PERFORMANCE EVALUATION OF SMALL SCALE PARABOLIC TROUGH SOLAR THERMAL COLLECTOR FOR SOLAR COOLING APPLICATIONS

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ABSTRACT: In this work, design, construction and experimental study of a simple parabolic trough solar collector have been conducted under the local climatic conditions for low-temperature applications. A small scale parabolic trough solar collector with 1.12m aperture, 2.5 m length and 90° rim angle has been developed with the locally available materials using the stainless steel sheet as the parabolic reflector and copper tube as the absorber/receiver. It has been outdoor tested at TKM College of Engineering, Kollam for the performance evaluation with and without glass cover. When glass cover is used over the absorber tube, the heat gained by the working fluid is observed to increase by 23.8% than that without a glass cover. The physical output indicates that by using an envelope glass to the absorber tube, high-temperature water can be produced for efficient hot water applications, in which working temperature of the system is lower than that of the hot water supply.

Keywords: Parabolic trough, Solar collector, Heat transfer fluid

INTRODUCTION

Concentrated solar power has great potential to utilize solar energy more efficiently than other solar systems. Parabolic Trough Collector found to have better efficiency with higher concentration ratios and effective conversion of solar energy. Parabolic trough solar collector is a line-focus solar thermal energy concentrator that reflects a larger area of beam solar radiation onto an absorber tube of smaller area with minimum loss. The collector surface focuses radiant energy from the sun on an absorber tube, and this is transmitted to working fluid. The metallic absorber tube is coaxial with the focal line of the parabolic reflector and has a glass covering to minimize the heat loss as shown in Fig.1. The performance of these parabolic collectors strongly dependent on the solar insolation available in the area where these collectors are installed. It is well recognized that insolation from the sun differs depending on the geographical position; therefore, it is necessary to consider the above in design, manufacture and functioning of solar thermal collectors.

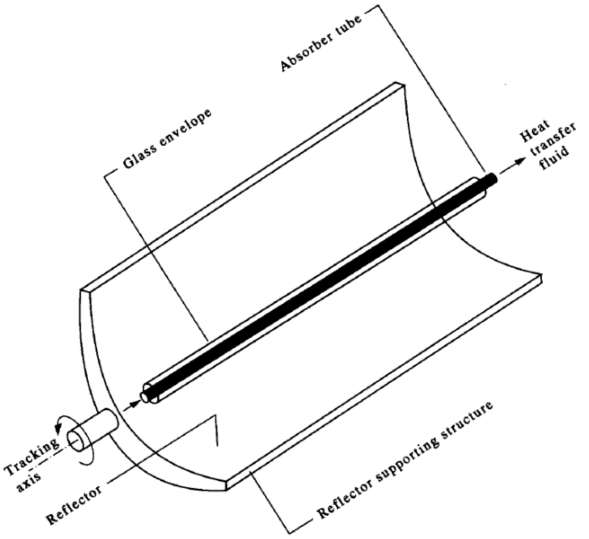

Fig.1. Parabolic trough solar collector(Thomas and Guven, 1993)

The advance of parabolic concentrated solar technology is constrained by large twisting moment, low useful heat gain and large initial investment. Hence the primary challenges with the parabolic solar concentrating technology are that minimizing the overhead of each part and enhancing the core technologies.(Kalogirou, 2002).

Solar thermal energy is commonly used up to medium temperature in sectors such as chemicals, fabrics, paper and food preparation. The main application includes Heating Ventilation and Air Conditioning (HVAC), solar distillation, drying, disinfecting and steaming. Hot water at 80 to100°C can be used either for pre-heating water (or other fluids), for household processes (washing, drying, etc.) for steam generation, or by direct coupling of the solar system, for individual processes in which working temperatures are lower than that of the hot water supply(Venegas-Reyes *et al.*, 2012). For low-temperature applications, the soil sterilization has excellent potential. Disinfection of soil using steam or warm water at a temperature ranging from 70 to 110°C in agriculture is nowadays getting great attention due to no ecological impact. .(Dabbene, Gay and Tortia, 2003)(Berruto *et al.*, 2004)(Gay *et al.*, 2010b)(Gay *et al.*, 2010a). Currently methyl bromide, which is harmful to stratospheric ozone is widely used for soil disinfection process and it will shortly be expelled in several countries. In this circumstances, soil disinfection using hot water represents a sustainable alternate to the use of methyl bromide.(Venegas-Reyes *et al.*, 2012). In addition to being used directly in heating, solar energy can also be used to power different cooling systems. By combining solar thermal energy with state-of-the-art adsorption technology, heat can be used to cool our houses as the sun supports thermal processes to produce cold for air-conditioning or directly drive a thermal heat-pump. For the adsorption cooling system, the ordinary working pairs are water-silica gel, water-zeolite and water-$CaCl_2$ etc. The regeneration temperature needed is between 60°C to 120°C, and the respective COP is 0.3 to 0.6 (Ge *et al.*, 2018).

The goal of this paper is to develop a small, light, rigid and low-cost solar technology to provide 70-120 ° C warm water that can be used for solar cooling, laundry, food processing, soil disinfection, other hot water applications in the kitchen sink and covering the requirements of the toilet, basin and shower. The advantage of this small trough is that it is relatively low weight and more comfortable to handle and can even be installed on roofs.

COLLECTOR DESIGN

A commercially available stainless steel sheet 2.5 m x 1.285 m was chosen as reflecting surface. The primary objective in this collector's design and construction was to demonstrate that a stable, effective parabolic profile was ensured on the reflective surface. (J.E. Shigley, 1986). The geometrical parameter of a parabolic trough solar collector is shown in the Fig.2.

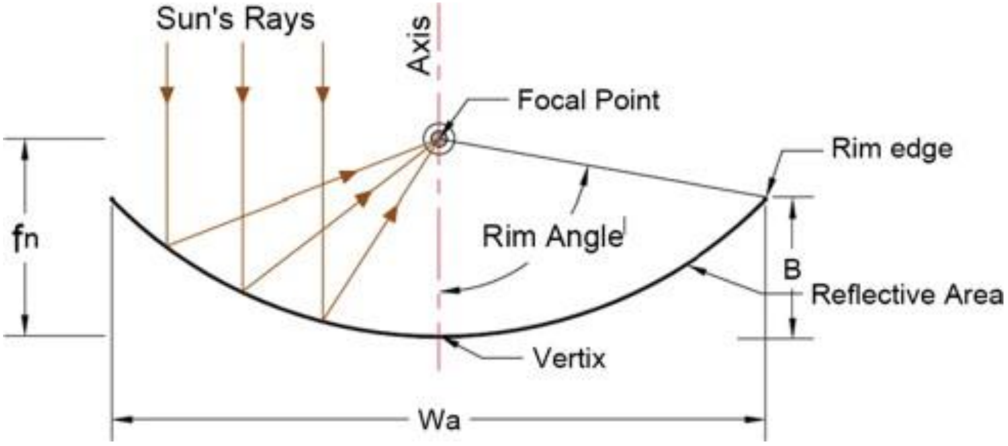

Fig.2. Nomenclature of Parabolic trough solar collector(Mokheimer *et al.*, 2014)

The ratio between the effective collector area and the surface area of the absorber tube is called the geometrical concentration ratio(JA Duffle, 2006). The equations of parabola involved in the design are(Kalogirou, 2009):

$$\mathrm{w_a} = \frac{2S\tan(\frac{\varphi_r}{2})}{(\sec(\frac{\varphi_r}{2})\tan(\frac{\varphi_r}{2})+\ln(\sec(\frac{\varphi_r}{2})+\tan(\frac{\varphi_r}{2})))} \quad (1)$$

$$\mathrm{fn} = \frac{\mathrm{w_a}}{4\tan(\frac{\varphi_r}{2})} \quad (2)$$

$$c = \frac{\mathrm{w_a}}{\pi D_o} \quad (3)$$

Where $\mathrm{w_a}$ is the aperture width of the concentrator, S is the width of the stainless steel sheet (arc-length), φ_r is the rim angle, fn is the focal length, c is the geometric concentration ratio and D_o is the outer diameter of the absorber. Assuming rim angle φr = 90°, in order to minimize the distance between the focal line and reflector and hence the optical losses.(Kalogirou, 2009), and solving the equations, would results an aperture width(w_a) 1.12m, focus(fn) 0.28 m and a geometric concentration ratio(c) of 11.88. The selected data of the designed parabolic trough collector has the following values, as shown in Table 1.

The material used for the absorber tube was copper with an absorptance of 0.89. It has been used because of its thermal conductivity characteristics, specific heat and is highly desirable and preferable to be used as an absorber/receiver tube in a parabolic trough solar thermal collector(Shinde and Sagade, 2016). The diameter of the absorber can be calculated as a function the half acceptance angle, the distance from the focus to the vertex and the rim angle as reported in(Kalogirou, 2004). However, in this work, the diameter was selected to reduce construction costs by considering the commercially available copper tube. The collector type selected was a non-evacuated tube with the benefit of being easier to construct as evacuated tubes require manufacturing precision, resulting in increased material costs(Kumar and Kumar, 2015).

Table 1: Geometrical data of the parabolic trough collector.

Parameter	Value
Rim angle	90°
Focal length (m)	0.28
Aperture width (m)	1.12
Length of the parabolic trough (m)	2.50
Inner diameter of absorber tube (m)	0.028
Outer diameter of absorber tube (m)	0.030
Inner diameter of the glass tube (m)	0.046
Outer diameter of the glass tube (m)	0.050
Collector aperture area (m^2)	2.80
Geometrical concentration ratio	11.88

Available support structures vary from small aperture width to larger ones. Total deflections and loads due to entire trough weight and wind loads and cost are two essential guides for proper design (JA Duffle, 2006). A simple structure is selected rather than a complex one and constructed simply. The structure is made of three rectangular galvanized iron tubes and four parabolic ribs which have a wide range of standard sizes and are easy to fabricate by electric arc welding. In the manufacture of this parabolic trough, there is no requisite for advanced equipment or expert labour. Figure 3 shows the schematic outline of the experimental configuration of the fabricated solar concentrator.

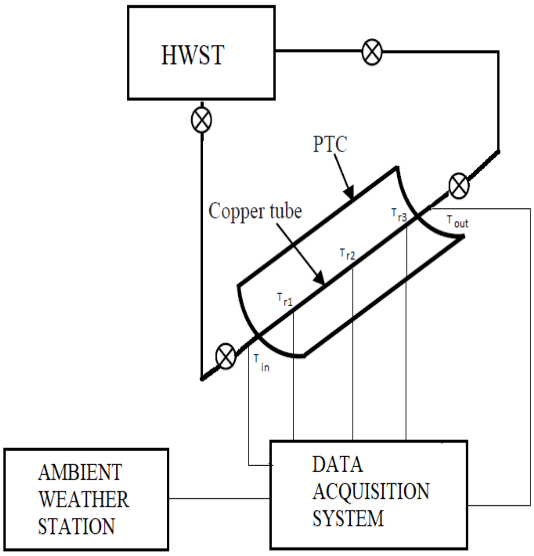

Fig.3. Schematic diagram of the test setup.

SYSTEM DESCRIPTION

In this work, design, construction and thermal evaluation of a parabolic trough collector with a rim angle of 90°, a length of 2.50 m, and an aperture area of 2.8 m^2 has been carried out. The copper absorber tube is having an inner diameter of 0.028 m and an outer diameter of 0.030 m within which the heat transfer fluid (water) naturally circulated from an overhead hot water storage tank [HWST]. The 50-litre storage tank was placed next to the parabolic collector, in a position which does not project a shadow on it. A view from the experimental setup is shown in Fig.4.

Fig.4 The solar collector setup.

The parabolic solar collector with copper absorber has been experimentally evaluated with and without glass envelope. The space between the copper tube and glass jacket was not evacuated due to cost constraints. The glass cover is having a transmittance of 0.95, emittance of about 0.84, an inner and outer diameter of 0.046m and 0.050m respectively. To receive maximum radiation supplied by the sun without solar tracking, the trough was oriented east-west. It needs daily adjusting the sun motion. K-type thermocouples with extension grade wires with an operating range of 0°C to 200°C and accuracy of ±1°C, were connected to measure both the temperature of the working fluid at the entrance and exit of the absorber tube and absorber surface temperature simultaneously. Ambient temperature, wind speed and direct normal solar irradiance during the test were recorded by using the Ambient Weather WS-2902A weather station installed nearby the location [Fig.5].

Fig.5. Ambient weather station WS-2902A

System performance assessment was conducted on 4th April 2019 for absorber without glass envelope and on 13th April 2019 for absorber with a glass envelope.

EXPERIMENTAL DATA COLLECTION AND CALCULATIONS

Recorded daytime ambient temperature and solar radiation from 6 hours to 18 hours on 4th April 2019 and 13th April 2019 and detailed in Fig. 6. The peak radiation was showered plot indicates that at 10.00 hours to 13.00 hours. Fig. 6(a) and 6(b) present the measured parameters at periodic intervals of the day. K-type thermocouples were used for the measurement of inlet and outlet water temperature of the absorber of the solar collector. The outside wall temperature of the absorber was also measured by K-type thermocouple.

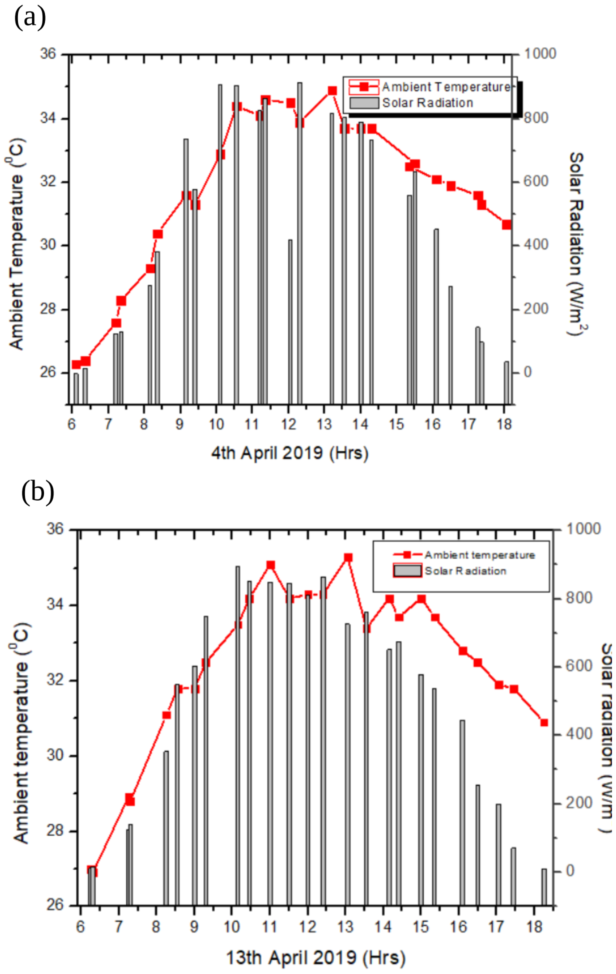

Fig.6. Solar radiation and ambient temperature on (a) 4th April 2019 (b) 13th April 2019.

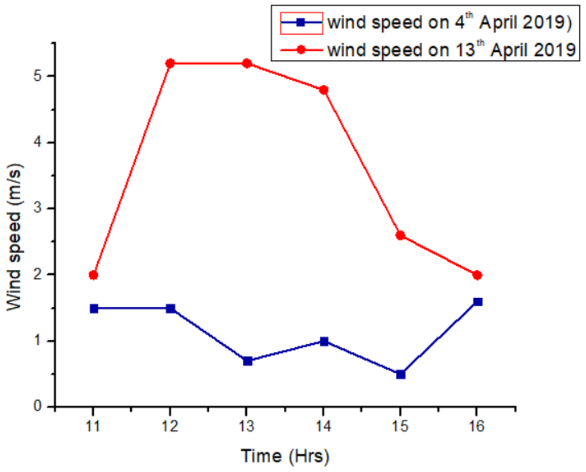

Fig. 7. Wind speed with time.

The PTC evaluation was carried outdoor and started at 10.00 hours and terminated at 16.00 hours local time. The Fig.8 shows the behaviour of inlet and outlet water temperatures concerning solar radiation and time for both with and without glass enveloped absorber. It is observed that the temperature gained by the working fluid with glass enveloped absorber is always higher. For the absorber without a glass cover, the maximum temperature of water at the outlet of the absorber was 60°C at 13 hours with a global beam radiation of 816.8 W/m^2 and the least was 46°C at 10 hours with a global beam radiation of 907.5 W/m^2. The weather conditions were partly cloudy and windy on the second day of the evaluation, as shown in the Fig.6 (b) and Fig.7. Even though, for the parabolic trough collector absorber with a glass envelop, the maximum output water temperature of 77°C at 13 hours has been recorded with a beam radiation of 717.3 W/m^2, the least value recorded was 51°C at 10 hours with a beam radiation of 891 W/m^2.

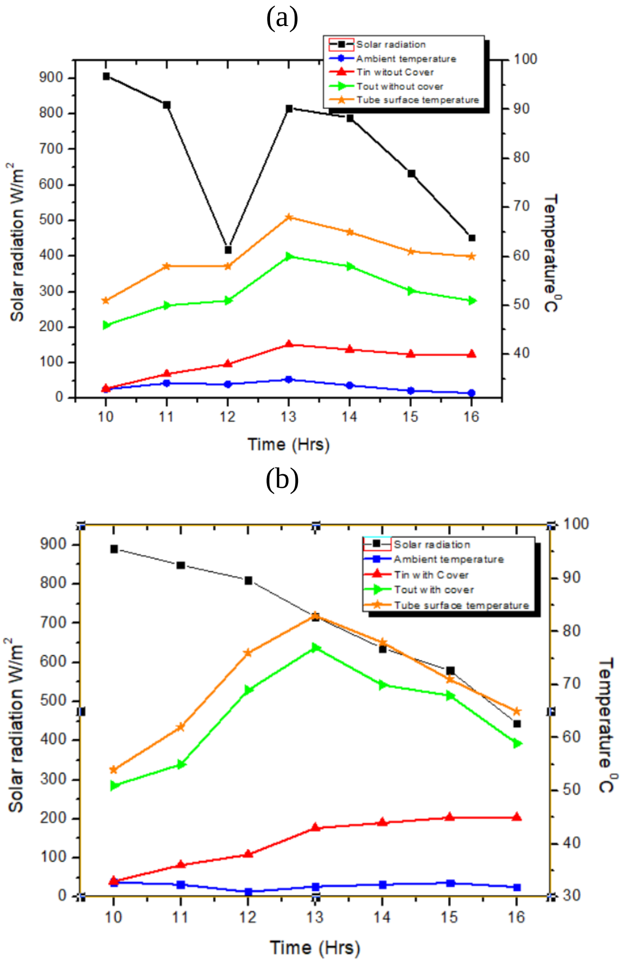

Fig.8. variation of inlet, outlet and absorber temperature with time and solar radiation (a) without glass cover (b) with a glass cover

During, experimentation period all the three temperatures, i.e. inlet water temperature, outlet water temperature and absorber tube temperature, increased in the same manner as illustrated in Fig.9.

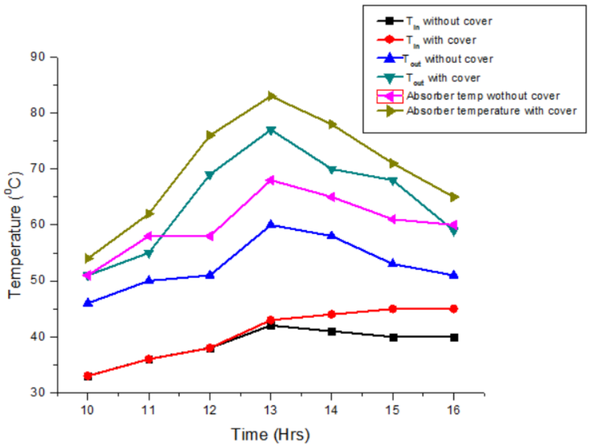

Fig.9. water inlet, outlet and absorber tube temperature as a function of experimentation time.

Outlet water temperature increased with respect to time to some extent and gradually fell after 13.00 hours. This gradual temperature reduction after 13.00 hours is due to the uninsulated piping and storage tank used, as shown in Fig.4 in the experimental setup. However, by keeping the retention level of the system by adequate insulation, the temperatures could be preserved constant. From Fig.4, it is clear that absorber temperature is a function of solar radiation. The absorber experiences more convective heat losses when the absorber is exposed to the atmosphere than the absorber with a glass cover. The leading cause of thermal loss is due to the gradation of temperature between the absorber and the ambient and, wind speed, thus increasing the convective and radiative heat losses from the absorber (Sagade, Aher and Shinde, 2013). Due to its high transparency, the glass envelope concentrates more solar energy on the absorber and minimizes energy losses to the surrounding by using the insulator property. It has been noted that the absorber temperature has been increased by 18 per cent with a glass cover, which ensures a hotter temperature of the water at the outlet. The temperature of the hot water supplied by the solar collector is observed to increase by 24.28 per cent when glass cover is used over the absorber tube. Figure 9 demonstrates that high temperature can be achieved with a glass-covered absorber. Figure10 (a) and 10(b) shows the collected data of absorber surface temperature and temperature of the outlet water with respect to solar radiation, with and without glass envelope. The solar flux has declined considerably when the time has passed 14.00, whereas the temperature of the outlet water remains well above 55^{0}C for the collector with a glass enveloped absorber tube. On the second day of evaluation of the collector with a glass enveloped absorber, there was a 16% reduction in solar radiation and a 71% more in wind speed. However, the maximum temperature of the supply water by the absorber with glass cover increased by 24.28% and the maximum absorber surface temperature increased by 18%.

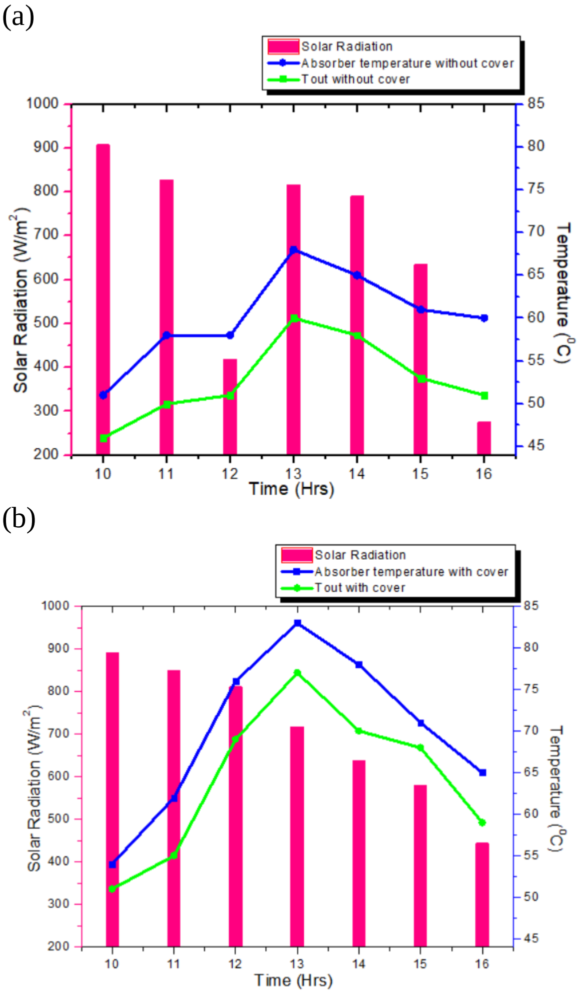

Fig. 10. (a) Absorber surface temperature with and without glass cover (b) water outlet temperature with and without glass cover

This study explains the effect of a glass enveloped absorber on a simple, low-cost PTC to produce hot water. In many industrial, domestic and rural applications, low concentration solar collectors can supply hot water or process heat(Soudani *et al.*, 2017).

CONCLUSIONS

In the present work, design, fabrication and performance evaluation of a small scale parabolic trough solar thermal collector has been conducted with and without a glass envelop on the absorber. The results showed that the useful heat gain increases as the solar radiation increases. It is also observed that the heat gain of a glass enveloped absorber system is more than the heat gain through the bare absorber system because the bare absorber experiences heavier convective losses than the absorber with the glass envelop. The water temperature at the outlet of the absorber with a glass cover reached 77°C, and it was about at13.00 hour after the point of maximum solar radiation flux. It was shown that this simple, low-cost parabolic solar thermal collectors could be effectively used to provide thermal energy for industrial process applications, solar cooling, as well as domestic heating even in days with cloudy periods. However, taking into account the temperature interval in which this parabolic trough collector operates (between 50 to 770C), which is indented for solar cooling, it is necessary to augment the thermal availability by adding thermal coating on the absorber tube, antireflection treated glazing on the glass cover, adding tank and piping insulations, together with solar tracking.

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