer. In some crisps manufacturing processes surveyed, the hot polluted air is recycled back into the combustion chamber while in others; they are sent to the stack directly and then get emitted into the environment.

Whatever method is adopted by any crisps manufacturing operation, it is observed that the quality of heat emitted as effluents from the stack and from the foul gas from the fryer is high. With the effluent heats at a temperature range of 120–212 °C they can be economically recovered and used to the benefit of the process.

As earlier mentioned, crisps manufacturing requires enormous amount of energy mainly in the form of electricity and natural gas

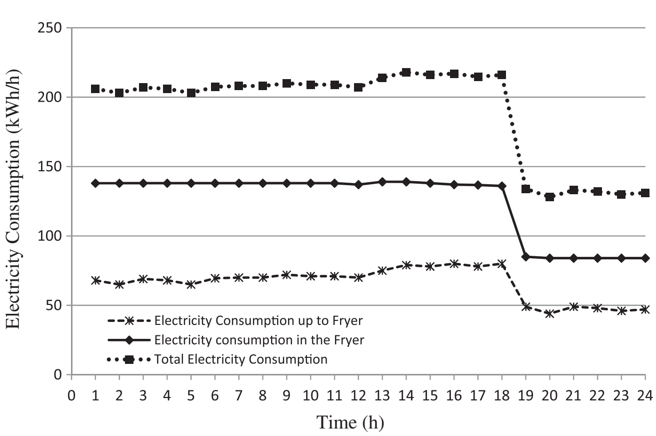

Fig. 1. Electricity consumption in crisps manufacturing plant.

for the space heating applications. The energy recovered from the waste gas stream can be used for electricity generation and space heating. Furthermore, since crisps manufacturing is always a single line of a huge food processing firm, the heat can also be used to provide refrigeration, air-conditioning and chilled water in other parts of the process where they are needed.

In the past, most thermal energy effluents from the process industries are regarded as low grade heat energy and hence are not always considered for recovery. Nowadays, the continuous increase in energy price, the need to save our environment by reducing CO_2 emission and the pressure from government policies throughout the world has resulted in an increased interest in utilising low grade heat.

Thermal energy recovery has been identified as a useful means to reduce energy wastage, increase resource savings and reduce the environmental impact of heat pollution and global warming, however, its implementation in commercial scale in some processes are yet to be achieved.

Thermal energy recovery through the use of ORC systems and Absorption Refrigeration (AR) or Absorption Chillers (AC) has been a well established technology. The ORC technology has been implemented in many processes in both commercial and pilot scale for waste heat recovery applications especially in the oil and gas [4–6], cement manufacturing [7], geothermal power generation [8–10], solar power generation [11–13] and power generation using hot effluents from exhaust of Ships and gas turbines [14–16] and has been proved to be both technologically feasible and economically rewarding venture. Similarly AR and AC technology for heat recovery application has also been in commercial operation and has been used over the years for providing air-conditioning, refrigeration and chilled water applications [17,18].

Although these technologies have been in existence over the years, its application for waste heat recovery from the fryer section of crisps manufacturing process has never been reported in the public domain and that is the subject matter which this paper wishes to investigate.

Considering the high number of crisps manufacturing and food processing plants in the UK, the successful transfer of this waste heat recovery technology; which has been successfully implemented in other processes like oil and gas, cement manufacturing and geothermal processes; for the recovery of waste heat from the frying section of crisps manufacturing process and other food processing processes where waste heat is in existence will not only help in resource savings, but also will help to reduce carbon footprint of food processing sectors thus leading to reduction in environmental impact of global warming which is associated with CO_2 emission.

2. Description of the frying section of the crisps manufacturing process considered in this investigation

The process flow diagram showing the fryer section of the crisps manufacturing process considered in this paper is shown in Fig. 2. In the process, natural gas, foul gas from the fryer which contain mainly fat (optional in some processes), combustion air, and water (used to control the temperature of the combustion chamber) are all combusted in the combustion chamber to a temperature of about 472 °C. After combustion, the effluent stream from the combustion chamber which is almost at the same temperature as the chamber is passed through the heat exchanger where it is used to heat the cooking oil from 154 °C to 170.2 °C. As the effluent stream looses heat to the cooking oil its temperature drops to 164 °C. In some process plants, after the effluent stream exits the heat exchanger, part of it is recycled back to the combustion chamber while the remaining is released through the industrial