Analysis of heat pipe solar collector using artificial neural network

B Sivaraman* and N Krishna Mohan
Department of Mechanical Engineering, Annamalai University, Annamalainagar 608 002

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Artificial neural network (ANN) has been used to analyze effects of \( L/d_i \) (total length/inner diam of heat pipe), \( L_c/L_e \) (condenser length/evaporator length), water inlet temperature, collector tilt angle and solar intensity on heat pipe solar collector (HPSC). Heat pipes (5 each) having two different \( L_c/L_e \) and \( L/d_i \) ratios have been designed, fabricated and used in solar collector absorber. Copper container, stainless steel wick material and methanol as working fluid were used for heat pipes, which are designed to have heat transport factor of around 194 W and 260 W of thermal energy. Experiments were conducted during summer with different collector tilt angles to the horizontal. Collector efficiency, which increases with decrease in \( L/d_i \) ratio and increase in \( L_c/L_e \) ratio, is due to increase in heat transport factor of heat pipe.

**Keywords:** Artificial neural network, Capillary limit, Heat pipe, Solar collector, Wick

**Introduction**

Heat pipes\(^{1-19}\) in solar absorbers have advantages over conventional collectors (efficiency, 25-30%) as improved collecting efficiency, superior heat conduction, quick response to changes in radiation intensity, and thermal diode benefit. Major shortcomings of conventional solar collector are liquid reverse motion during night and freezing of liquid in tube during cold conditions. Bienert & Wolf\(^4\) first reported use of heat pipes in solar collector (HPSC). Soin et al\(^{17, 18}\) investigated the performance of solar collector with fluid undergoing phase change and reported effect of INSOLATION (incoming solar radiation) and liquid level on performance of thermosyphon collector containing acetone and petroleum ether. Schreyer\(^4\) reported increase in instantaneous efficiency (6%) by using refrigerant R-11 in a thermosyphon collector. Akyurt\(^{12}\) designed heat pipes on prototype solar water heater as heat transfer elements. Nesreen & Yvonne\(^{13}\) fabricated R-11 charged solar collector with an integrated condenser for secondary cooling water flow. Hussein et al\(^9\) investigated transient thermal behaviour of a wickless heat pipe flat plate solar collector (FPSC). Kamminga\(^11\) investigated performance of an evacuated tubular collector with heat pipe using Fourier frequency domain.

Ismail & Abogederah\(^9\) presented time constant study on HPSC. Al-Hindi et al\(^7\) developed an intermittent duty solar refrigerator assisted by heat pipes. Hammad\(^7\) studied performance of FPSC cooled by a set of heat pipes. Jorge Facaco\(^10\) analyzed hybrid solar collector (plate type heat pipe) using artificial neural network (ANN) for better efficiency and time saving. Soteris et al\(^{19}\) modeled solar water heating system using ANN.

This paper presents use of ANN to analyze effects of \( L/d_i \), (total length/inner diam of heat pipe), \( L_c/L_e \) (condenser length/evaporator length), water inlet temperature, collector tilt angle and solar intensity on HPSC.

**Experimental Setup**

Experiments were conducted with HPSC for different mass flow rates (0.0033 & 0.0083 kg/sec) on various days and observations were recorded every 20 min (10.00 AM - 4.00 PM). Solar intensity at test site (Annamalainagar, Latitude: 11° N) was measured using EPPLY pyranometer. Water inlet and exit temperatures were measured using mercury in glass thermometer. Flow rate was measured using graduated rotameter.

**Design of Heat Pipes**

Heat pipes (\( L_i \), 1 m; two different internal diam and two different \( L_c/L_e \) ratios) were designed, fabricated, and used in the solar collector (Table 1). Heat pipe transfers...
Heat from evaporator to condenser by evaporation and condensation of methanol in a sealed system.

Capillary action of stainless steel wick is to return condensate to evaporator. Outstanding feature of system is the ability of heat pipe to accept heat non-uniformly (considerable change in heat flux input may not affect the performance of heat pipe). Two sets of heat pipe (each set of 5 numbers) with copper pipe (L 1 m, L_e 0.85 m, L_c 0.15 m) having two internal diam (17 and 19 mm) were designed, fabricated and used in HPSC to study the effect of L/d_i ratio. To analyse L_c/L_e effect, another two sets of heat pipe (each set of 5 numbers) with internal diam of 17 mm having two each of L_e (0.75 and 0.85 m) and L_c (0.25 and 0.15 m) were designed and fabricated. Maximum capillary limit (heat load on heat pipe due to maximum capillary pressure for liquid wick combination) of heat pipes were 194.25 W and 268.48 W. Designed heat transfer limit is sufficient to transfer the heat intercepted and gained by the absorber plate of solar collector, as maximum heat gained by plate was around 300 W only. Such heat pipes (5) were used in solar collector and placed over absorber plate (Fig. 1). Wrapped screen wick structure with two layers of wick was used in heat pipe (Fig. 2).

**Design of Solar Collector**

Solar collector is a flat plate collector (0.85 m x 0.5 m) with single glass covering. Collector absorber (2 mm thick) is black painted aluminum sheet. Heat pipes (5; evenly spaced over collector) were mounted on to absorber sheet such that evaporator section of heat pipe is within collector and condenser section is protruding outside collector. Sides and back of the collector were properly insulated. All five-condenser sections of heat pipes were connected serially. Collector was placed facing directly south with different tilt angles to the horizontal, to study its effect on HPSC. Copper-Constantan thermocouples were provided in collector to measure temperatures of absorber plate, glass plate and surface of heat pipe at two locations on each heat pipe in evaporator section, one being nearer to condenser section.

### Artificial Neural Networks

Multilayer feed forward ANN architecture, adopted in present work, has a two-layers with six inputs and an output (Fig. 3). The first layer uses three log sigmoid neurons and second layer uses one positive linear neuron. For training data, conjugate gradient back propagation with Powell-Beale training function was used. The 168 data were used for training and 66 for testing the network. Evaluation of the best performance was based on the...
mean square error calculated for the test data set and \( R^2 \) value obtained was 0.9234.

**Results and Discussion**

Experimental instantaneous efficiency of the collector (L/d, = 52.63 & 58.82) was plotted against time (Fig. 4). Efficiency (L/d, = 52.63; Lc/Le of 0.1767; water flow rate, 0.0033 kg/sec) has been found varying (34-69%) over the day (Fig. 4a). Efficiency plots of collector with same L/d, ratio (Fig. 4 a-c) indicated that ANN simulated values closely follow the trend of experimental pattern. Since ambient temperature and wind velocity were not considered in simulation of collector system, ANN simulation may have some noise effect, which resulted in non-uniform variation of simulated data with experimental one. For same flow rate, Lc/Le and L/d, (58.82), maximum efficiency (47%) was achieved during peak hours of sunshine (Fig. 4 d & e). Increase of Lc/Le value from 0.1767 to 0.3333 results in increase of efficiency for the same flow rate of water and L/d, ratio (Fig. 5). The test results with two different L/d, ratios clearly shows that when the ratio decreases, there is a considerable improvement in HPSC performance, since heat transport capability of heat pipe increases due to increase of internal diameter, which is one of the factors that determines heat transport\(^{16}\). Experimental analysis of HPSC with two different Lc/Le values\(^{15}\) states that improved performance can be achieved with increase in Lc/Le. When ratio was increased, performance was better, since condensation rate got improved resulting in more quantity of working fluid flow to evaporator at any given instant, consequently increasing evaporation rate.

Simulated results of ANN were compared with experimental data. Solar intensity (W/m\(^2\)), water inlet temperature (K), Lc/Le ratio, collector tilt (degrees), mass flow rate of water (kg/sec) and L/d, ratio were taken as input parameter while water outlet temperature (K) as
output parameter of ANN. About 66 data were used to test output of the network used for analysis. Best linear fit of experimental and simulated values yields a \( R^2 \) value of 0.9234. Variation of experimental and simulated values has been found within 10% on either side.

Plot of time vs water outlet temperature (experimental and simulated) on various days (Fig. 6) shows that simulated values were acceptable. Maximum difference of observed water outlet temperature (on 19.03.04) and predicted one was found to be 0.64%. Compared to high flow rate of water (0.0083 kg/sec), predicted water outlet temperature was high (Fig. 7a) at low flow rate.

![Fig 4—Time vs efficiency](image)

\[ \frac{L_e}{L_c} = 0.1767 \]

![Fig 5—Time vs efficiency on different days](image)

\( L/d_i = 58.82 \);
\( L_c/L_e = 0.3333 \)
(0.0033 kg/sec). For a collector tilt of 11° and $L_c/L_e$ ratio of 0.1767, predicted value of water outlet temperature was also high for lesser $L/d$ ratio (Fig. 7b). Though outlet temperature was higher with increase in inlet temperature (Fig. 7c), heat gain by water was higher at low inlet water temperature (Fig. 8a). Effect of change in $L_c/L_e$ ratio has considerable effect on HPSC performance as indicated by experimental and ANN analysis. With increase in $L_c/L_e$ ratio, heat gain by water increases and ultimately system efficiency improved (Fig. 8b). Higher water outlet temperatures were predicted with lower collector tilt angle (Fig. 7d). Simulations were confined to collector tilt equal to latitude angle plus 6° in the analysis. System efficiency was more at 11° collector
Fig. 7—Solar Intensity vs ANN simulated temperature at different parameters: a) Flow rate (FR, kg/sec); b) L/d, ratios; c) inlet temperature (°C); d) tilt angle (°)

Fig. 8—Solar intensity vs heat gain at: a) different inlet temperature; b) different L/L_e ratio
tilt in both cases (Fig. 9). At 11° collector tilt, HPSC with L/d\textsubscript{i} ratio of 52.63 has higher efficiency.

Conclusions
Collector with L/d\textsubscript{i} ratio 52.63 was found more efficient than collector with L/d\textsubscript{i} ratio 58.82, while developing solar collector using ANN. Improved efficiency is due to increase of heat transport capability due to increase of d\textsubscript{i}, which influences heat transport of heat pipe, which increases with decrease in L/d\textsubscript{i} ratio. Simulated values of water outlet temperature of HPSC using ANN were found very close to experimental values. ANN analysis of HPSC shows that the collector (L/d\textsubscript{i} ratio 52.63, L\textsubscript{c}/L\textsubscript{e} ratio 0.3333, water inlet temperature 34°C) has edge over other cases for water flow rate of 0.0033 kg/sec. This guides designers to fabricate solar collector to give optimum collecting efficiency.

References