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Heat recovery and heat pumping opportunities in a slaughterhouse

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ABSTRACT

Pinch analysis was employed to recover and reuse a part of the waste energy during the production and cleaning periods of a slaughterhouse in Canada. The INTEGRATION software was used to find possible options for HR (heat recovery). Several HR opportunities were identified in various systems of the slaughterhouse including boilers, hot water production, singeing, refrigeration, and barn air heating. A recommendation was also made to store more energy in the form of hot water. Opportunities for using heat pumps for additional HR were also investigated. The proposed projects can significantly reduce natural gas consumption in the steam and hot water boilers as well as in the air heating systems. It is shown that the proposed projects can reduce natural gas use by approximately half a million dollars per year.

1. Introduction

Higher energy prices and the global climate change have increased the need for efficient energy use in the food industry. Energy consumption represents a significant proportion of the production costs in this industry. In 2010, food processing establishments in Canada consumed approximately 102.4 PJ of energy, of which 30.3% was electricity and 69.7% was other purchased fuels [1]. Significant energy-demanding sectors in the food industry are slaughterhouse and meat processing plants that use approximately 18% of the total energy consumption in the Canadian food industry [2]. The most important energy consumers in a slaughterhouse are the refrigeration system, the singeing process [3], the steam production system, the hot water production system and the compressed air system [4]. In slaughterhouses, an issue that makes optimal energy recovery difficult is the presence of discontinuous heat sources, normally available during the production periods, and semi-continuous heat sinks. The most important semi-continuous heat sink is the production of hot water which is needed during both production and cleaning periods [5,6]. The Canadian food industry also contributes to the GHGs (generation of greenhouse gases) from three direct sources of emission: combustion of fossil fuels in steam and hot water boilers, loss of HFCs (hydrofluorocarbons) from refrigeration systems, and methane generation in wastewater treatment systems. This industry generates approximately 3500 kt/y of CO_2 [7]. Energy recovery projects are not only beneficial for food companies to improve their bottom line, but also for the environment as they decrease GHG emissions.

PI (process integration) is a method that can be used during the design and retrofit of many application and industrial processes [8] in order to optimize the use of energy and other resources [9]. PI allows defining the best opportunities for HR (heat recovery) in a process and focuses on the efficient use of energy. Pinch analysis, a PI technique, uses graphical tools for the calculation of energy targets and applies heuristics to achieve those targets [10]. Recently, a new methodology was proposed by Bakhtiari and Bédard [11] for retrofitting heat exchanger network in industrial plants. Their methodology includes the capability to handle some practical constraints more systematically than other pinch analysis methods while offering a systematic step-by-step approach.

Heat pumps are commonly used when a certain amount of low grade energy is available to be used effectively at an insufficient temperature level [12]. This technology can significantly increase HR in a process when it is appropriately located and designed [13]. PI can also be used to identify opportunities for the application of heat pumps in a process [14]. In slaughterhouses and meat processing plants, a considerable amount of low temperature heat is rejected through evaporative condensers and cooling towers. Some of this heat could be used for air and process water heating purposes through the use of heat pumps [15].

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Nomenclature

HU	hot utility requirement
C_P	heat capacity (kJ/kg °C)
eff	efficiency
HR	heat recovery
m	mass flow rate (kg/s)
NG	natural gas
Q	energy (kJ/s)
YOH	yearly operating hours (h/y)
ΔH	enthalpy of vaporization/condensation (kJ/kg)
ΔT	temperature difference (°C)

PI was used to identify HR potential in various food processing industries, mainly dairies [16] and breweries [17]. Fritzson and Berntsson [5,6] used pinch analysis techniques in a slaughterhouse in Sweden and found significant potential for electricity and fuel savings. This slaughterhouse was already quite efficient, notably due to the use of a heat pump for process water heating. The refrigeration plant was modified in this study by changing the temperature levels of the refrigeration system, resulting in a 10% reduction of the electricity consumption. In addition, HR in the slaughterhouse was increased by reducing the ΔT of existing heat exchangers to 5 °C. It was reported in another study by MAYEKAWA Europe [18] that the use of two ammonia heat pumps for hot water generation at 52 °C in a Norwegian slaughterhouse saved approximately 1.6 GW of natural gas consumption per year (based on lower heating value).

In this paper, the results of a PI study performed in a slaughterhouse located in Canada are presented. In addition to HR projects, the potential for implementing heat pumps is also investigated. The INTEGRATION software, a process integration software developed by CanmetENERGY, was used to identify the HR projects proposed in this work. INTEGRATION uses a sequential interactive approach originally proposed by Asante and Zhu [19], called Network Pinch, and extended by Varbanov and Klemes [20]. Additional improvement to the algorithm was made by Bakhtiari and Bédard [11] to reduce the number of retrofit options that are considered using the Match Penalty concept. In addition, the software includes models to calculate the amount of waste heat, and the temperature levels, that can be recovered from industrial boilers, air compressors and refrigeration systems [21].

2. Pork slaughterhouse

Fig. 1 presents the main processing steps in the pork slaughterhouse, with the main departments being the barn, the kill floor, the evisceration department, the clean floor, the cold warehouses and the powerhouse. Animals are received by truck in the barn where a large amount of fresh air is needed. On the kill floor, animals are put through different processing steps such as slaughtering, bleeding, scalding, hair removal, and singeing. The hogs are then going to the evisceration and head removal processes. The kill floor requires hot water at 56 °C and 87 °C. The hot water heating and the singeing processes are the two largest natural gas users in the slaughterhouse. The singeing process generates flue gas with a temperature of approximately 500 °C. After final washing, hogs are sent in a blast tunnel to rapidly freeze their surface to prevent water loss. They are then sent to cold storages so that they can entirely cool down to the temperature of approximately 4 °C. Following the cool down, the hogs are sent to the cut floor to be processed. The cut floor requires hot water at 56 °C and 87 °C for cleaning and sterilization purposes. The temperature of the cut floor is maintained at about 4 °C.

The refrigeration system is a two-stage ammonia system with screw compressors, having a refrigerant discharge temperature of 71 °C in average. The low-stage system consists of booster compressors with a suction temperature of −40 °C and is used mainly for the blast tunnel and the freezers. The suction temperature of the high-stage system is maintained at −10 °C and is used mainly for the cut floor and the cold storages. The superheated ammonia from the compressors is cooled in a HR desuperheater from 71 °C to 28 °C, which corresponds to the condensing temperature at the

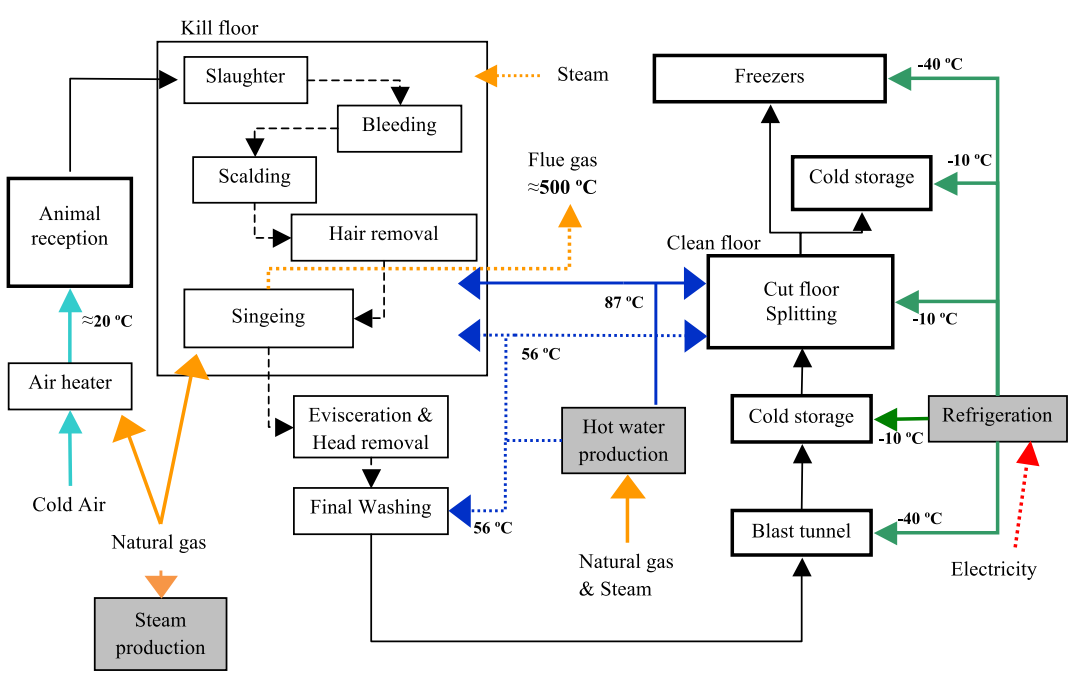

Fig. 1. Simplified diagram of the slaughterhouse.