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Optimum heat pump in milk pasteurizing for dairy

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Abstract

A thermo economic optimization analysis is presented yielding simple algebraic formula for estimating the optimum operating conditions of interconnected heat pump-refrigeration systems with auxiliary heating that are used in milk pasteurizing applications. A simple economic method is used in the present study, together with the thermal analyses of all system components, for thermo economic analysis of the system.

Keywords: Thermo economics; Heat pump; Dairy; Milk pasteurizing; Optimization

1. Introduction

Optimization of the operating temperatures and the sizes of system elements for heat pump applications is extremely significant in order to get maximum earnings when using a regenerative heat exchanger and yielding to minimum cost for these systems. There exist many parameters in optimizing heat pump and refrigerating systems with auxiliary heating in milk pasteurizing for dairy as depicted in Fig. 1 in a thermo economical manner. The milk pasteurizing system employs a regenerative heat exchanger, an auxiliary heater and a complete heat pump, which includes a condenser, an evaporator, and a compressor as shown in this figure. Fixing and, so eliminating all these thermal and economical parameters, except the main operating temperatures, T_2, and T_3, depending on the certainty of operating characteristics of applications and the most efficient operating condition of the system, can determine optimum operating temperatures. Operating pressures and so that operating temperatures for the condensing and evaporating units are assumed to be constant due to the correctly selected refrigerant and pre-designed compression ratio of the compressor for the heat pump. The importance of energy saving application is increasing continuously, and interconnected heat pump and refrigeration systems with auxiliary heating systems may be employed for this purpose. It is known that the thermal performance of these types of systems is directly related to its operating temperatures. And the capacity of the system components whose initial and operating costs depend upon to these temperatures. A thermo economic feasibility study is necessary before installing the combination of heat pump-refrigeration systems. The basic topic of the present work depends upon this idea. A new thermo economic optimization technique is realized and presented for this purpose. An original formula is developed for calculating the optimum operating condition of the system at which minimum life cycle system cost occurs. A search of the current literature showed that there were no previous studies on optimizing the heat pump-refrigeration for obtaining maximum thermo economic performance from these systems in detail. A practical method, the P_1–P_2 method (Duffie & Beckman, 1980), is used for optimizing the operating temperatures of heat pump-refrigeration milk pasteurizing system for dairies

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Nomenclature

A	fixed parameter defined as in Eq. (25)
A_C	area of heat transfer surface of the condenser (m^2)
A_E	area of heat transfer surface of the evaporator (m^2)
A_{HX}	area of heat transfer surface of the regenerative heat exchanger, (m^2)
B	aixed parameter defined as in Eq. (26)
C	fixed parameter defined as in Eq. (27)
C_C	area dependent first cost of the condenser ($/$m^2$)
C_E	area dependent first cost of the evaporator ($/$m^2$)
C_{EL}	cost of electricity [$/(kW h)]
C_{EN}	cost of energy used in auxiliary heater [$/(kW h)]
C_H	capacity dependent first cost of the auxiliary heater ($/kW)
C_{HX}	area dependent first cost of the regenerative heat exchanger ($/$m^2$)
C_P	specific heat of the milk [kJ/(kg K]
C_Q	capacity dependent first cost of the heat pump system ($/kW)
COP	coefficient of performance of the heat pump based on evaporator capacity
COP_C	coefficient of performance of the Carnot refrigeration cycle
D	fixed parameter defined as in Eq. (28)
d	market discount rate in fraction
E	fixed parameter defined as in Eq. (29)
F	fixed parameter defined as in Eq. (30)
G	fixed parameter defined as in Eq. (31)
H	annual time of operation, (h/year)
i	energy price rate in fraction
IC_C	initial cost of the condenser ($)
IC_{comp}	initial cost of the compressor ($)
IC_E	initial cost of the evaporator ($)
IC_H	initial cost of the auxiliary heater ($)
IC_{HX}	initial cost of the regenerative heat exchanger ($)
m	mass flow rate of milk (kg/s)
M_S	ratio of annual maintenance and operation cost into first original cost
N	technical life of the heat pump system (year)
NTU	number of transfer units
OC_{comp}	life cycle operation cost of the compressor ($)
OC_H	life cycle operation cost of the auxiliary heater ($)
P_1	ratio of the life cycle energy cost or savings to that for the first year (year)
P_2	ratio of the life cycle expenditures incurred because of the additional capital investment to the initial investment
Q_C	heating capacity of the condenser (W)
Q_E	cooling capacity of evaporator (W)
Q_H	heating capacity of the auxiliary heater (W)
R_V	ratio of resale value to the first original cost
TC	total cost throughout the whole life of the system ($)
T_C	condensing temperature (K)
T_E	design temperature of evaporator due to milk outlet temperature (K)
$T_{m,in}$	inlet temperature of milk (K)
$T_{m,out}$	design outlet temperature of milk (K)
$T_{m,hot}$	design pasteurizing temperature of heated milk (K)
T_1	temperature of milk entering into condenser (K)
T_2	temperature of milk leaving the condenser (K)
$T_{2,opt}$	optimum temperature of milk leaving the condenser (K)
T_3	temperature of milk entering the evaporator (K)
$T_{3,opt}$	optimum temperature of milk entering the evaporator (K)
U_C	overall heat transfer coefficient of the condenser [kW/(m^2 K)]
U_E	overall heat transfer coefficient of the evaporator [kW/(m^2 K)]
U_{HX}	overall heat transfer coefficient of the regenerative heat exchanger [kW/(m^2 K)]
W_{comp}	power input to the compressor (kW)
ε_E	effectiveness of the evaporator
ε_C	effectiveness of the condenser
ε_{HX}	effectiveness of the regenerative heat exchanger

yielding to the best economy, and original interesting results are presented. Variable parameters used in formulating the thermo economically optimum operating temperatures of the system are listed as technical life of the system, first cost of the system elements per unit capacity or area, annual interest rate, present net price of energy and electricity, annual energy price rate, design temperature for the evaporator and the condenser of the system due to the design limitations, overall heat transfer coefficient of the evaporator, condensers and regenerative heat exchanger, design temperatures for milk pasteurizing together with inlet-outlet milk temperatures, mass flow rate