Experimental study of epoxy based graphite coating on parabolic trough solar collector

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Abstract. Parabolic Trough Solar Collector is a line concentration method employed to harness solar energy for high-temperature applications. Attempts are made to improve the heat transfer of PTSC by reducing convectional losses of the absorber tube by using covering on the absorber tube. The study attempts to improve the Parabolic Trough Solar Collector performance using epoxy-based graphite coating through experimentation. The experiment is attempted for varied flow rates of 0.3, 0.7 and 1.1 litres per minute. The study highlighted that the coating method improved the rise in thermal fluid temperature over the absorber tube covering method by 24%. The improvement in heat transfer due to the graphite coating can be accounted for by the improvement in absorptivity and insulation, leading to better heat transfer to the thermal fluid utilized in the absorber tube.

1. Introduction
Solar energy has been one of the popular sources of renewable energy. One of the methods to harness the heat energy from the sun is using Parabolic Trough Solar Collector (PTSC). This line focusing method noted for concentrating solar energy for high-temperature applications like cooking, power generation, agricultural drying to name a few.

One of the critical components involved in the PTSC is the absorber tube, which is responsible to transfer the solar heat into the thermal fluid passing through it. However, due to operational conditions, convectional losses can lead to a reduction in the overall efficiency of the PTSC.

Approaches involve the use of inserts in the absorber tube to improve the heat transfer from the absorber tube to the heat transfer fluids, which have highlighted improvement by 20% [1].

In contrast, the attempts to restrict the heat loss and improve the absorber tube behaviour highlighted improvement by 30-35% [2]. Similar researches have aimed at improvements of absorber tube behaviour with selective coatings. One of the studies involving nickel-chromium and nickel-aluminium on copper by thermal spray improved the PTSC performance by reducing the losses [3]. However, an effective improvement is observed in the study involving graphite-based coating using paraffin wax. The experimentation concluded that the use of graphite showed an improvement of 15% in the Scheffler disc type solar collector [4-5]. Although attempts have been made with graphene [6] on flat plate collectors showing promising results, similar studies for PTSC have been limited. It also has been concluded in studies that the effects can be varying among the collectors due to the operational temperature and principle. The variation in the thermal behaviour in Solar Collectors can also vary significantly with the binder used for the coating.
As epoxy has been observed to withstand moderate temperatures of 200°C and noted for ease of coating as well as preparation. Hence, this paper aims to experimentally compare the effects of coating and covering on absorber tube used in PTSC. The study also attempts to understand the individual effectiveness of both the methods over an unmodified absorber tube. This study will also attempt to understand the thermal behaviour of epoxy with graphite as an effective method for coating for PTSC.

2. Experimental Setup
To understand and compare the thermal performance of covering and coating approaches, an experimental approach is used. For this experimental study, a PTSC test rig has been constructed which utilizes water as the thermal fluid. The thermal fluid is operated at atmospheric pressure. The key parts of the PTSC test rig are the components of PTSC, flow control system and measurement instrumentation.

2.1. Components of PTSC Test Rig
Components include the structural as well as the tracking mechanism utilized for the test rig. The components are highlighted in Fig 1. The parabolic frame provides the basic structure and shape of the PTSC. The frame has an aperture of 1.1m and the length of the module is 2.5 m. Steel based construction is utilized with suitable supports to ensure the parabolic shape is maintained under operational conditions. The absorber tube is mounted at the focal point of the trough to ensure that solar energy is concentrated accurately along the length of the tube. The PTSC is equipped with a single axis solar tracker to focus the solar radiation on the absorber tube.

![Figure 1. PTSC test rig with components used for the experiment.](image)

2.2. Flow Control System
The flow of water in the PTSC is regulated using the flow control system. This part of the system is used to control the thermal fluid flow rate. This factor is a vital input parameter for the comparison of the performance. As the system requires a constant water flow at the constant pressure to study the performance. This is achieved using a recirculating bypass piping system. The schematic of the flow control system is shown in Figure 2.
2.3. Measurement Instrumentation

To understand the thermal behaviour of the absorber tube, a series of calibrated K type thermocouples are used to monitor the surface temperature of the absorber tube. These thermocouples are mounted at the inlet, mid-length and outlet of the absorber tubes. The location of the thermocouples is highlighted in the schematic of the test rig is shown in Figure 3. The water temperature at the inlet and outlet is measured using a calibrated K type thermocouple.

To ensure that the sun is constantly tracked in the East-West direction by the parabola throughout the day, the PTSC axis has been aligned along the North-South axis as per the test site location at Bangalore at 29° 58' (latitude) North and 76° 53' (longitude) East.

3. Methodology and Experimentation

The focus of the experimentation study has been on the improvement in thermal performance by using two approaches for PTSC. One of the approaches uses surface modification for the absorber tube to improve the PTSC performance and the other approach involves reducing the losses by providing a covering for the absorber tube.
As each PTSC performance is observed to vary with the physical dimensions and material, hence a study with no modifications is conducted. In this study, the stainless-steel absorber tube designed with PTSC is used without any modifications was used. This absorber tube is referred to as a bare absorber tube. The approaches have been compared based on the increase in the thermal fluid temperature used in the PTSC. The flowchart of the methodology is expressed in Figure 4. The experimentation has been carried out for each modification for a period of 10 days to account for variations in climatic conditions.

The solar irradiation during the testing period has been considered based on the Metrological Observations from Bangalore Station. The data during the testing duration has been compared based on the average irradiation during each of the testing phase. The Figure 5 highlight that the average irradiation during each of the testing condition show a limited variation. Hence based on the observations it can be concluded that the testing conditions had limited effects due to climatic variation. However, to account for the variations during various conditions of operation, an average value of the monitored temperatures has been considered in the comparison.

![Figure 4. Methodology of the study.](image)

![Figure 5. Average variation of solar irradiation during testing.](image)
3.1. Absorber Tube with Epoxy-Graphite Coating

The proposed approach relates to surface modification to improve the PTSC performance. One of the routes is by coating heat absorptive material onto the absorber tube. In this method, graphite-based coating has been selected as it is noted for improvement in heat absorption. Graphite powder is also found to be resistant to any chemical modifications under high heat conditions. Graphite powder has been adhered to the absorber tube using epoxy. The epoxy serves as an adhesive to bond the graphite particles to the absorber tube as well as among themselves. The selected epoxy has a rated temperature resistance of 200°C along with excellent mechanical properties. Hence the study utilizes epoxy-graphite coating for modifying the absorber tube behaviour.

The coating material involved uses LY556 epoxy along with the HY951 hardener. The graphite powder of 40 microns and 98% purity is added and stirred using a magnetic stirrer for 30 minutes to achieve a uniform consistency. The coating mixture is uniformly applied upon the cleaned stainless steel absorber tube with rollers and cured using a heater. The process is repeated and an average coating thickness of 2mm is achieved on the absorber tube.

3.2. Acrylic Covering for Absorber Tube

The approach is directed at reducing thermal losses by using a covering over the absorber tube. This is achieved for the proposed PTSC using a clear acrylic tube, which is used to cover the stainless-steel absorber tube. The covering is mounted with concentric Teflon rings along the length of the absorber tube to ensure a uniform gap of 4mm. The acrylic covering is sealed at both ends to ensure that a constant air gap is maintained.

The experimentation procedure considers the rise in water temperature as an output parameter. Hence to monitor this output parameter, the inlet and outlet water temperature are measured at regular intervals for every 15 minutes using a thermal probe. The average increase in water temperature is calculated for the operation of a complete day from 11:00 hours to 16:00 hours. Simultaneously, the surface temperature of the absorber tube is monitored using the thermocouple. The test is conducted for flow rates of 0.3, 0.7 and 1.1 litres per minute (lpm) under three conditions. The experimental procedure is followed for each of the approaches individually. The tests have been conducted in a randomized order and each of the tests has been repeated for three trials. This procedure is to account for any variations or errors which can occur during the testing.

4. Results and Discussions

To understand the thermal behaviour of the approaches the temperatures of the fluid and the absorber tube are monitored during the experimental procedure. The results have been compared among the operating conditions of the absorber tube of each factor separately. The increase in fluid temperature describes the heat transfer from the absorber tube to the fluid. Whereas the surface temperature expresses the heat transferred from the parabola to the absorber tube.

4.1. Performance Comparison of Bare Absorber Tube with Covered Absorber Tube

Comparison of the temperature among the bare and the covered absorber tube highlighted significant variation. The average surface temperatures have been monitored with time. The temperature is plotted for different flow rate under both the absorber tube methods. The comparison of the plot is shown in Figure 6.

The comparison plot highlighted that the temperature variation that the heat transfer from the parabola to the absorber tube is affected by the covering. This improvement in heat transfer can be attributed to the reduction of the convective losses occurring during the PTSC operation. The significant variation in the surface temperature with flow rate also pointed that surface temperature can be sensitive to flow rates. The results for the flow rate conditions of 0.3 lpm, 0.7 lpm and 1.1 lpm have been tabulated in Table 1,2 and 3.
Table 1. Average surface and outlet temperatures under bare and covered absorber tube conditions under 0.3 litres per minute rate.

| Time Elapsed (hours) | Flow Rate (lpm) | Bare Absorber Tube | Covered Absorber Tube |
|----------------------|-----------------|--------------------|-----------------------|
|                      |                 | Surface Temperature (°C) | Outlet Water Temperature (°C) | Surface Temperature (°C) | Outlet Water Temperature (°C) |
| 1                    | 0.3             | 50                  | 17.1                  | 93                     | 28.9                  |
| 2                    | 0.3             | 51                  | 16.9                  | 94                     | 29.1                  |
| 3                    | 0.3             | 50                  | 17.1                  | 98                     | 29.8                  |
| 4                    | 0.3             | 50                  | 16.8                  | 95                     | 29.9                  |
| 5                    | 0.3             | 51                  | 17.2                  | 96                     | 29.7                  |
| 6                    | 0.3             | 50                  | 16.9                  | 99                     | 29.8                  |

Table 2. Average surface and outlet temperatures under bare and covered absorber tube conditions under 0.7 litres per minute rate.

| Time Elapsed (hours) | Flow Rate (lpm) | Bare Absorber Tube | Covered Absorber Tube |
|----------------------|-----------------|--------------------|-----------------------|
|                      |                 | Surface Temperature (°C) | Outlet Water Temperature (°C) | Surface Temperature (°C) | Outlet Water Temperature (°C) |
| 1                    | 0.7             | 47                  | 6.7                   | 88                     | 9.3                   |
| 2                    | 0.7             | 47                  | 6                    | 88                     | 8.9                   |
| 3                    | 0.7             | 48                  | 6.5                  | 86                     | 9                    |
| 4                    | 0.7             | 47                  | 6.2                  | 89                     | 9.5                   |
| 5                    | 0.7             | 47                  | 5.9                  | 86                     | 9.5                   |
| 6                    | 0.7             | 48                  | 6.8                  | 87                     | 9.2                   |

Table 3. Average surface and outlet temperatures under bare and covered absorber tube conditions under 1.1 litres per minute flow rate.

| Time Elapsed (hours) | Flow Rate (lpm) | Bare Absorber Tube | Covered Absorber Tube |
|----------------------|-----------------|--------------------|-----------------------|
|                      |                 | Surface Temperature (°C) | Outlet Water Temperature (°C) | Surface Temperature (°C) | Outlet Water Temperature (°C) |
| 1                    | 1.1             | 43                  | 4.2                  | 73                     | 5.6                   |
| 2                    | 1.1             | 42                  | 4                   | 72                     | 5.5                   |
| 3                    | 1.1             | 42                  | 4.1                 | 73                     | 5.7                   |
| 4                    | 1.1             | 43                  | 4.3                 | 77                     | 5.8                   |
| 5                    | 1.1             | 42                  | 4                   | 77                     | 5.6                   |
| 6                    | 1.1             | 43                  | 4.2                 | 76                     | 5.7                   |
The average increase in the water temperature is also plotted with time elapsed for both conditions. The plot is shown in Figure 7, which highlights that the covered absorber tube can be more effective than the bare absorber tube. Both the absorber tubes are found to be very sensitive to the flow rates. Here it can be observed that the increase in temperature improved by an average of 52% as compared to the bare absorber tube.

4.2. Performance Comparison of Bare Absorber Tube with Coated Absorber Tube
Temperature comparison of the bare and coated absorber tubes based on the experimentation over time is tabulated and plotted for varied flow rates. The tabulated data for the flow rates of 0.3 lpm, 0.7 lpm and 1.1 lpm can be observed in Table 4, 5 and 6 respectively. The plot of the variation in surface temperatures with time is shown in Figure 8. The comparison showed that the average surface temperature of the coated absorber tube is having a minimum difference when compared to the bare absorber tube under similar conditions.

Table 4. Average surface and outlet temperatures under bare and coated absorber tube conditions under 0.3 litres per minute flow rate.

| Time Elapsed (hours) | Flow Rate (lpm) | Bare Absorber Tube | Coated Absorber Tube |
|----------------------|-----------------|--------------------|----------------------|
|                      |                 | Surface Temperature (°C) | Rise in Water Temperature (°C) | Surface Temperature (°C) | Rise in Water Temperature (°C) |
| 1                    | 0.3             | 50                 | 17.1                 | 54                   | 36.3                   |
| 2                    | 0.3             | 51                 | 16.9                 | 54                   | 37.5                   |
| 3                    | 0.3             | 50                 | 17.1                 | 52                   | 36.7                   |
| 4                    | 0.3             | 50                 | 16.8                 | 53                   | 34.8                   |
| 5                    | 0.3             | 51                 | 17.2                 | 52                   | 36.4                   |
| 6                    | 0.3             | 50                 | 16.9                 | 53                   | 35.9                   |
Table 5. Average surface and outlet temperatures under bare and coated absorber tube conditions under 0.7 litres per minute flow rate.

| Time Elapsed (hours) | Flow Rate (lpm) | Bare Absorber Tube | Coated Absorber Tube |
|----------------------|-----------------|---------------------|----------------------|
|                      |                 | Surface Temperature (°C) | Rise in Water Temperature (°C) | Surface Temperature (°C) | Rise in Water Temperature (°C) |
| 1                    | 0.7             | 47                  | 6.7                  | 49                  | 11.2                  |
| 2                    | 0.7             | 47                  | 6                    | 50                  | 11.4                  |
| 3                    | 0.7             | 48                  | 6.5                  | 49                  | 11.6                  |
| 4                    | 0.7             | 47                  | 6.2                  | 49                  | 11.4                  |
| 5                    | 0.7             | 47                  | 5.9                  | 50                  | 11.3                  |
| 6                    | 0.7             | 48                  | 6.8                  | 49                  | 11.4                  |

Table 6. Average surface and outlet temperatures under bare and coated absorber tube conditions under 1.1 litres per minute flow rate.

| Time Elapsed (hours) | Flow Rate (lpm) | Bare Absorber Tube | Coated Absorber Tube |
|----------------------|-----------------|---------------------|----------------------|
|                      |                 | Surface Temperature (°C) | Rise in Water Temperature (°C) | Surface Temperature (°C) | Rise in Water Temperature (°C) |
| 1                    | 1.1             | 43                  | 4.2                  | 44                  | 7.4                  |
| 2                    | 1.1             | 42                  | 4                    | 44                  | 6.8                  |
| 3                    | 1.1             | 42                  | 4.1                  | 45                  | 7.4                  |
| 4                    | 1.1             | 43                  | 4.3                  | 44                  | 7.1                  |
| 5                    | 1.1             | 42                  | 4                    | 45                  | 7.3                  |
| 6                    | 1.1             | 43                  | 4.2                  | 45                  | 7.2                  |

Figure 8. Average surface temperature of absorber tube with time - bare and coated condition.

Figure 9. Variation in increase in water temperature for bare and coated condition with time.

The rise in water temperature has been observed and plotted in Figure 9 for both the bare and coated conditions. The plot represented that the water temperature improved significantly under coated conditions. The average improvement of water temperature is found to be 88% with the use of epoxy-graphite coating when compared to the uncoated surface.

The improvement can be attributed to the epoxy-graphite coating which increases the absorptivity of the tube leading to heat transfer to the thermal fluid. From Figure 8 and 9 it can be also observed that the epoxy-graphite coating can achieve higher heat transfer without the rise in surface
temperature. This behaviour can be attributed to improvement in thermal behaviour and limited heat losses occurring due to lower surface temperature and higher heat transfer due to the presence of the coating.

4.3. Performance Comparison of Coated Absorber Tube with Covered Absorber Tube

The coated absorber tube and covered absorber tube use two different approaches to improve the PTSC performance. To compare these approaches, the surface temperatures of the absorber tube and rise in fluid temperatures monitored with time under varied flow rate are observed. The average data has been tabulated for flow rates of 0.3 lpm, 0.7 lpm and 1.1 lpm in Table 7,8 and 9 respectively.

Table 7. Average surface and outlet temperatures under covered and coated absorber tube conditions under 0.3 litres per minute flow rate.

| Time Elapsed (hours) | Flow Rate (lpm) | Covered Absorber Tube | Coated Absorber Tube |
|----------------------|-----------------|------------------------|----------------------|
|                      |                 | Surface Temperature (°C) | Rise in Water Temperature (°C) | Surface Temperature (°C) | Rise in Water Temperature (°C) |
|                      | 0.3             | 93                     | 28.9 | 54 | 36.3 |
|                      | 0.3             | 94                     | 29.1 | 54 | 37.5 |
|                      | 0.3             | 98                     | 29.8 | 52 | 36.7 |
|                      | 0.3             | 95                     | 29.9 | 53 | 34.8 |
|                      | 0.3             | 96                     | 29.7 | 52 | 36.4 |
|                      | 0.3             | 99                     | 29.8 | 53 | 35.9 |

Table 8. Average surface and outlet temperatures under bare and coated absorber tube conditions under 0.7 litres per minute condition.

| Time Elapsed (hours) | Flow Rate (lpm) | Covered Absorber Tube | Coated Absorber Tube |
|----------------------|-----------------|------------------------|----------------------|
|                      |                 | Surface Temperature (°C) | Rise in Water Temperature (°C) | Surface Temperature (°C) | Rise in Water Temperature (°C) |
|                      | 0.7             | 88                     | 9.3 | 49 | 11.2 |
|                      | 0.7             | 88                     | 8.9 | 50 | 11.4 |
|                      | 0.7             | 86                     | 9    | 49 | 11.6 |
|                      | 0.7             | 89                     | 9.5 | 49 | 11.4 |
|                      | 0.7             | 86                     | 9.5 | 50 | 11.3 |
|                      | 0.7             | 87                     | 9.2 | 49 | 11.4 |
Table 9. Average surface and outlet temperatures under bare and coated absorber tube conditions under 1.1 litres per minute condition.

| Time Elapsed (hours) | Flow Rate (lpm) | Covered Absorber Tube | Coated Absorber Tube |
|----------------------|-----------------|------------------------|-----------------------|
|                      |                 | Surface Temperature (°C) | Rise in Water Temperature (°C) | Surface Temperature (°C) | Rise in Water Temperature (°C) |
| 1                    | 1.1             | 73                     | 5.6                   | 44                     | 7.4                   |
| 2                    | 1.1             | 72                     | 5.5                   | 44                     | 6.8                   |
| 3                    | 1.1             | 73                     | 5.7                   | 45                     | 7.4                   |
| 4                    | 1.1             | 77                     | 5.8                   | 44                     | 7.1                   |
| 5                    | 1.1             | 77                     | 5.6                   | 45                     | 7.3                   |
| 6                    | 1.1             | 76                     | 5.7                   | 45                     | 7.2                   |

A plot of the average surface temperature of the absorber tube with time is shown in Figure 10. The comparison showed that the average temperature of the coated absorber tube is having a considerable difference when compared to the covered absorber tube under similar conditions.

The surface temperature variation highlighted that the covered approach utilized solar energy to heat the stainless steel and the covering maintained the high temperature by reducing the losses. Whereas, the low surface temperature of coating showed that the coating is effective in not only receiving the heat but transferring the heat into the absorber tube over which it is coated.

![Figure 10. Average surface temperature of absorber tube with time - covered and coated condition.](image1)

Figure 10. Average surface temperature of absorber tube with time - covered and coated condition.

![Figure 11. Variation in increase in water temperature for covered and coated condition with time.](image2)

Figure 11. Variation in increase in water temperature for covered and coated condition with time.

The plot of the variation in the rise of water temperature under the coated and covered conditions with time is shown in Figure 11. The variation highlight that the coated approach provides a considerable improvement in water temperature over the covered conditions. It can be observed that an average improvement of 24% can be observed with a coated approach over the covered approach. This improvement can be attributed to the improved heat absorption and heat transfer to the fluid of the absorber tube due to the enhancement with epoxy-graphite coating.

The overall comparison of the average rise of fluid temperatures has been compared in Table 10 and Figure 12. This highlights that such approaches on absorber tube can affect the performance of the absorber tube significantly, and can be effective at low flow rates. The overall comparison also suggests that the epoxy-based graphite coating to be effective over the acrylic covering approach. This can be attributed to the improvement in heat absorption of the absorber tube by the presence of graphite in the coating leading to effective heat transfer to the water within the absorber tube. Hence providing a simple and effective approach to improve the performance of the PTSC.
Table 10. Overall performance comparison.

| Approach                                      | Thermal Fluid Temperature Difference (°C) |
|----------------------------------------------|------------------------------------------|
|                                              | 0.3 lpm  | 0.7 lpm  | 1.1 lpm  |
| Bare Absorber Tube                          | 17.6     | 6.7      | 4.2      |
| Acrylic Covered Absorber Tube               | 29.3     | 9.4      | 5.8      |
| Epoxy based Graphite Coated Absorber Tube   | 36.3     | 11.5     | 7.3      |

5. Conclusions
An experimental study is performed using PTSC to understand the use of epoxy-based graphite coating for the absorber tube. The coating performance on the absorber tube is compared against a similar uncoated and acrylic covered absorber tube under various flow rates. An average increase of 96% and 28% in water temperature is achieved by the epoxy-graphite coating over a bare absorber tube and acrylic covered absorber tubes respectively. This suggests that the epoxy graphite coating can be an effective method to improve the PTSC performance.

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