Performance Evaluation of Solar based Milk Cooling System

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Objective

The performance of vapour compression refrigeration system of the milk cooler plays very important role in deciding the operating electricity cost. The literature review revealed that no work has been reported on solar based milk cooling system and performance evaluation of the system. Therefore, the project work was undertaken with the following objectives.

To develop experimental milk cooling system with vapour compression refrigeration system operated on solar photovoltaic panels.

To carry out energy analysis of the solar system.

To carry out performance evaluation of the milk cooling system under different operating conditions.

To evaluate the heat transfer performance of the system.

Methodology

The experimental bulk milk cooler and photovoltaic panels were installed in a laboratory and the roof of the laboratory, respectively in the Dairy Engineering Department, SMC College of Dairy Science, AAU, Anand. The capacity of the photovoltaic panel was selected, having 1kWh rated capacity. A power storing unit of two batteries rating 12 V; 300 Ah each were connected in series along with an inverter of 1000VA capacity, which was attached to an electric board to supply power to the VCRS of BMC. To measure the evaporation temperature of BMC, the temperature sensor of RTD type was attached inside the evaporator and temperature was recorded. The input power consumption for the period of one hour was taken as instantaneous input power consumption which was not exactly steady throughout the experimental trials. The energy meter reading was set to zero for every trial, to estimate actual power consumption of the VCRS during the operation of BMC. The comparison of the operating conditions and the performance of both BMC and photovoltaic panel in terms of actual COP and efficiency respectively was the main focus area of the study.

The milk storage tank having 40 litres storage capacity was fabricated using 1.5 mm thick AISI 304 grade stainless steel plate. The copper tube was wrapped on the outer surface of the tank to form the evaporator of the VCRS. The refrigerant was throttled through the capillary type expansion valve to supply the refrigerant in the evaporator. The refrigerant flows through the copper piping and gets evaporated by absorbing the heat from the milk filled in the tank. The heat will transfer through the SS plate and copper tube to the refrigerant. The effective surface area of the SS plate involved in heat transfer depends on the quantity of milk filled in the tank and accordingly the area in contact with the milk was considered in calculation of overall heat transfer co-efficient.

Result and Discussion

The experimental milk cooler was developed to operate on electricity produced by photovoltaic solar PV panels. The experimental BMC was also equipped with digital ampere meter, digital volt meter, digital energy meter and temperature indicator in order to measure different variable during the experimental trials.

The solar intensity of sun on solar panels ranged from 324.7 to 698.4 W/m^2, 322.1 to 692.8 W/m^2 and 298.0 to 688.7 W/m^2 in the months of April, May and June, 2013 respectively. The regression equations

obtained correlating solar intensity and time were $y = 0.35x^3 - 34.053x^2 + 714.63x - 3591.3$ (R^2=0.987), $y = 0.3489x^3 - 34.287x^2 + 718.44x - 3811.7$ (R^2=0.987) and $y = -0.6223x^3 + 3.0483x^2 + 257.52x - 1814.6$ (R^2=0.966) for month of April, May and June, 2013 respectively. It is found that solar intensity gradually increase from morning to about 13:00 h and subsequently it reduces in afternoon period.

The efficiency of solar panels ranged from 10.558 to 12.653 %, 10.626 to 12.770 % and 10.883 to 12.930 % in the month of April, May and June, 2013 respectively. The regression equations obtained correlating efficiency (%) with time of the day were $y = -0.1072x^2 + 2.8757x - 6.8242$ (R^2=0.976) $y = -0.1129x^2 + 3.0123x - 7.5265$ (R^2=0.969) and was $y = -0.1017x^2 + 2.7686x - 6.1257$ (R^2=0.888) for month of April, May and June, 2013 respectively. The efficiency of solar panels varied with solar intensity of radiation which was maximum at about 13:00 h of the day. The efficiency decreased during the afternoon period. The trend was almost similar during experiment period of months April, May and June, 2013.

The use of agitation gave significant improvement in actual COP of VCRS of BMC. The values of actual COP of the BMC ranged from 0.86 to 1.55 and 1.03 to 1.76 without and with agitation respectively. It is found that operation of the BMC at optimal design cooling load gave higher COP_{act} as compared to part load operation.

The overall heat transfer co-efficient (U-values) of evaporator of experimental BMC ranged from 76.13 to 160.09 W/m^{2}K, and 87.64 to 197.69 W/m^{2}K without and with agitation respectively during study period.

The values of actual electrical power consumption of the BMC ranged from 0.65 to 0.69 kWh and 0.58 to 0.64 kWh without and with agitation respectively. The study reveals that solar based milk cooling system has a potential to adopt for chilling of milk.

Conclusion

There are several small milk producers' co-operative societies located in remote place where availability of electric power supply is uncertain. Solar based milk cooling system has a great potential for developing milk cooling system. The average solar intensity ranged from 324.7 to 698.4 W/m^2, 322.1 to 692.8 W/m^2 and 298.0 to 688.7 W/m^2 during 9:00 to 17:00 h in the month of April, May and June, 2013 respectively. The efficiency of solar panels ranged from 10.558 to 12.653 %, 10.626 to 12.770 % and 10.883 to 12.930 % in the month of April, May and June, 2013 respectively. The values of actual COP of the BMC obtained at different loadings during the study period ranged from 1.03 to 1.76 and 0.86 to 1.55 with and without agitation respectively. These values of actual COP are useful for the supply of input power for operation of BMC. The U-values of experimental BMC ranged from 87.64 to 197.69 W/m^2°C and 76.13 to 160.09 W/m^2°C during operation of BMC with and without agitation respectively for different cooling load. The heat transfer data generated will be very useful for the optimum design of evaporator of BMC for balancing of various components of VCRS of BMC. The values of electrical energy consumption of the BMC obtained under different loadings during operations of the BMC ranged from 0.58 to 0.64 kWh and 0.65 to 0.69 kWh with and without agitation respectively. It is suggested to develop a milk cooling system operating on DC power so that the DC power generated can be supplied to the cooling system. Battery backup may be kept for the storage of power when solar intensity is low or not available.