

SYSTEMATIC DESIGN, FABRICATION AND EXPERIMENTAL STUDIES ON SOLAR THERMAL WATER PUMP

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ABSTRACT

The solar thermal pump is a good option where electrical power is not available and solar energy is in plenty. The design of the solar pump which entailed detailed calculations to obtain the optimal volumes of vessels and experimentation on the fabricated set up are presented in this paper. The pump employs ethyl ether as the working substance which is an organic fluid with a low boiling point. The flat plate solar collector of area 1 m² generates vapour and its pressure is adequate to pump water from a well. The inclusion of storage tank for vapour and a separate condenser facilitates greater freedom in the pump's operation and thereby improved performance. The performance of solar water pump has been analyzed for three different discharge heads 3, 4 and 5 m with a maximum efficiency of 0.14×10^{-2} .

Key Words: Solar Thermal Pump, Optimal Design, Performance Analysis

I INTRODUCTION

Pumps which operate utilizing solar energy are of special significance in countries where the farming communities are scattered over large and distant areas and where electrical power is not readily available. This would include tropical countries like India. In specific, for the places which are separated far away from the grid, the large distances involved and the low energy requirements make the transmission of electrical energy quite uneconomical option. Oil engines meet the requirements of those areas to some extent but it also becomes expensive when the transportation charges for oil are high, also maintenance and operation of oil engines will be a problem in remote areas. During the past few decades efforts have been taken to meet the power requirement for irrigation from local energy sources. Renewable energy sources like solar energy, wind energy and biogas may provide the solution to this problem.

A number of attempts have been made in different countries, to use solar energy for pumping water. These attempts have used different principles and have been successful to varying degrees. A perusal of the literature, on the subject of solar water pumps, reveals that a pump can be operated mainly on any of the following three principles: (1) Pump driven by turbine operating with steam or any organic vapour generated using solar flat-plate collectors or concentrators; (2) Pump driven by electricity obtained from solar cells; (3) An unconventional pump in which the vapour of a low boiling point liquid is generated through flat plate collectors provides the motive power for lifting the water, while condensation of the vapour and the subsequent decrease in pressure provides for suction. In the first method, not only the capital cost of the system is high, but also the operation and maintenance problems are many because of the number of stages involved in conversion of solar energy to hydraulic work. In the second method, the present cost of solar cells makes the system uneconomical. The third method appears to be an attractive proposition and this paper presents the basic design, fabrication and experimentation on such a pump.

Sumathy *et al.* [1] designed experimental set up with cooling coil in tank for condensing the working fluid and conducted experimental studies [2, 3] on solar thermal water pump with both ethyl ether and pentane as working fluids with separate storage tank for a delivery of 15 litres/cycle at 6 m, 8 m and 10 m delivery heads. Maximum efficiencies of 0.36% [9] and 0.42% [3] were reported with pentane and ethyl ether as working fluids, respectively at the delivery head of 6 m. Sumathy *et al.* [4] discussed the importance of effective condensation and design of the condensation coil. Effect of the condensation time and heating time on the performance of solar thermal water pump and change in condensation time as well as cycle time with inclusion of separate condenser at different delivery heads were reported by Wong and Sumathy [5].

The present work focuses attention on an unconventional pump with ethyl ether as working fluid. The inclusion of separate condenser for condensing the vapour facilitates greater freedom in the pump's operation and thereby improves the performance. In this paper the system is designed for a maximum discharge head of 10 m and for a collector having an area of 1 m². The optimized volumes of tanks have been obtained from the detailed consideration of the processes that occur in each of the tanks. The performance of the pump is evaluated experimentally at three different discharge heads 3, 4 and 5 m.

II SYSTEM DESCRIPTION

The pump operates on the following principle: evaporation of a liquid of low boiling point, energized by flat plate solar collector, provides the motive force to lift water, while condensation of the vapour and the subsequent decrease in pressure provides the suction. The schematic diagram and photograph of solar thermal water pump are shown in Figs. 1 and 2, respectively. The system consists of the following main components:

- (1) Flat-plate solar collector coupled to an insulated tank S both containing liquid ethyl ether
- (2) Insulated vapour storage tank N which stores ethyl ether vapour
- (3) Insulated vessel A, completely filled with brine solution initially
- (4) Un-insulated vessel B initially containing air under atmospheric conditions

- (5) Vessel C immersed in the well water and provided with a one way valve
- (6) Overhead tank D and (7) Condenser

The choice of the working substance, to a large extent, depends on the boiling point and its miscibility with water. The normal boiling point of ethyl ether is 35 °C and it is only slightly miscible with water and is found to be immiscible with brine solution. When the pump is initially put into operation, tank N is in communication with tank S. Liquid ethyl ether, set in motion by thermo syphon action is heated in the flat-plate collector. As a consequence of heating, the temperature and the pressure increase. The saturated vapour separated in tank S is stored in the vapour storage tank N. When the pressure in tank N reaches a pre-determined value, it is isolated from tank S by closing valve 1. Then valve 2 is opened so that vapor from N flows quickly to vessel A. As a consequence, brine solution in tank A is displaced into tank B, which initially contains air at atmospheric conditions. The rising column of brine solution in B compresses the air in it and the compressed air in turn pushes the water in vessel C to the overhead tank D and this constitutes the pumping operation. At the end of pumping, valve 2 is closed and valve 1 is opened so that tank N is replenished with ethyl ether vapor for the next cycle. Concurrently, valve 3 is opened to discharge the expanded vapor to condenser and by opening the valve 4 the water from the overhead tank D is allowed to flow through the cooling coil in the condenser (before the water goes for end use) to condense the vapour in it. The flow rate of cooling water cannot be increased indefinitely. This is because the amount of cooling water available in each

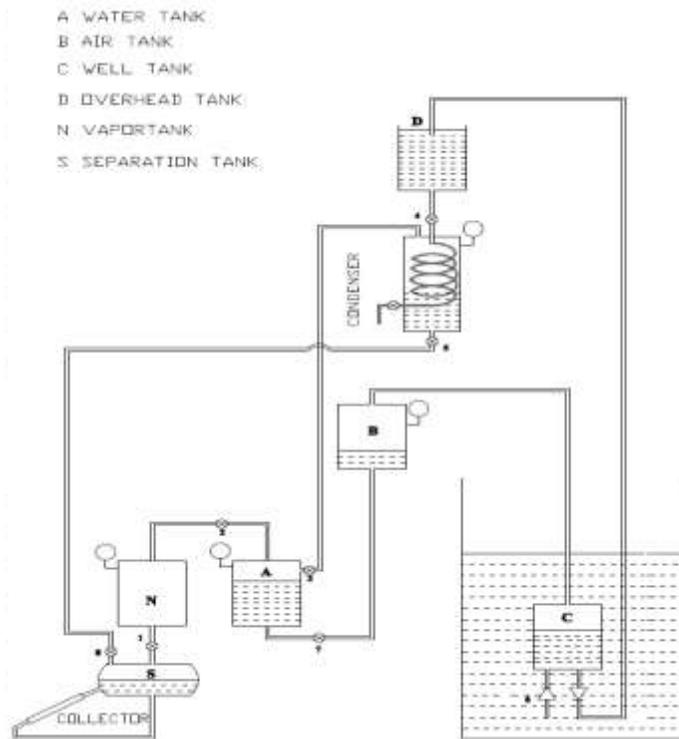


Fig. 1 Schematic diagram of the solar thermal water pump

cycle is restricted by the water lifted per cycle. Once vapour is discharged to the condenser the pressure in vessel A decreases, as a result of which the brine solution in vessel B returns to vessel A. During this period, the pressure of air in vessel B returns to its initial value. Consequently, the well water is sucked into vessel C through the one-way valve 6. One cycle of operation is thus completed and the pump is now ready for the next cycle.

Inclusion of the separate condenser in the pumping system facilitates greater freedom in the operation of the system and improvement in the performance of the system due to

- (a) Reduction in the condensation time which causes the reduction in the total time required to complete a cycle and
- (b) Saving in time required for the removal of condensed working fluid from tank A after every 5 or 6 working cycles when there is no separate condenser.

The P-V diagram shown in Fig. 3 represents the various states followed by the working fluid (ethyl ether) during the pumping and condensation operations in a complete cycle. Here, 1-2 represents heating of the working fluid due to thermo syphon circulation in the collector at constant volume. During the process 2-3 the saturated vapor is (at state 3) separated out from tank S and is stored in tank N. process 3-4 represents isentropic expansion of vapour to



Fig. 2 Photograph of the solar thermal water pump

the pressure corresponding to discharge head (P_D), in the tanks N and A. At the end of the pumping, the expanded vapour at state 4 in vessel A flows into the condenser to further expansion to reach state 5. The processes 5-6 and 6-7 corresponds to the ideal processes of cooling and condensation of the vapour inside the condenser with which the execution of the working cycle will be completed.

III DESIGN OF EXPERIMENTAL SETUP

The pump employs a flat-plate collector of area 1 m^2 exposed to solar radiation. The volumes of the tanks used in the system depend largely on the collector area, delivery head of the pump and the quantity of water to be lifted per cycle.

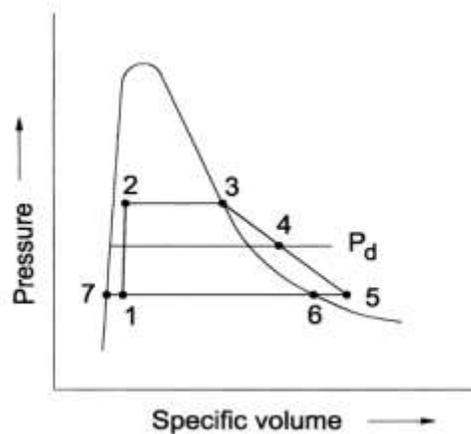


Fig. 3 p-V diagram [5]

The air in tank B has to be first compressed to the pressure corresponding to the discharge head and thereafter the compressed air entering tank C accomplishes the task of pumping water. The compression of air is assumed to be isothermal (because the tank B and the long pipe connecting tanks B and C, which contain the air during the compression process, are not insulated and as such are exposed to atmospheric air, and also the air column is in communication with water at both ends). For isothermal compression, neglecting the internal volumes of the connecting pipes [1],

$$P_1 V_B = P_D V_{BF} \quad (1)$$

Where P_1 is the initial pressure of air in vessel B (=1 bar) and V_{BF} is the final volume of air when the pressure in B just reaches the discharge pressure, P_D . The compression of air in turn is accomplished by the volume of brine solution entering from A to B. If V_X is the volume of brine solution that has entered B from A, then [1],

$$V_{BF} = V_B - V_X$$

$$V_B = P_D (V_B - V_X)$$

Hence,

$$V_B = \frac{V_X}{\left(1 - \frac{1}{P_D}\right)} \quad (2)$$

From this instant, the pump is ready for operation, and for every additional litre of water entering B, a litre of air is displaced from B to C to cause pumping of one litre of water at constant discharge pressure, P_D . Therefore [1],

$$V = V_X + V_C \quad (3)$$

Where, V is the total volume of ethyl ether vapour in tank A at a final pressure P_D , to pump V_C litres of water in one cycle. Here, water to be lifted per cycle V_C is fixed as 5 litres and hence substituting for V_C in Eq. (3) gives,

$$V_x = V - 5 \quad (4)$$

When V_x is replaced by $V - 5$, Eq. (2) reduces to,

$$V_B = \frac{(V-5)}{\left(1-\frac{1}{P_D}\right)} \quad (5)$$

But for a head of 10 m, delivery pressure $P_D = 2$ bar (abs), hence,

$$V = 0.5V_B + 5 \quad (6)$$

Table 1 gives the quantity of ethyl ether vapour (V) required for various assumed volumes of tank B calculated using Eq. (6).

For successful operation of the pump, the volume of B should be larger than that of C and also the volume of vapour V should be less than or equal to V_B . Also, it is advantageous to have as less V as possible; otherwise (1) the collector will take a longer time to generate this vapour; (2) losses from tank N will also be more, as its size directly depends on V . It can be readily seen from Table 1 that 10 litres appears to be the appropriate volume for tank B, and the corresponding value of V is also 10 litres.

The volume of V_A depends on the volume of vapour V required per cycle. V_A must be such that there is always a water seal at its bottom to avoid the entry of ethyl vapour into tank B and that it can accommodate 1 to 2 litres of liquid ethyl ether floating on water. Thus, the volume of tank A has to be at least 5 litres more than the volume of vapour it has to accommodate. ie. $V_A = V + 5$. As a result, the volume of tank A is taken as 15 litres.

Table 1 Relation between volume of tank B (V_B) and volume of ethyl ether vapour (V)

V_B (litres)	5	10	15	20	25	30	35	40
V (litres)	7.5	10	12.5	15	17.5	20	22.5	25

At the start of the first cycle the pressure of vapour in N must be higher than the discharge pressure. In fact, this pressure has to be such that at the end of the pumping process the pressure of ethyl ether vapour, now occupying tanks N and A, must be equal to the discharge pressure. When tank N communicates with tank A, the vapour expands (assumed to be reversible and adiabatic, since tanks N and A are well insulated) to P_D and occupies a final volume of $(V_N + V)$. Let P_N be the final pressure of ethyl ether vapor in tank N. The relation [1],

$$P_N V_N^\gamma = P_D (V_N + V)^\gamma \quad (7)$$

fixes the value of V_N for an assumed value of P_N . γ is the ratio of specific heats for working fluid which is taken as 1.05 and V is 10 litres.

The mass of ethyl ether initially in tank N is m_i , which is equal to the ratio of V_N and the specific volume of saturated vapour at P_N . Now, a check is made to assess the correctness of the volume and the assumed initial pressure of ethyl ether. If the pressure assumed is correct, the following energy balance must be satisfied [1],

$$\text{i.e.} \quad m_i (u_f - u_i) = W_1 + W_2 \quad (8)$$

Where W_1 is the work done by the diethyl ether vapour in compressing the air in tank B isothermally to the discharge pressure and is given by [1],

$$W_1 = P_1 V_B \ln \left(\frac{V_{BF}}{V_B} \right) \quad (9)$$

Where P_1 and V_B are the initial pressure and volume of air in tank B before compression and V_{BF} is the final volume of air after compression and W_2 is the hydraulic work done by the pump per cycle to lift V_C litres of water and is given by [1],

$$W_2 = V_C \cdot \rho g h \quad (10)$$

Here, u_i is the specific internal energy of ethyl ether corresponding to the initial state in tank N (before expansion), and u_f the final internal energy of ethyl ether (existing finally in tanks N and A) at the discharge pressure. During the reversible adiabatic expansion process, the entropy remains constant. Thus, finally two properties, namely the pressure and the entropy are known and hence the final state of the ethyl ether vapour can be fixed, so that u_f can be calculated. If the arbitrarily assumed P_N does not satisfy the above energy equation, a new value is assumed and the procedure is repeated until the energy balance is established. The volume corresponding to the value of pressure that satisfies the above procedure will be about 15 litres.

From the literature review [4] it is found that the condensation time is critical for these pumps in achieving greater number of cycles per day. Here the expanded vapour after pumping is allowed to flow in to a separate tank inside which the copper coils are arranged as shown in Fig 4. The cooling water from the overhead tank will flow through these coils and the vapour surrounding these coil will come in contact with surface of coil will get condensed and is stored in the tank itself. For the next day before exposing collector to sun condensed liquid is fed into S tank through the pipe connected between these two. The advantage of providing such a condenser is that, it is possible to start the next cycle before the condensation of vapour in previous cycle is over. Assuming expansion of vapour from tank A to condenser chamber as isentropic (process 4-5), from state equation,

$$P_A V_A^\gamma = P_{COND} V_{COND}^\gamma \quad (11)$$

where P_A and V_A are the pressure and volume in tank A and P_{COND} is the pressure in the condenser and it should be 1 bar. This fixes the volume of condenser as 30 litres.

In Fig. 3 process 5-7 is the isobaric condensation in which the process 6-7 is in vapour dome hence is isothermal whereas in process 5-6 the temperature decreases. Hence the energy to be extracted to condense the vapour is,

$$Q = m_v c_p (T_5 - T_6) + m_v (h_6 - h_7) \quad (12)$$

Where, m_v is the mass of ethyl ether vapour to be condensed which is equal to the ratio of volume of tank A to the specific volume of vapour at state 4. In the condenser cooling water circulated in the coil should carry away this much heat. If the condensation is to be accomplished within 3 minutes (comparable with heating time) then rate of heat removal is

$$q_c = \frac{Q}{3 \times 60} \text{ kJ/s.} \quad (13)$$

For the cooling water side, rate of heat carried by the cooling water is given by,

$$q_w = m_w c_p (T_{out} - T_{in}) \quad (14)$$

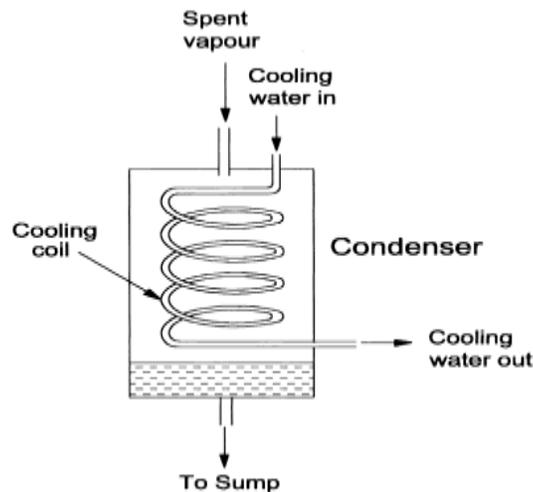


Fig. 4 Schematic representation of condenser

Under steady state conditions, $q_c = q_w$. Since the working fluid is ethyl ether the maximum value of ΔT can be only 4°C (assuming $T_{in} = 30^\circ\text{C}$ and T_{out} can be maximum 34°C). Mass flow rate of cooling water can be estimated from this and a check is made to make sure that the cooling water mass flow rate does not exceed the mass of water pumped per cycle.

The condenser coil material selected is copper of nominal size 6 mm diameter. For the flow through uniform tubes, mass flow rate $m = \rho_w AC$ where, ρ_w is the density of water, A is the cross sectional area of the copper tube and C is the velocity of flow. Since all other quantities are fixed, velocity of flow can be determined and is found to be 0.53 m/s. Using this, Reynolds number and the Prandtl number are calculated and it is found that the flow inside the tube is fully developed turbulent flow. Hence by using the appropriate correlation for heat transfer coefficient (h_w)

at the water side can be evaluated and the correlation used is [12],

$$Nu = \frac{\left(\frac{f}{8}\right) \cdot Re \cdot Pr \cdot \left(\frac{\mu_m}{\mu_w}\right)^n}{1.07 + 12.7 \left(\frac{f}{8}\right)^{0.5} (Pr^{0.67} - 1)} \quad (15)$$

where, $n = 0.11$ for heating of fluids [12] and friction factor is f is given by [12],

$$f = 0.25[1.82 \cdot \log_{10} Re_D - 1.64]^{-2} \quad (16)$$

On the vapour side the condensation is assumed to be film wise and the appropriate correlation is used to determine the heat transfer coefficient at vapour side. For laminar film wise condensation in bank of N (N is assumed as 8) horizontal tubes [12],

$$h = 0.728 \left\{ \frac{k^3 \rho^2 g h_{fg}}{\mu_l N D (T_v - T_s)} \right\}^{0.25} \quad (17)$$

As the ethyl ether vapour condenses, the coil is progressively submerged in liquid ethyl ether. In order to consider this effect, the expression for the heat transfer coefficient (h) is modified as [13],

$$h_v = h N^{-\frac{1}{6}} \quad (18)$$

Once heat transfer coefficient on both sides is calculated, then by neglecting the resistance of tube wall thickness the overall heat transfer coefficient U_o is given by [4],

$$U_o = \left\{ \frac{d_o}{d_i} \left(\frac{1}{h_w} + \frac{1}{h_v} \right) \right\}^{-1} \quad (19)$$

Here d_o and d_i are inside and outside diameter of the tube. Then the rate of heat transfer from vapour to cooling water is [4],

$$q_c = U_o A_s (T_{sv} - T_w) \quad (20)$$

where T_{sv} is the saturated vapour temperature and T_w is the average water temperature. Since q_c , U_o and temperatures are known surface area can be determined which decides the length of tube to be used.

The high pressure vapour expanded from N tank to A tank accomplishes the pumping work in a solar thermal water pump. So the mass of ethyl ether used per cycle is the amount of vapour that is present in the tank A. Since the state of vapour in the tank A after expansion and size of tank is already known the mass of vapour used per cycle can be easily determined. From the literature reviews it is found that the overall efficiency of these types of pumps is around 0.14%. The equation to find the overall efficiency is given by [1],

$$\eta = \frac{N W_2}{H_{tot}} \quad (21)$$

where N the number of cycles per day is W_2 the hydraulic work done by the pump and H_{tot} is the total solar radiation incident on the collector during the period of operation of the pump. Since all other quantities are known, the number of cycles per day N can be determined from the above equation. Once the number of cycles per day is known the mass of ethyl ether used per day is given by,

$$\text{Mass of diethyl ether per day} = (\text{number of cycles} \times \text{mass of diethyl ether per cycle}) \quad (22)$$

Here mass of pentane used per day is found to be 5 kg. The outlet from the collector in to tank S must not be higher than the level of liquid in S to ensure thermo syphon flow in the collector. Hence some excess liquid is to be kept in the S tank, considering these also the mass of diethyl ether required in a day is fixed as 10 kg. Since mass of ethyl ether used per day is known, volume of S tank can be found easily.

Table 2 provides the details of the flat plate collector used in the set up. Based on the procedure discussed above the optimum sizes of different tanks to pump 5 litres of water per cycle is determined and the design results are tabulated in Table 3.

Table 2 Details of various components in the Collector (Surface area of the collector = 1 m²)

Component	Material	Specification
Absorber plate	Copper sheet	0.71 mm
Plate coating	Black mat paint	Absorptance= 0.98
Insulation	PUF	k=28*10 ⁻³ W/m-K
Riser tube	Copper	12.5 mm
Header tube	Copper	18.5 mm
Casing	Mild steel plate	1.2 mm thickness
Transparent cover	Glass	Emissivity=0.88

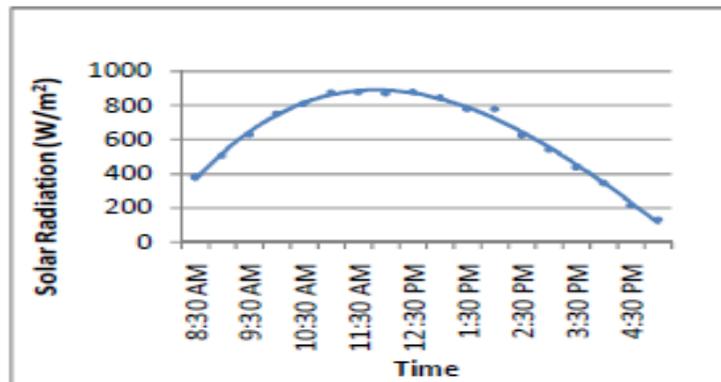
Table 3 Details of various tanks

Tank	Volume (litre)	Diameter (mm)	Length (mm)	Thickness (mm)	Material	Insulation
N	15	300	225	3	Mild steel	PUF
S	12	300	200	3	Mild steel	PUF
A	15	300	225	3	Mild steel	PUF
B	10	300	150	3	Mild steel	Not applicable
C	5	200	160	3	Mild steel	Not applicable
Condenser	30	300	425	3	Mild steel	PUF

IV RESULTS AND DISCUSSION

The experiments were conducted for three different delivery heads of 3 m, 4 m and 5 m during March and April 2014 months at which the availability of solar radiation is maximum at a place like Calicut. The maximum solar radiation during the test period is found to be around 880 W/m^2 . The experiments were conducted continuously for four days at each delivery head. Every day the collector is exposed to radiation from 8.00 AM onwards and the pump is ready to execute its first cycle around 10.30 AM. Consistent results at each discharge head were observed on all days at a particular discharge head.

The variation of the solar radiation with time on a typical solar day in which the experiments were conducted is plotted in Fig. 5. It is clear that the solar radiation is very less in the morning and gradually increases till the noon thereafter it decreases which is a standard trend of variation. But the maximum availability of solar radiation in a day compatible to the experiment is found to be between 10.30 AM and 3.00 PM. The pump is expected to give the best performance during this time interval and the experimental results are exactly matching. The heating time during the solar noon time is found to be much lesser as compared to other time.

**Fig. 5 Variation of solar radiation with time**

Since the solar radiation directly influences the ambient temperature, the ambient temperature variation also shows the same trend as that of the solar radiation curve which is shown in Fig. 6. If the ambient temperature remains more than that of the normal boiling point of the working fluid for a very long time then this will adversely affect the condensation process. A long time taken to complete the condensation process leads longer cycle time, with which achieving the advantage of the special condenser in this system will become considerably difficult. The variation of ambient temperature is found to be within limit during the present experimentation as shown in Fig. 6.

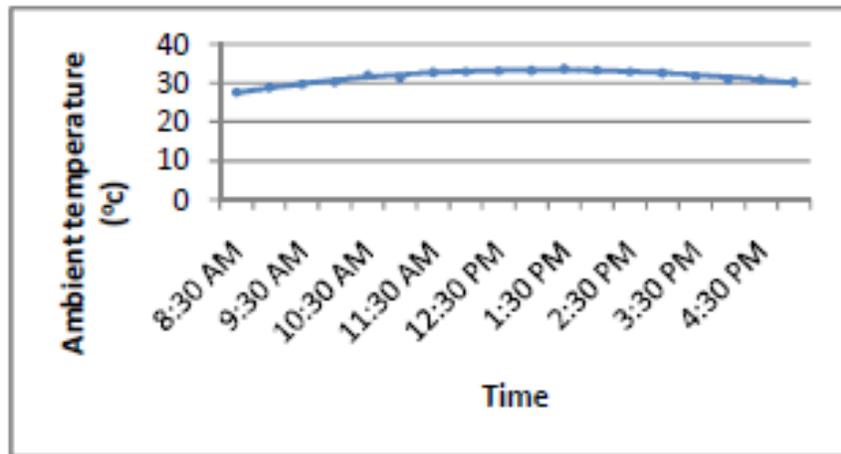


Fig. 6 Variation of ambient temperature with time

The maximum pressure and temperature achieved are found to be around 4 bar and 90 °C when the pump is not in operation which means the valve 2 is closed. The maximum pressure achieved is more than 3.5 bar which is the theoretical pressure to be attained to pump the water to a head of 10 meter. Moreover, it is observed that the designed value of 10 bar which is more than two times the maximum pressure value and the system is always safe. Since pumping is not performed there will not be any fluctuation in the pressure and temperature build up, but in the case of pumping it will be frequently fluctuating. The variation of pressure in S tank is shown in Fig. 7 and the variation of temperature in the S tank is shown in Fig. 8.

When the pump is in operation, once the required pressure in tank N reaches, the valve 2 is opened and valve 1 is closed and the vapour expands to push the brine solution from tank A to tank B to achieve pumping. During this period the S tank is isolated from N tank so the pressure in N tank only reduces. But once pumping is over and valve 2 is closed and valve 1 is opened. When tank N is in communication with tank S (after the expansion from tank N to tank A and the opening of the valve 1) there will be a flashing of high pressure vapour from S tank to N tank to reach the equilibrium state between the two tanks. These flashing of vapour reduce the pressure in the S tank to a lower value and equilibrium pressure is attained between these two tanks. For a head of 3 m it is found that the pressure reduces from the discharge pressure of 2 bar to 1.34 bar. So for the next cycle to perform the pressure again has to reach at least the minimum value. The time taken for this is called the heating time. So the nature of the curve will be fluctuating between two limits. During the first cycle of each day the pressure is to be built up from zero to

the required value so heating time will be always more for the first cycle and there- after heating time will be less. Figs 9 and 10 show the exact variation of the pressure and temperature when the pump is in operation.

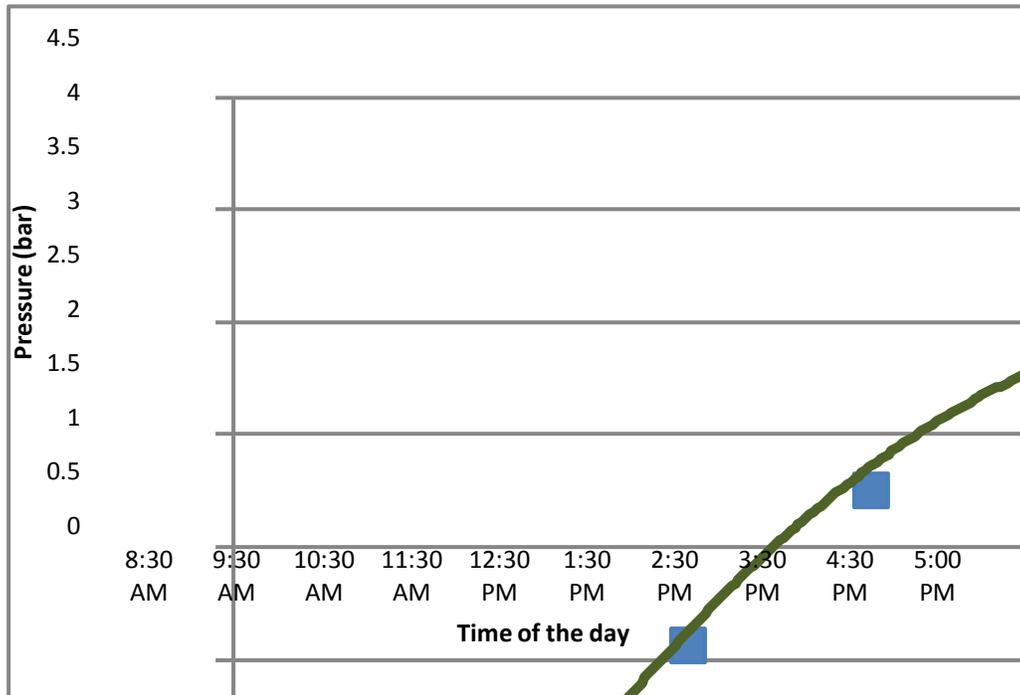


Fig. 7 Variation of pressure in S tank in a day when the pump is not in operation

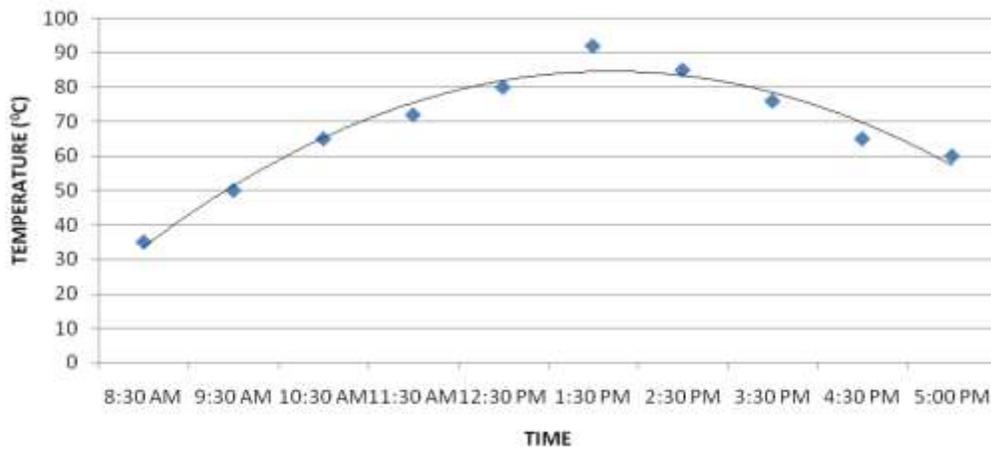


Fig. 8 Variation of temperature in S tank in a day when the pump is not in operation

Table 4 shows the effect of delivery head on the number of cycles performed per day for the pump. It is found that the maximum number of cycles that the pump performed for a head of 3 m is 7 and as expected it is getting reduced to 4 times for a head of 4 m and 3 times for 5 m head. The reason for the reduction in number of cycle is as head increases the pressure for pumping increases and more time is needed to achieve the required pressure. The

maximum quantity of water pumped in a day is found to be 35 litres for a head of 3 m and the same at a head of 5 m is found to be 15 litres as shown in Table 4. Efficiency depends upon the number of cycles per day and the work output per cycle at a discharge head. Since the effect of increase in efficiency due to increase in work output per cycle dominated by the effect of decrease in efficiency due to reduction in number of cycles per day at higher delivery heads, efficiency decreases with increase in delivery head as shown in Table below.

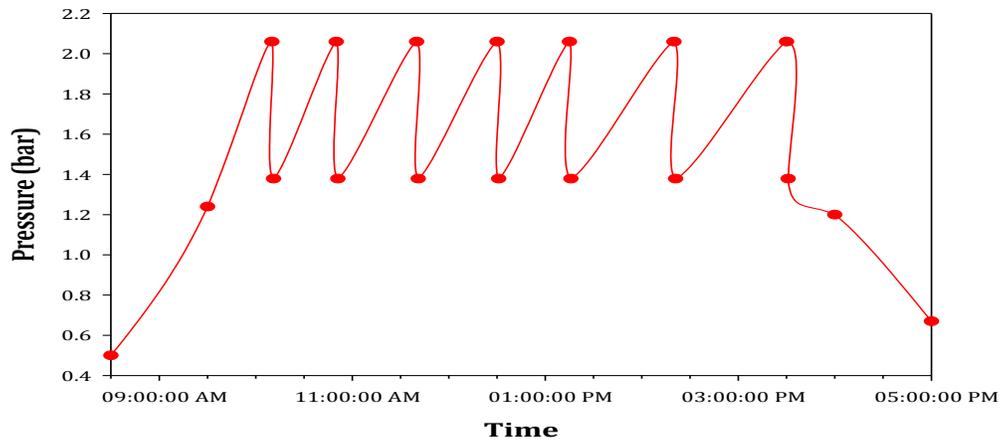


Fig. 9 S tank pressure variation when pump is in operation

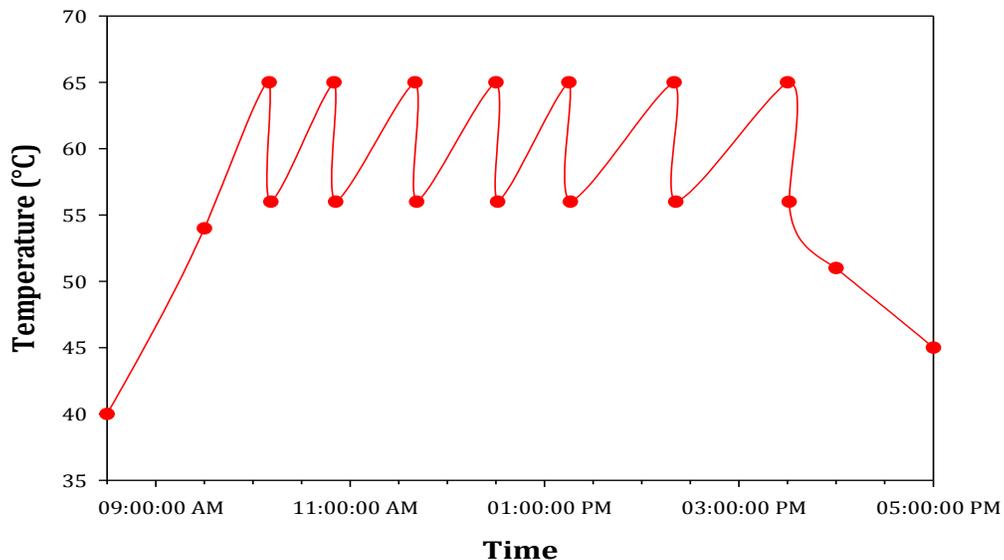


Fig. 10 S-tank temperature variation when pump is in operation

From the performance analysis it is clear that as the head increases heating time also gets increased since required pressure for pumping is more. Since the performance parameters like efficiency and mass flow rate of water are depending on this they are also getting reduced as the head increases. There is little difference in the theoretical

pressure calculated to pump water and the actual pressure. This may be due to the condensation of some part of vapour while coming in contact with the brine solution in A tank. This condensation reduces the pressure inside the tank. It is found that the difference in theoretical and actual pressure is getting increasing as head increases. The more the difference in temperature between brine solution and vapour more will be the rate of condensation. During

Table 4 Number of cycles per day, discharge and efficiency

Sl. No.	Delivery Head (m)	No. of cycles per day	Discharge (litres per day)	Efficiency x 10 ² %
1	3	7	35	0.14
2	4	4	20	0.125
3	5	3	15	0.09

the experiment it is noticed that some amount of vapour is reaching even up to C tank. This means that since water column in A tank is not a rigid one there occurs some bubbling of vapour through the brine solution so that it reaches C tank along with the air. This difficulty can be overcome by introducing a floating body over brine solution.

V UNCERTAINTY ANALYSIS

The errors involved in measuring instruments will influence the accuracy of the calculated results. So, determination of uncertainty in the measurements of experimentation is important. The only measurement required to know performance of the pump is solar radiation and the others such as number of cycles per day and quantity of water lifted per cycle are general observations. The error involved with the pyranometer which is used to measure the solar radiation is $\pm 5\%$.

Propagation of uncertainty method [16] is used to determine the combined effect of random measurement errors. According to this method the result R is a given function of variables $x_1, x_2, x_3, x_4, \dots, x_n$. Thus,

$$R = R(x_1, x_2, x_3, x_4, \dots, x_n)$$

Let w_R be the uncertainty in the result and $w_1, w_2, w_3, w_4, \dots, w_n$ be the uncertainties in the independent variables. If the uncertainties in the independent variables are all given with the same odds, then the uncertainty in the result will

$$\text{be } w_R = \sqrt{\left(\frac{\partial R}{\partial x_1} w_1\right)^2 + \left(\frac{\partial R}{\partial x_2} w_2\right)^2 + \left(\frac{\partial R}{\partial x_3} w_3\right)^2 + \dots \dots \dots \left[\frac{\partial R}{\partial x_n} w_n\right]^2}$$

By following this method percentage of uncertainty in the performance parameter (energy efficiency) is 0.7245 %.

VI CONCLUSIONS

A systematic design of a thermal water pump is presented for ethyl ether as working fluid. Experiments on fabricated solar thermal water pump have been carried out for different heads of 3 m, 4 m and 5 m. The performance parameters like the efficiency of the pump and mass flow rate of water were estimated. The pump is found to be capable of operating 7 cycles per day. The heating time for the working fluid and condensation of the vapour are found to be the critical factors for time required to complete any working cycle. The high heating time for every working cycle at any delivery head was observed as a significant reason for obtaining less number of cycles per day which can be improved by using a more efficient solar collector. Since the number of cycles per day is less the overall efficiency of the pump obtained ($0.14 \times 10^{-2} \%$) is also very less than expected.

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