Heat Pump Technology: Opportunity for Energy Conservation in Dairy Industry

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Heat pumps have occupied a small niche in the energy conservation and recovery of heat. It takes low temperature heat from the environment and turns it into higher temperature heat by using electrical or thermal energy (Nave, 2012). Heat pumps operate on a thermodynamic principle known as the Carnot Cycle. Heat flows naturally from a higher to a lower temperature. Heat pumps, however, are able to force the heat flow in the other direction, using a relatively small amount of high quality drive energy such as electricity, fuel, or high-temperature waste heat (Fawcett, 2011). Thus, heat pumps can transfer heat from natural heat sources in the surroundings, such as the air, ground or water, or from man-made heat sources such as industrial or domestic waste, to a building or an industrial application. Heat pumps can reversibly be used for both heating as well as cooling.

Heat pump technologies are being widely used in many places in the world where renewable energy sources are mated with the heat pump technology to mitigate societal carbon emissions (Spiers *et al*., 2010). Heat pumps are the only heat source that emits zero emissions when the electricity used is renewable. According to IEA, heat pumps could save 50% and 5% CO_2 emissions of building sector and industrial sector respectively. This means that 1.8 billion tonnes of CO_2 per year could be saved by heat pumps. Increased energy cost and awareness of the need for reduction of CO_2 emissions are drivers for large heat pumps (Jakobs *et al*., 2010).

Electric heat pump water heaters are more efficient than conventional storage hot water heaters (EERE, 2005). Heat pump water heaters also offer the added benefits of dehumidification and space cooling because they pull warm vapour from the air (Dubay *et al*., 2008). The UK's Royal Academy of Engineering says that 'the costs of large heat pump installations per kW are a quarter of that for domestic-scale installations' (RAE, 2012).

Principle of Heat Pump

Electric compression heat pumps take low temperature heat energy from the environment and turn it into higher temperature heat by using electrical energy. Heat pumps make use of the fact that when liquids evaporate they absorb a large amount of energy, equivalent to latent heat of vaporisation, and this energy is released when the vapour condenses back to a liquid. By using this property, large amounts of energy can be absorbed by and released from the heat pump. Low temperature heat is absorbed from the environment by the working fluid in the evaporator. This energy turns the low temperature, low pressure liquid into a vapour. This vapour reaches the compressor, which increases the pressure of the vapour, thereby increasing its temperature. In the condenser energy moves from this high temperature, high pressure vapour to the (lower-temperature) environment, and the vapour condenses to a liquid. When this high temperature, high pressure liquid passes through the expansion valve, it is transformed into a low pressure and therefore low temperature liquid (Ashdown *et al*., 2004; Sinha and Dysarkar, 2008).

Classification of Heat Pumps

Heat pumps are classified by different ways as under.

Based on heat source

- Air source
- Water source
- Ground source

Based on use of energy

- Thermal heat pumps
- Electrical heat pumps

Based on cycle of operation

- Vapour compression cycle
- Vapour absorption cycle

Open or closed cycle heat pumps

- Closed-Cycle Mechanical Heat Pumps
- Open-Cycle Mechanical Vapour Compression (MVC) Heat Pumps
- Open-Cycle Thermo compression Heat Pumps

The majority of heat pumps currently in operation are electrically driven close cycle compression type systems. The system driven by gas engines or absorption cycle heat pumps has found niche markets. Also, the major types of industrial heat pumps used in the industry are, Mechanical Vapour Recompression systems (MVRs), Closed-cycle compression heat pumps, Absorption heat pumps (Type I), Heat transformers (Type II), Reverse Brayton-cycle heat pumps, etc. (UNEP, 2003; EERE, 2003).

Energy Conservation through Heat Pumps and Energy Efficiency

Heat pumps offer the most energy efficient way to provide heating and cooling in many applications, as they can use renewable heat sources. Even at temperatures we consider to be cold, air, ground and water contain useful heat that is continuously replenished by the sun. By applying a little more energy, a heat pump can raise the temperature of this heat energy to the level needed. Similarly, heat pumps can also use waste heat sources, such as from industrial processes, cooling equipment or ventilation air extracted from buildings. Heat pumps are energy efficient. For each kW of electricity consumed by a heat pump, about 4 kW of thermal energy is generated. A typical electrical heat pump will just need 100 kWh of power to turn 200 kWh of freely available environmental or waste heat into 300 kWh of useful heat (IEA, 2014).

The Specific Moisture Extraction Rate (SMER) for a well-designed heat pump drier lies between 1-4 kg/kWh whereas the SMER of a single pass hot air drier is only 0.95 kg/kWh (Rahman, 2007). Muller *et al.* (2013) reported the energy conservation through heat pumps in waste water systems. He also reported on it applications in food and beverages industry for energy conservation mainly in drying processes which are high energy intensive in nature. NREL (2001) reported that when properly installed, an air-source heat pump can deliver 1.5 to 3.0 times more heat energy as compared to the electrical energy it consumes at domestic purposes.

Heat pumps use waste heat that would otherwise be rejected to the environment. Heat pumps consume less energy to increase the temperature of waste heat and reduce the use of other fossil fuels. The quantity of energy saved and the cost of operating the heat pump depend on the application and the heat-pump characteristics.

Hudon *et al.* (2012) studied on evaluation of energy saving potential of heat pump water heater technology and reported that HPWHs are expected to provide significant energy savings upto 64 % in many climate zones in US when compared to other types of water heaters.

Through this unique ability, heat pumps can improve the energy efficiency and environmental value of any heating system that is driven by primary energy resources such as fuel or power. The following six facts should be considered when any heat supply system is designed (IEA, 2014).

i. Direct combustion to generate heat is never the most efficient use of fuel.

ii. Heat pumps are more efficient because they use renewable energy in the form of low-temperature heat.

iii. If the fuel used by conventional boilers were redirected to supply power for electric heat pumps, about 35-50% less fuel would be needed, resulting in 35-50% less emissions.

iv. Around 50% savings are made when electric heat pumps are driven by Combined Heat and Power (CHP) or Co-generation systems.

v. Whether fossil fuels, nuclear energy, or renewable power is used to generate electricity, electric heat pumps make far better use of these resources than do resistance heaters.

vi. The fuel consumption, and consequently the emissions rate, of an absorption or gas-engine heat pump is about 35-50% less than that of a conventional boiler.

Performance of Heat Pump

The heat delivered by a heat pump is theoretically the sum of the heat extracted from the heat source and the energy needed to drive the cycle. The performance of heat pumps can be evaluated through either of the four factors: Coefficient of Performance (COP), Energy Efficiency Ratio (EER), Seasonal Performance Factor (SPF), and Seasonal Energy Efficiency Ratio (SEER). The steady-state performance of an electric compression heat pump at a given set of temperature conditions is referred to as the Coefficient of Performance (COP). It is defined as the ratio of heat delivered by the heat pump and the electricity supplied to the compressor. EER is the cooling capacity (in Btu/h) per unit electrical energy input (W). SPF is the estimated seasonal heating output (in Btu/Wh). The SPF can be used for comparing heat pumps with conventional heating systems (e.g. boilers), with regards to primary energy saving and reduced CO_2 emissions. SEER is the ratio of cooling (in Btu) to the energy consumed (Wh) during a typical cooling season (Dincer and Kanoglu, 2011).

Factors affecting Heat Pump Performance

The performance of heat pumps is affected by a large number of factors which are listed below.

a. The climate - annual heating and cooling demand and maximum peak loads.

b. The temperatures of the heat source and heat distribution system.

c. The auxiliary energy consumption (pumps, fans, supplementary heat for bivalent system etc.);

d. The technical standard of the heat pump.

e. The sizing of the heat pump in relation to the heat demand and the operating characteristics of the heat pump.

f. The heat pump control system.

Applications of Heat Pump in Food Industry

Industrial heat pumps are mainly used for heating and cooling of process streams, heating water for cleaning and sanitation, steam production, drying/dehumidification, evaporation, distillation, concentration etc. When heat pumps are used in drying, evaporation and distillation processes, heat is recycled within the process. Heat pumps utilise (waste) heat sources between 20ºC and 100ºC for air heating, heating of process streams and steam production. The most common waste heat streams in industry are cooling water, effluent, condensate, moisture, and condenser heat from refrigeration plants. Heat pump technology offers particular advantages for drying high value heat liable food products, especially where the low humidity drying environments are required and the discharge of volatile organic compounds or combustion must be minimised (Hui, 2008).

Heat pumps are used as heat recovery in fruit juice concentration, fluid milk processing, corn milling/corn syrup, beer by-product recovery, coffee/tea concentration, tomato paste, candy and chocolate manufacture, poultry processing and meat packing, soft drink bottling plants (Rahman, 2007). Heat pumps have also been used in soda water manufacturing and sugar concentration plants (Korzenszky and Geozi, 2012).

Heat pumps are also used in drying of products having low volatile contents. Ginger dried in a heat pump drier was found to retain over 26 % of gingerol (principal volatile flavour component) in comparison to 20 % obtained in rotary dried product. Heat pump dried high moisture nuts (like macadamia nuts) does not show the development of brown colour defect at centre. The sensory values of heat pump dried herbs are nearly double when compared with commercially dried products (Rahman, 2007).

Applications of Heat Pump in Dairy Industry

Heat pumps are also used in HTST milk pasteurization process. Two stage heat pump with thermal storage system is used to provide the 88^{o}C water (Flynn *et al.*, 2011). Electric heat pump is designed to preheat boiler feed water to around 80°C and cools the return water for the chiller by about 4°C.

Heat pumps operational in Verka Dairy plant, Punjab achieves an annual energy saving of about 35 % or 19 tonnes of oil equivalent with operating time 3672 hours per year. It also achieves an annual reduction in CO_2 emissions of 62.6 tonnes which is about 38 % (TERI, 2013).

Recent Advancements in Heat Pumps

There are various types of heat pump available for different applications. The most common are air source heat pumps (ASHP), which absorb energy from the air, and ground source heat pumps (GSHP), which absorb energy from the ground. Heat pumps that provide both space and water heating are most popular in the UK housing sector (Roy and Caird, 2008). The recent advancements include fuel cell ejector heat pumps, use of surfactants to increase efficiency in vapour absorption systems, use of CO_2 as a refrigerant in heat pumps, combining of renewal energy resources. e.g. solar energy with the heat pumps. A new electrochemical heat pump using a combination of an electrolytic reaction at lower temperature to absorb low grade thermal energy and a thermochemical reaction at higher temperature to produce more efficient thermal energy is proposed (Ishihara *et al*., 1999).

Conclusion

Heat pump plays important role for energy conservation and CO_2 emission reduction in food industry, by utilizing the waste heat. Heat pump can be used profitably if waste heat sources are able to achieve high enough C.O.P. to overcome the operational cost. Since, the energy cost keeps on rising up, industrial payback period for heat pumps is more easily attainable. Need for research & development of high-temperature heat pump potential for energy conservation and reduction of CO_2 emissions is required. The objective behind the application of industrial heat pumps is to reduce the use of energy and emissions of greenhouse gases by increasing their implementation in industrial and commercial application.

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