

CHAPTER - IV

RESULTS AND DISCUSSION

4.1 PERFORMANCE ANALYSIS

The performance of a single slope and a pyramid cover solar still was analyzed in this study for a number of normal sunny days and the best results are chosen. Temperature profiles of water, ambient, cover, air and amount of distillate output were observed along with the measurement of solar insolation for every half an hour interval. The performance of the single slope and pyramid cover solar still was also analyzed with storage material of tar coated blue metal and phase change material (paraffin wax) for augmenting the productivity. The nocturnal output was also measured in both stills with and without storage material. The values are tabulated in the table (3.7). Out of the two stills constructed, the pyramid solar still functioned with reasonable output with and without storage media. An attempt has also been made to analyse the pyramid solar still with electrical backup unexposed to sunshine at a desired temperature to compare the cost effectiveness of electrical energy consumed and solar energy utilized. The instantaneous and daily efficiency were calculated along with the computation of heat transfer coefficients. Numerical calculations were carried out for comparing the observed values of heat transference with theoretical simulation values for the same. The system reliability and viability were estimated by a techno economic analysis. The standard and quality of distilled water yield is examined by physical and chemical properties test carried out on a collected sample of water in the regional laboratory, Tamil Nadu Water Supply and Drainage Board, Coimbatore.

4.2 EFFICIENCY OF THE SYSTEM

The variation of the instantaneous efficiency observed in the study is in the range of 2.27% to 27.30%, 4.41% to 39.52% and 4.41% to 36.86% for the single slope still without any storage material, with tar coated blue metal and with paraffin wax respectively.

The variation of the instantaneous efficiency observed in the study is in the range of 2.52% to 32.73%, 4.41% to 42.01% and 4.41% to 38.79% for the

pyramid still without any storage material, with tar coated blue metal and with paraffin wax respectively.

Studies indicate that the instantaneous efficiency of both single slope and pyramid solar still with tar coated blue metal is found to be more than that with other materials for the same stills. In the performance study with paraffin wax instantaneous efficiency is low in both stills compared to that with tar coated blue metal. Even though instantaneous efficiency is lowered, distillate output is increased due to the effect of paraffin wax, which maintains the temperature of basin water for longer time. Instantaneous water collection is maintained even at night times due to the continuous heat extraction from the paraffin wax.

Performance study in both single slope and pyramid solar stills with phase change material (paraffin wax) shows slightly less value of instantaneous efficiency, average efficiency observed is higher than that compared to study with tar coated blue metal. Efficiency is maintained even after 2:00 pm at a steady rate due to the storage property of the paraffin wax. Hence still with phase change material (paraffin wax) shows higher value of average efficiency, in spite of less instantaneous efficiency.

4.3 DISTILLATE OUTPUT OF THE STILLS

The maximum distillate output produced without storage material is observed to be 0.18 kg, while that with storage material of tar coated blue metal and paraffin wax were observed to be 0.192 kg and 0.196 kg respectively for single slope solar still.

The maximum distillate output produced without storage material is observed to be 0.183 kg, while that with storage material of tar coated blue metal and paraffin wax were observed to be 0.194 kg and 0.202 kg respectively for pyramid solar still.

The distillate output is increased as a result of fast evaporation due to high temperature retention in the storage material. Studies have shown that pyramid still with phase change material gives maximum distillate output.

In case of pyramid still with paraffin wax , amount of distilled yield is slightly more than that of pyramid still with tar coated blue metal due to water collection maintained even at off shine hours by the storage effect of paraffin wax.

4.4 THERMAL ANALYSIS

The thermal analysis of computation of the internal and external heat transfer coefficients with and without storage material for the single slope and pyramid cover solar still has been made and the results were tabulated in the table (3.1). The heat transfer coefficients due to internal and external heat transference are observed. Results show that internal and external heat transfer coefficients are less both with tar coated blue metal and paraffin wax.

4.5 COMPUTATION OF DISTILLATE OUTPUT AND EFFICIENCY

The experimentally observed values of distillate output and the efficiency compared with the theoretically predicted values are shown in the table (3.2). The values are in agreement with slight deviation. This is due to the change of varied solar insolation on different dates and the different storage materials. However in general the system with paraffin wax is found to be more efficient than with other storage materials.

4.6 TECHNO ECONOMIC ANALYSIS

Techno economic analysis is done on the system to compute the total annual cost of the newly fabricated pyramid solar still. The economic analysis is performed by assuming the life span of the constructed solar still to be 7 years. The first annual cost of the system is computed and found to be Rs. 912/-. The first annual salvage value was found to be Rs. 117/-. The total annual cost is calculated by adding the first annual cost of the system and the maintenance cost of the system and by deducting the salvage value from it. The total annual cost of the fabricated solar still was calculated and found to be Rs. 995/- (first year) and similarly the analysis is done for 7 years and the results are tabulated in the table(3.4).

4.7 COMPUTATION OF THE ANNUAL DISTILLATE YIELD

The amount of distillate yield annually by the process of solar desalination is computed and the results are obtained. There are approximately 200 solar days

in a year and eight hours of bright sunshine in a day. Nearly 270ml (average of with and without storage material) of distillate water is produced per hour for pyramid solar still. Based on the above data, the total cost of distillate water obtained in a year was found to be Rs. 12,960/-. This cost is expected to increase by proper handling and maintenance of the system.

4.8 COST – BENEFIT ANALYSIS

The cost – benefit analysis of the system is done and the annual profit obtained is Rs. 12,500/- obtained. Hence the capital investment of Rs. 5000/- can be recovered in a period of less than a year.

4.9 PHYSICAL AND CHEMICAL ANALYSIS OF THE DISTILLATE

Regional Laboratory, Tamil Nadu Water Supply and Drainage Board, Coimbatore. The solar distilled water was found to be superior in quality. The analysis shows clearly in the tables (3.5) & (3.6), that the total dissolved solids were reduced to very low values and pH was found to be 7.52, which is the normal pH of distilled water and the values of calcium, magnesium, nitrate, chloride, fluoride and sulphate are found to be negligible. Hence the solar distilled water was found to be superior to the saline water in physical as well as chemical analysis of the water samples. El – Kassaby (1991)

4.10 PERFORMANCE ANALYSIS OF SINGLE SLOPE SOLAR STILL WITH TAR COATED BLUE METAL AND PARAFFIN WAX

The performance of the single slope solar still was analysed with tar coated blue metal and phase change material (paraffin wax). The following parameters are estimated and the performance is discussed in this chapter.

The radiative heat transfer (Q_{ri}), convective heat transfer (Q_{ci}) and evaporative heat transfer (Q_{ei}) under internal heat transfer modes are predicted. Similarly external heat transfer modes by conduction heat transfer (Q_{be}), external heat transfer through radiation from the glass cover (Q_{re}) and heat transfer from top cover to atmosphere by convection (Q_{ce}) are also estimated. The instantaneous efficiency, performance ratio,

saturation vapour pressure, latent heat and dimensionless parameters are also calculated for the single slope solar still and also with tar coated blue metal and phase change material (paraffin wax) separately. The readings are recorded for a number of clear sunny days and almost equal average radiation received in the three studies are considered for the analysis and reported.

Photographic view of a single slope solar still with tar coated blue metal and phase change material (paraffin wax) is shown in fig (4.1) and fig (4.2).



Fig (4.1) Photographic view of tar coated blue metal

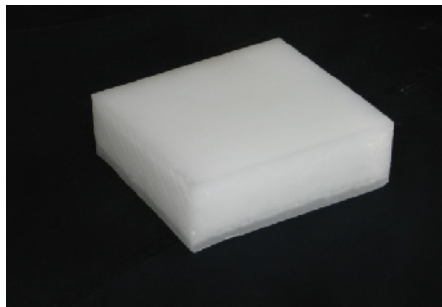


Fig (4.2) Photographic view of phase change material (paraffin wax)

Fig (4.3) shows the variation of temperature for water, air, inner surface of the cover, outer surface of the cover and ambient with respect to time in single slope solar still performance study. The maximum rise in water temperature is observed as 57.5 °C. Similarly the maximum air temperature of 59.5 °C is obtained. The variation of ambient temperature is in the range of 31.5 °C to 37 °C in the study. The impact of the ambient temperature over the still is more because the condensation at the top cover is mainly based on it. Similarly the variation of top

cover temperature is in the range of 32 °C to 43.5 °C. Normally, the rise in top cover temperature affects the condensation of water vapour over the top cover, because the top cover temperature rises to a maximum of 43.5 °C. This rise in top cover temperature is higher than the ambient temperature. The difference between top cover temperature and ambient temperature is only 6.5 °C. Hence distillate yield obtained from the still is not slowed down. The difference in the rate of yield for the regular intervals measured between 2.00 p.m. and 5.00 p.m. is more than the rate of yield measured between from 9.30 a.m. and 2.00 p.m. Finally the yield reduces at 7.00 p.m. due to the decrease of water temperature and evaporation rate.

Fig (4.4) shows the variation of instantaneous efficiency and performance ratio with respect to time for performance study of single slope solar still. The instantaneous efficiency is increased according to the time. The variation of the instantaneous efficiency observed in the study is in the range of 2.27% to 27.30% for the single slope still.

The performance ratio predicted for the single slope solar still is increased with respect to time. The performance ratio observed during the study is in the range of 1.94 % to 7.05 % for the single slope still performance. The warming up period causes a change in the performance ratio during rise in temperature. When it rises to maximum, the performance ratio is not maintaining a steady state. This effect reveals that the single slope solar still requires an adequate temperature for evaporation.

Fig (4.5) shows the variation of solar insolation and water collection with respect to time for the single slope solar still. Solar insolation increases linearly with time and reaches the maximum value from 12 p.m. to 2 p.m. and then decreases. Solar insolation received during this study is in the range of 60.38 W/m² as minimum value to 1050.69 W/m² as maximum value for single slope still performance. The average insolation received during the study is around 766.88 W/m².

The variation of distilled water collection is in the range of 0.013 kg to 0.18 kg for the single slope still performance. This instantaneous water collection is observed as maximum of 0.18 kg at 2.00 p.m. and minimum water collection of 0.013 kg at 9.30 a.m. Water collection is increased linearly in the initial hours even

though the instantaneous yield rate at regular intervals is less than the actual distillate yield since the initial insolation is completely utilized to warm up water.

Fig (4.6) shows the variation of temperature of water, air, ambient, inner surface and outer surface temperature of the cover of the single slope solar still with tar coated blue metal. The water temperature of the single slope solar still rises in the initial sunshine hours and it decreases due to decrease of radiation intensity. The maximum rise in water temperature is observed as 60 °C, while the maximum air temperature in the basin was 62 °C. The variation of ambient temperature was in the range of 33 °C to 37 °C during the study. The impact of the ambient temperature over the still is less because the condensation is occurred at the top cover. The surface area of the top cover of single slope is less compared to the pyramid top cover used in the still. Similarly the variation of top cover temperature is in the range of 33 °C to 45.5°C. The water temperature rise for the performance study with tar coated blue metal reaches to an optimum value and it increased the evaporation rate. Water temperature of the still with tar coated blue metal starts to increase linearly in the initial period (9.00 a.m. to 10.00 a.m.). Due to the heat storage effect, heat energy is transferred from the tar coated blue metal to the water. Therefore water temperature of the still increases simultaneously with respect to time and maintains temperature almost the same value during 12.30 a.m. to 3.00 p.m. Marginal decrease in temperature is observed in the evening. The difference in the rate of yield for the regular intervals measured between 10.30 a.m. and 2.00 p.m. is more than the difference in rate of yield measuring from 9.00 a.m. to 10.30 a.m. The collection rate is more only during 11.00 p.m. to 3.00 p.m. due to heat storage effect.

Fig (4.7) shows the variation of instantaneous efficiency and performance ratio with respect to increase of day hours for performance study of single slope solar still with tar coated blue metal. The instantaneous efficiency is increased with respect to increase in sunshine hours. The variation of the instantaneous efficiency observed in the study is in the range of 4.41% to 39.52% for the single slope still with the same material. The efficiency is found to be more in this case than that in other studies.

The performance ratio calculated is found to increase with respect to day hours and reaches a steady state after 12:00 pm. Performance ratio also shows the same trend as that of instantaneous efficiency. The performance ratio observed in the study is in the range of 2.64 % to 8.28 % for the single slope still with tar coated blue metal. In the single slope solar still, performance ratio reveals that radiation received by the still is utilized more for raising the water temperature. So performance ratio is not reached a steady state. The presence of tar coated blue metal with the still causes the increase in temperature to the optimum value for evaporation. Thus it maintains a constant yield rate for longer period. Thus performance ratio curve shows a steady state during 11.00 a.m. to 3.00 p.m. The increase in performance ratio value confirmed that the yield rate of the still during the performance with tar coated blue metal is increased to 8.28% compared to the performance ratio value of 7.05 % for single slope solar still without tar coated blue metal.

Fig (4.8) shows the variation of solar insolation and water collection with respect to day hours for single slope solar still with tar coated blue metal. Insolation increases with respect to time and reaches the maximum value from 12.00 p.m. to 2 p.m. and then decreases. Insolation received during this study is in the range of 108.69 W/m^2 as minimum value to 1074.85 W/m^2 as maximum value for single slope still with tar coated blue metal.

The variation of distilled water collection is in the range of 0.013 kg to 0.192 kg for the single slope still with tar coated blue metal. Water collection of the single slope still is boosted due to the presence of the tar coated blue metal with it. Instantaneous distilled water collection is more in the sunshine hours due to the energy transfer from the tar coated blue metal. This instantaneous water collection is observed as maximum of 0.192 kg at 1.30 p.m. and minimum water collection of 0.013 kg at 9.30 a.m. The increase in water collection during the initial hours even though the instantaneous yield rate at regular interval is less because the initial radiation is completely utilized for the warm up temperature than to produce distillate yield. In the later case the temperature is fully utilized for evaporation simultaneously the rise in temperature causes an increase in saturation vapour pressure.

Fig (4.9) shows the variation of temperature for water, air, inner surface of the cover, outer surface of the cover of the solar still and ambient temperature with respect to day hours in single slope solar still with paraffin wax. The maximum rise in water temperature is observed as 59.5 °C. Similarly, the maximum air temperature of 61.5 °C is obtained. The maximum paraffin wax chamber temperature was obtained as 67.5 °C. The variation of ambient temperature is in the range of 32.5 °C to 37 °C during the study. Similarly the variation of top cover temperature is in the range of 33 °C to 44°C. Normally, the rise in top cover temperature affects the condensation of water vapour over the top cover, because the temperature rises to a maximum of 44°C. This rise in temperature is higher than the ambient. The difference between top cover temperature and ambient temperature is only 7 °C. Moreover the water temperature inside the still is maintained due to the heat transfer from wax chamber. So distillate yield obtained from the still is not slowed even at, off sunshine hours. The yield rate difference is less for the regular intervals measured between 2.00 p.m. and 5.00 p.m. and finally the yield started to reduce after 6.00 p.m. due to the decrease of water temperature and evaporation rate.

Fig (4.10) shows the variation of instantaneous efficiency and performance ratio with respect to day hours for single slope solar still with paraffin wax. The instantaneous efficiency is increased according to the time. The variation of the efficiency observed during the study is in the range of 4.41% to 36.86% for the single slope solar still with paraffin wax. Even though the instantaneous efficiency is less than the still with tar coated blue metal, water collection is increased due to the effect of paraffin wax, which maintains the temperature of basin water for longer time. Instantaneous water collection is maintained even at night times due to the continuous heat extraction from the paraffin wax.

Even though the single slope still with paraffin wax performance study shows slightly less value of instantaneous efficiency than the still with tar coated blue metal, average efficiency observed is higher than that compared to study with tar coated blue metal. Efficiency is maintained even after 2:00 pm at a steady rate due to the storage property of the paraffin wax. Hence still with paraffin wax shows higher value of average efficiency, in spite of less instantaneous efficiency.

The performance ratio calculated by eq (3.24) is found to increase with respect to time and reaches a steady state in the afternoon. Performance ratio shows a similar trend as that of instantaneous efficiency. The performance ratio observed during the study is in the range of 2.64 % to 10.46 % for the single slope still with paraffin wax. Performance ratio value is increasing steadily with respect to water temperature. The energy transferred from the paraffin wax to water is less and so the rise in water temperature is not reached the optimum value around 65 °C. But in this case due to the storage capacity of the paraffin wax chamber, it helps to maintain a required temperature for evaporation in still even at off sun shine hours. So the performance ratio increases without reaching a steady state with respect to time even with substitution of energy from the paraffin wax chamber.

Fig (4.11) shows the variation of solar insolation and water collection with respect to time for single slope solar still with paraffin wax. Solar insolation increases with respect to time and reaches the maximum value from 12 p.m. to 2 p.m. and then decreases. Solar insolation received during this study was in the range of 108.69 W/m² to 1038.62 W/m² for the single slope still with the same material.

The distillate yield is in the range of 0.013 kg to 0.196 kg for the single slope still with paraffin wax. This instantaneous water collection is observed as maximum of 0.196 kg at 2.00 p.m. and minimum water collection of 0.013 kg at 9.30 a.m. Water collection is maintained even at off shine hours due to the presence of paraffin wax. Even though the temperature is fully utilized for evaporation, the rise in temperature causes to increase the saturated vapour pressure. So the collection yield during the period of 30 minutes interval is almost nearer to one another. Thus the yield rate is maintained after attaining the warm up period almost a higher rate at maximum temperature. Amount of distilled yield is less than that of still with tar coated blue metal till 2:00 pm. But after 2:00 pm, water collection is maintained due to continuous heat gain from the paraffin wax. The paraffin wax storage capacity is supported to attain the yield rate even at off sunshine hours.

Fig (4.12) shows the variation of saturation vapour pressure inside the single slope still on three modes of (without storage,with TCBM,PCM) studies. Saturation

vapour pressure starts to increase with respect to time and it reaches the peak value around 1:30 p.m. to 2:00 p.m. Saturation vapour pressure reaches maximum value when water collection is more and tends to decrease when water collection decreases. Saturation vapour pressure predicted by eq (3.23) is in the range of 4774.98 to 11171.33 Pa for single slope solar still, 4980.48 to 13609.64 Pa for single slope solar still with tar coated blue metal and 5121.7 to 12646.83 Pa for single slope solar still with paraffin wax. The difference in saturated vapour pressure is very less at higher temperature compared to the warm up period. So it suggests that the latent heat value has started to increase and at the same time saturation vapour pressure started to decrease. Saturation vapour pressures for single slope solar still in both the study shows a similar trend due to increase in water temperature due to the effect of storage material.

Fig (4.13) shows the variation of latent heat predicted by eq (3.22) for the single slope still on three modes of (without storage,with TCBM,PCM) studies. It shows that the latent heat decreases initially with respect to time. It reaches a low value around 1:00 p.m. because the water temperature at this region is more. So it shows that the latent heat is decreased at higher order of temperature. Most of the incoming radiation is utilized for evaporation at this stage. Latent heat value is observed in the range of 2417.31742 to 2378.98195 kJ kg⁻¹ for single slope solar still performance study w/o storage, 2415.53223 to 2369.29723 kJ kg⁻¹ for single slope solar still with tar coated blue metal and 2414.34157 to 2372.93456 kJ kg⁻¹ for single slope solar still with paraffin wax. Latent heat is fully utilized for boosting the condensation commencing at lower temperature from 9.00 a.m. to 1.30 p.m. Thus the effect of latent heat is not completely utilized for condensation at higher temperatures. Latent heat values for the performance are reduced due to the reason of high values of water temperature. Hence latent heat value is predominant in single slope still performance with respect to other two studies.

Fig (4.14) shows the variation of Grashof number and Nusselt number computed by equations (3.1) & (3.2) with respect to time for single slope solar still in three modes of (without storage,with TCBM,PCM)study. It concludes that Grashof

number increases with respect to time. Grashof number is found as 5123 to 112706.02 for the single slope still performance study, 5123 to 128075.03 for the single slope still with tar coated blue metal and 10246 to 143444.04 for the single slope still with paraffin wax. Grashof value is found to increase steadily during warm up period and then it starts to decrease with respect to decrease in water temperature.

Nusselt number is found to be increased with respect to time. Nusselt number values are observed in the range of 1.65 to 3.58 for the single slope still study, 1.65 to 3.77 for the single slope still with tar coated blue metal and 1.96 to 3.80 for the single slope still with paraffin wax. Nusselt number is found to have close linearity similar to that of internal convective heat transfer rates. After attaining the maximum value at higher temperature, the Nusselt value maintains a steady state.

Fig (4.15) shows the 'S' ratio between the evaporative heat transfers and the total heat transferred from the water to the cover with respect to time. It shows the linear increase for all the mode of study and 'S' value is found in the range of 0.32 to 0.69 for the single slope still performance study, 0.32 to 0.72 for the single slope still with tar coated blue metal and 0.34 to 0.72 for the single slope still with paraffin wax. Comparing fig (3.9), fig (3.12) and fig (3.15) with fig (3.21) shows that the range of temperature of still operation are sensitive to water temperature and less sensitive to change in top cover temperature.

Fig (4.16), fig (4.17) and fig (4.18) show the variation of hourly heat transfer rates by evaporation, radiation and convection with respect to time for the considered day under three modes of study. In the solar still, the evaporative heat transfer coefficient (Q_{ei}) is the major heat loss and is greater than the other two modes together. It was observed that the radiative heat transfer coefficient (Q_{ri}) and convective heat transfer coefficient (Q_{ci}) do not vary much in comparison to evaporative heat transfer coefficient (Q_{ei}). This indicates the strong dependence of evaporative heat transfer coefficient (Q_{ei}) on the operating water temperature (T_w).

Table 4.1 Heat Transfer Coefficients for Single Slope Solar Still

	Q_{ci} (W/m ²)	Q_{ri} (W/m ²)	Q_{ei} (W/m ²)	Q_{ce} (W/m ²)	Q_{re} (W/m ²)	Q_{be} (W/m ²)
Single Slope Solar Still	14.28	47.97	114.45	32.13	77.84	4.35
Single Slope Solar Still with Tar Coated Blue Metal	17.57	57.07	156.15	38.71	84.08	5.32
Single Slope Solar Still with Phase change material (paraffin wax)	21.42	67.75	193.78	33.63	87.80	5.98

The thermal conductivity of water is computed by eq (3.19) and it is observed for the single slope solar still w/o storage is in the range of $26.87 \times 10^{-3} \text{ Wm}^{-2} \text{ }^{\circ}\text{C}^{-1}$ to $28.10 \times 10^{-3} \text{ Wm}^{-2} \text{ }^{\circ}\text{C}^{-1}$ and with tar coated blue metal is $26.93 \times 10^{-3} \text{ Wm}^{-2} \text{ }^{\circ}\text{C}^{-1}$ to $28.40 \times 10^{-3} \text{ Wm}^{-2} \text{ }^{\circ}\text{C}^{-1}$ and with wax is $26.92 \times 10^{-3} \text{ Wm}^{-2} \text{ }^{\circ}\text{C}^{-1}$ to $28.29 \times 10^{-3} \text{ Wm}^{-2} \text{ }^{\circ}\text{C}^{-1}$. The dynamic viscosity of water predicted by eq (3.20) is in the range of $18.67 \times 10^{-6} \text{ Nsm}^{-2}$ to $19.40 \times 10^{-6} \text{ Nsm}^{-2}$ for single slope still and $18.70 \times 10^{-6} \text{ Nsm}^{-2}$ to $19.59 \times 10^{-6} \text{ Nsm}^{-2}$ for single slope still with tar coated blue metal and $18.69 \times 10^{-6} \text{ Nsm}^{-2}$ to $19.52 \times 10^{-6} \text{ Nsm}^{-2}$ for single slope still with paraffin wax. The thermal conductivity and dynamic viscosity increase with respect to time and possess almost the same trend. The density of water is predicted by eq (3.21) for the still is observed as 1156 kg/ m^3 to 1099 kg/ m^3 for single slope still performance study, 1153 kg/ m^3 to 1085 kg/ m^3 for single slope still with tar coated blue metal and 1151 kg/ m^3 to 1090 kg/ m^3 for single slope still with paraffin wax.

The performance analysis is made for the single slope solar still under three modes (without storage, with TCBM,PCM) by analyzing the same climatic conditions which is observed by taking the average radiation of 760.42 W/m^2 . It is shown in fig (4.5), fig (4.8) and fig (4.11).

A comparative study is made from the fig (4.3), fig (4.6) and fig (4.9) and the maximum rise in water temperature is observed as 60 °C for single slope solar still with tar coated blue metal. But in the case of single slope still and single slope still with paraffin wax, water temperature is less, such as 57.5 °C and 59.5°C respectively. Similarly the water temperature maintained in the still at 5 O' clock is comparatively higher for the single slope still with paraffin wax than other studies.

The fig (4.5), fig (4.8) and fig (4.11) show the water collection for single slope still without storage, with tar coated blue metal and with paraffin wax. These figures reveal that water collection rate per day is very much improved in single slope still with tar coated blue metal and with paraffin wax. But in the case of single slope still with paraffin wax, results in maximum yield compared to other studies. The average yield rate observed including night water collection is 2.2057 kg for single slope still with paraffin wax than that of 1.874 kg and 1.6532 kg for single slope still with tar coated blue metal and single slope still w/o storage performance individually.

Fig (4.4), fig (4.7) and fig (4.10) show the variation of efficiency for the three modes of studies (without storage, with tar coated blue metal and with paraffin wax). The average efficiency is observed as 19.55% for single slope still without storage. Similarly 32.62% and 33.41% with tar coated blue metal and with paraffin wax. It shows that the average efficiency is more in the case of single slope solar still with paraffin wax than that of other two studies. This increase in efficiency is due to decrease in overall loss. By comparing the performance studies it shows that a marginal increase in efficiency for single slope solar still with paraffin wax than single slope solar still with storage material and normal still study at off sunshine hours due to the storage property of paraffin wax.

Fig (4.4), fig (4.7) and fig (4.10) show the performance ratio for single slope solar still without storage, with tar coated blue metal and with paraffin wax. When comparing the performance ratio values the maximum value obtained for single slope solar still is 7.05 %, with tar coated blue metal is 8.28 % and with paraffin wax is 10.46 %. It reveals that performance ratio value is higher in the case of single slope solar still with paraffin wax than the single slope solar still without storage and with tar coated blue metal. Water temperature of the still in the case of single slope solar

still with tar coated blue metal is higher than that of the other two studies, even though a lesser value of performance ratio is observed for single slope solar still with tar coated blue metal. Thus it confirms that the increase in performance ratio value to higher order is only due to the water temperature of the still maintained at higher values. So this effect is observed in the case of single slope solar still with paraffin wax which is due to storage capacity of the paraffin wax. Performance ratio value is also depending upon the evaporation rate of the single slope solar still.

Fig (4.12) and fig (4.13) show the variation of saturation vapour pressure and latent heat values for three different operating modes of (without storage, with TCBM, PCM) solar still. These studies confirm that the latent heat decreases with the increase of water temperature. A less value of heat storage is observed for single slope solar still with tar coated blue metal than that of other two studies, because the maximum water temperature is obtained for the single slope solar still with tar coated blue metal. Similarly saturation vapour pressure value is higher for single slope solar still with tar coated blue metal analysis than that of other studies. It is confirmed that latent heat is inversely proportional to saturation vapour pressure.

4.11 PERFORMANCE ANALYSIS OF PYRAMID COVER SOLAR STILL WITH TAR COATED BLUE METAL AND PARAFFIN WAX

The performance of the pyramid solar still is analysed without storage materials and also with tar coated blue metal and phase change material (paraffin wax). The following predictions are made for all the studies and their performance is discussed in this chapter.

The radiative heat transfer (Q_{ri}), convective heat transfer (Q_{ci}) and evaporative heat transfer (Q_{ei}) under internal heat transfer modes are predicted. Similarly external heat transfer modes by conduction heat transfer (Q_{be}), external heat transfer through radiation from the glass cover (Q_{re}) and heat transfer from glass cover to atmosphere by convection (Q_{ce}) are also estimated. The instantaneous efficiency, performance ratio, saturation vapour pressure, latent heat and dimensionless parameters are also calculated for the pyramid solar still, which is with tar coated blue metal and with paraffin wax. The readings are recorded for number of clear sky days and almost

equal average insolation received during the three studies are considered for the analysis and reported.

Fig (4.19) shows the variation of temperature for water, air, inner surface of the cover, outer surface of the cover and ambient with respect to time in pyramid solar still performance study. The maximum rise in water temperature is observed as 58 °C. Similarly the maximum air temperature of 59.5 °C is obtained. The variation of ambient temperature is in the range of 32 °C to 37 °C during the study. The impact of the ambient temperature over the still is more because the condensation at the top cover is mainly based on it. Similarly the variation of top cover temperature is in the range of 32 °C to 44 °C. Normally, the rise in top cover temperature affects the condensation of water vapour over the top cover, because the top cover temperature rises to a maximum of 44°C. This rise in top cover temperature is higher than the ambient temperature. The difference between top cover temperature and ambient temperature is only 7 °C. Hence distillate yield obtained from the still is not slowed down. The difference in the rate of yield for the regular intervals measured between 12.00 p.m. and 4.00 p.m. is more than the rate of yield measured between from 9.30 a.m. and 12.00 p.m. Finally the yield reduces at 8.00 p.m due to the decrease of water temperature and evaporation rate.

Fig (4.20) shows the variation of instantaneous efficiency and performance ratio with respect to time for performance study of pyramid solar still. The instantaneous efficiency is increased according to the time. The variation of the efficiency observed in the study is in the range of 2.52% to 32.73% for the pyramid still performance study.

The performance ratio calculated is found increase with respect to time and reaches a steady state in the afternoon. The performance ratio observed during the study is in the range of 2.11% to 7.25 % for the pyramid still performance study. The warming up period causes a change in the performance ratio during rise in temperature. When it rises to maximum, the performance ratio maintains a steady state. This effect is due to the rise in temperature completely utilized for evaporation.

Fig (4.21) shows the variation of solar insolation and water collection with respect to time for pyramid solar still. Insolation increases linearly with time and reaches the maximum value from 12 p.m. to 2 p.m. and then decreases. Insolation received during this study is in the range of 96.62 W/m^2 as minimum to 1050.7 W/m^2 as maximum for pyramid still performance study.

The variation of distilled water collection is in the range of 0.014 kg to 0.183 kg for the pyramid still performance study. This instantaneous water collection is observed as maximum of 0.183 kg at 2.00 p.m. and minimum water collection of 0.014 kg at 9.30 a.m. Water collection is increased linearly during the initial hours even though the instantaneous yield rate at regular interval is less than the actual distillate yield since the initial insolation is completely utilized to warm up water. In later case the temperature is fully utilized for evaporation simultaneously the rise in temperature causes an increase in saturated vapour pressure. So the collection yield during the period of interval is almost nearer to one another. So the yield rate difference in regular interval is less compared to the warm up period. The production rate of distilled water after 2 p.m. is higher than that of warming up period. So the still systems produce more condensation only at optimum temperature.

Fig (4.22) shows the variation of temperature of water, air, ambient, inner surface and outer surface temperature of the cover for the pyramid solar still with tar coated blue metal. As a result water temperature rises during the initial sunshine hours and it falls down when the insolation intensity falls down. The maximum rise in water temperature is observed as $61 \text{ }^\circ\text{C}$. Similarly the maximum air temperature of $63 \text{ }^\circ\text{C}$ is obtained. The variation of ambient temperature is in the range of $33 \text{ }^\circ\text{C}$ to $37.5 \text{ }^\circ\text{C}$ during the study. The impact of the ambient temperature over the still is more because the condensation at the top cover is mainly based on it. Similarly the variation of top cover temperature is in the range of $33 \text{ }^\circ\text{C}$ to $45.5 \text{ }^\circ\text{C}$. Normally the rise in top cover temperature affects the condensation of water vapour over the top cover, because the top cover temperature rises to a maximum of 41°C . This rise in top cover temperature is higher than the ambient temperature. The difference between top cover temperature and ambient temperature is only $8 \text{ }^\circ\text{C}$. So distillate yield obtained from the still is not slowed down. Water temperature of the still and tar

coated blue metal starts to increase individually during the initial period (9.00 a.m. to 10.00 a.m.). Due to heat storage effect, heat energy is transferred from the tar coated blue metal to water. Therefore water temperature of the still increases simultaneously with respect to time and maintains temperature almost the same value during 12.30 a.m. to 3.30 p.m. A small decrease in temperature is observed in the evening. The difference in the rate of yield for the regular intervals measured between 10.30 a.m. and 2.00 p.m. is more than the difference in rate of yield measuring from 9.00 a.m. to 10.30 a.m. The collection rate is more only during 10.30 a.m. to 3.00 p.m. due to heat storage effect.

Fig (4.23) shows the variation of instantaneous efficiency and performance ratio with respect to time for performance study of pyramid solar still with tar coated blue metal. The instantaneous efficiency is increased according to the time. The variation of the instantaneous efficiency observed in the study is in the range of 4.41% to 42.01% for the same material. The efficiency is found to be more in this case than that in other studies.

The performance ratio calculated by eq (3.24) is found to increase with respect to time and reaches a steady state after it. Performance ratio also shows the same trend as that of instantaneous efficiency. The performance ratio observed during the study is in the range of 2.64 % to 8.66 % for the pyramid still with tar coated blue metal. The increase in performance ratio value confirmed that the yield rate of the still during performance is increased compared to the performance ratio value of 7.25 % for pyramid solar still. The warming up period causes a change in the performance ratio during rise in temperature. When it rises to maximum, the performance ratio maintains a steady state. This effect is due to the rise in temperature completely utilized for evaporation.

Fig (4.24) shows the variation of solar insolation and water collection with respect to time for pyramid solar still with tar coated blue metal. Solar insolation increases with respect to time and reaches the maximum value from 12.00 p.m. to 2 p.m. and then decreases. Solar insolation received during this study was in the range of 96.62 W/m² as minimum to 1074.85 W/m² as maximum for pyramid still with tar coated blue metal.

The variation of distilled water collection was in the range of 0.014 kg to 0.194 kg for the pyramid still with tar coated blue metal. Water collection of the pyramid still is boosted due to the presence of the tar coated blue metal within it. Instantaneous distilled water collection is more during the sunshine hours due to the effect of tar coated blue metal. After sunshine hours, the effect of tar coated blue metal reduces and the system acts as a simple still. This instantaneous water collection is observed as maximum of 0.194 kg at 2.00 p.m. and minimum water collection of 0.014 kg at 9.30 a.m. The increase in water collection during the initial hours is less because the initial radiation is completely utilized for the warm up temperature. Afterwards the temperature is fully utilized for evaporation. Simultaneously the rise in water temperature causes an increase in saturation vapour pressure. So the collection yield during the period of 30 minutes interval is maximum. Even though the yield rate is higher in this period, the yield rate difference in regular interval is less, compared to the warm up period. Thus this still system produces more condensation only at optimum temperature.

Fig (4.25) shows the variation of temperature of water, air, inner surface of the cover, outer surface of the cover of pyramid solar still and ambient temperature with respect to hours of the day in pyramid solar still with paraffin wax. The maximum rise in water temperature is observed as 60 °C. Temperature of the water circulated over Paraffin wax chamber heats the pyramid still steadily and the temperature is maintained even after the sunshine hours. and, the maximum air temperature of the still was 62 °C. The maximum temperature obtained for Paraffin wax chamber is 68 °C. The variation of ambient temperature is in the range of 32 °C to 37 °C during the study. Similarly the variation of top cover temperature is in the range of 33 °C to 45°C. Normally, the rise in top cover temperature affects the condensation of water vapour over the top cover, because the temperature rises to a maximum of 45°C. This rise in temperature is higher than the ambient. The difference between top cover temperature and ambient temperature was only 8 °C. Moreover the water temperature inside the still is maintained due to the circulation of water over the paraffin wax chamber. So distillate yield obtained from the still is continued for a certain interval

and then slowed down even at, off sunshine hours. The yield rate difference is more for the regular intervals measured between 2.00 p.m. and 5.00 p.m. and finally the yield starts to reduce after 6.00 p.m. due to the decrease of water temperature and evaporation rate.

Fig (4.26) shows the variation of instantaneous efficiency and performance ratio with respect to time for pyramid solar still with paraffin wax. The instantaneous efficiency is increased with respect to increase in sun shine hours. The variation of the efficiency observed during the study is in the range of 4.41% to 38.79% for the pyramid still performance study with the same material. Even though the instantaneous efficiency is lowered, water collection is increased due to the presence of paraffin wax. Instantaneous efficiency is maintained even at night times due to the continuous heat extraction from the paraffin wax.

Even though the pyramid solar still with paraffin wax performance study shows slightly less value of instantaneous efficiency than the still with tar coated blue metal, average efficiency observed is higher than that compared to study with tar coated blue metal. Efficiency is maintained even after 2:00 pm at a steady rate due to the thermal storage property of the paraffin wax. Hence still with paraffin wax shows higher value of average efficiency, in spite of less instantaneous efficiency.

The performance ratio calculated by eq (3.24) is found to increase with respect to time and reaches a steady state. Performance ratio shows a similar trend as that of instantaneous efficiency. The performance ratio observed during the study is in the range of 2.72 % to 11.3 % for the pyramid still with paraffin wax. Performance ratio value is increasing steadily during the initial warm up temperature. On reaching the maximum value, the performance value shows a linear change with small values. This is due to the fact that the temperature is fully utilized for the evaporation. This increase in performance ratio value of 11.3 confirmed the further increase in yield rate.

Fig (4.27) shows the variation of solar insolation and water collection with respect to time for pyramid solar still with paraffin wax. Insolation increases with respect to time and reaches the maximum value from 12 p.m. to 2 p.m. and then

decreases. Insolation received during this study is in the range of 96.62 W/m^2 as minimum to 1038.62 W/m^2 as maximum for the pyramid still performance study with the same.

The distilled yield is in the range of 0.014 kg to 0.202 kg for the pyramid still with paraffin wax. This instantaneous water collection is observed as maximum of 0.202 kg at 2.00 p.m. and minimum water collection of 0.014 kg at 9.30 a.m. Water collection is maintained even at off shine hours due to the presence of phase change material (paraffin wax). Even though the temperature is fully utilized for evaporation, the rise in temperature causes to increase the saturated vapour pressure. So the collection yield during the period of 30 minutes interval is almost nearer to one another. Thus the yield rate is maintained after attaining the warm up period almost steady state at maximum temperature. The Paraffin wax storage capacity is supported to attain the yield rate even at off sunshine hours. Thus water collection is maintained due to continuous heat gain from the phase change material (paraffin wax).

Fig (4.28) shows the variation of saturation vapour pressure inside the pyramid still for three modes of (without storage,with TCBM,PCM) studies. Saturation vapour pressure starts to increase with respect to time and it reaches the peak value around $1:30 \text{ p.m.}$ to $2:00 \text{ p.m.}$ Saturation vapour pressure reaches maximum value when water collection is more and tends to decrease when water collection decreases. Saturation vapour pressure is predicted by eq (3.23) in the range of 4842.65 to 11889.52 Pa for pyramid solar still, 5050.66 to 14114.04 Pa for pyramid solar still with tar coated blue metal and 5121.7 to 13281.98 Pa for pyramid solar still with paraffin wax. The difference in saturated vapour pressure is very less at higher temperature compared to the warm up period. So it suggests that the latent heat value starts to increase at the same time saturation vapour pressure starts to decrease. Saturation vapour pressures for pyramid solar still in both the study shows a similar trend due to increase in water temperature . In phase change material (paraffin wax) performance study, saturation vapour pressure is maintained more than the other two studies even at off sunshine hours due to water temperature maintained inside the pyramid solar still.

Fig (4.29) shows the variation of latent heat predicted by eq (3.22) for the pyramid still on three modes of (without storage,with TCBM,PCM) studies. It shows that the latent heat decreases initially with respect to time. It reaches a low value around 1.00 p.m. because the water temperature at this time interval is more. So it shows that the latent heat is decreased at higher temperature. Most of the incoming insolation is utilized for evaporation at this stage. Latent heat value is calculated for pyramid solar still w/o storage in the range of 2416.72246 to 2375.96052 kJ kg^{-1} , 2414.93696 to 2367.47598 kJ kg^{-1} with tar coated blue metal and 2414.34148 to 2370.51043 kJ kg^{-1} with paraffin wax. Latent heat is fully utilized for boosting the condensation commencing at lower temperature from 9.00 a.m. to 1.30 p.m. Thus the effect of latent heat is not completely utilized for condensation at higher temperatures. Latent heat values for the performance are reduced due to the reason of high values of water temperature. Hence latent heat value is predominant in pyramid still performance alone than that of the other two studies. The latent heat is maintained at low temperature for pyramid still with paraffin wax due to energy gain by the still from the Paraffin wax chamber during evening periods.

Fig (4.30) shows the variation of Grashof number and Nusselt number computed by eq (3.1) & (3.2) with respect to time for pyramid solar still in three modes of (without storage,with TCBM,PCM)study. It concludes that Grashof number increases with respect to time. Grashof number is found as 10246 to 128075.03 for the pyramid still w/o storage , 5123 to 163936.03 with tar coated blue metal and 10246 to 143444.03 with paraffin wax. Grashof value is found to increase steadily during warm up period and then it starts to decrease with respect to decrease in water temperature.

Nusselt number is found to be increased with respect to time. Nusselt number values are observed in the range of 1.96 to 3.70 for the pyramid still w/o storage , 1.65 to 3.93 with tar coated blue metal and 1.96 to 3.80 with paraffin wax. Nusselt number is found to have close linearity similar to that of internal convective heat transfer rates. After attaining the maximum value at higher temperature, the Nusselt value maintains a steady state.

Fig (4.31) shows the ratio between the evaporative heat transfers and the total heat transferred from the water to the cover (S) with respect to time. It shows the linear increase for all the mode of study and 'S' value is found pyramid solar still w/o storage in the range of 0.34 to 0.71 , 0.33 to 0.74 with tar coated blue metal and 0.36 to 0.72 with paraffin wax. Comparing fig (4.19), fig (4.22) and fig (4.25) with fig (4.31) shows that the range of temperature of still operation are sensitive to water temperature and less sensitive to change in top cover temperature.

Fig (4.32), (4.33) and (4.34) show the variation of hourly heat transfer rates by evaporation, radiation and convection with respect to time for the considered day under three modes of study. In the solar still, the evaporative heat transfer coefficient (Q_{ei}) is the major heat loss and is greater than the other two modes together. It was observed that the radiative heat transfer coefficient (Q_{ri}) and convective heat transfer coefficient (Q_{ci}) do not vary much in comparison to evaporative heat transfer coefficient (Q_{ei}). This indicates the strong dependence of evaporative heat transfer coefficient (Q_{ei}) on the operating water temperature (T_w). Higher value of convective heat transfer coefficient (Q_{ci}) in the still is due to the wind effect.

Table 4.2 Heat Transfer Coefficients for Pyramid Solar Still

	Q_{ci} (W/m ²)	Q_{ri} (W/m ²)	Q_{ei} (W/m ²)	Q_{ce} (W/m ²)	Q_{re} (W/m ²)	Q_{be} (W/m ²)
Pyramid Solar Still	17.22	51.52	127.47	37.11	78.93	4.65
Pyramid Solar Still with Tar coated blue metal	23.41	64.96	247.16	41.43	84.09	5.81
Pyramid Solar Still with Phase change material (paraffin wax)	24.22	72.83	223.74	43.27	86.14	6.26

The thermal conductivity of water is computed by eq (3.19) and it is observed in the range of $26.89 \times 10^{-3} \text{ Wm}^{-2} \text{ }^\circ\text{C}^{-1}$ to $28.19 \times 10^{-3} \text{ Wm}^{-2} \text{ }^\circ\text{C}^{-1}$ for the pyramid still performance study, $26.95 \times 10^{-3} \text{ Wm}^{-2} \text{ }^\circ\text{C}^{-1}$ to $28.46 \times 10^{-3} \text{ Wm}^{-2} \text{ }^\circ\text{C}^{-1}$ for the pyramid still with tar coated blue metal and $26.97 \times 10^{-3} \text{ Wm}^{-2} \text{ }^\circ\text{C}^{-1}$ to $28.33 \times 10^{-3} \text{ Wm}^{-2} \text{ }^\circ\text{C}^{-1}$ for

the pyramid still combined with phase change material (paraffin wax). The dynamic viscosity of water is predicted by eq (3.20) is in the range of $18.68 \times 10^{-6} \text{ Nsm}^{-2}$ to $19.46 \times 10^{-6} \text{ Nsm}^{-2}$ respectively for the pyramid still performance study, $18.71 \times 10^{-6} \text{ Nsm}^{-2}$ to $19.62 \times 10^{-6} \text{ Nsm}^{-2}$ respectively for the pyramid still with tar coated blue metal and $18.73 \times 10^{-6} \text{ Nsm}^{-2}$ to $19.57 \times 10^{-6} \text{ Nsm}^{-2}$ for the pyramid still with paraffin wax. The thermal conductivity and dynamic viscosity increase with respect to time and possess almost the same trend. The density of water is predicted by eq (3.21) for the still and it is observed as 1155 kg/m^3 to 1094 kg/m^3 for the pyramid still performance study, 1152 kg/m^3 to 1083 kg/m^3 for the pyramid still with tar coated blue metal and 1151 kg/m^3 to 1087 kg/m^3 for the pyramid still with paraffin wax.

The performance analysis is made for the system by analyzing the same climatic conditions which is observed by taking the average insolation of 762.23 W/m^2 . It is shown in fig (4.21), fig (4.24) and fig (4.27).

A comparative study is made from the fig (4.19), fig (4.22) and fig (4.25) and the maximum rise in water temperature is observed as 61°C for pyramid solar still with tar coated blue metal. But in the case of pyramid still with and without phase change material (paraffin wax), water temperature is less such as 60°C and 58°C respectively. Similarly the water temperature maintained in the still at 5 o' clock is comparatively higher for the pyramid still with phase change material (paraffin wax) than pyramid still without and pyramid still with tar coated blue metal. In the case of pyramid still with paraffin wax the water temperature is maintained at higher order due to the storage capacity of the paraffin wax. But in the case of the other two studies the storage capacity is not having a specific role.

The fig (4.21), fig (4.24) and fig (4.27) show the water collection for pyramid still, pyramid still with tar coated blue metal and pyramid still with paraffin wax. These figures reveal that water collection rate per day is very much improved in pyramid still with paraffin wax. The average yield rate observed including night water collection is 2.2955 kg . But in the case of pyramid still with tar coated blue

metal, average yield rate observed including night water collection is 1.922kg. These results suggest that the yield rate 1.6899 kg attained by pyramid solar still is less which is effectively inferred that the substitution of tar coated blue metal and paraffin wax gives an improvement in water collection rate.

Fig (4.20), fig (4.23) and fig (4.26) show the variation of efficiency for the three modes of (without storage, with TCBM,PCM) studies. The average efficiency is observed as 21.60% for pyramid still. Similarly 35.32% and 36.61% for pyramid still with tar coated blue metal and pyramid still with phase change material (paraffin wax). It shows that the average efficiency is more in the case of pyramid solar still with phase change material (paraffin wax) than the other two studies. This increase in efficiency is due to decrease in overall loss for pyramid solar still. By comparing the performance studies it shows a marginal increase in efficiency for pyramid solar still with paraffin wax than that of pyramid slope solar still with storage material and normal study.

Fig (4.20), fig (4.23) and fig (4.26) shows the performance ratio for pyramid solar still, pyramid solar still with tar coated blue metal and pyramid solar still with phase change material (paraffin wax). When comparing the performance ratio values the maximum value obtained for pyramid solar still is 7.25 %, pyramid solar still with tar coated blue metal is 8.66 % and pyramid solar still with phase change material (paraffin wax) is 11.33 %. It reveals that performance ratio value is higher in the case of pyramid solar still with paraffin wax than the pyramid solar still and pyramid solar still with tar coated blue metal. Even the water temperature of the still in the case of pyramid solar still with tar coated blue metal is higher than that of the two studies, even though a lesser value of performance ratio is observed for pyramid solar still with tar coated blue metal. Thus it confirms that the increase in performance ratio value to higher order is only due to the water temperature of the still maintained at higher values. So this effect is observed in the case of pyramid solar still with paraffin wax which is due to storage capacity of the paraffin wax. Performance ratio value is also depends upon the evaporation rate of the pyramid solar still.

Fig (4.28) and fig (4.29) show the variation of saturation vapour pressure and latent heat values for three different operating modes of (without storage,with

TCBM,PCM) solar stills. These studies confirm that the latent heat decreases with the increase of water temperature. A less value of latent heat is observed for pyramid solar still with tar coated blue metal than the pyramid solar still and pyramid solar still with paraffin wax. Because the maximum water temperature obtained for the pyramid solar still with tar coated blue metal is higher. Similarly saturation vapour pressure value is higher for pyramid solar still with tar coated blue metal analysis than that of pyramid solar still and pyramid solar still with phase change material (paraffin wax). It is confirmed that latent heat is inversely proportional to saturation vapour pressure.

4.12 ANALYSIS OF SIMULATION MODEL FOR SINGLE SLOPE SOLAR STILL

Solar insolation measured experimentally for Coimbatore, India (11° N) latitude is used in the present simulation model. Hourly water collection and hourly instantaneous efficiency is calculated along with heat transfer co-efficient and thermophysical properties. Heat transfer co-efficient is calculated under two modes, namely internal and external modes. This simulation work is done by using the following parameters.

τ_c	0.88	α_w	0.94
d_w	0.05	d_g	0.003
C_w	4190	C_c	670
ρ_w	1000	ρ_c	2600
T_{amb}	30°C		

Fig (4.35) shows the variation of temperature for water and cover temperature inside the still in both the experimental and theoretical study. The maximum rise in water temperature is observed as 55.71 °C for theoretical and 53.5 °C for experimental study. Similarly, the maximum cover temperature is observed as 45.59 °C for theoretical and 43.5 °C for experimental study.

Fig (4.36) shows the variation of water collection in experimental and theoretical modes with respect to time for single slope solar still. The variation of distilled water collection is in the range of 0.012 kg to 0.333 kg and 0.002 kg to 0.245 kg for the still performance under theoretical and experimental modes of study. The theoretical and experimental determination of water collection maintains the same trend.

Fig (4.37) shows the variation of instantaneous efficiency with respect to time for single slope solar still. The instantaneous efficiency is increased according to the time. The variation of the efficiency observed during the study is in the range of 3.12% to 36.27% and 2.52% to 32.73% for theoretical and experimental study.

Fig (4.38) shows the variation performance ratio with respect to time for single slope solar still. The performance ratio calculated is found to increase with respect to time and reaches a steady state. Performance ratio also shows a similar trend as that of instantaneous efficiency. The performance ratio observed during the study is in the range of 24% to 48% for theoretical and 14% to 47% for experimental study.

Fig (4.39) shows the variation of saturation vapour pressure inside the single slope solar still. Saturation vapor pressure starts to increase with respect to time and it reaches the peak value around 1:30 p.m. to 2:00 p.m. Saturation vapor pressure reaches maximum value when water collection is more and tends to decrease when water collection decreases. Saturation vapour pressure is predicted in the range of 4842.65 Pa to 12584.77 Pa and 4774.98 Pa to 11171.33 Pa for both the theoretical and experimental study. The theoretical and experimental values are almost nearer to each other.

Fig (4.40) shows the variation of latent heat for the single slope solar still in both theoretical and experimental study. It shows that the latent heat decreases initially with respect to time. It reaches low value when the water temperature at this region is more. So it shows that the latent heat is decreased at higher order of temperature. Latent heat value is observed in the range of 2416.722 kJkg^{-1} to 2373.176 kJkg^{-1} and 2417.317 to 2378.981 kJkg^{-1} for theoretical mode and experimental mode of study.

Fig (4.41) shows the variation of hourly heat transfer rates by evaporation, radiation and convection with respect to time for single slope solar still study. In the solar still, the evaporative heat transfer coefficient (Q_{ei}) is the major heat loss and is greater than the other two modes together. It was observed that the radiative heat transfer coefficient (Q_{ri}) and convective heat transfer coefficient (Q_{ci}) do not vary much in comparison to evaporative heat transfer coefficient (Q_{ei}). This indicates the strong dependence of evaporative heat transfer coefficient (Q_{ei}) on the operating water temperature (T_w). The values obtained under experiment are more consistent with the theoretical values.

Fig (4.42) shows the ratio between the evaporative heat transfers to the total heat transferred from the water to the cover (S) with respect to time. It shows the linear increase for all the mode of study and 'S' value is found in the range of 0.37 to 0.70 for the theoretical and 0.32 to 0.68 for experimental study. Comparing fig (4.35) and fig (4.42) it reveals that the range of temperatures of still operation is sensitive to water temperature and less sensitive to change in top cover temperature.

Fig (4.43) shows the variation of Grashof number with respect to time for single slope solar still. It concludes that Grashof number increases with respect to time. Grashof number is found as 10246 to 118752 for theoretical and 5123 to 107583 for the experimental study.

Fig (4.44) shows the variation of Nusselt number with respect to time for single slope solar still. Nusselt number is found to be increased with respect to time. The theoretical and experimental Nusselt number values are observed in the range of 1.96 to 3.63 and 1.65 to 3.54 respectively.

The thermal conductivity of water is predicted and it is observed in the range of $26.89 \times 10^{-3} \text{ Wm}^{-2} \text{ }^\circ\text{C}^{-1}$ to $28.28 \times 10^{-3} \text{ Wm}^{-2} \text{ }^\circ\text{C}^{-1}$ and $26.87 \times 10^{-3} \text{ Wm}^{-2} \text{ }^\circ\text{C}^{-1}$ to $28.10 \times 10^{-3} \text{ Wm}^{-2} \text{ }^\circ\text{C}^{-1}$ for both the theoretical and experimental study.

The dynamic viscosity of water is predicted in the range of $18.68 \times 10^{-6} \text{ Nsm}^{-2}$ to $19.52 \times 10^{-6} \text{ Nsm}^{-2}$ and $18.67 \times 10^{-6} \text{ Nsm}^{-2}$ to $19.40 \times 10^{-6} \text{ Nsm}^{-2}$ for both the theoretical and experimental study. The thermal conductivity and dynamic viscosity are increasing with respect to time and possess almost same trend.

The density of water is predicted for the still and it is observed as 1155 kgm^{-3} to 1090 kgm^{-3} and 1156 kgm^{-3} to 1099 kgm^{-3} for both the theoretical and experimental study.

Table 4.3 Heat Transfer Coefficients (for Modeling)

	$Q_{ci} \text{ (W/m}^2\text{)}$	$Q_{ri} \text{ (W/m}^2\text{)}$	$Q_{ei} \text{ (W/m}^2\text{)}$
Theoretical	16.85	56.21	153.15
Experimental	15.59	51.80	131.73

4.12.1 Conclusion

A mathematical model of a single slope solar still is presented by making use of energy balance equation. This model is encompassing of boundaries and initial conditions. The thermal performance of the still is analysed by using the experimentally measured solar insolation. The water collection rate for single slope solar still of this model and the hourly efficiency is also analysed. A slight deviation in experimental and theoretical data are observed during this analysis which will be reduced by adopting the three dimensional mathematical model.

4.13 PERFORMANCE ANALYSIS OF PYRAMID SOLAR STILL WITH ELECTRICAL BACKUP

Figure (4.45) shows the variation of water temperature profile and distillate output with respect to time for pyramid solar still decoupled with electrical thermal controller. Temperature and the distillate yield increases in the morning hours and starts to decrease in the afternoon because of decrease in solar insolation.

Figure (4.46) shows the variation of water temperature and distillate output with respect to time for the still with electrical thermal controller performed on three days at desired temperatures 40°C , 50°C , 60°C each at same interval of time. It is found that water collection is more for higher temperatures than that of at lower temperatures. Distillate water yield with time for various set temperatures is shown in table 4.4 and table 4.5.

This shows that both studies give approximately distillate output for corresponding temperatures. In general still performance which is decoupled with electrical thermal controller is reasonable with a good daily output, even though it

has slight lesser distillate yield. The conventional still is cost effective, even though it gives slight lesser daily output similar to the still decoupled with electrical thermal controller.

Table (4.4) Performance study of the pyramid cover still with electrical temperature controller (Indoor setting) w/o storage material –Day Study

Setting temperature: 40°C

Time of the day	Water collection (kg)	Water temperature (°C)
9:15a.m.-9:45a.m	0.031	40
9:45a.m.-10:15 a.m.	0.035	41
10:15a.m.-10:45 a.m.	0.037	39
10:45a.m.-11:15 a.m.	0.042	41
11:15a.m.-11.45 a.m.	0.047	40
11:45a.m.-12:15 p.m.	0.052	41

Setting temperature: 50°C

Time of the day	Water collection (kg)	Water temperature (°C)
12:45p.m.-1:10p.m	0.078	51
1:10p.m.-1:40 p.m.	0.089	50
1:40p.m.-2:10 p.m.	0.090	50
2:10p.m.-2:40 p.m.	0.112	51
2:40p.m.-3:10 p.m.	0.120	50

Setting temperature: 60°C

Time of the day	Water collection (kg)	Water temperature (°C)
4:10p.m.-4:40p.m	0.197	59
4:40p.m.-5:10 p.m.	0.201	60
5:10p.m.-5:40 p.m.	0.217	59
5:40p.m.-6:10 p.m.	0.220	59
6:10p.m.-6:40 p.m.	0.227	60
6:40p.m.-7:10 p.m.	0.230	60

Table 4.5 Performance study of the pyramid cover still with electrical temperature controller (Indoor setting) w/o storage material-Night Study

Setting temperature: 40°C

Time of the day	Water Collection (kg)	Water temperature(°C)
6:50p.m.-7:10 p.m.	0.041	40
7:10p.m.-7:40 p.m.	0.045	39
7:40p.m.-8:10 p.m.	0.052	41
8:10p.m.-8:40 p.m.	0.059	40

Setting temperature: 50°C

Time of the day	Water collection (kg)	Water Temperature(°C)
5:50p.m.-6:20 p.m.	0.102	49
6:20p.m.-6:50 p.m.	0.115	50
6:50p.m.-7:20 p.m.	0.128	50
7:20p.m.-7:50 p.m.	0.132	50

Setting temperature: 60°C

Time of the day	Water collection (kg)	Water temperature(°C)
6:30p.m.-7:00 p.m.	0.185	60
7:00p.m.-7:30 p.m.	0.197	59
7:30p.m.-8:00 p.m.	0.201	59
8:00p.m.-8:30 p.m.	0.222	61

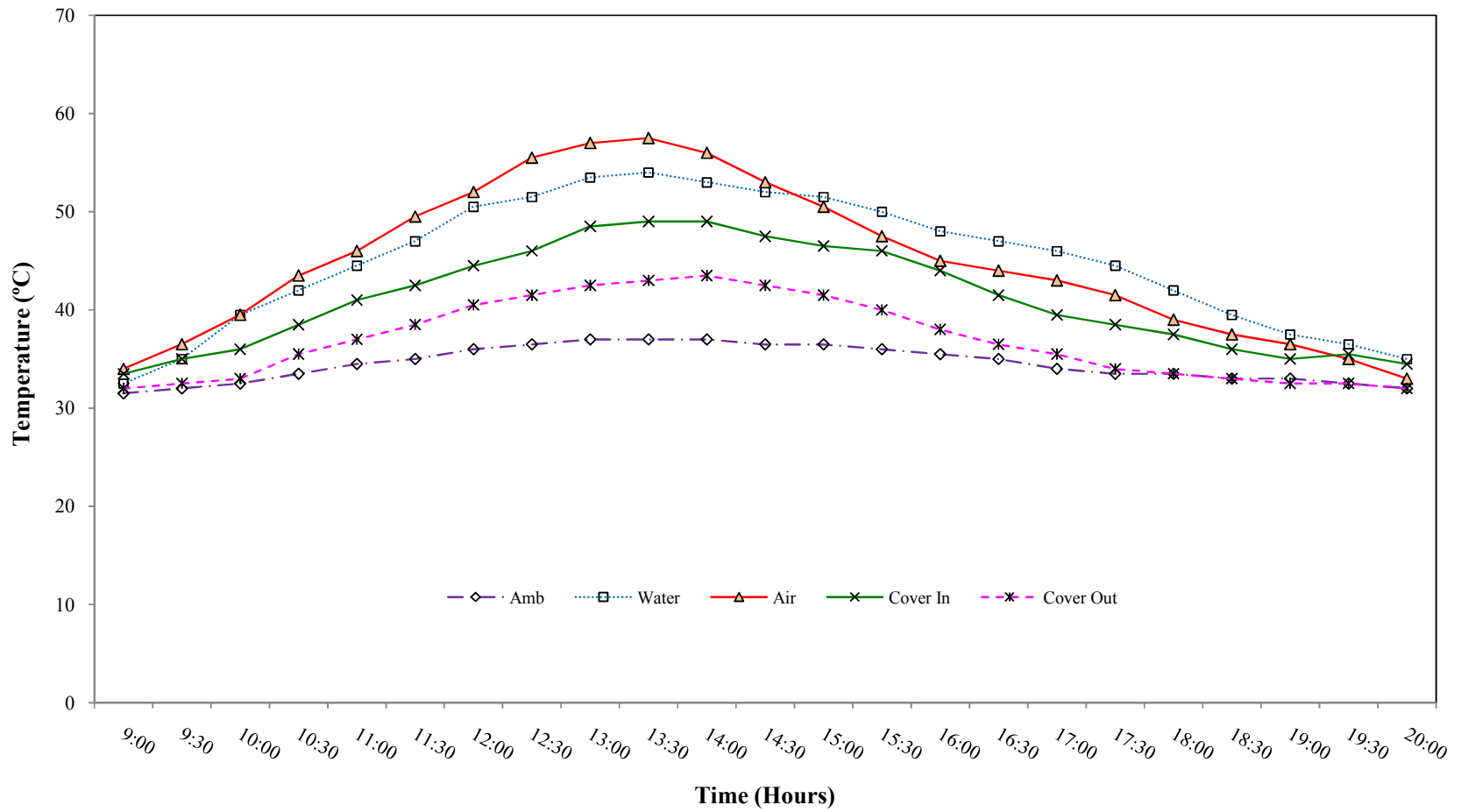


Fig (4.3) Variation of temperature with respect to time for single slope solar still (without storage material)

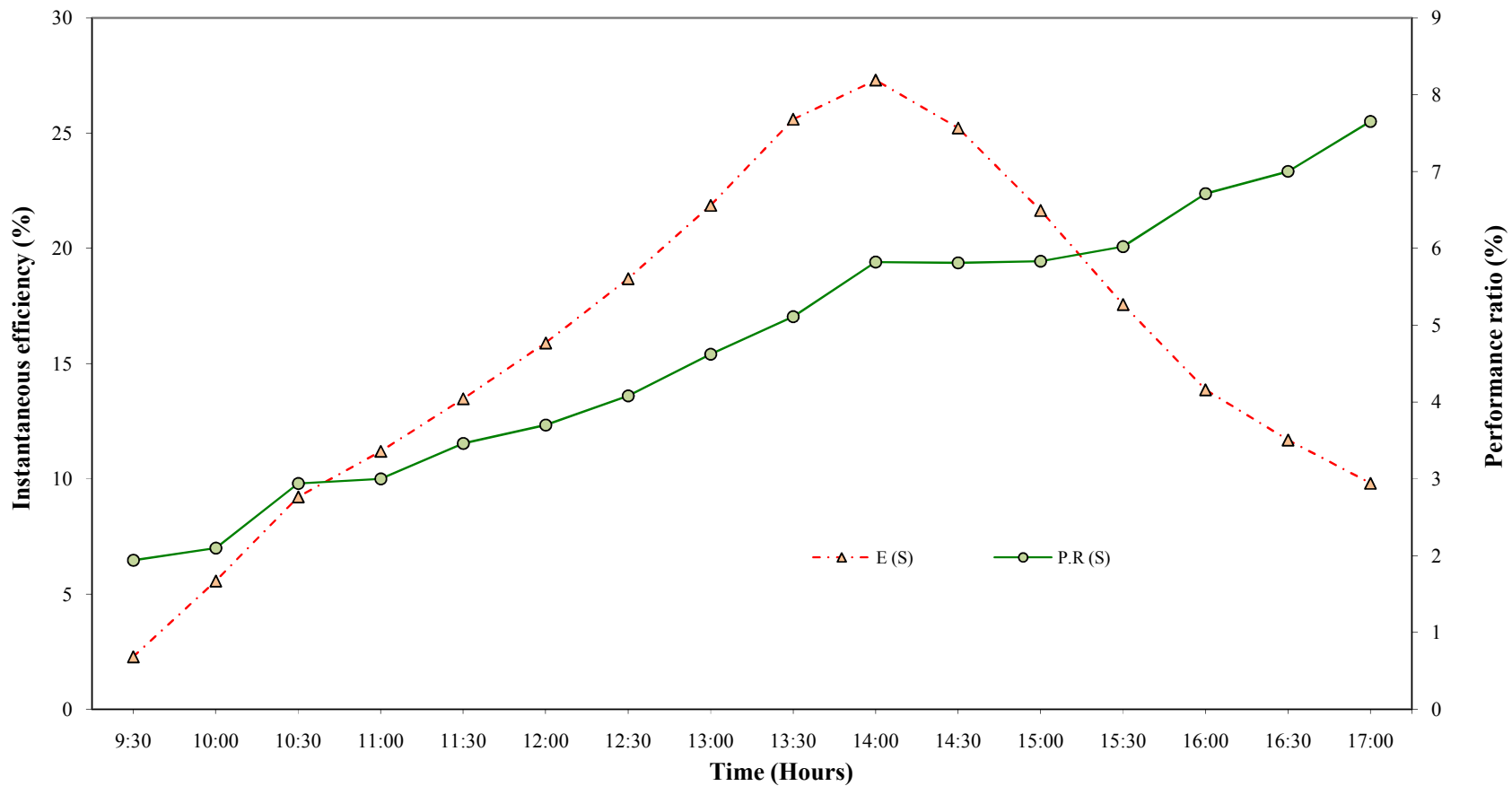


Fig (4.4) Variation of instantaneous efficiency and performance ratio with time for single slope solar still (without storage material)

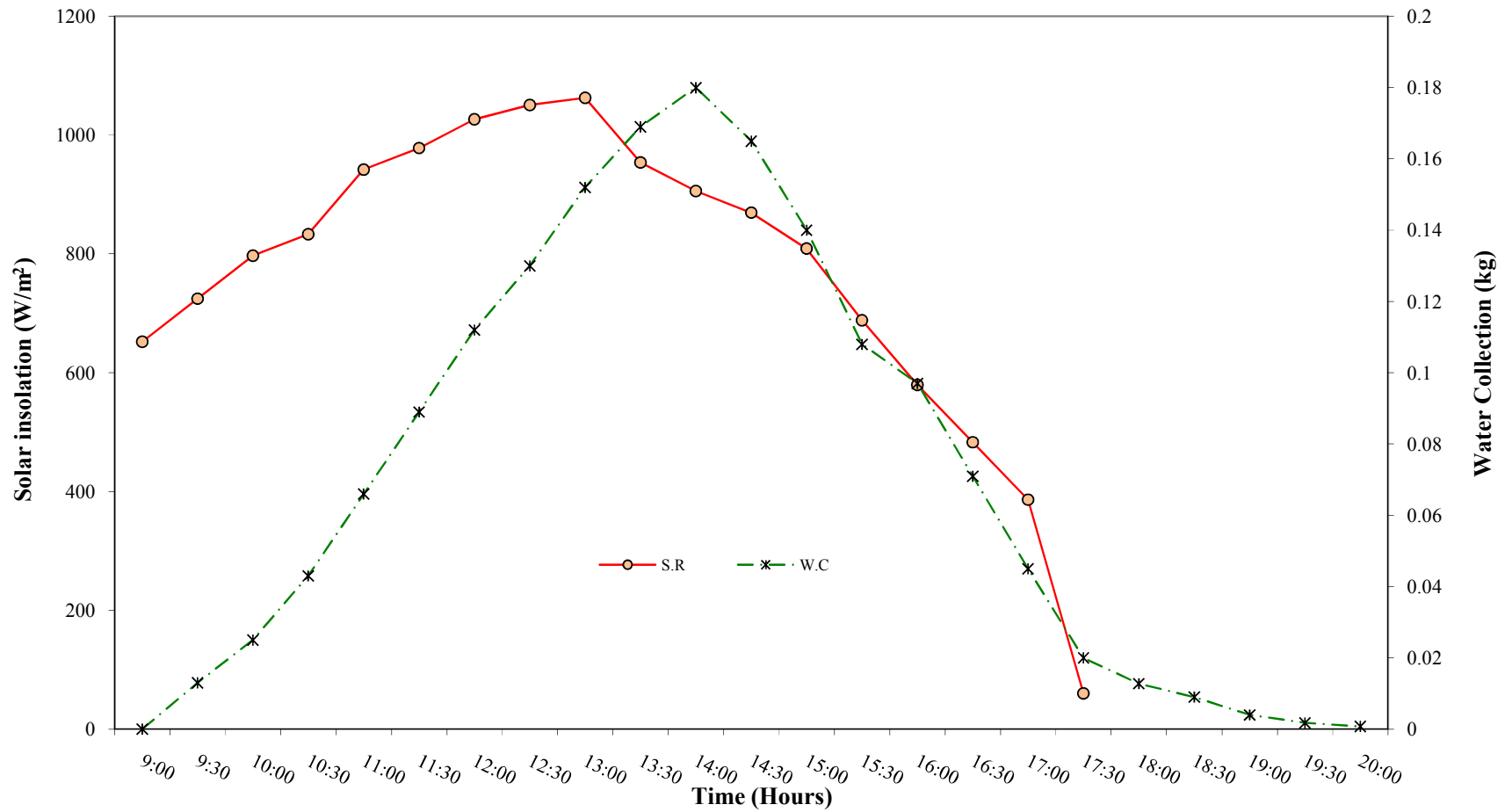


Fig (4.5) Variation of solar insolation and water collection with respect to time for single slope solar still (without thermal storage material)

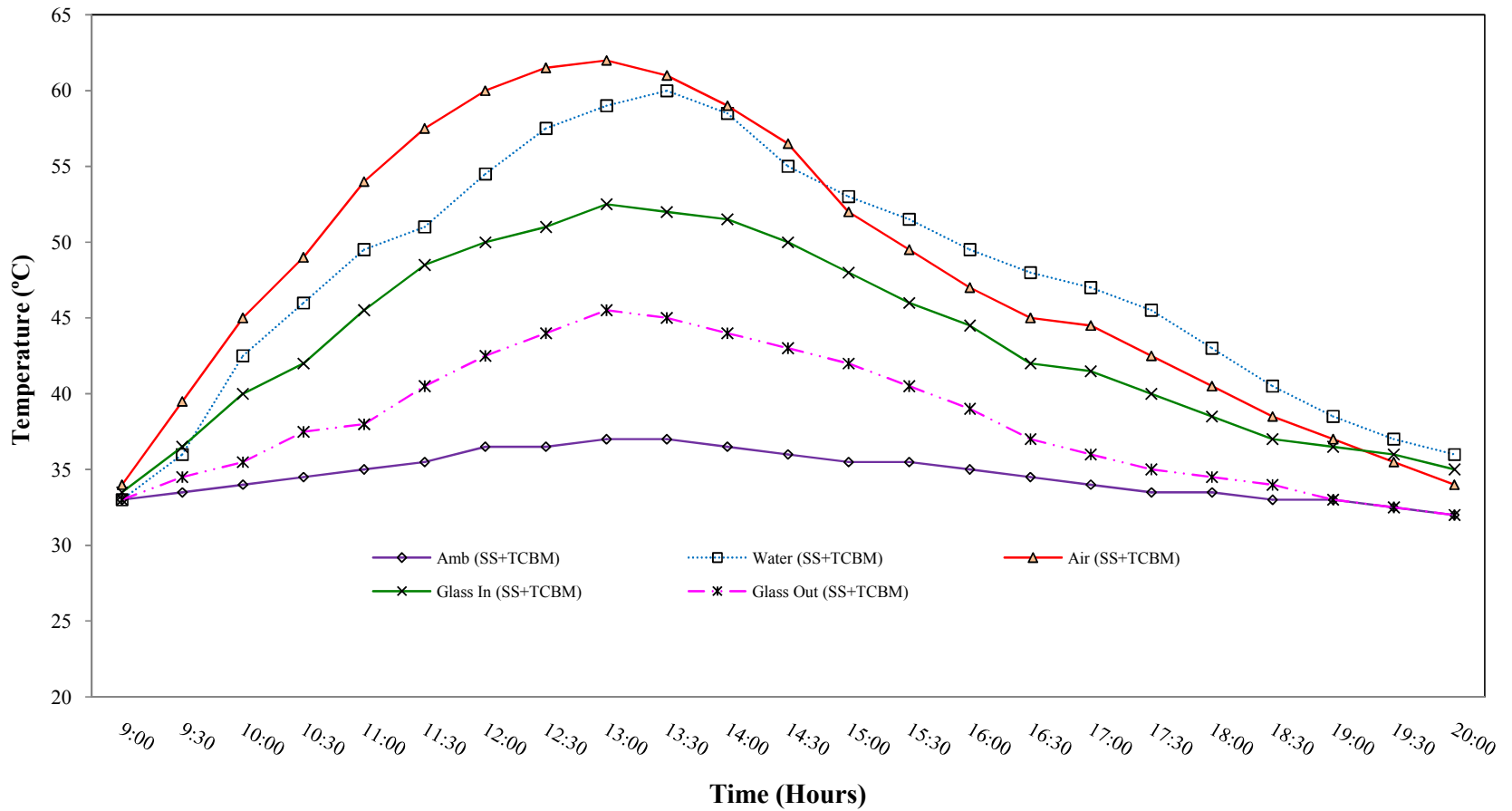


Fig (4.6) Variation of temperature with respect to time for single slope solar still with tar coated blue metal

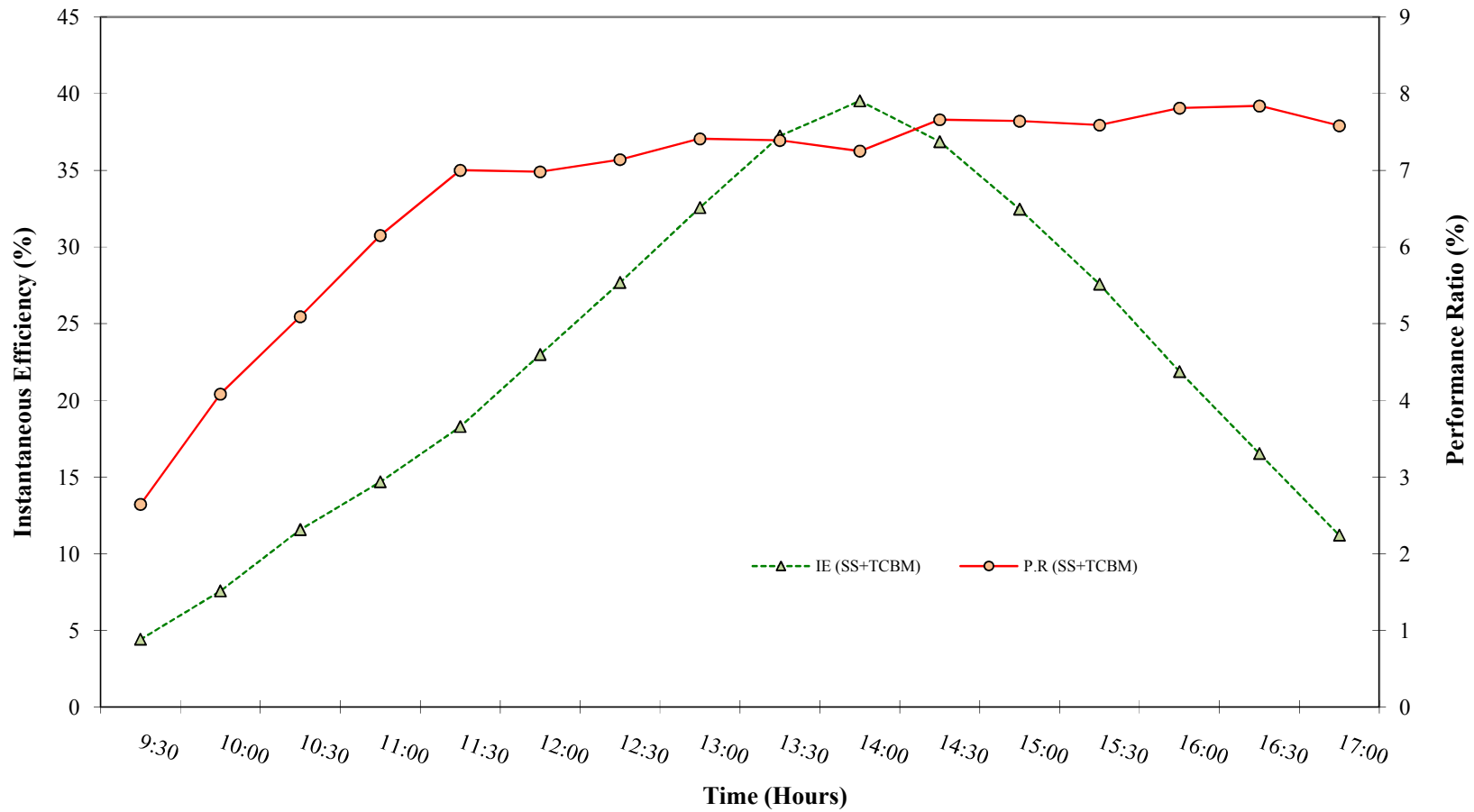


Fig (4.7) Variation of instantaneous efficiency and performance ratio with time for single slope solar still with tar coated blue metal

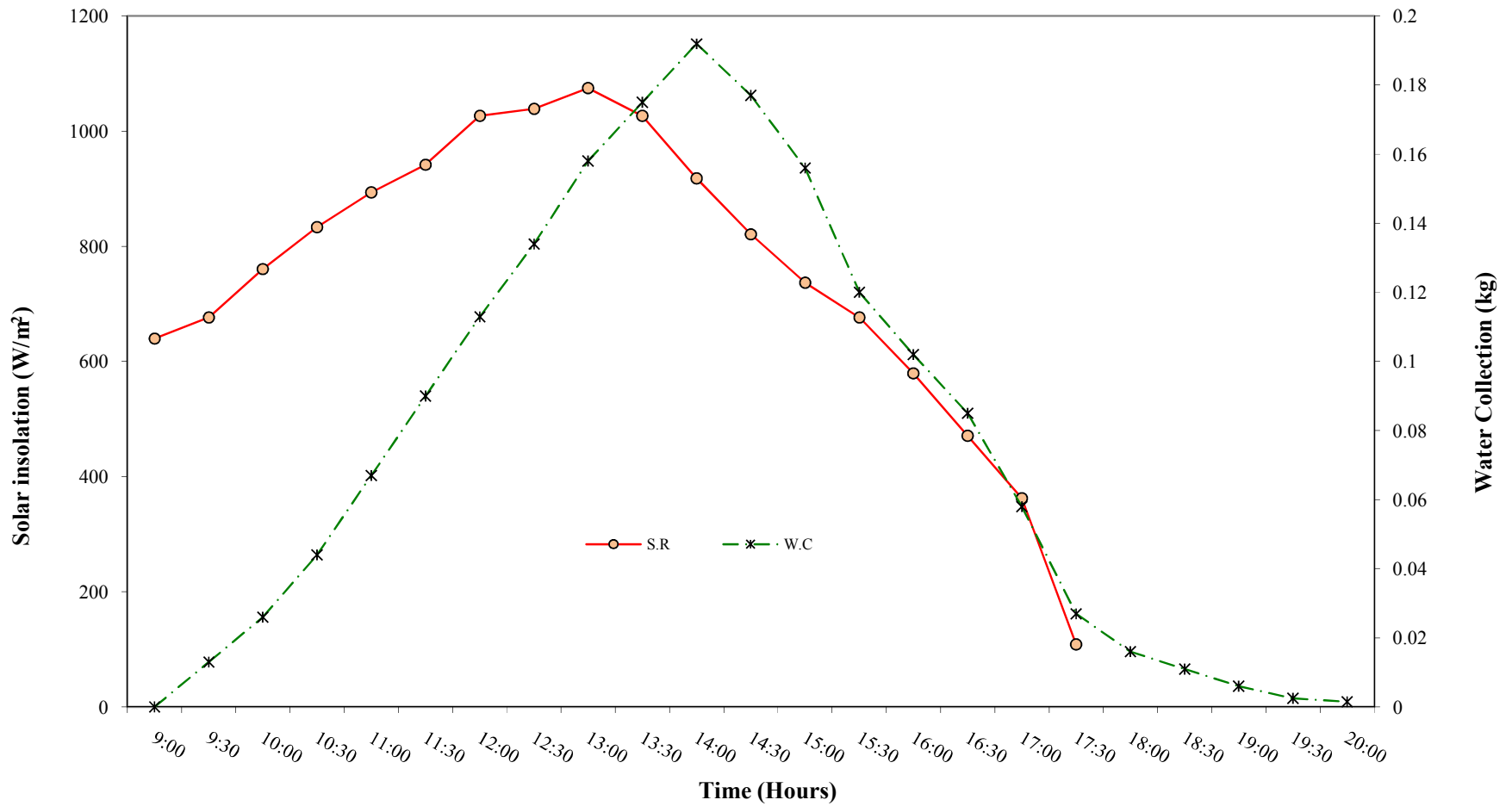


Fig (4.8) Variation of solar insolation and water collection with respect to time for single slope solar still with tar coated blue metal

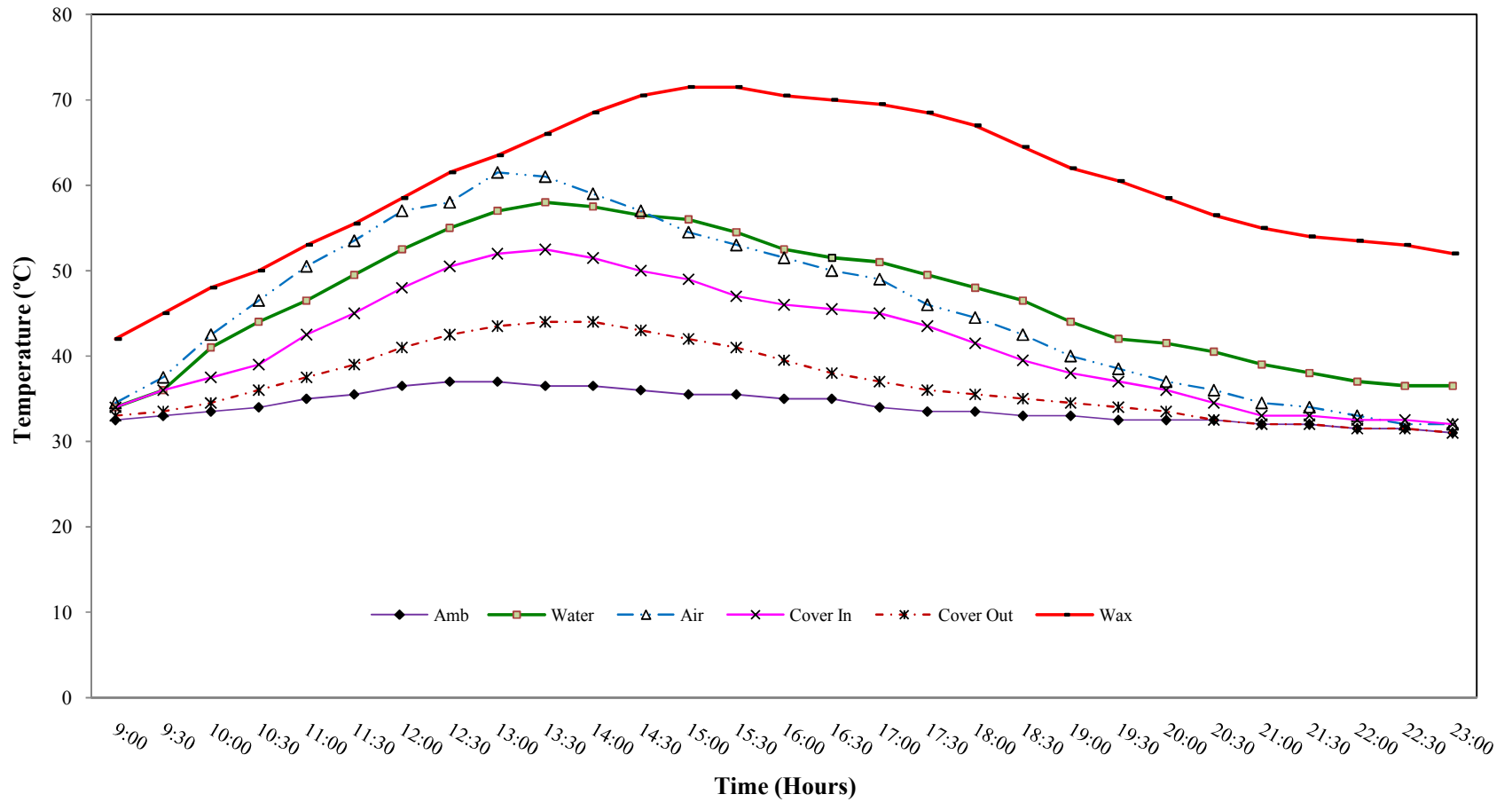


Fig (4.9) Variation of temperature with respect to time for single slope solar still with phase change material (paraffin wax)

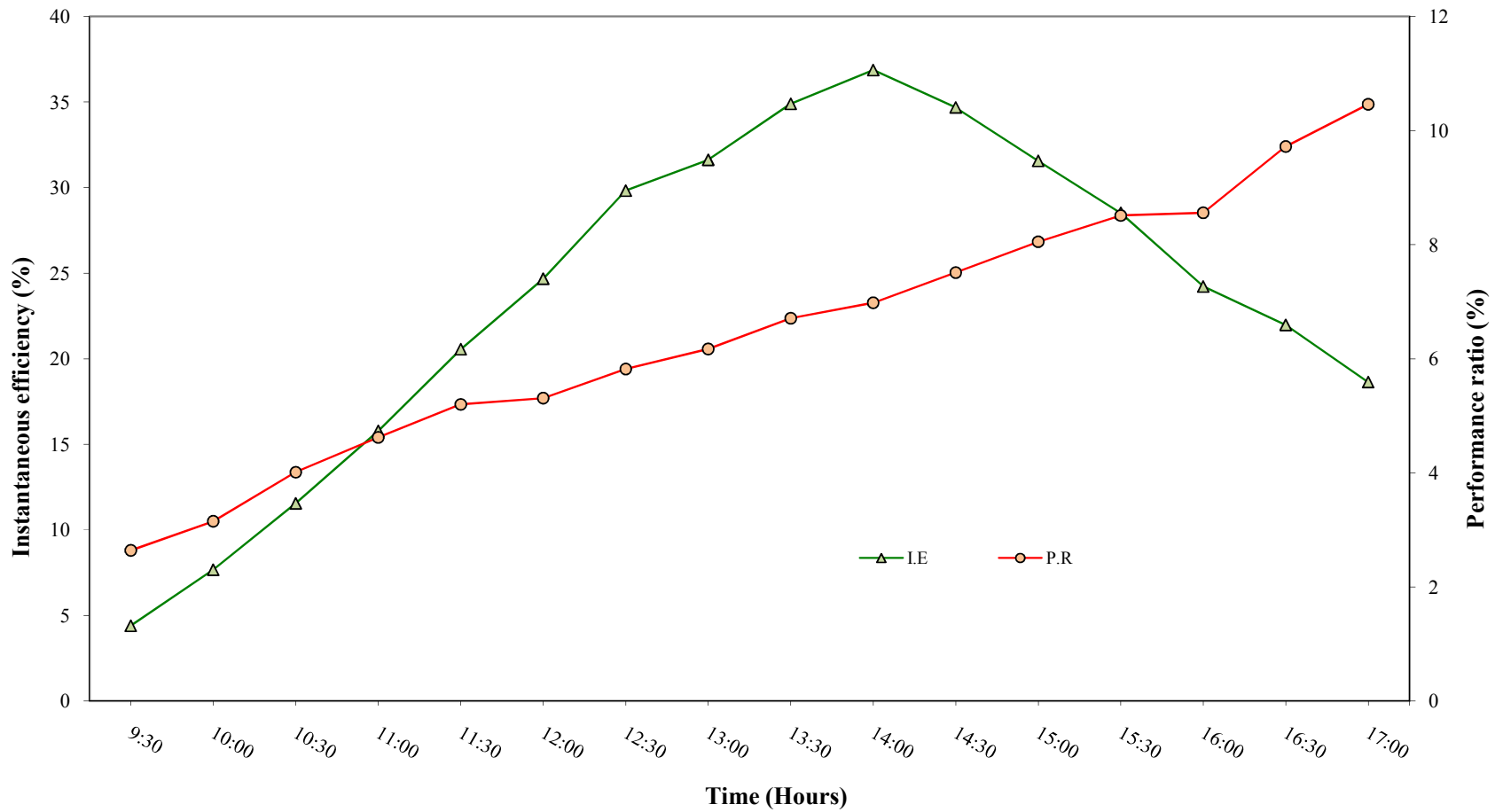


Fig (4.10) Variation of instantaneous efficiency and performance ratio with respect to time for single slope solar still with phase change material (paraffin wax)

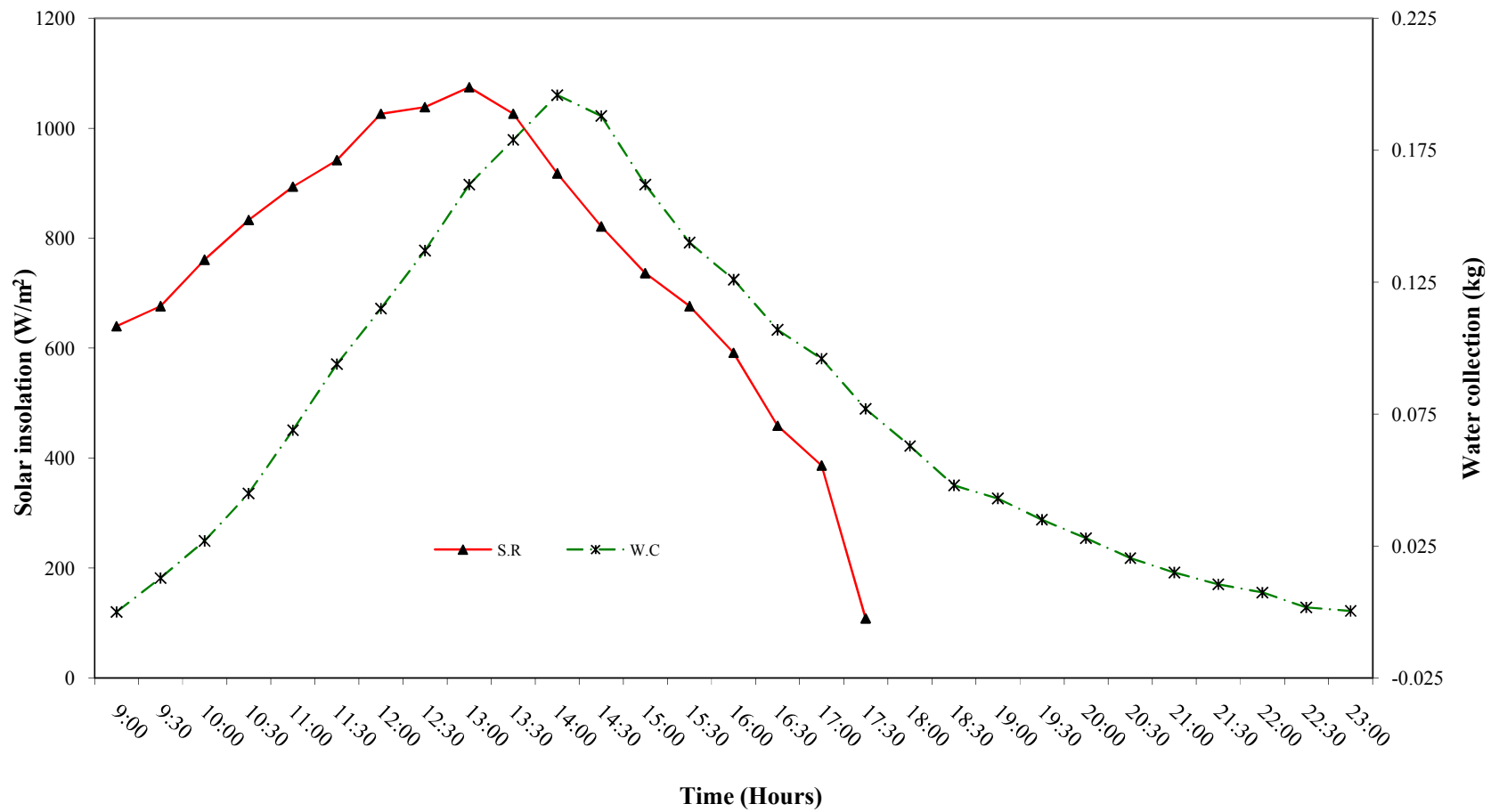


Fig (4.11) Variation of solar insolation and water collection with respect to time for single slope solar still with phase change material (paraffin wax)

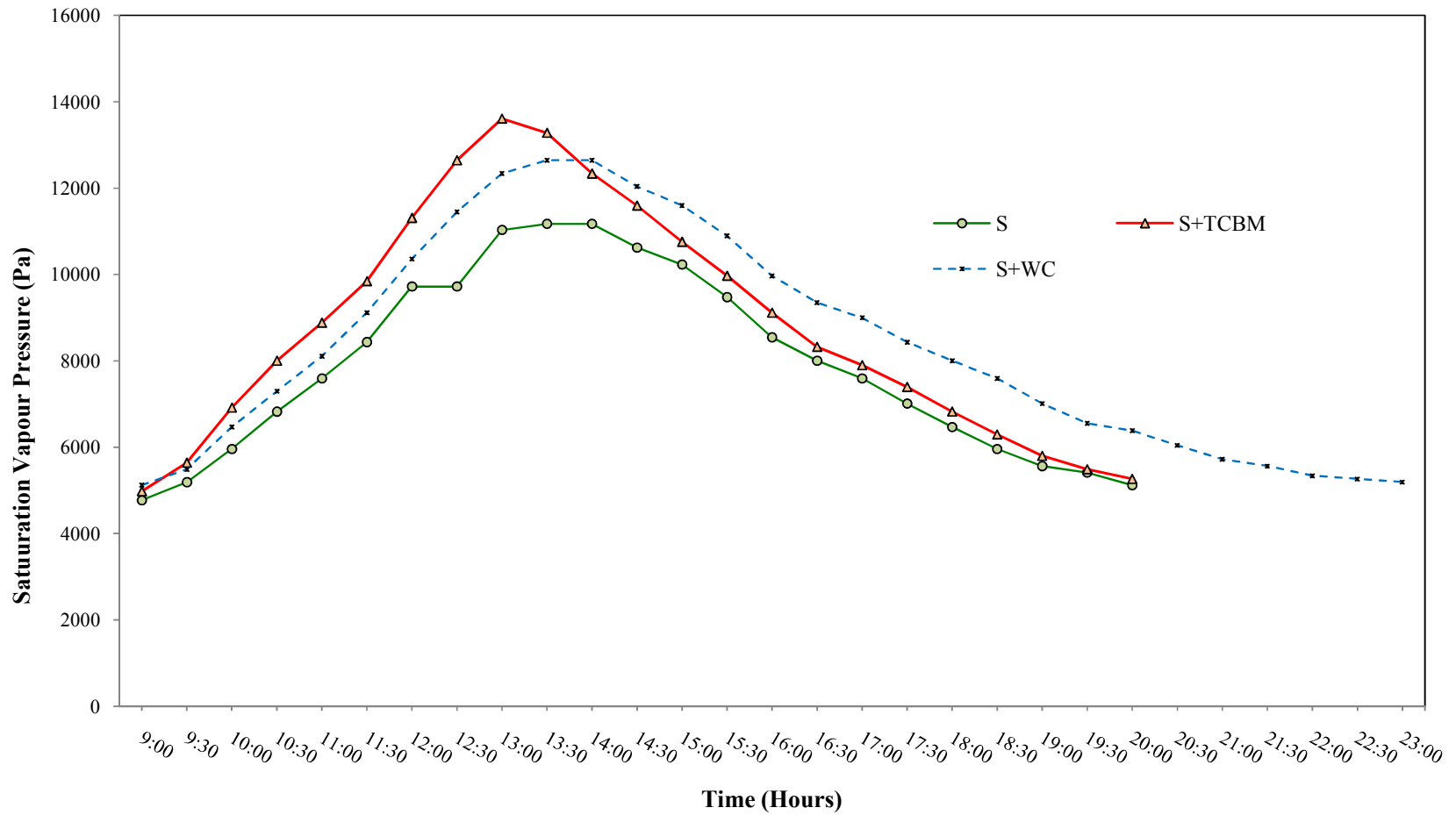


Fig (4.12) Variation of saturation vapour pressure with respect to time for single slope solar still under three modes of study

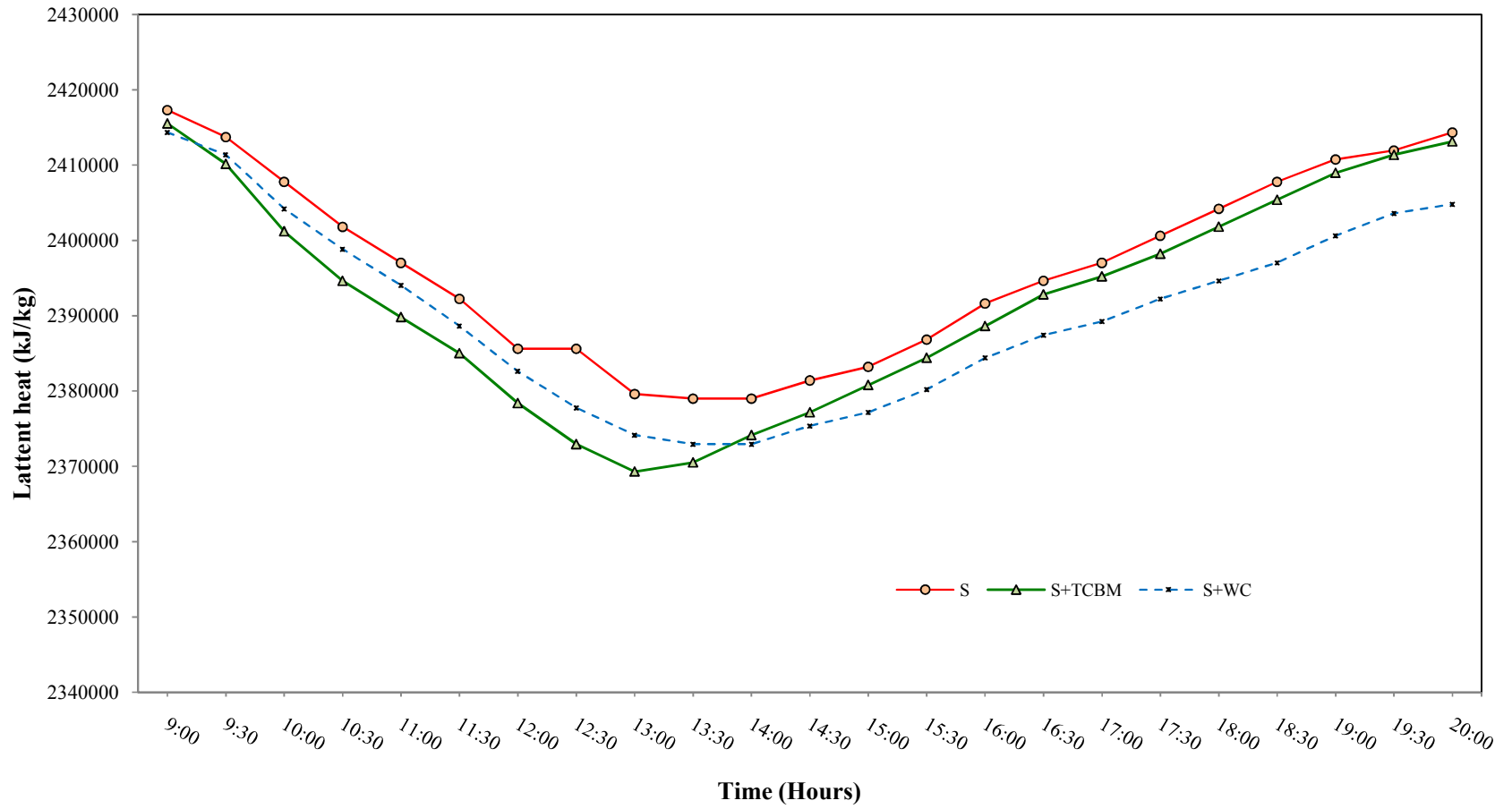


Fig (4.13) Variation of latent heat with respect to time for single slope solar still under three modes of study

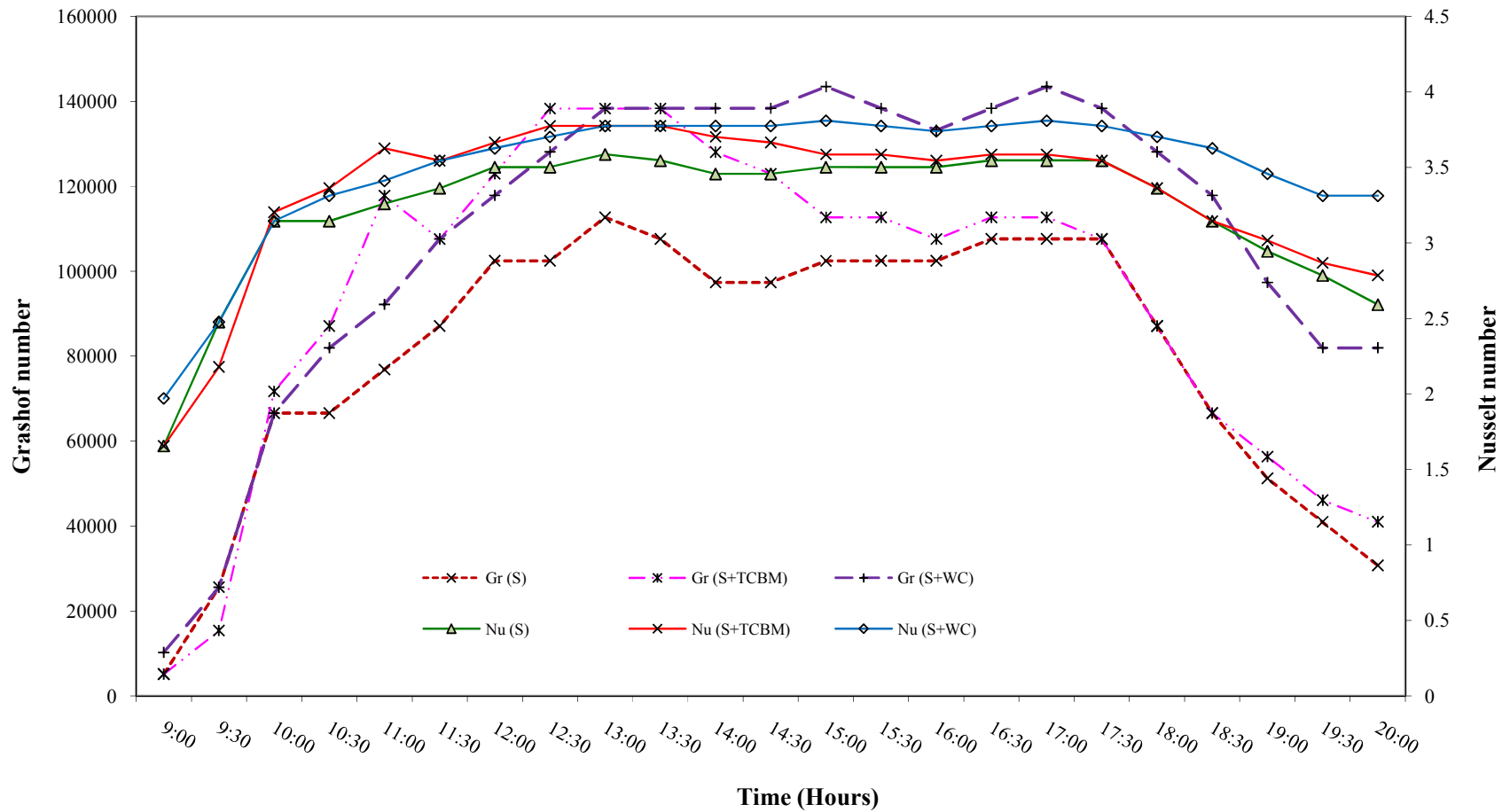


Fig (4.14) Variation of Grashof and Nusselt number with respect to time for single slope solar still under three modes of study

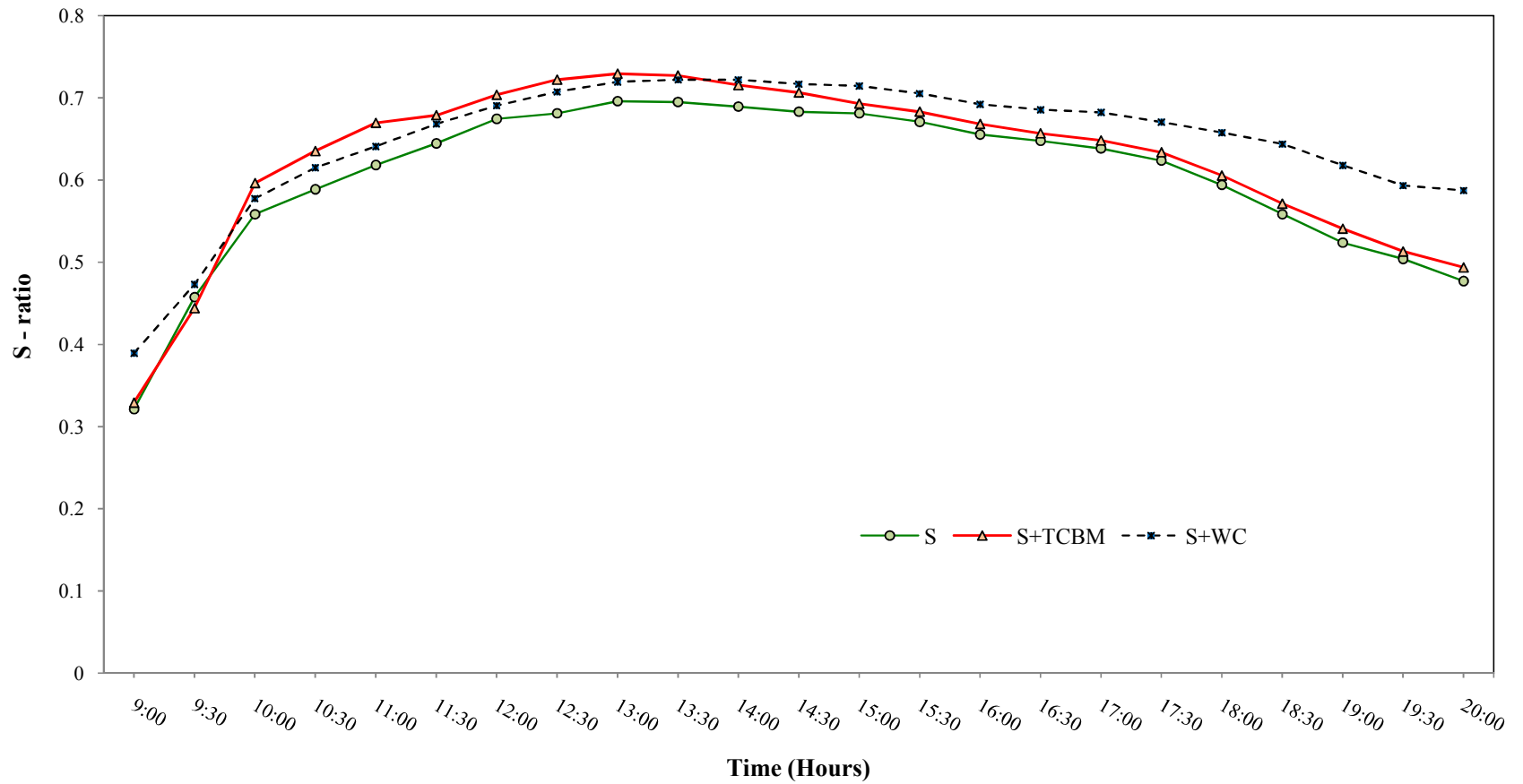


Fig (4.15) Variation of S ratio with respect to time for single slope solar still in three modes of study

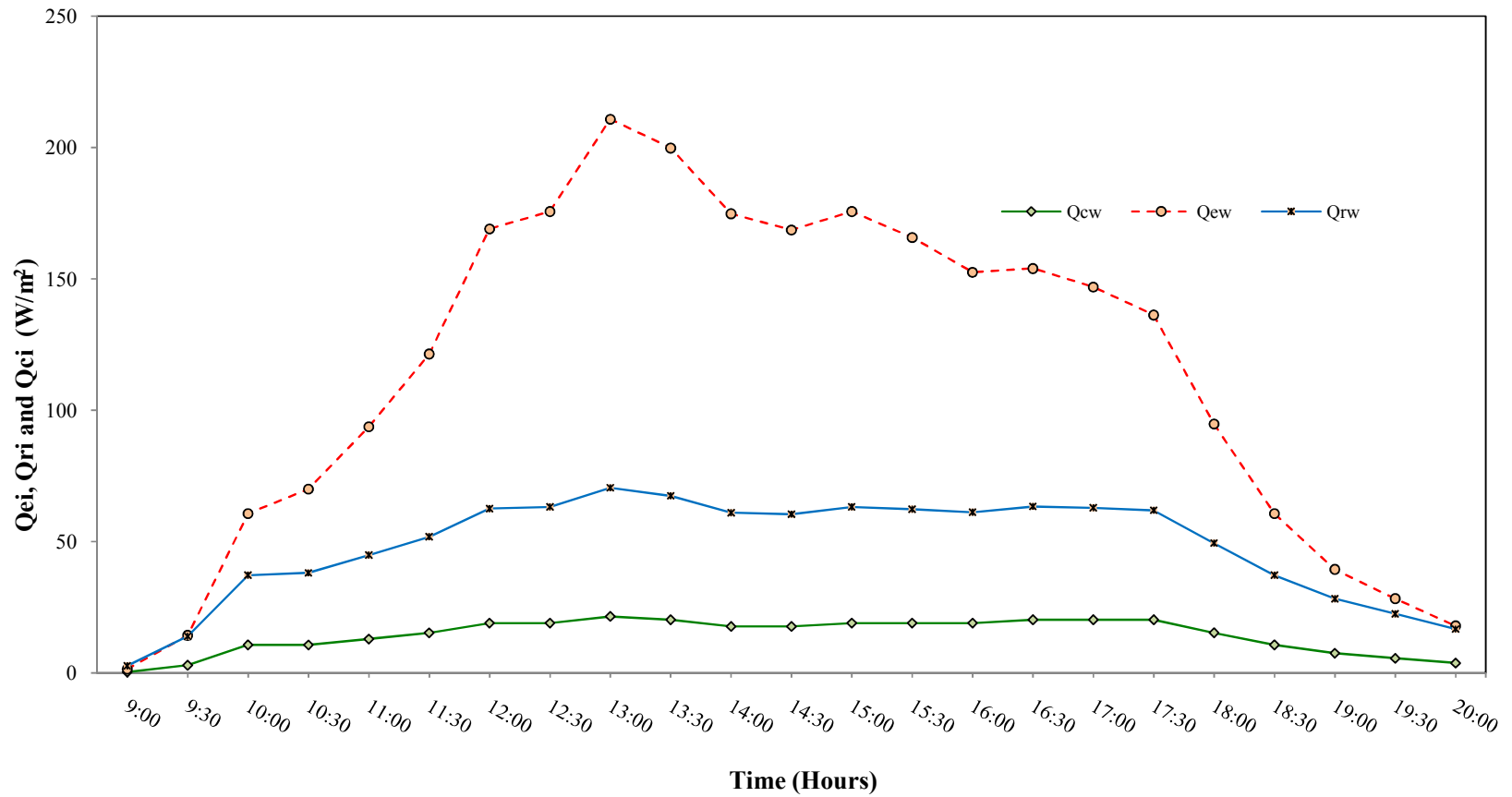


Fig (4.16) Variation of heat transfer rate by evaporation (Qei), radiation (Qri) and convection (Qci) inside the single slope solar still (without thermal storage material)

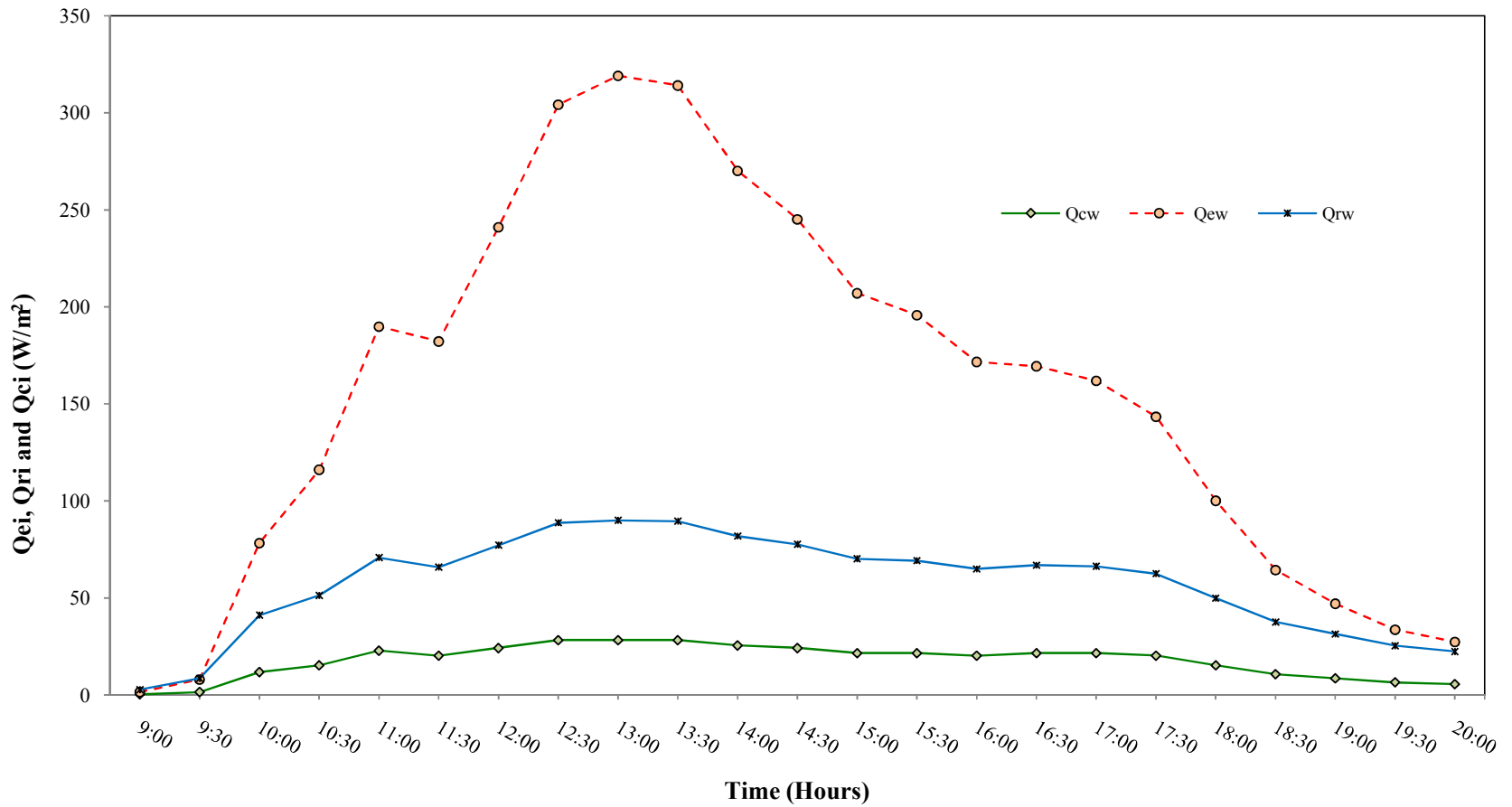


Fig (4.17) Variation of heat transfer rate by evaporation (Qei), radiation (Qri) and convection (Qci) inside the single slope solar still with tar coated blue metal

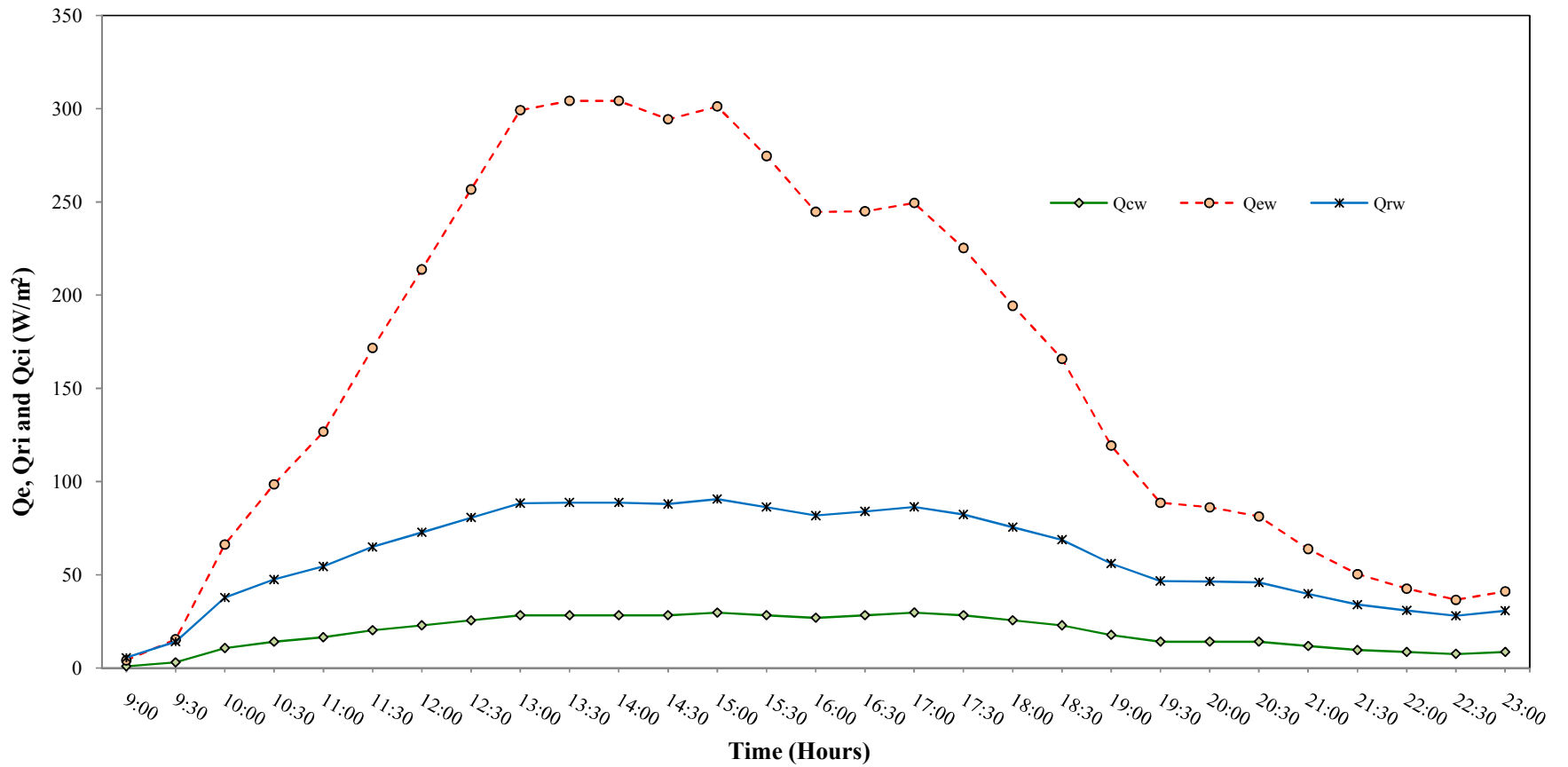
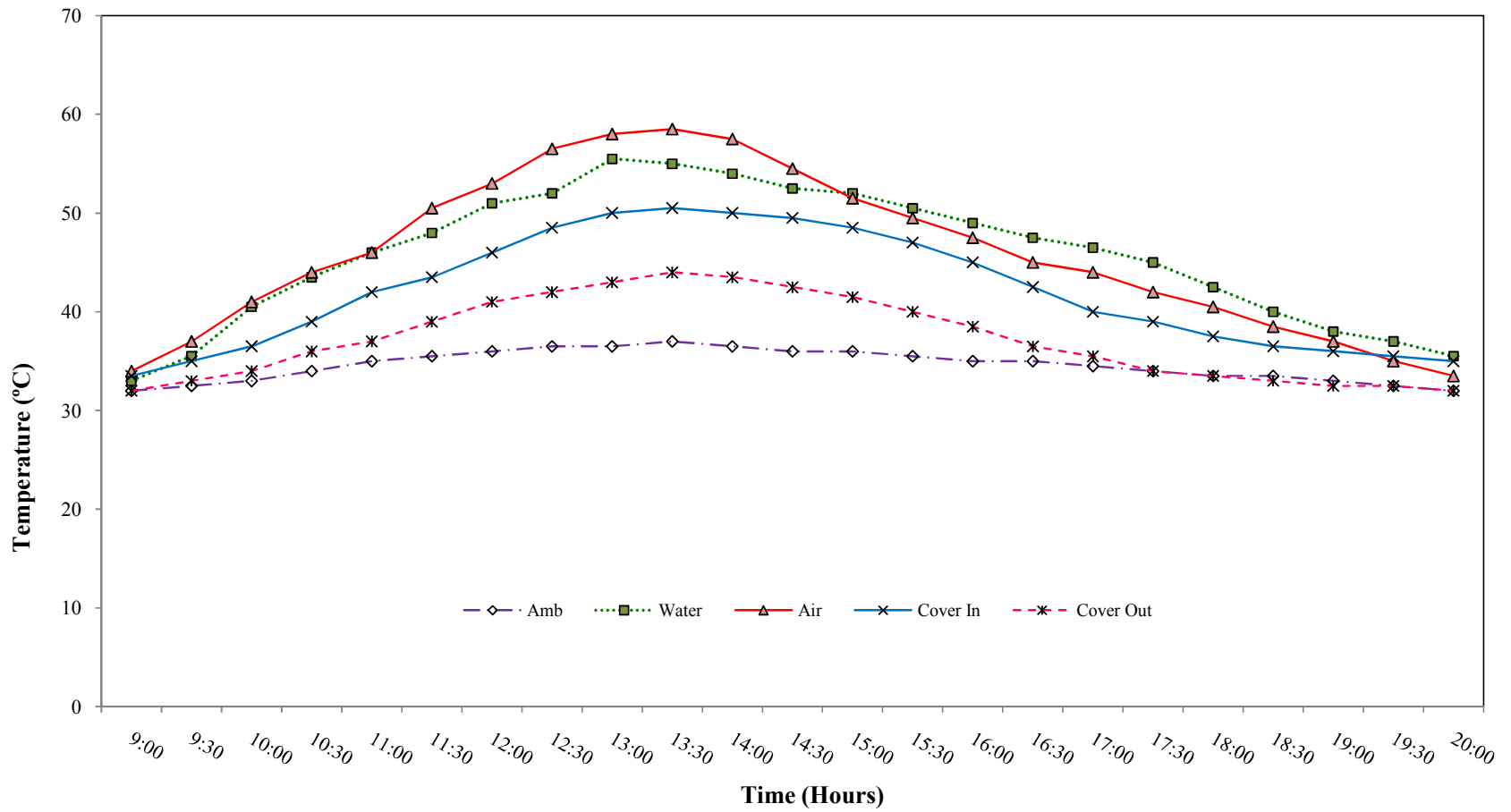
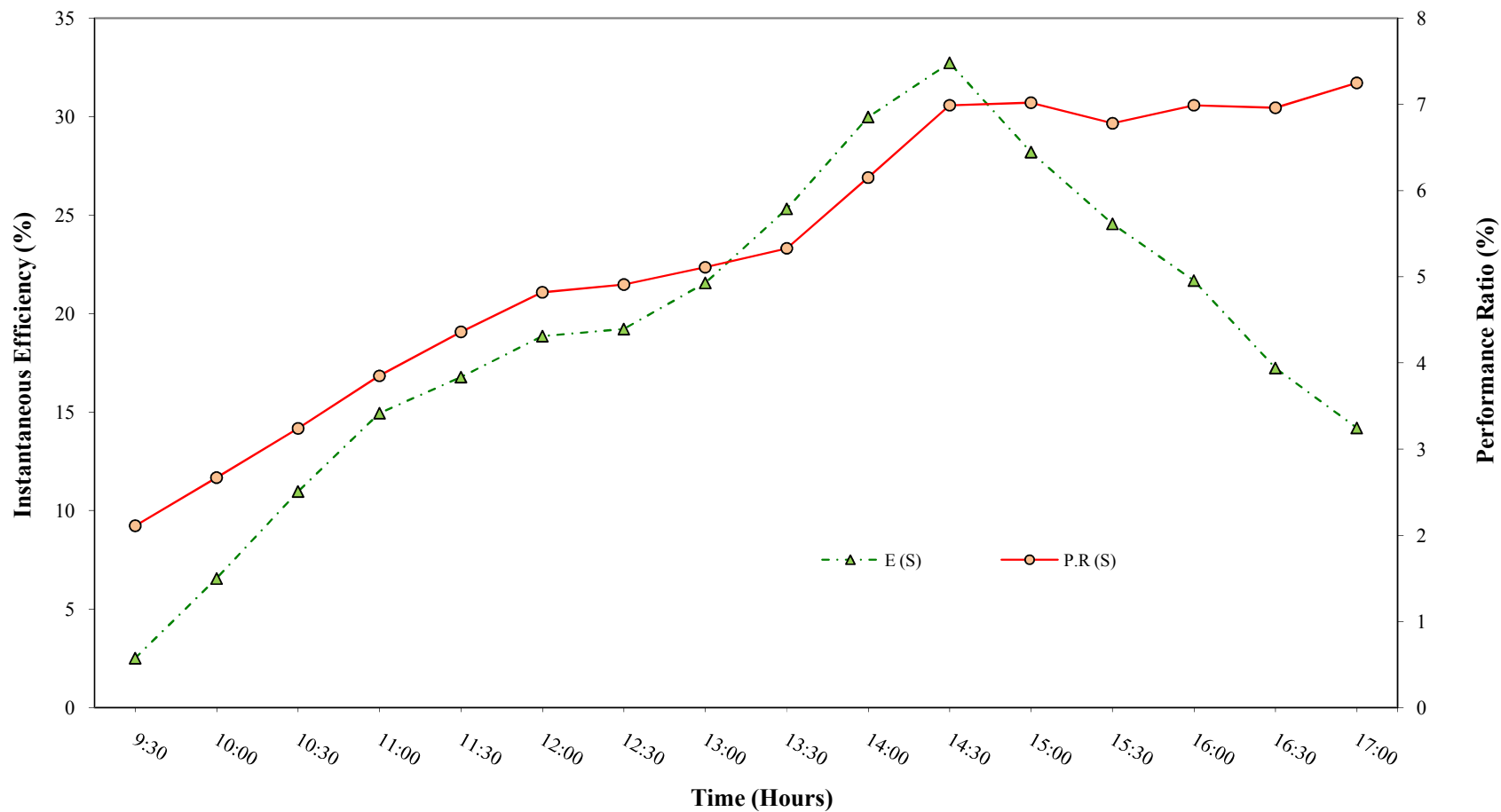


Fig (4.18) Variation of heat transfer rate by evaporation (Q_{ei}), radiation (Q_{ri}) and convection (Q_{ci}) inside the single slope solar still with phase change material (paraffin wax)



Fig(4.19) Variation of temperature with respect to time for pyramid solar still study (without thermal storage medium)



Fig(4.20) Variation of instantaneous efficiency and performance ratio with time for pyramid solar still (without thermal storage medium)

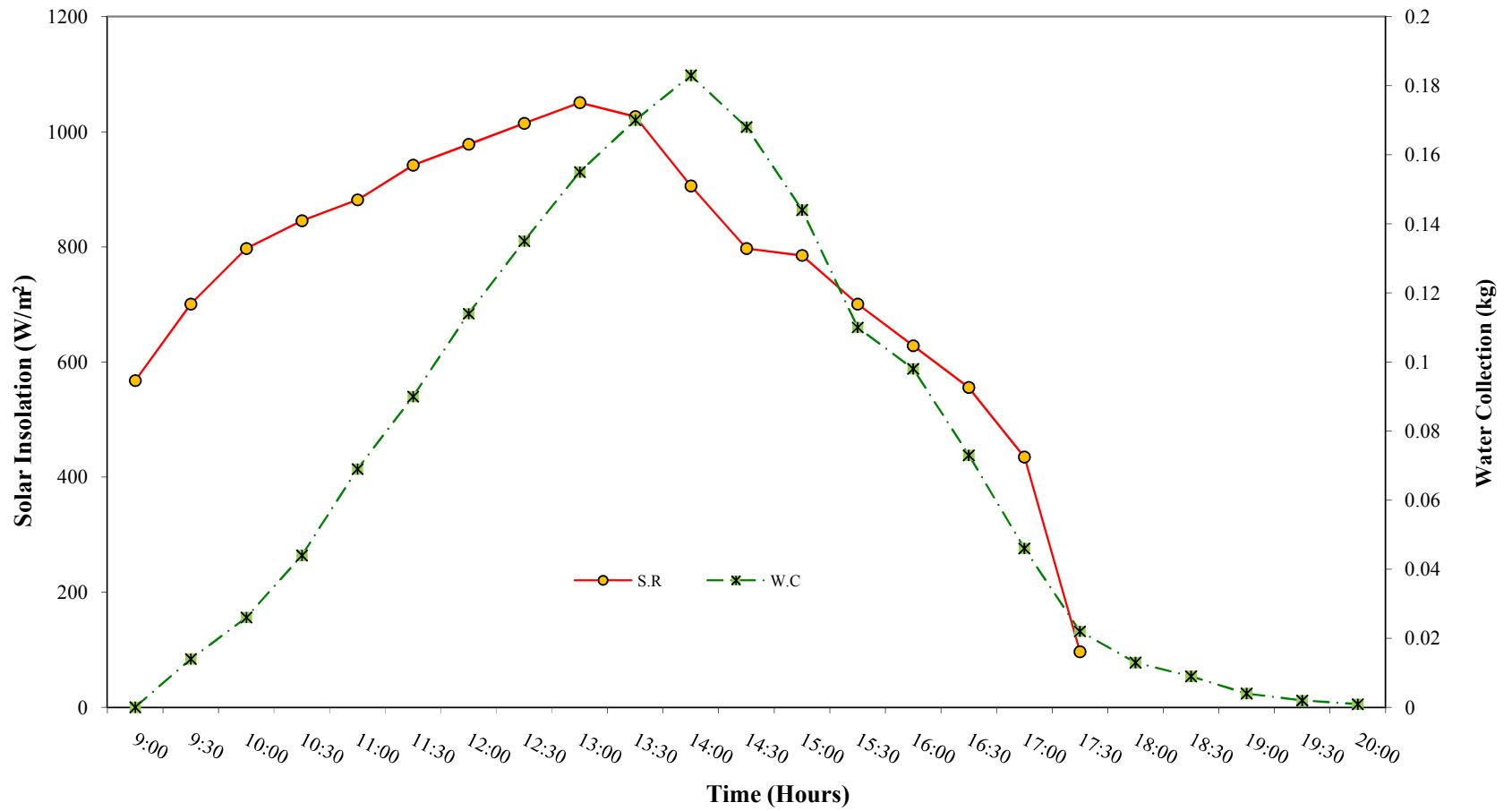
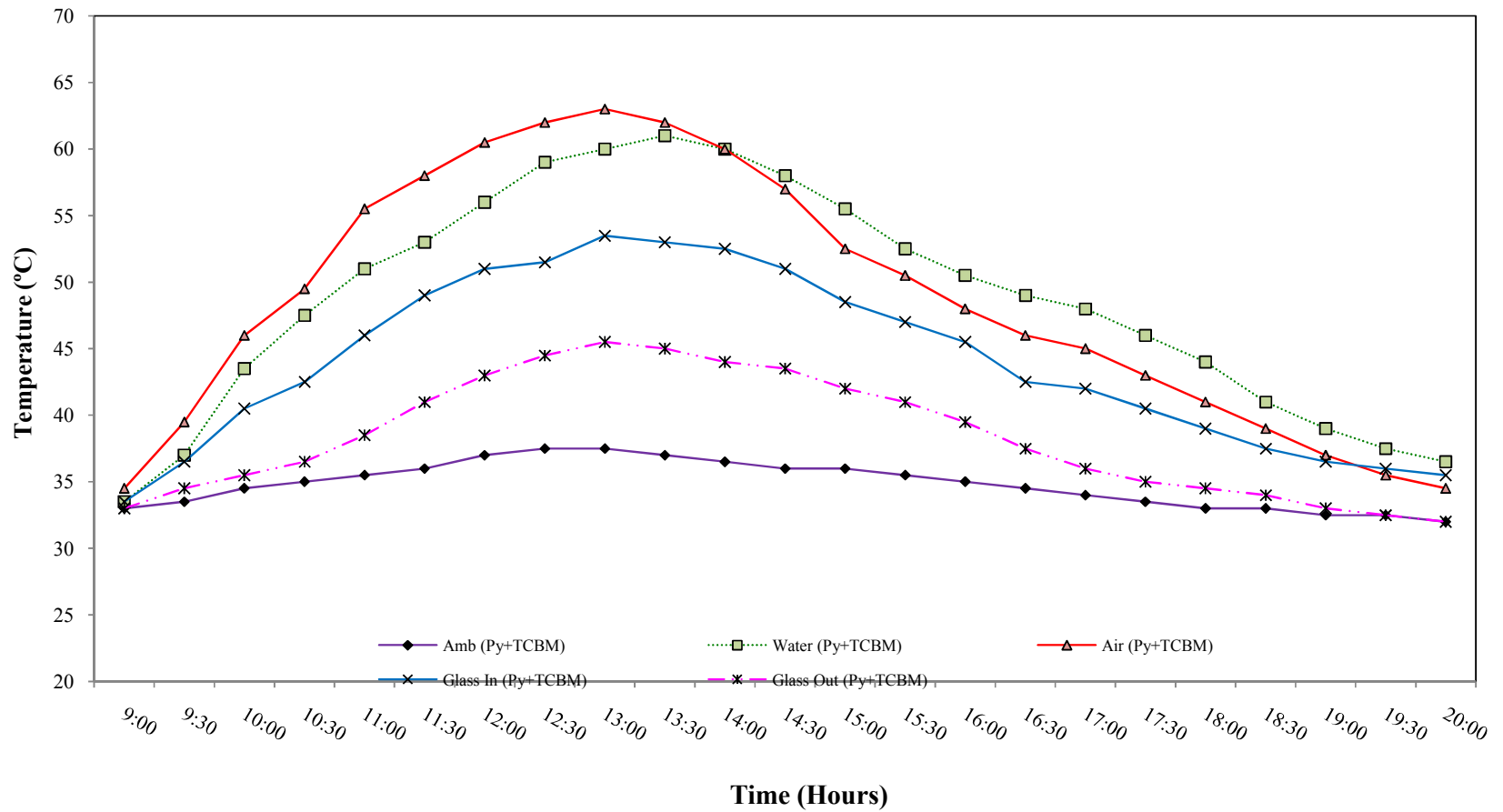
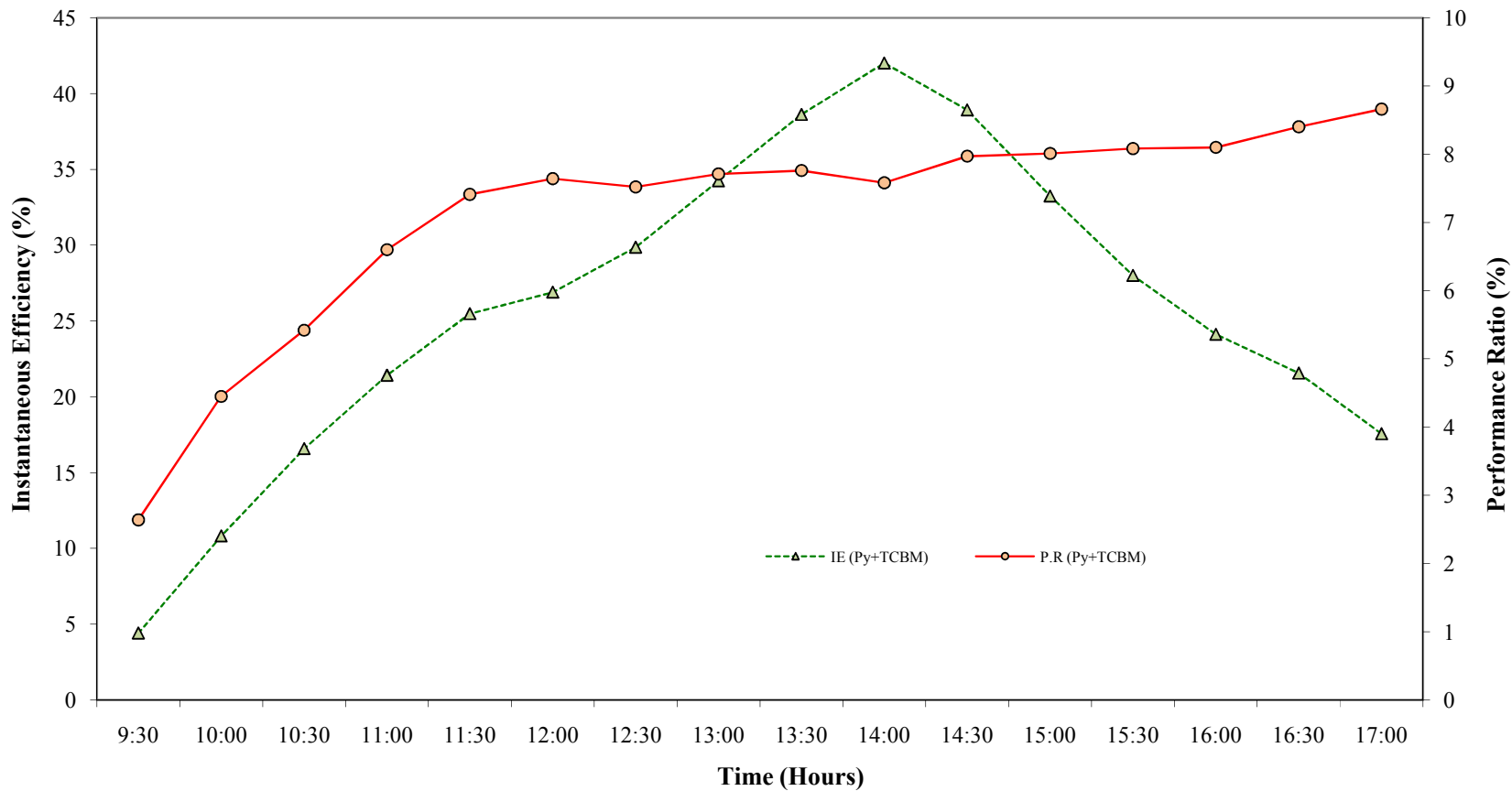


Fig (4.21) Variation of solar insolation and water collection with respect to time for pyramid solar still (without thermal storage medium)



Fig(4.22) Variation of temperature with respect to time for pyramid solar still with tar coated blue metal



Fig(4.23) Variation of instantaneous efficiency and performance ratio with time for pyramid solar still with tar coated blue metal

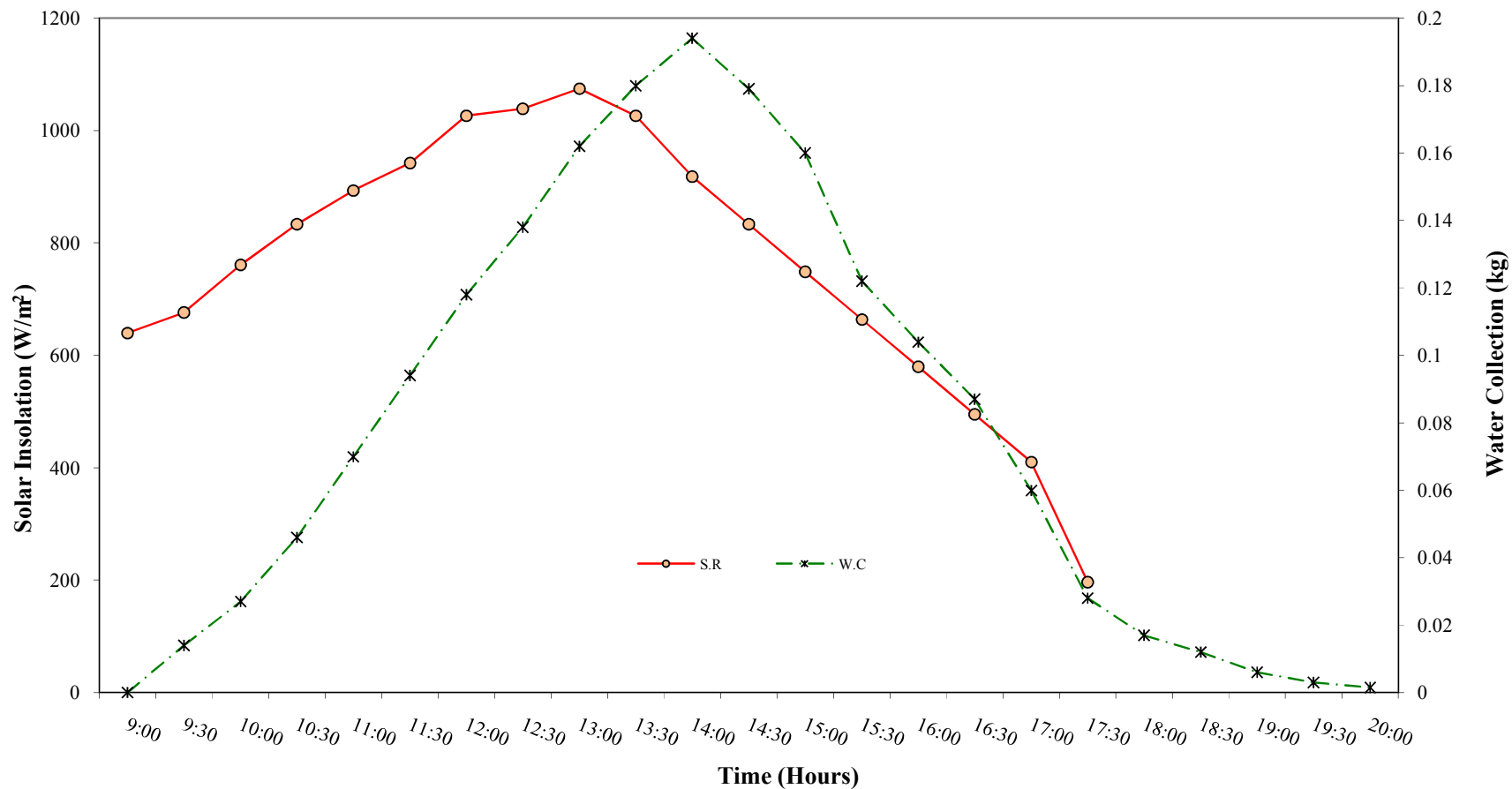


Fig (4.24) Variation of solar insolation and water collection with respect to time for pyramid solar still with tar coated blue metal

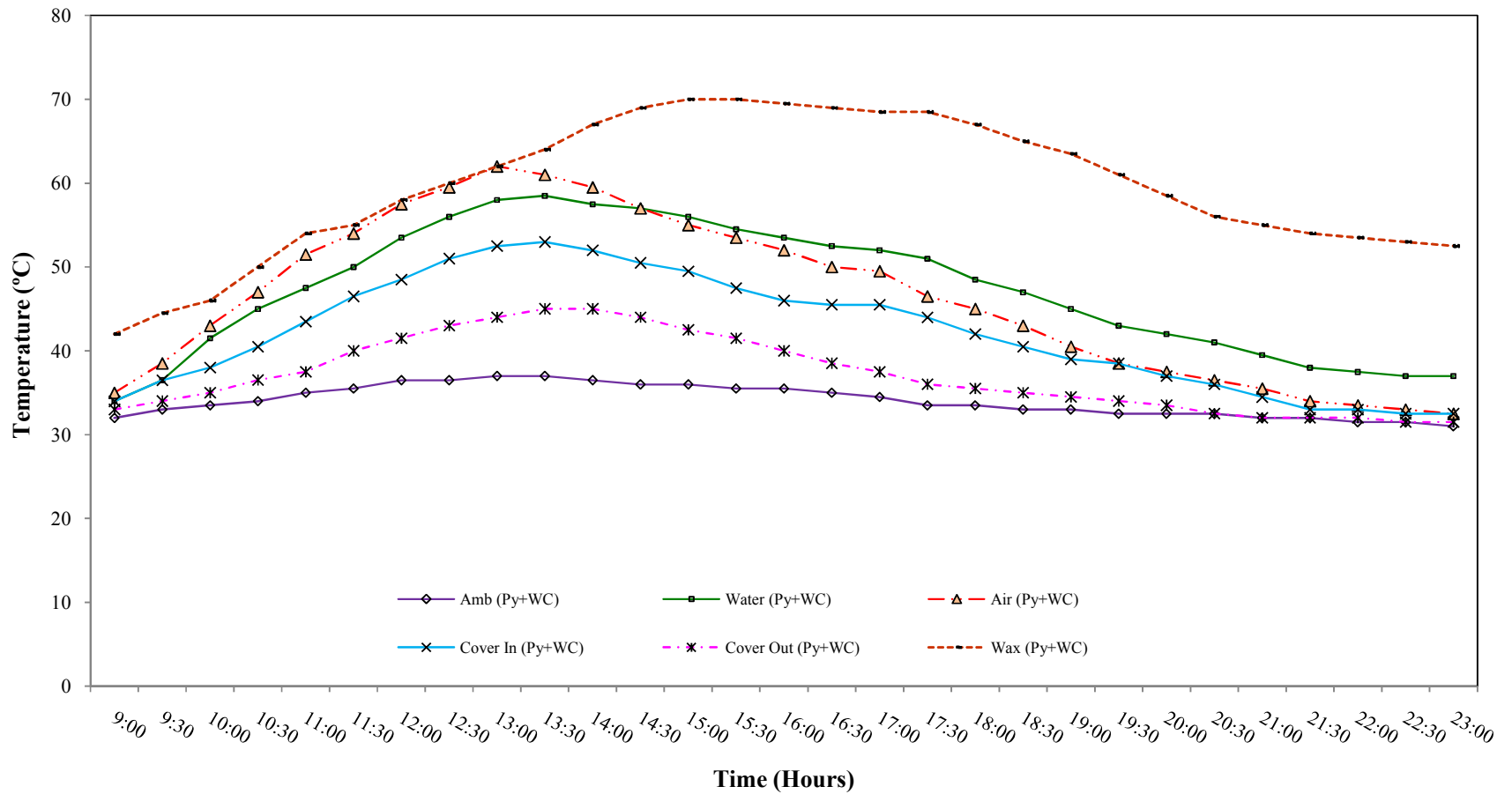
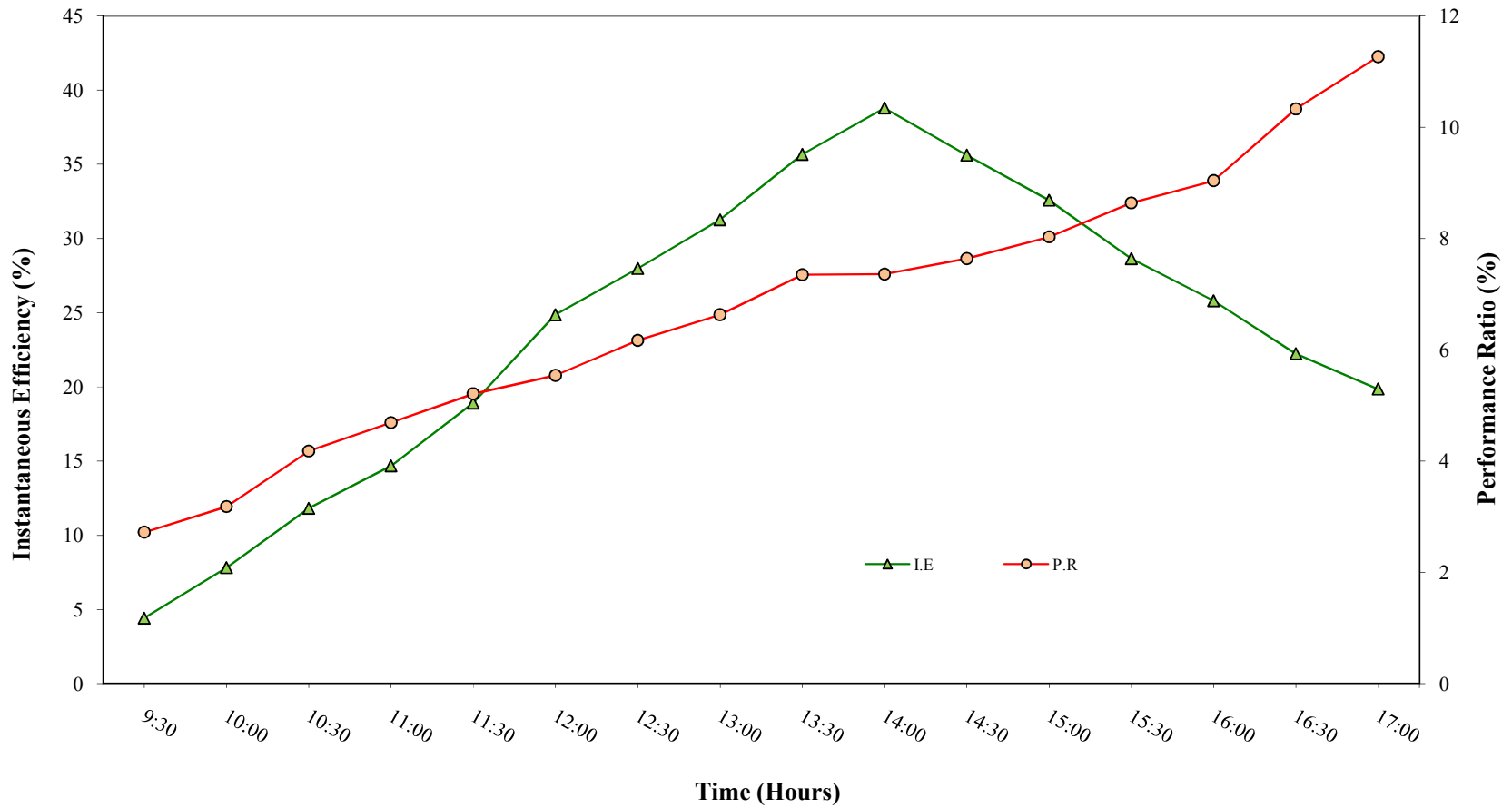


Fig (4.25) Variation of temperature with respect to time for pyramid solar still with phase change material (paraffin wax)



Fig(4.26) Variation of instantaneous efficiency and performance ratio with respect to time for pyramid solar still with phase change material (paraffin wax)

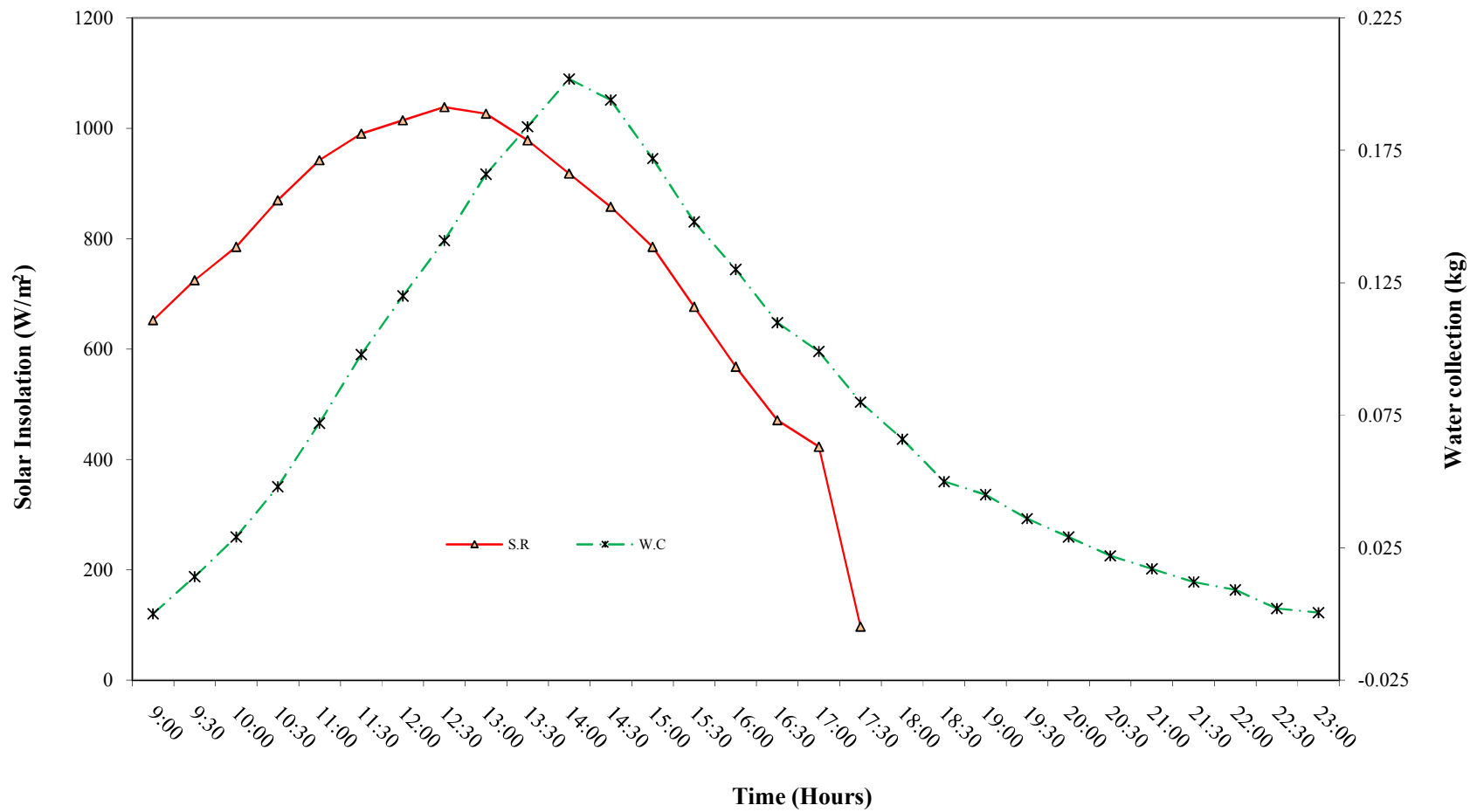
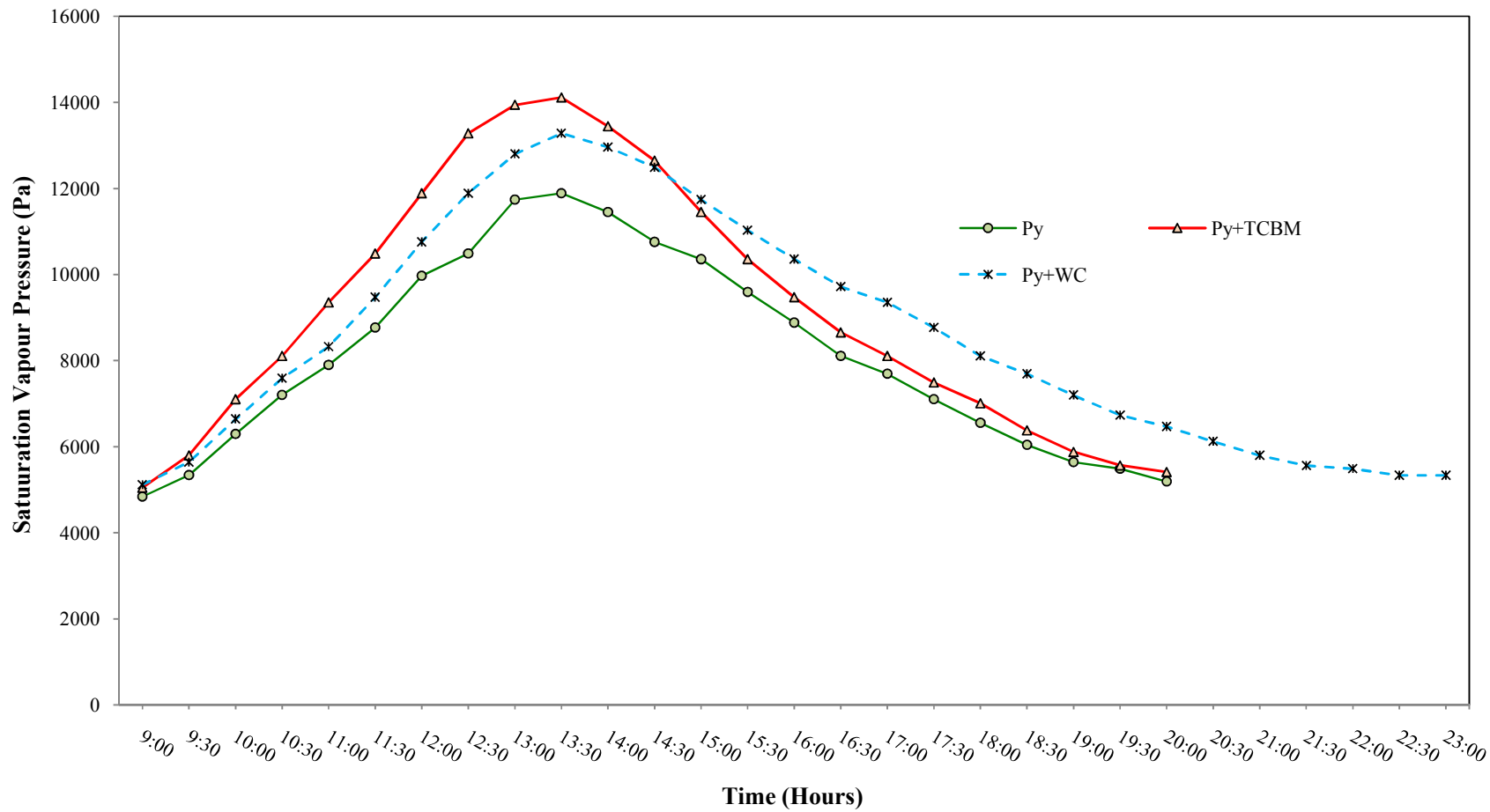
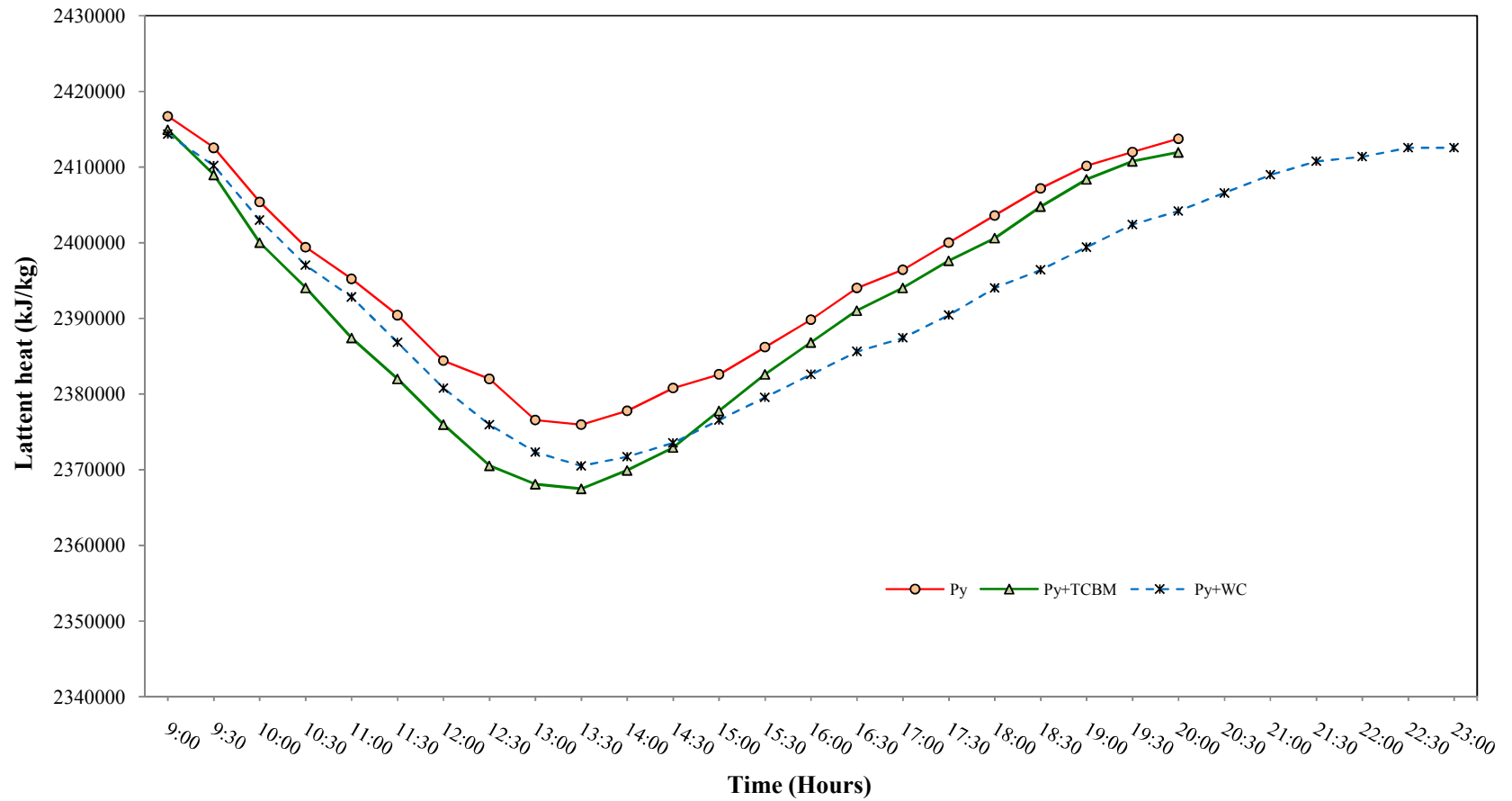


Fig (4.27) Variation of solar insolation and water collection with respect to time for pyramid solar still with phase change material (paraffin wax)



Fig(4.28) Variation of saturation vapour pressure with respect to time for pyramid solar still under three modes of study



Fig(4.29) Variation of latent heat with respect to time for pyramid solar still under three modes of study

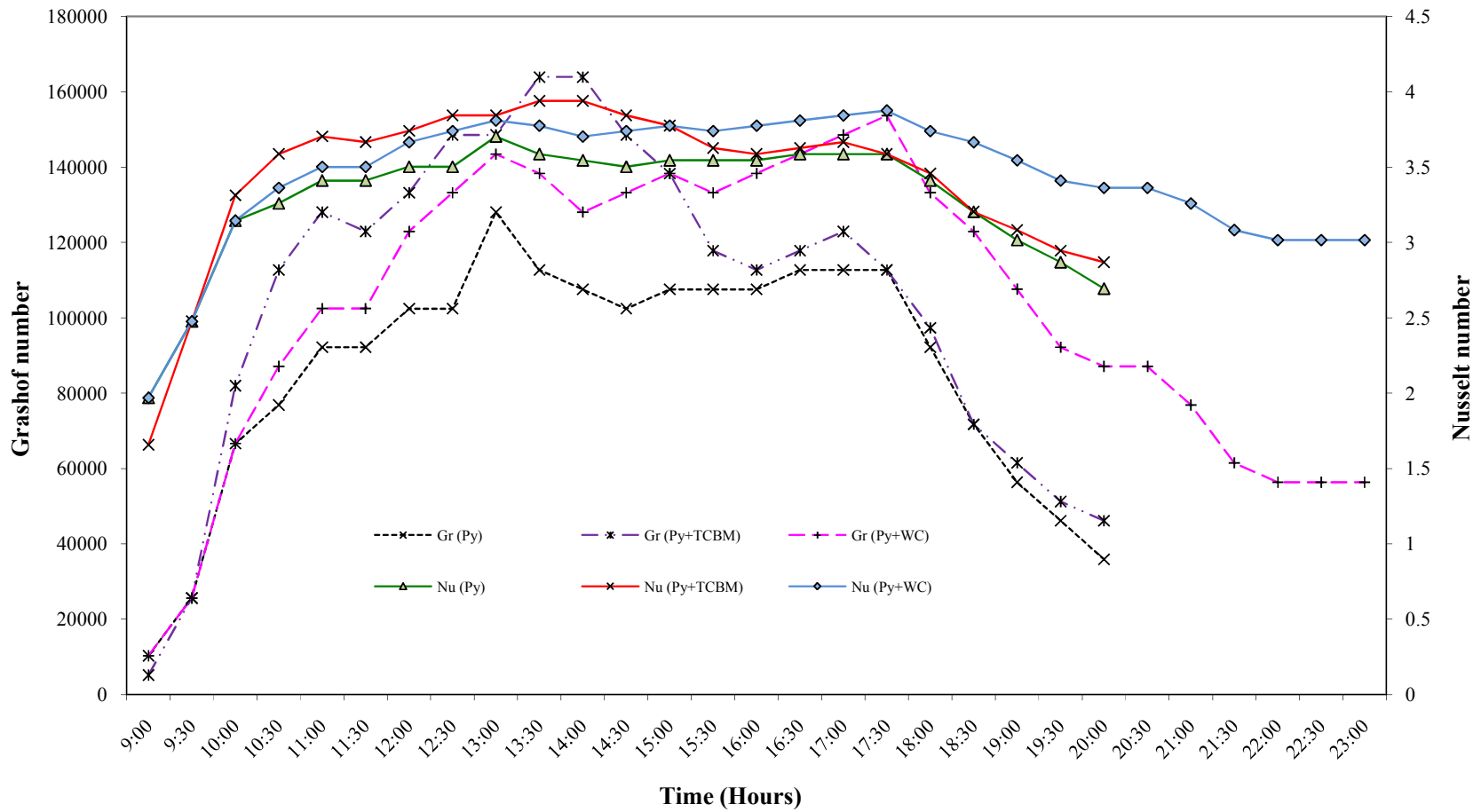
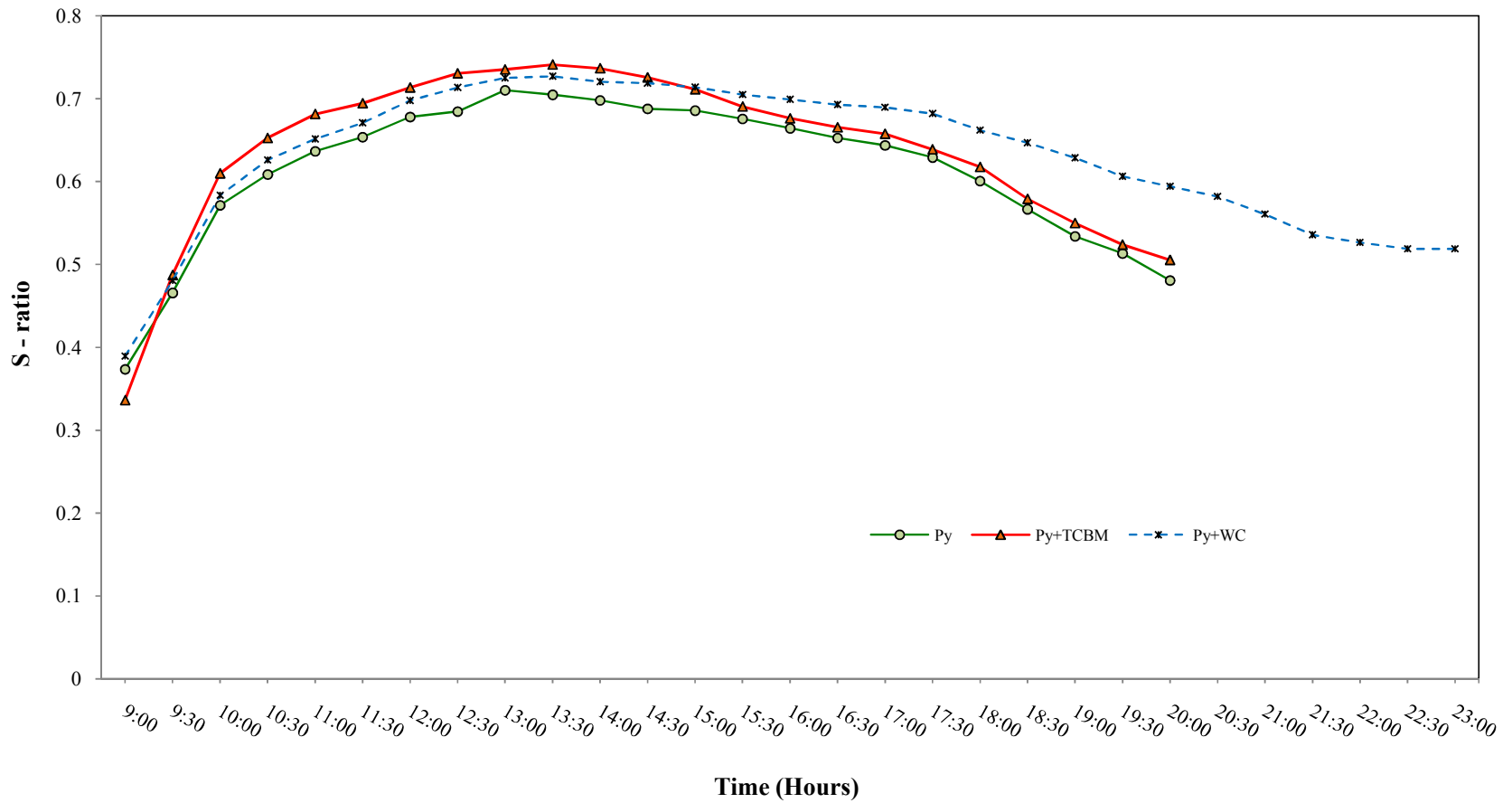


Fig (4.30) Variation of Grashof and Nusselt number with respect to time for pyramid solar still under three modes of study



Fig(4.31) Variation of S ratio with respect to time for pyramid solar still in three modes of study

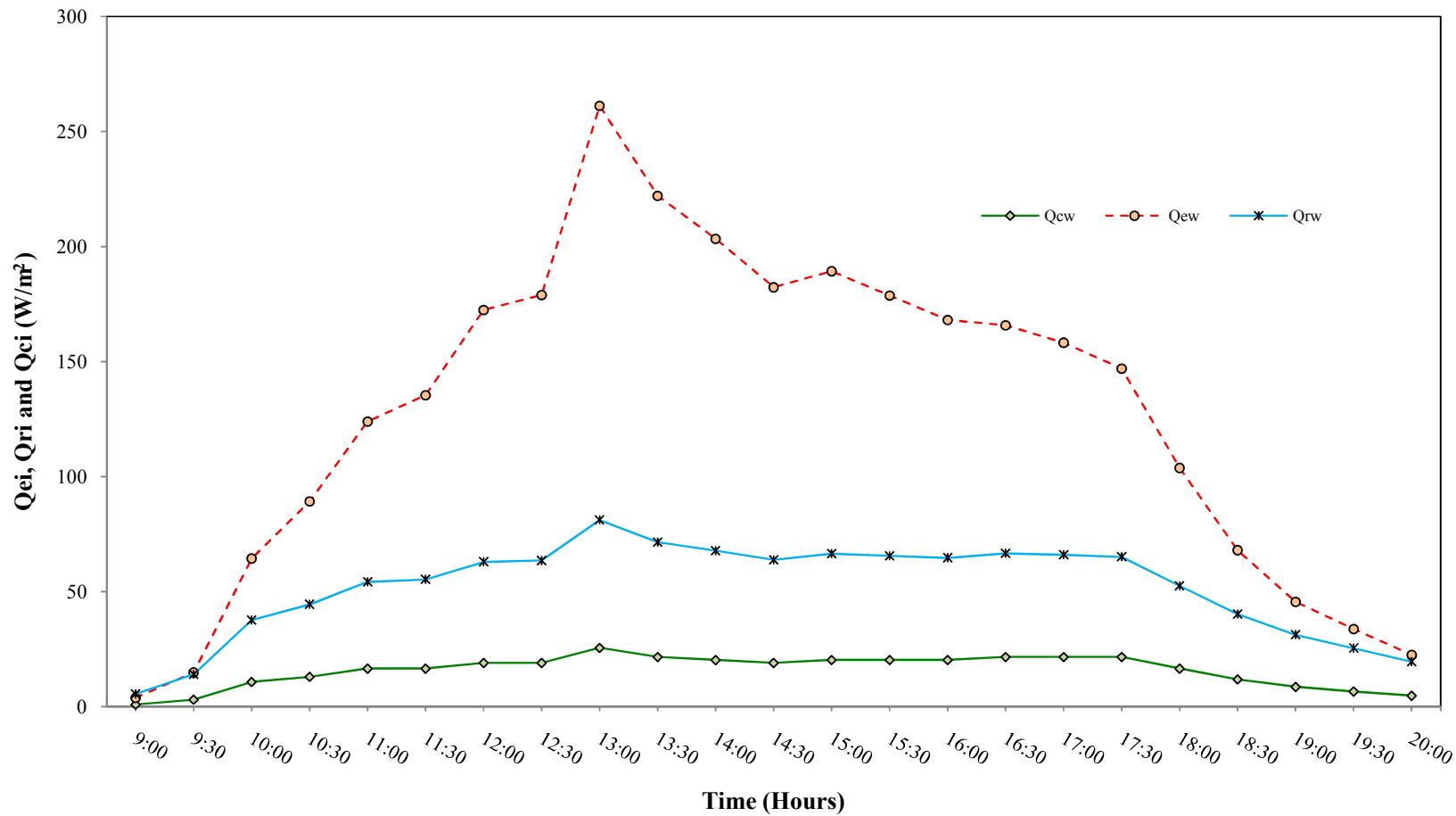


Fig (4.32) Variation of heat transfer rate by evaporation (Qei), radiation (Qri) and convection (Qci) inside the pyramid solar still (without thermal storage medium)

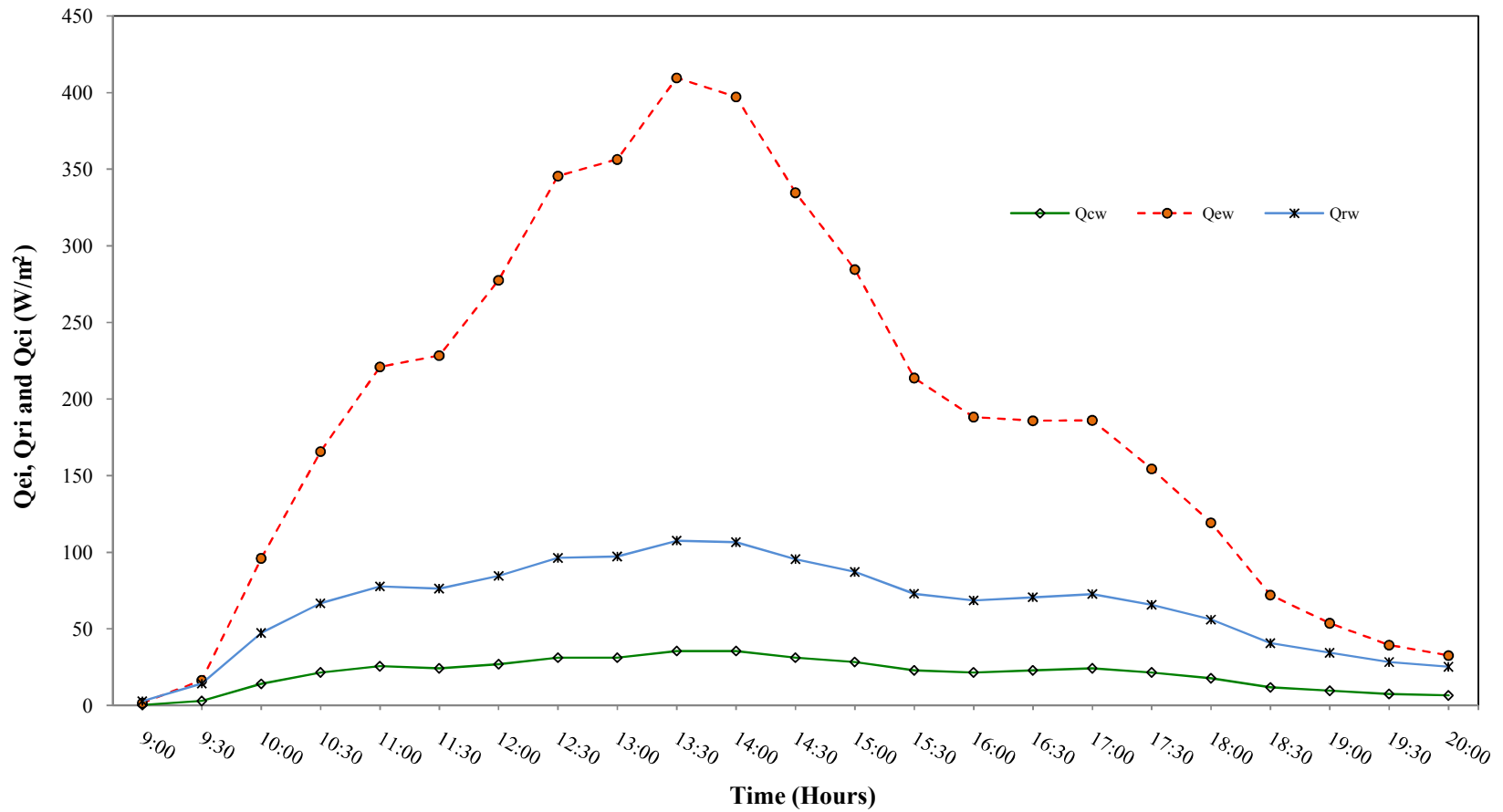


Fig (4.33) Variation of heat transfer rate by evaporation (Qei), radiation (Qri) and convection (Qci) inside the pyramid solar still tar coated blue metal

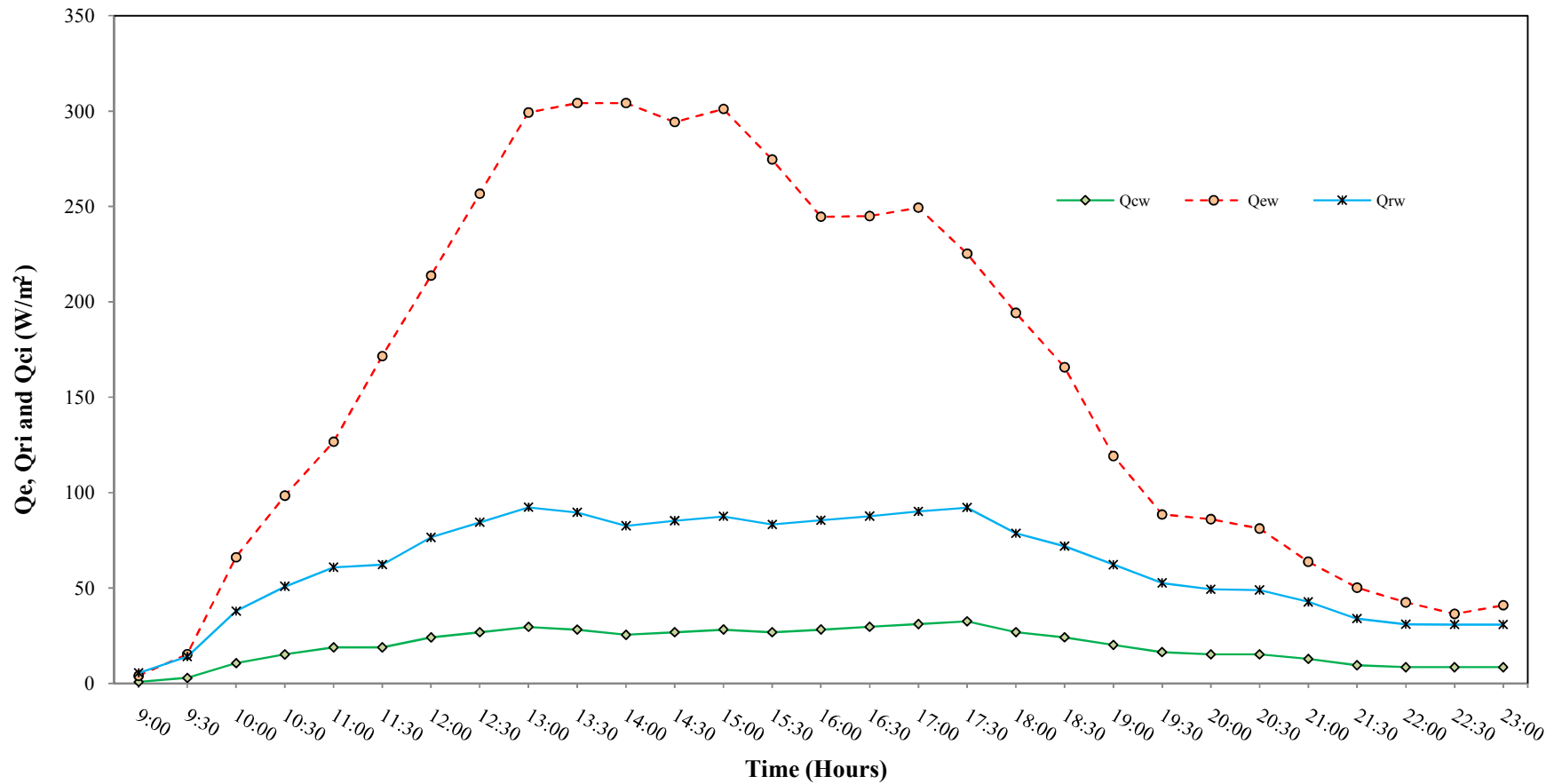
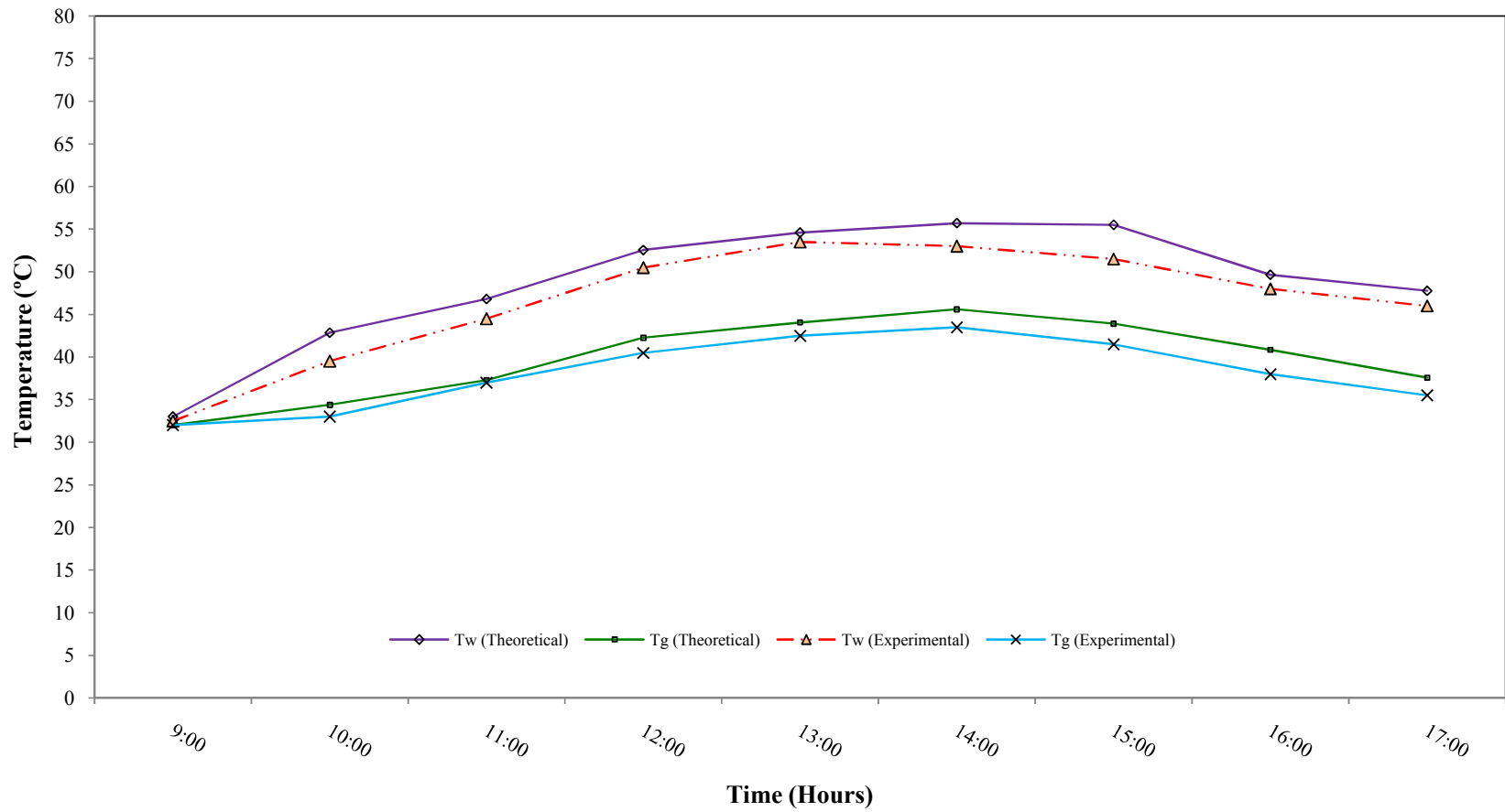
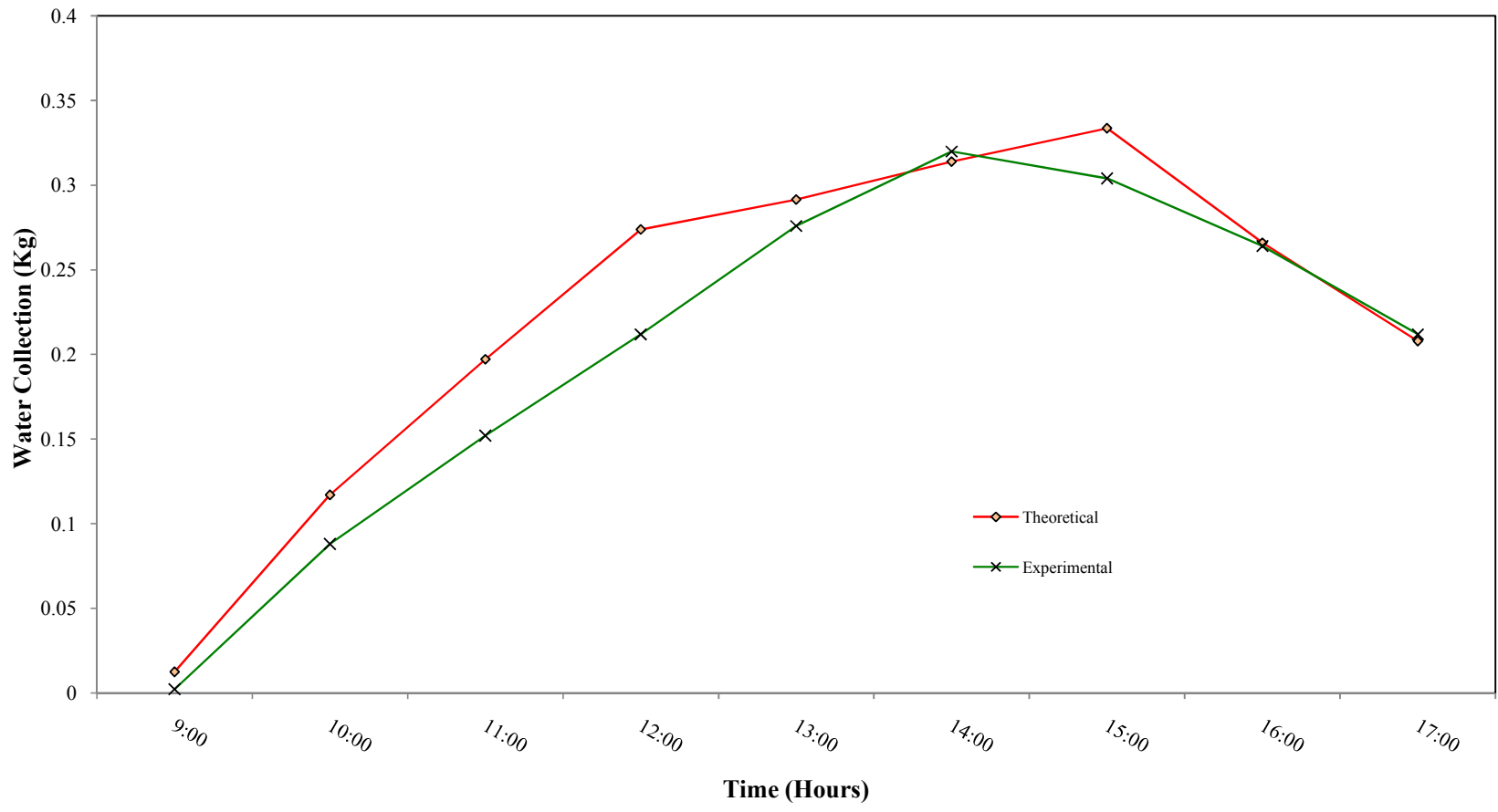


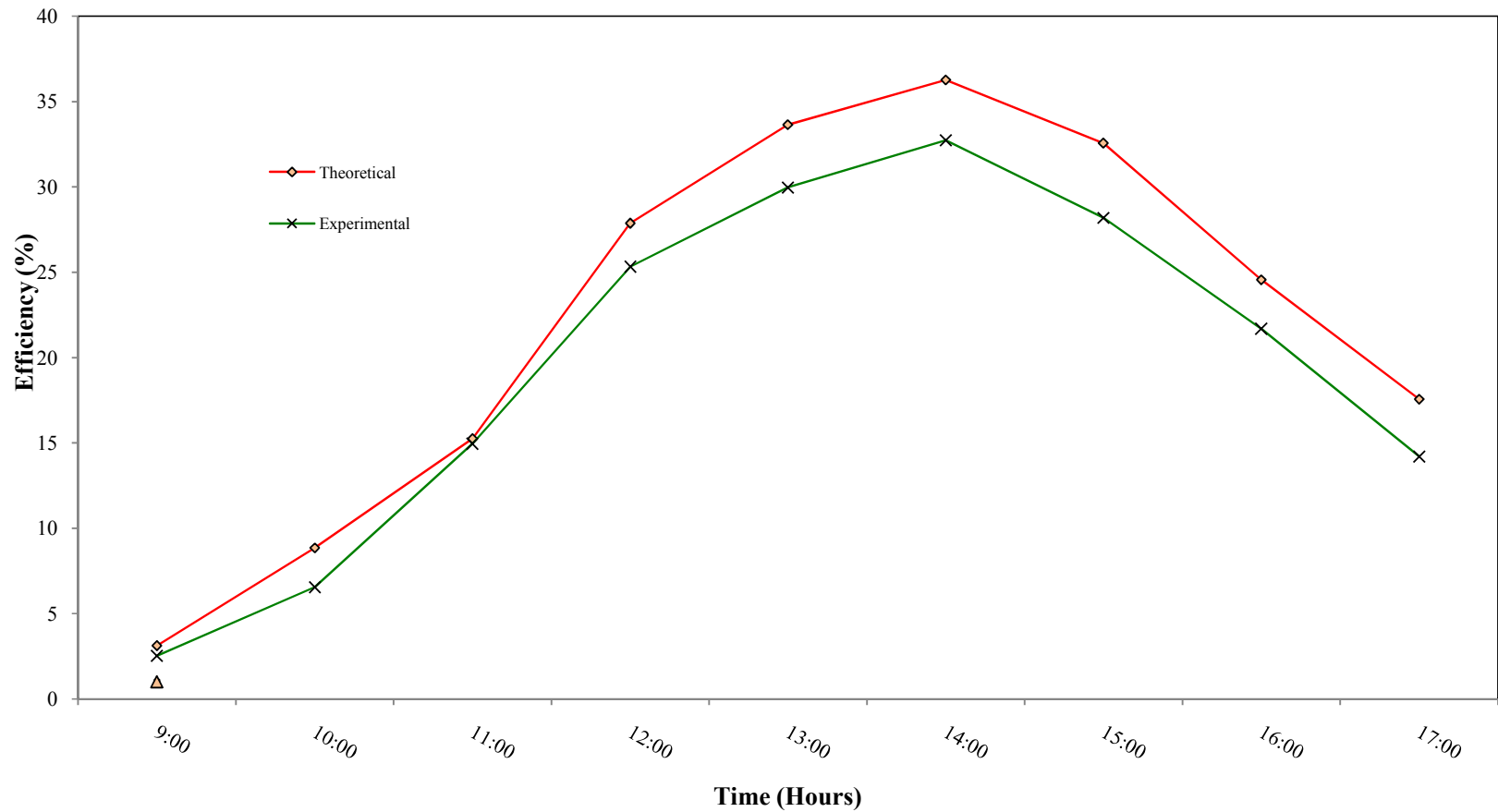
Fig (4.34) Variation of heat transfer rate by evaporation (Q_{ei}), radiation (Q_{ri}) and convection (Q_{ci}) inside the pyramid solar still with phase change material (paraffin wax)



Fig(4.35) Variation of water and air temperature with respect to time for pyramid solar still without absorbing medium



Fig(4.36) Variation of theoretical and experimental water collection with respect to time for pyramid solar still without absorbing medium



Fig(4.37) Variation of theoretical and experimental efficiency with respect to time for pyramid solar still without absorbing medium

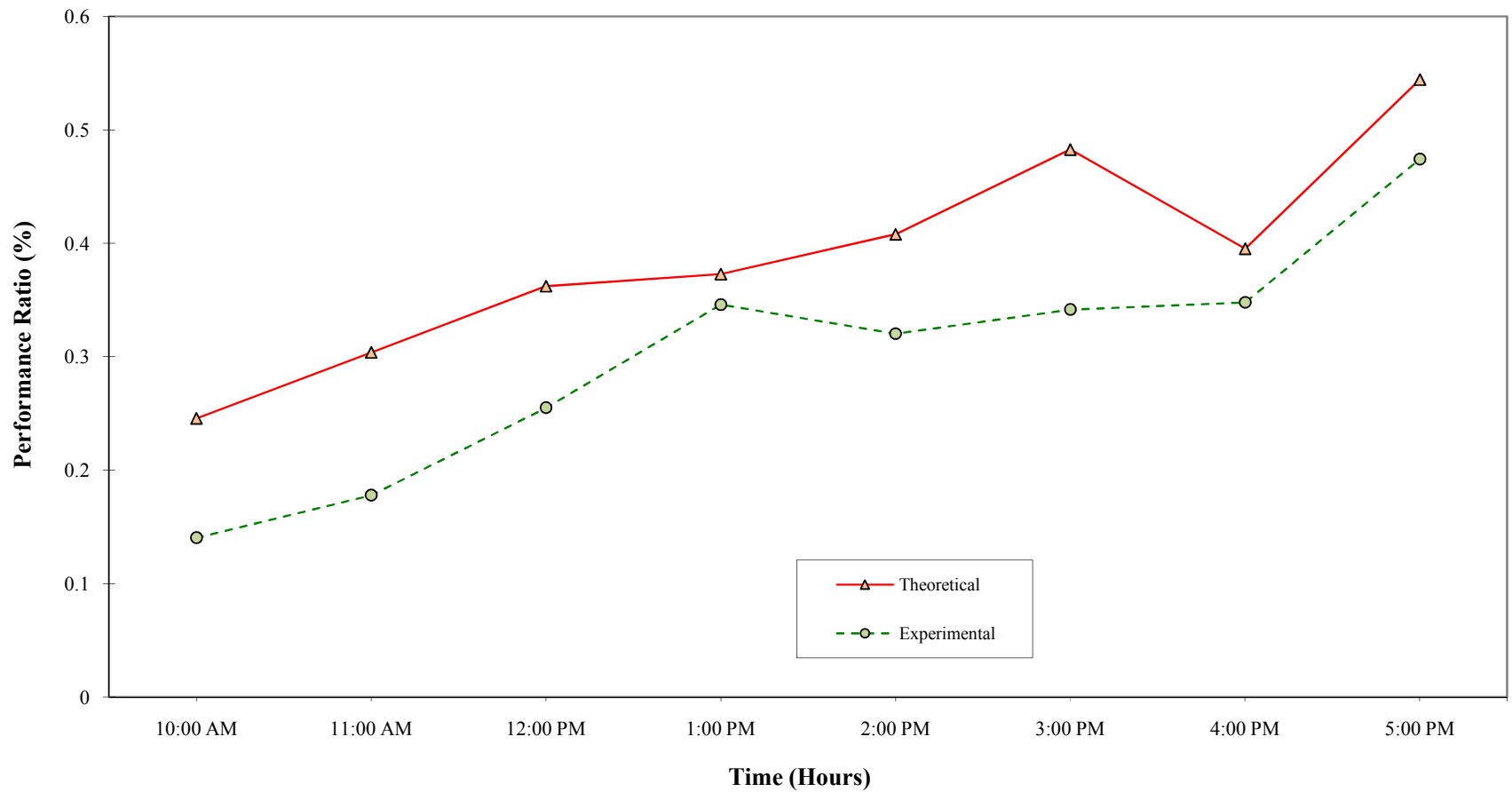
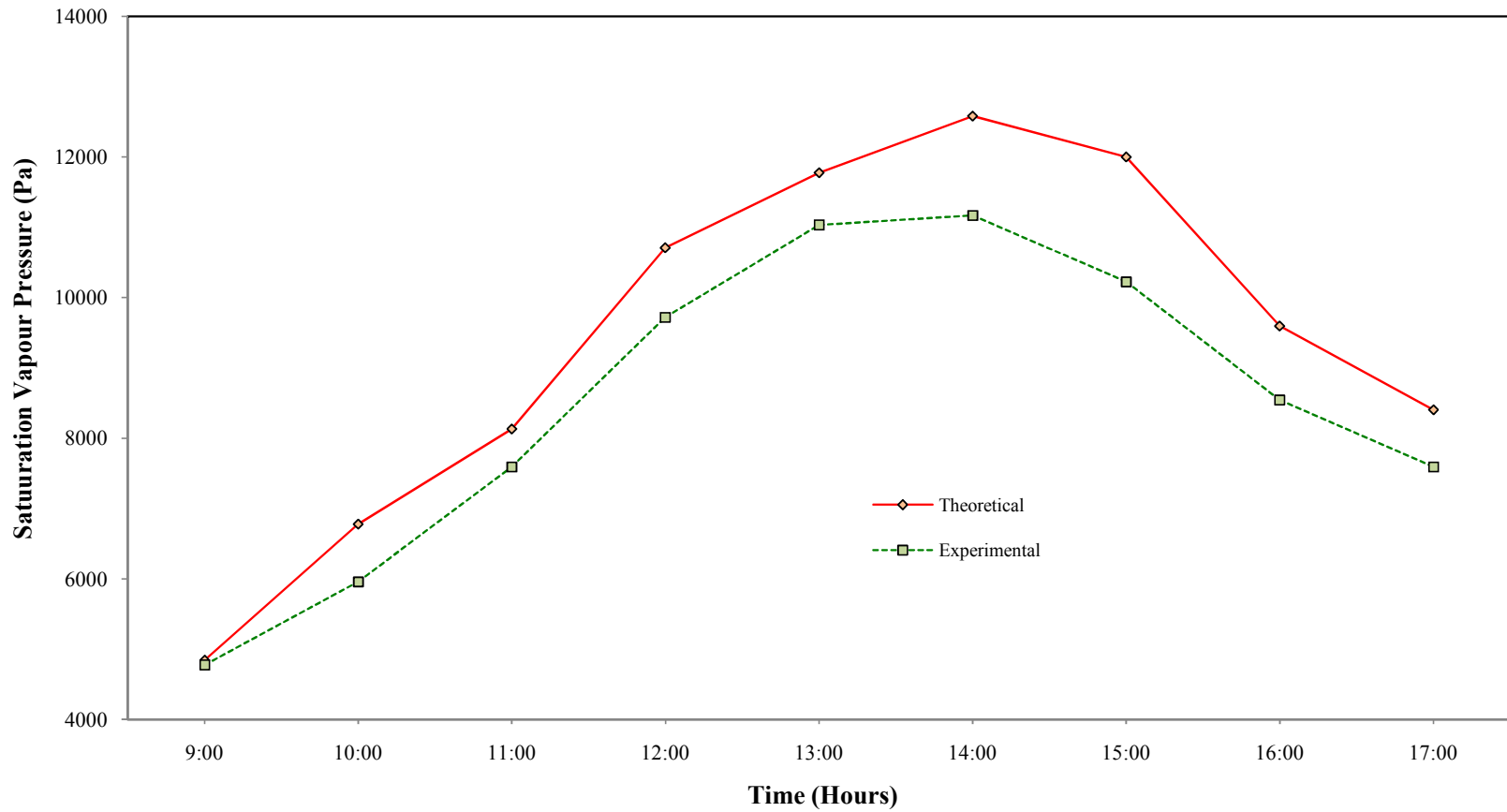
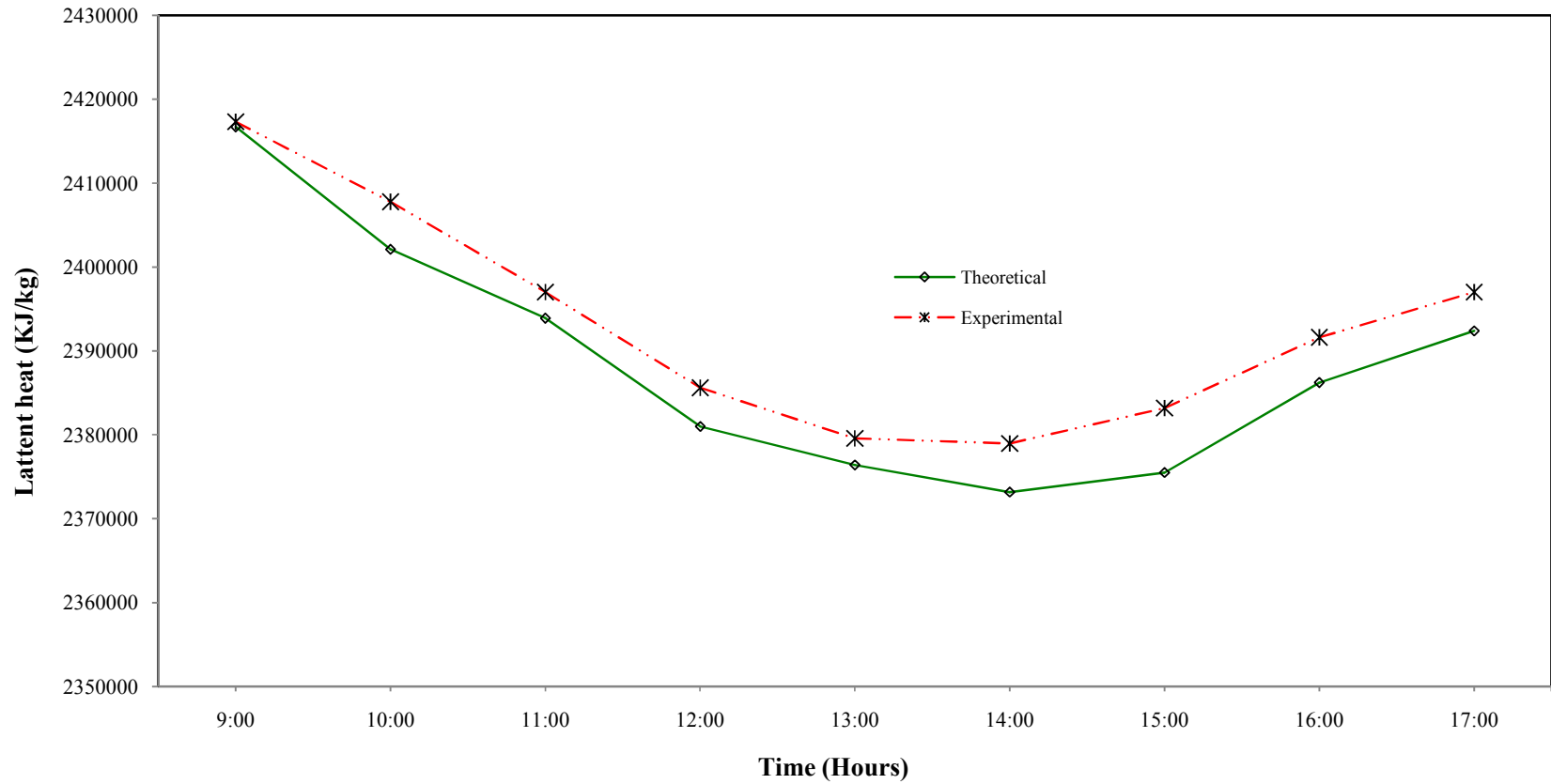


Fig (4.38) Variation of performance ratio with respect to time for pyramid solar still without absorbing medium



Fig(4.39) Variation of saturation vapour pressure with respect to time for pyramid solar still without absorbing medium



Fig(4.40) Variation of latent heat with respect to time for pyramid solar still without absorbing medium

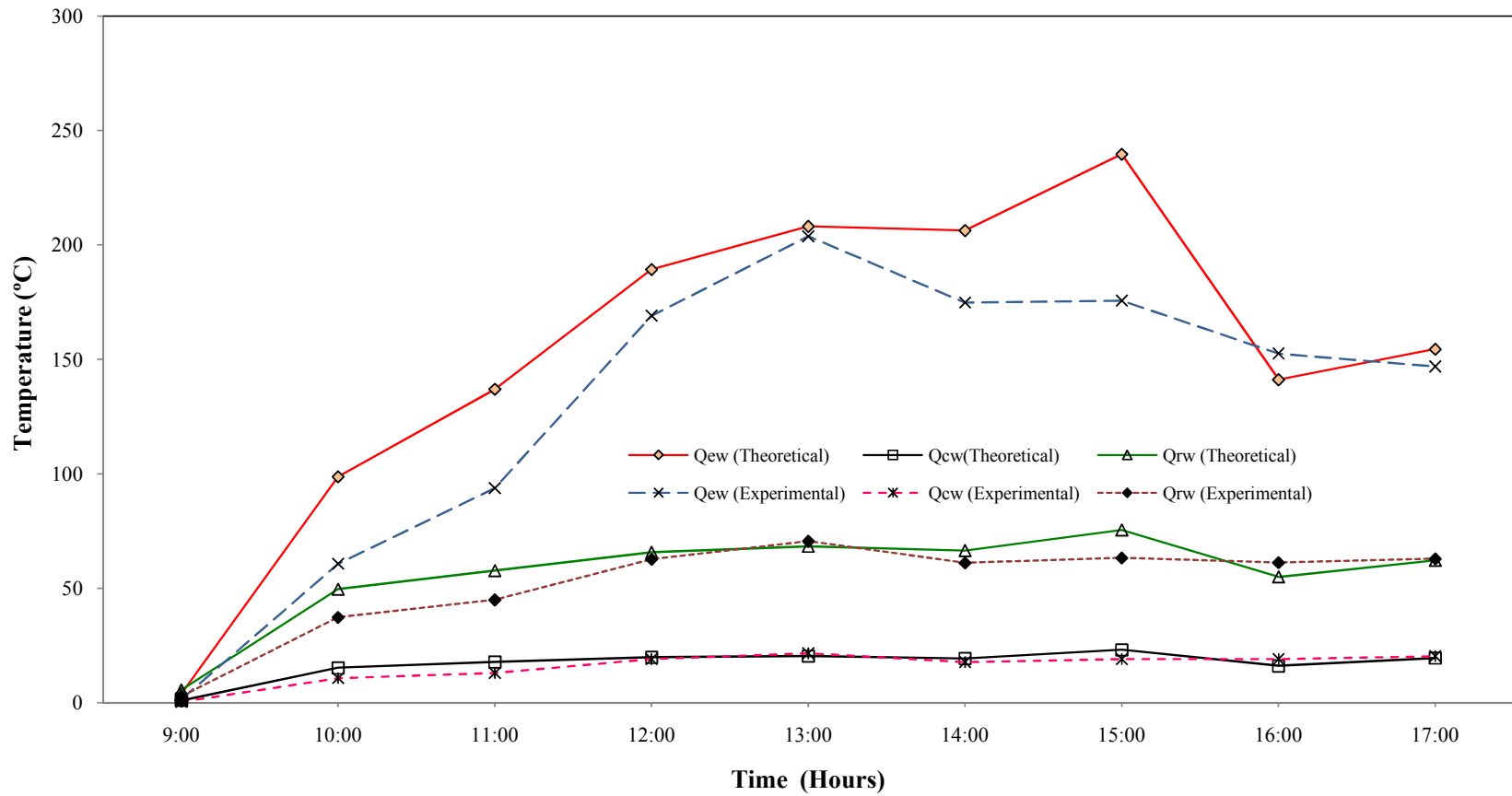
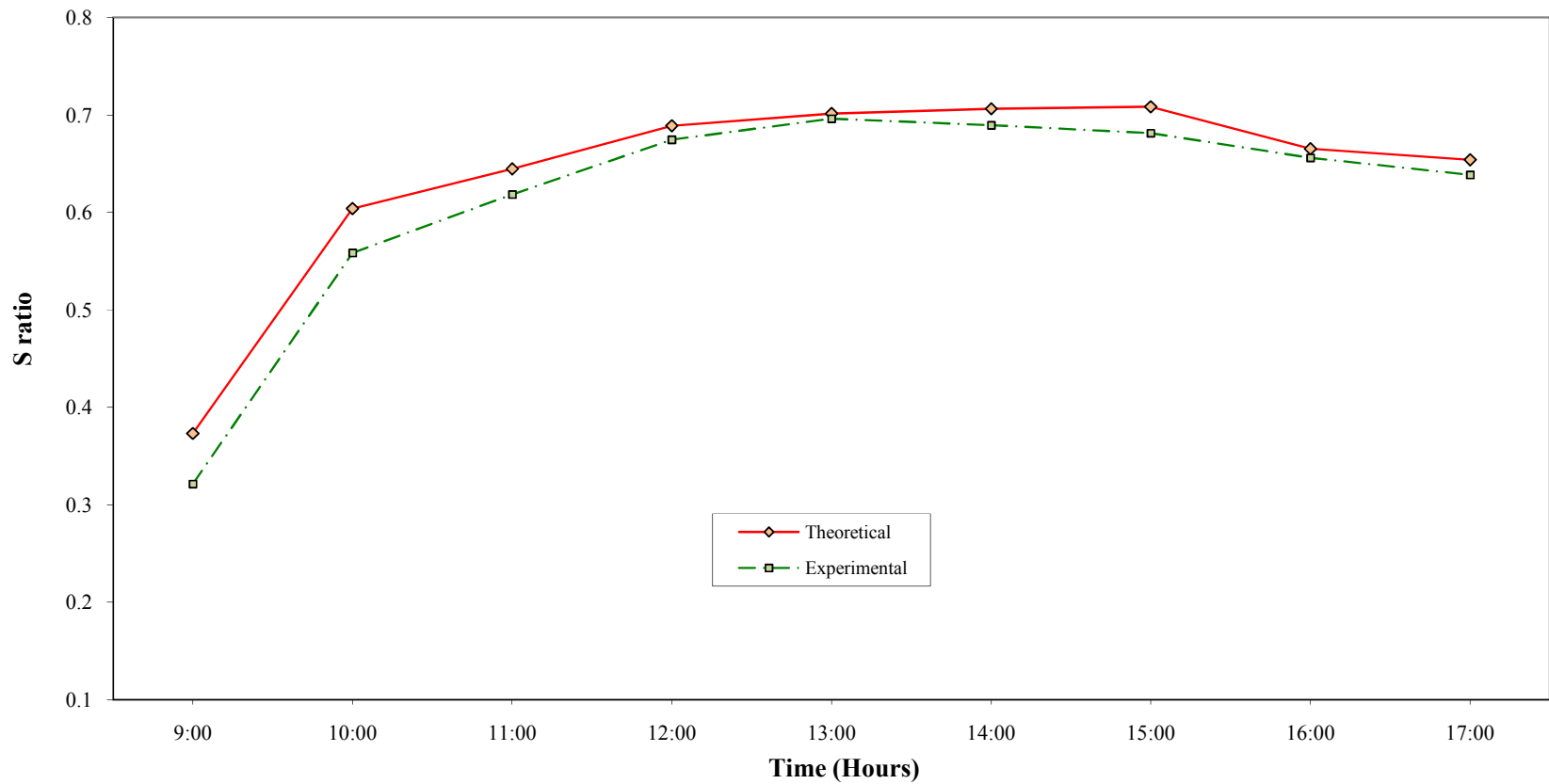
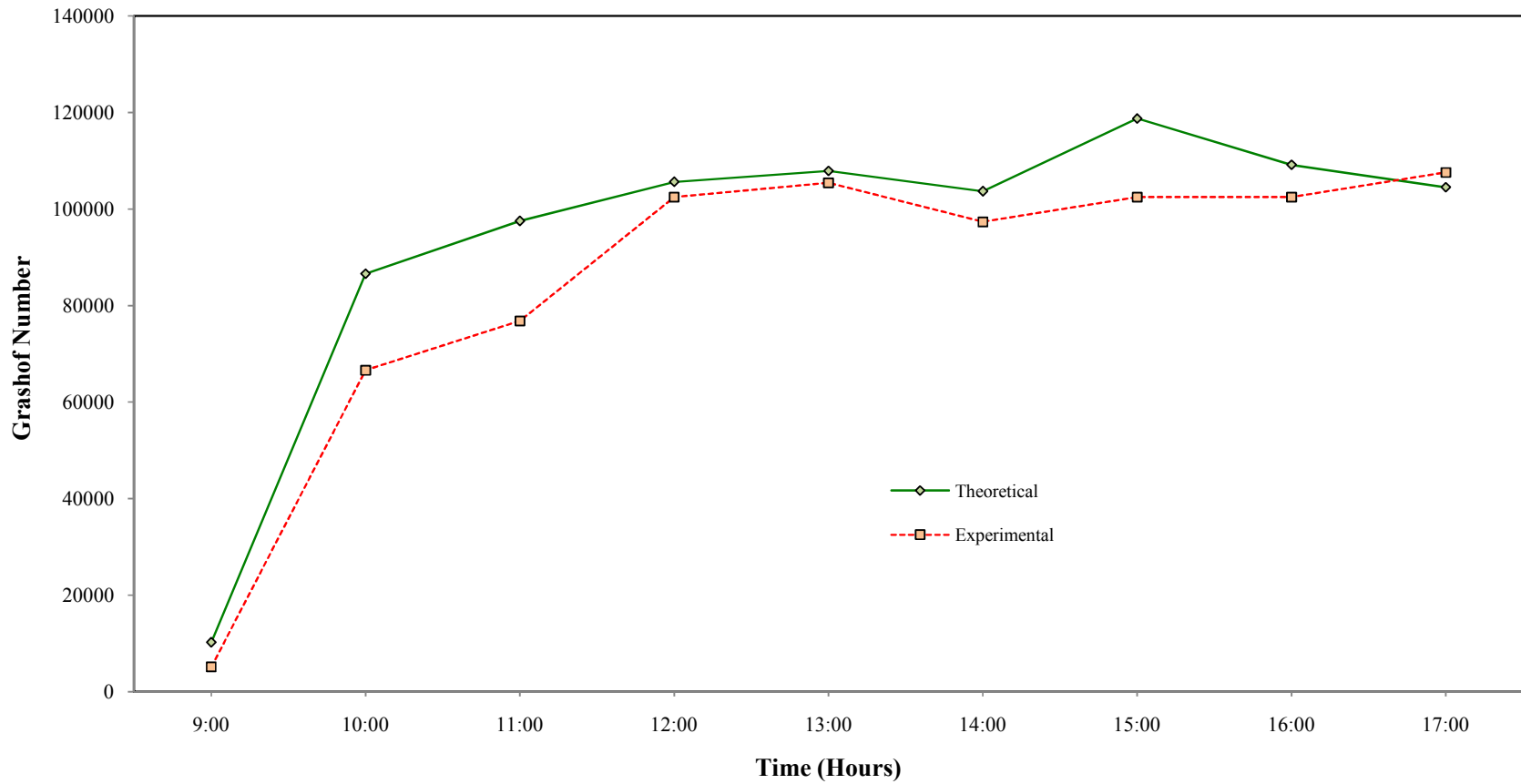


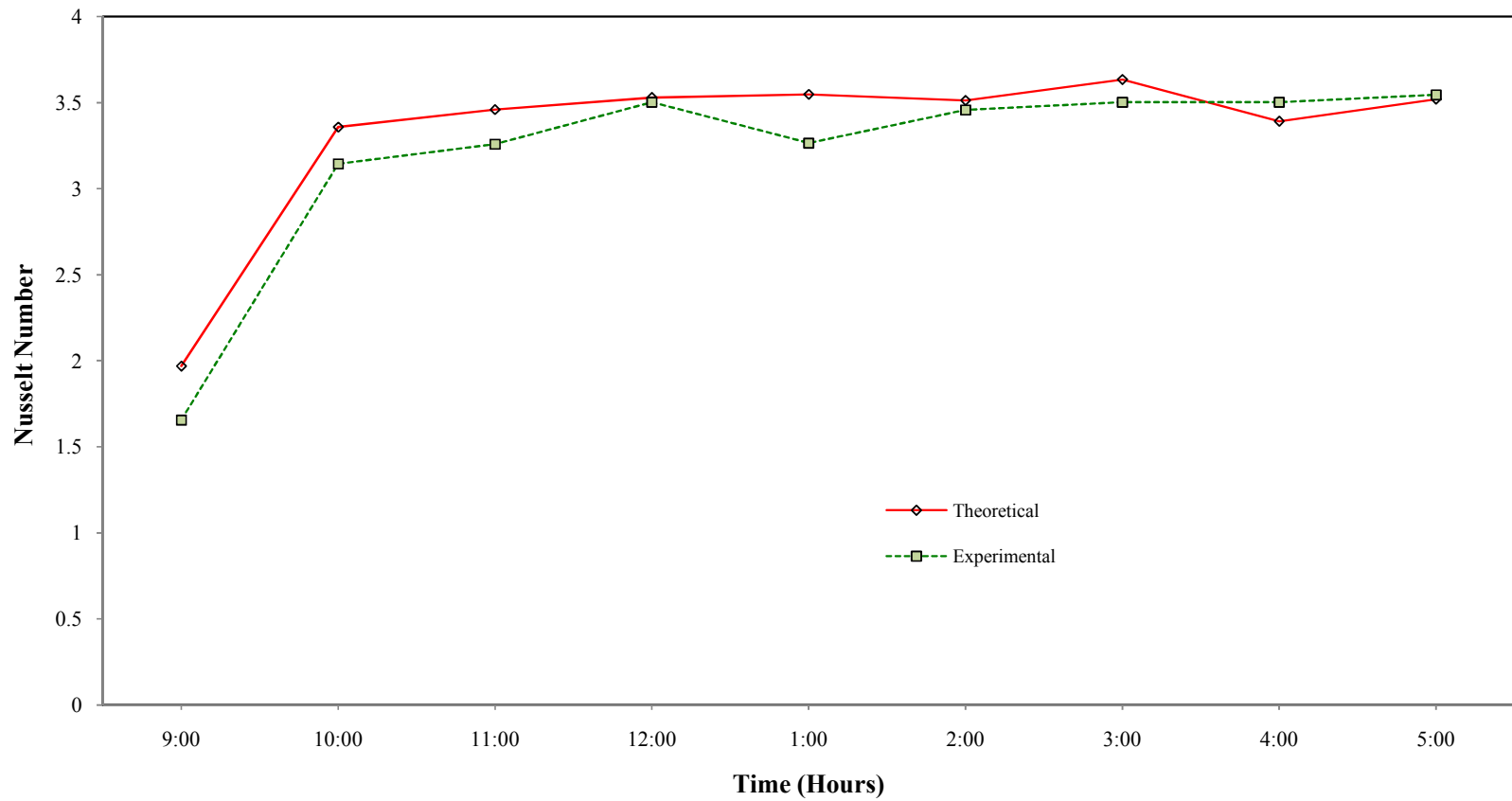
Fig (4.41) Variation of heat transfer rates by evaporation (Q_{ei}), radiation (Q_{ri}) and convection (Q_{ci}) inside the pyramid solar still without absorbing medium



Fig(4.42) Variation of S ratio with respect to time for pyramid solar still without absorbing medium



Fig(4.43) Variation of Grashof number with respect to time for pyramid solar still without absorbing medium



Fig(4.44) Variation of Nusselt number with respect to time for pyramid solar still without absorbing medium

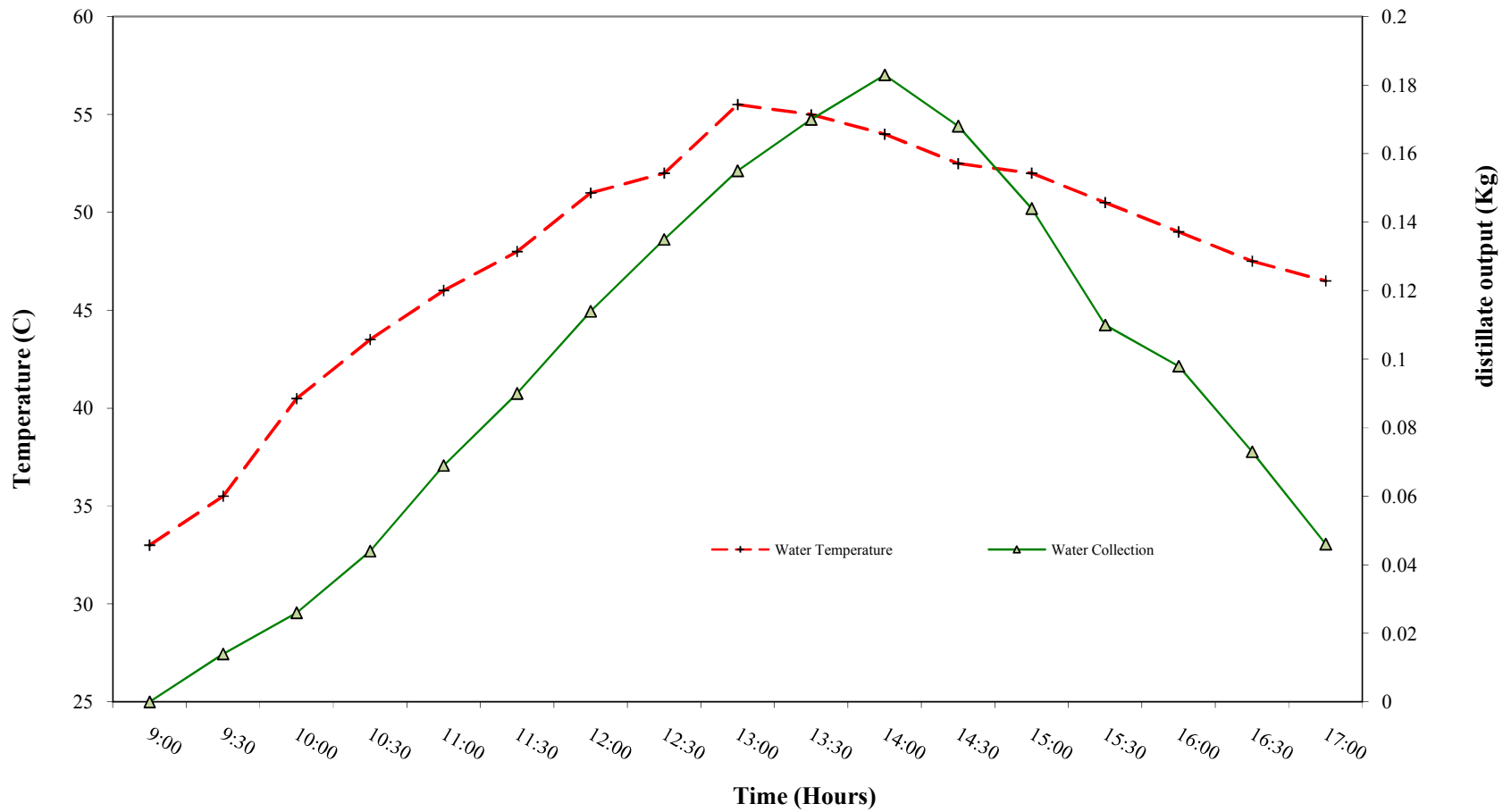


Fig (4.45) Variation of water temperature profile and distillate output with respect to time for pyramid solar still decoupled with electrical temperature controller.

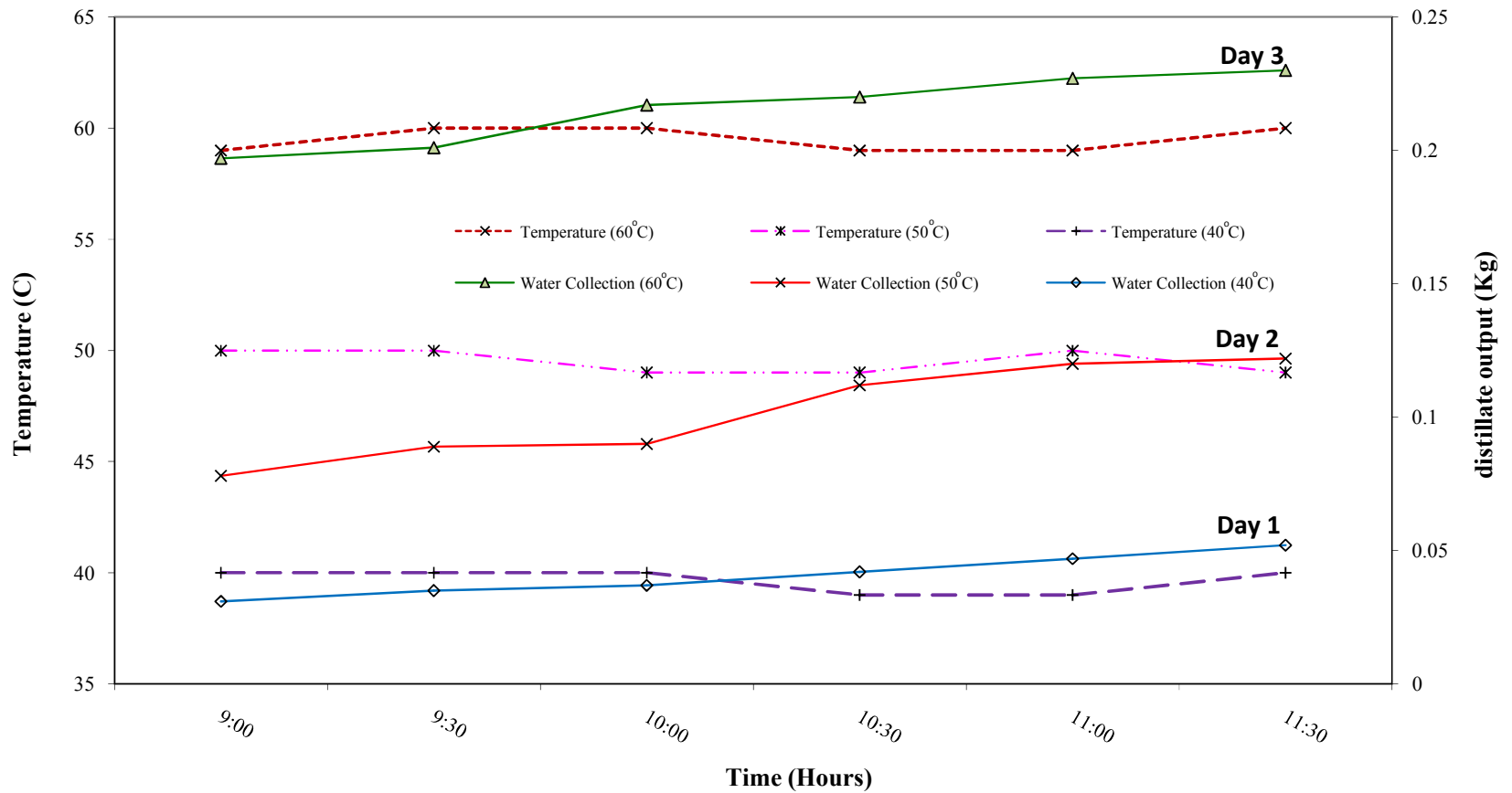


Fig (4.46) Variation of water temperature and distillate output with respect to time for the still with electrical temperature controller