Study of the Impact of Automatic Backflush on Direct SDHW Thermosyphon Systems

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Abstract

Thermosyphon solar water heaters are often deployed in regions where freezing ambient conditions do not occur, allowing potable water from the storage tank to be directly circulated through the solar collectors. In many regions "hard water" conditions exist where dissolved minerals can deposit on hot surfaces within the solar collector's flow tubes, restricting the flow of water and resulting in increasing collector temperatures. A recent development aims to alleviate this condition by introducing a novel flow configuration and valving system that reverses the flow of cold "mains" water through the solar collectors each time hot water is drawn from the system. This flushes the collector, and the regular introduction of cooler "mains" water significantly reduces the potential of hardwater scaling in the solar collectors. This study investigates the effect of this flow reversal on the energy delivered to the end user through a side-by-side comparison of two thermosyphon solar systems; one with the backflush feature and one without.

Keywords: thermosyphon, backflush, valve, SDHW

1 Introduction

Thermosyphon solar water heaters have existed for over a century as an inexpensive and simple method to heat domestic water and other process fluids (Ragheb, 2014). These systems typically consist of solar thermal collectors that circulate water from elevated thermal storage during charging. A feature of thermosyphon systems is the low parasitic energy consumption, as buoyancy forces in heated solar collectors cause the circulation of water, to and from an elevated thermal storage. Most of these systems are deployed in regions where freezing ambient conditions do not occur, allowing potable water from the storage tank to be directly circulated through the solar collectors. In many regions, however, "hard water" conditions exist where dissolved minerals in the water supply can deposit on hot surfaces within the solar collector's flow tubes, restricting the flow of water and resulting in increasing collector temperatures (Arunachala et al., 2009). If this condition is allowed to continue, flow through the solar collectors will be restricted such that solar collectors stagnate, potentially damaging the system components and causing systems to over-temperature.

A recent development aims to alleviate this condition by introducing a novel flow configuration and valving system that reverses the flow of cold "mains" water through the solar collectors each time hot water is drawn from the system. This configuration allows a thermosyphon system to provide heat normally while reversing the flow direction within the collector when there is a draw of hot water, Fig. 1. This flushes the system, and the regular introduction of cooler "mains" water significantly reduces the potential of hardwater scaling in the solar collectors. This approach was previously applied to backflushing plate style heat exchanger (Harrison, 2005). This study investigates the effect of flow reversal in thermosyphon solar systems on the energy delivered to the end user, through a side-by-side comparison of two thermosyphon solar systems; one with the backflush feature and one without.

2 Methodology

Two identical direct thermosyphon systems were set up, one with the flow reversal (automatic backflush) feature and the other without, as a baseline system, Fig. 2. Programmed hot-water draws were made on the systems at regular intervals. The systems were controlled with an NIST DA system to draw water from the thermosyphon tanks using a United States Department of Energy specified draw schedule of 120 liters/day (Tab. 1). The equation used for calculating delivered energy can be found below, (eq.1).

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Each system was supplied by mains water and included a 110 L horizontally mounted tank on top of the collector. Each tank contained a temperature probe, containing 8 thermocouples, to measure temperatures vertically at 5 cm intervals. This allowed measurement of the degree of stratification and the impact of backflushing on stratification within the tank. No diffusers or baffles were used on the inlet water pipes to aid stratification. The system also included a pyranometer and other thermocouples to measure the inlet, outlet, and ambient conditions.

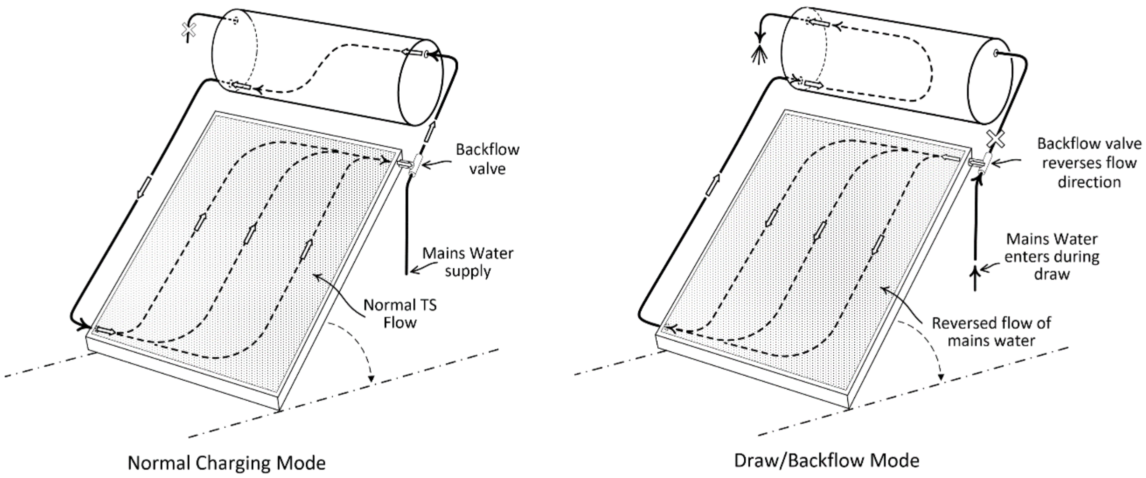

Fig. 1: Illustration of backflush operation during charge and discharge operation.

Check valves on the inlet to each system were installed and a 10-minute delay was set between the hot water withdrawal from each system to prevent mixing and to allow each system to receive full mains pressure and flow. Each draw consisted of three parts: (1) a pre-draw that flushed the exterior mains line, thus cooling the water and ensuring similar inlet water temperatures for both systems; (2) a draw from the backflush system and (3) an identical draw from the baseline system. A Supervisory Control and Data Acquisition (SCADA) system was set up in LABVIEW™ to gather data, view current conditions, and change system operating parameters as required. This setup allows a high degree of versatility, and users can change the automatic draw schedule on an hourly basis.

The system was set up in the summer of 2023 and operated until late October. It was then drained for the winter and restarted in May 2024. The energy performance results are from the 2023 testing period and the impact of higher flow rates were taken from the 2024 testing period. The system is currently operating under varied operating conditions.

Fig. 2: Installation of identical thermosyphon domestic hot water heaters installed for testing.

2.1 Energy Calculation Equation

$$Q = \int \dot{Q}.dt = \int \dot{m}.c_w.(T_{delivered} - T_{mains\ in}).dt \qquad \text{(eq. 1)}$$

where: Q: is the energy delivered (kJ) over the draw period

$\dot{Q}$ is the power delivered (kW) over the draw period

$\dot{m}$ is the mass flow rate of water (kg/s), calculated from water volumetric flow rate ($\dot{V}$) and density

$T_{delivered}$ is the water temperature at the outlet (°C)

$T_{mains\ in}$ is the water temperature at the inlet (°C)

c_w is the specific heat capacity of water (kJ/kg. K)

T is the time interval between each reading (i.e. scan rate). In this DA system, t=0.5s

The density and specific heat capacity of water are calculated based on the water average temperature. (($T_{delivered}$ +$T_{mains\ in}$) / 2).

Tab. 1: U.S Department of Energy small draw profile in liters, (L).

Draw Schedule												
Time (h:mm)	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00
Draw Volume (L)	0	0	0	0	0	1.82	10.91	12.73	10.91	7.28	7.28	5.46
Draw Schedule												
Time (h:mm)	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
Draw Volume (L)	5.46	3.64	1.82	3.64	5.46	5.46	7.28	9.09	7.28	5.46	5.46	3.64

3 Results

Over a 23-day testing period, the results showed a 0.12% increase in the energy output from the system equipped with the automatic backflush feature when compared to the baseline thermosyphon system, Fig. 3. The results of this test indicate that the automatic backflush valve configuration had no apparent impact on the delivered energy when subjected to daily hot water draws consistent with normal usage patterns. A review of delivery hot water temperatures and stratification temperatures in the hot water tanks indicated insignificant differences between the system equipped with automatic backflush and the baseline system.

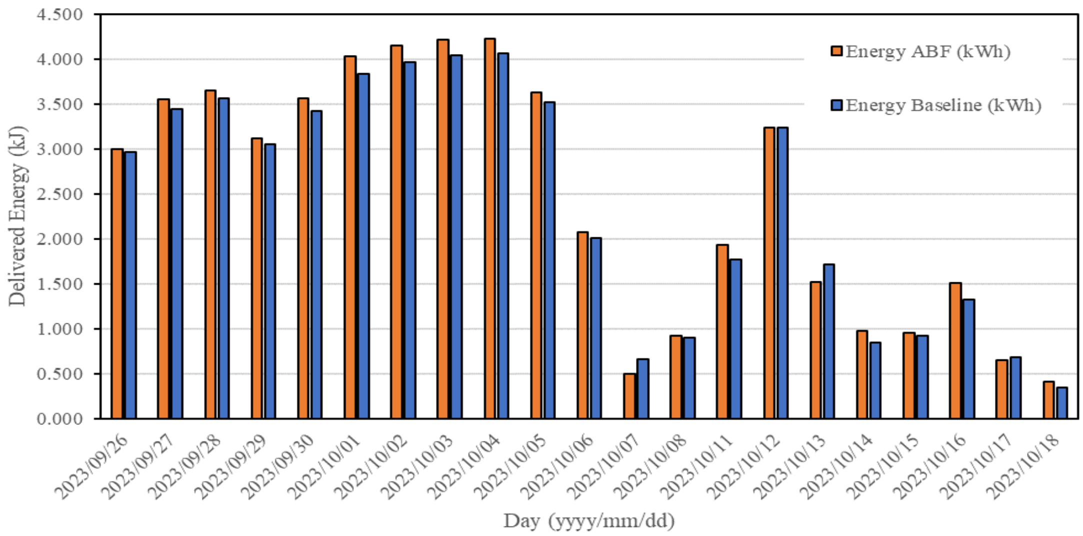

Fig. 3: Comparison of daily energy delivered by the ABF and baseline thermosyphon systems over a 22-day period.

It was also observed that the backflush operation had no significant impact on the thermosyphon flow rate as compared to the baseline, Fig. 4 & 5, and the system had no issue restarting its buoyancy-driven flow after a backflush, as seen in the IR pictures of a 1-minute backflush at 0.26-liter s^{-1} (16 liters/min). At the end of the backflush, the collector resumed its thermosyphon flow in 1-2 minutes under optimal solar irradiance conditions (clear sunny day, at 11:30 am, with approximately 1000 W/m^2), Fig. 6.

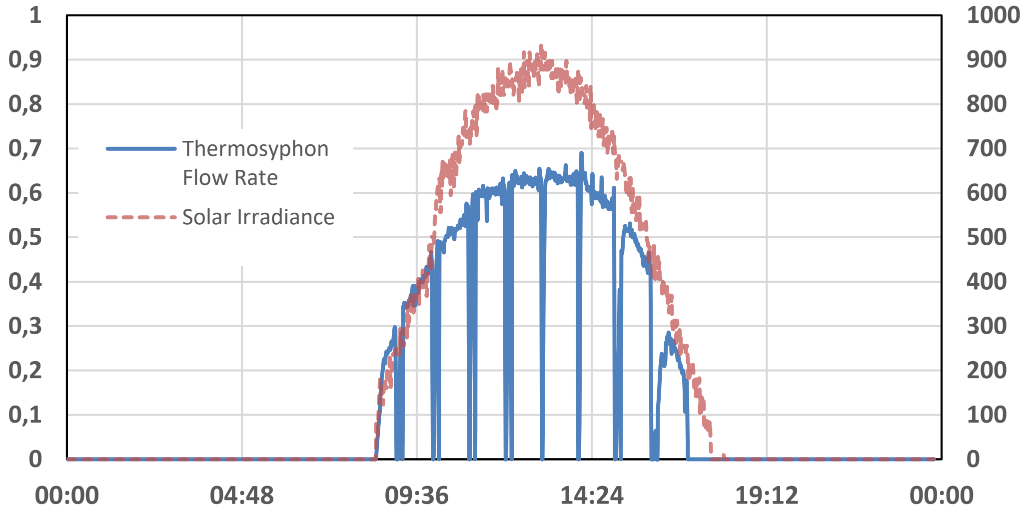

Fig. 4: Thermosyphon flow rate (liters/min) & solar irradiance (W/m^2) vs. time (sunny clear sky). Automatic Backflush valve installed and draw profile during operation.

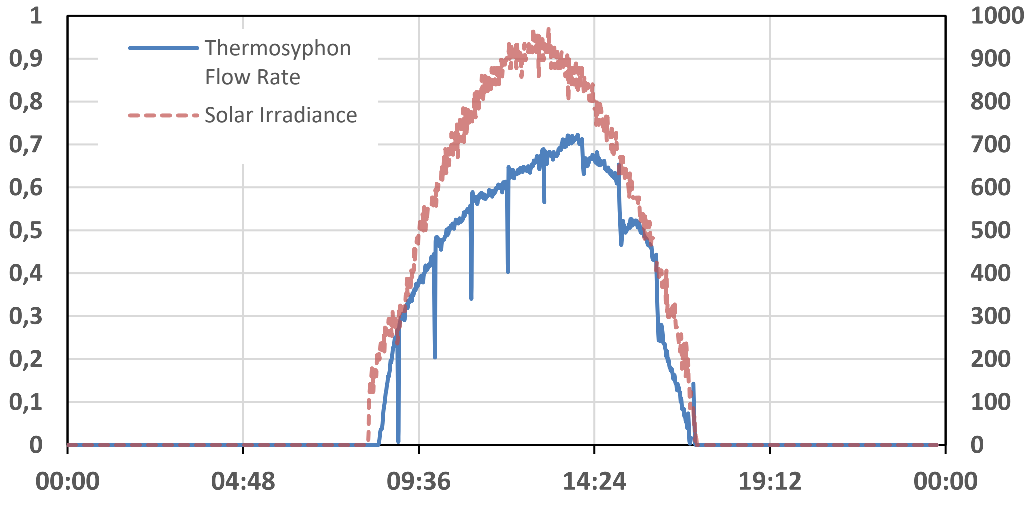

Fig. 5: Thermosyphon flow rate (liters/min) and solar irradiance (W/m^2) vs. time (clear sunny day) without Automatic Backflush valve installed and draw profile during operation.

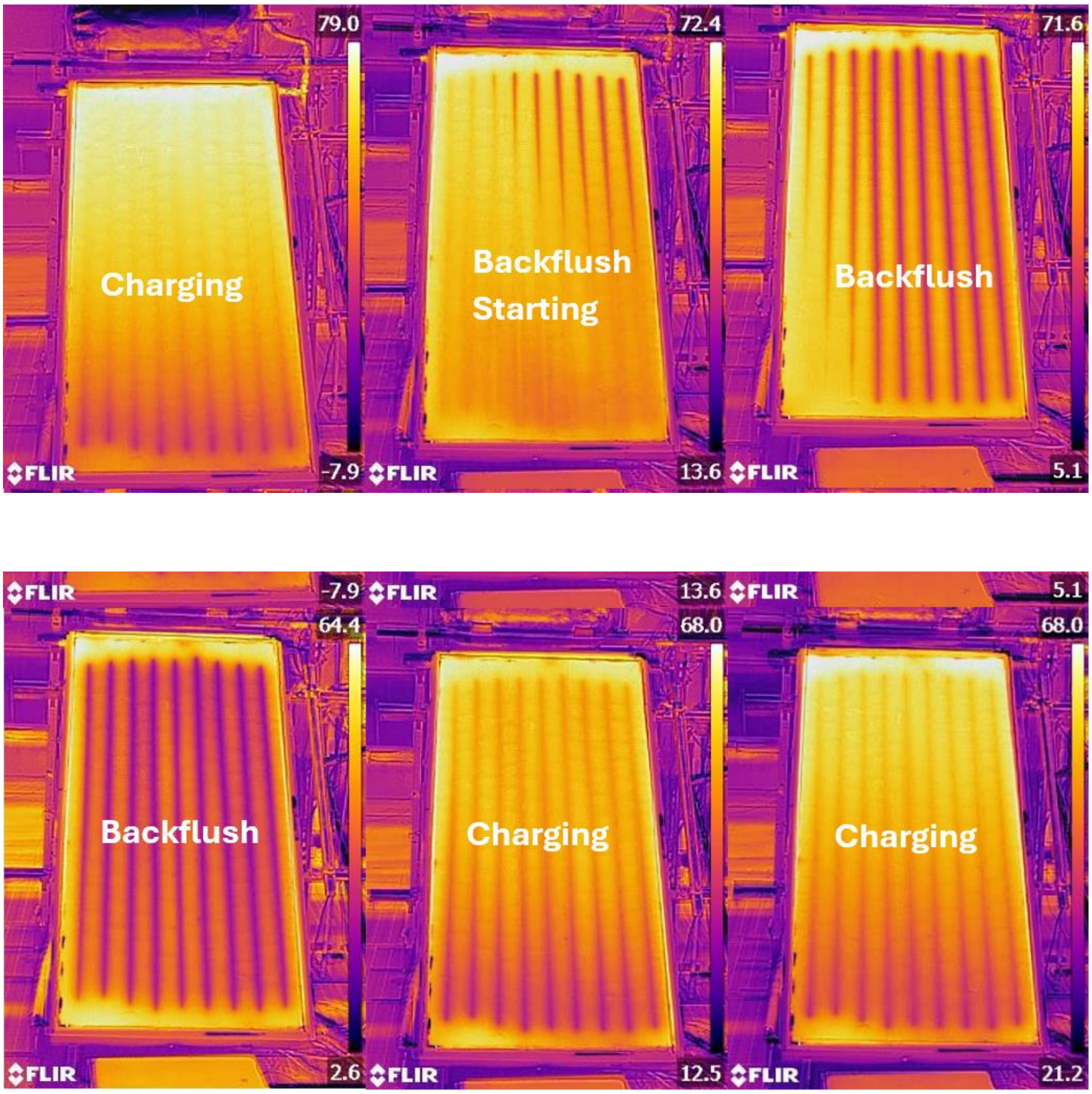

Fig. 6: Backflush through a solar thermal collector with an IR camera. The draw was conducted at 6L/min for one minute. The total time of the test was 4 minutes.

Stratification in the tank was also a key indicator of the energy performance, and thus, the temperatures in the tanks were compared. Tests were conducted at 2 flow rates: 0.1 liters s^{-1} (6 liters/min) Fig. 7 & 8 and 0.166-liters s^{-1} (10 liters/min), Fig. 9 & 10. The results indicated that backflushing had virtually no impact on the stratification in the tank at 0.1 liters s^{-1} (6 liters/min). At 0.166 liters s^{-1} (10 liters/min), there is minimal impact, but with a less than 1% difference in energy delivered in a 24-hour period.

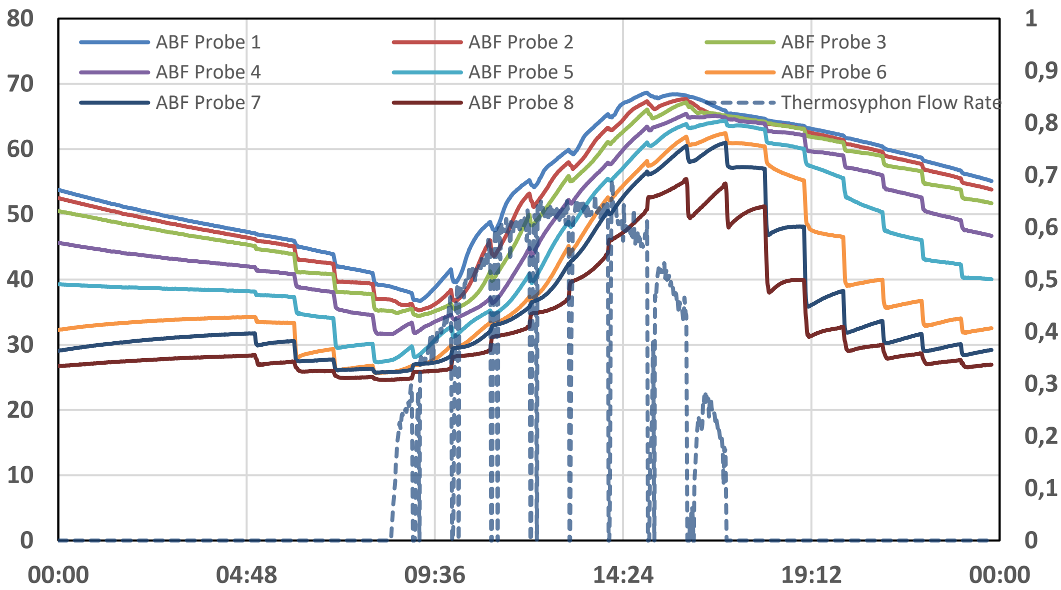

Fig. 7: Tank temperatures (°C) in the backflush system with thermosyphon flow rates shown on the right under high solar irradiance conditions with a draw flow rate of 0.1 liters s^{-1} (6 liters/min). The spikes represent hourly draws/backflushes as per DOE. Draw profile.

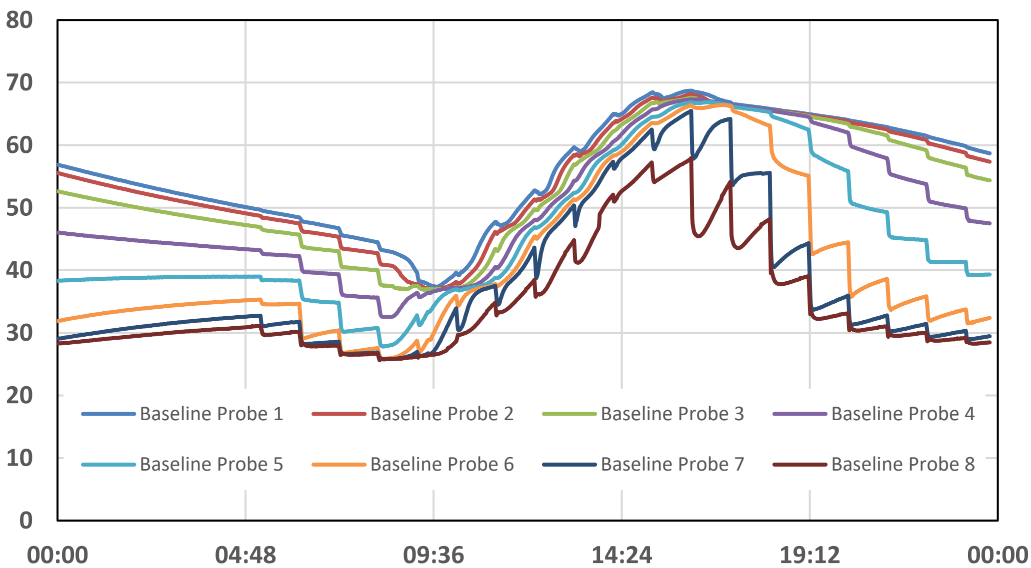

Fig. 8: Baseline thermosyphon tank temperatures (°C) vs. Time under high solar irradiance with a flow rate of 0.1 liters s^{-1} (6 liters/min).

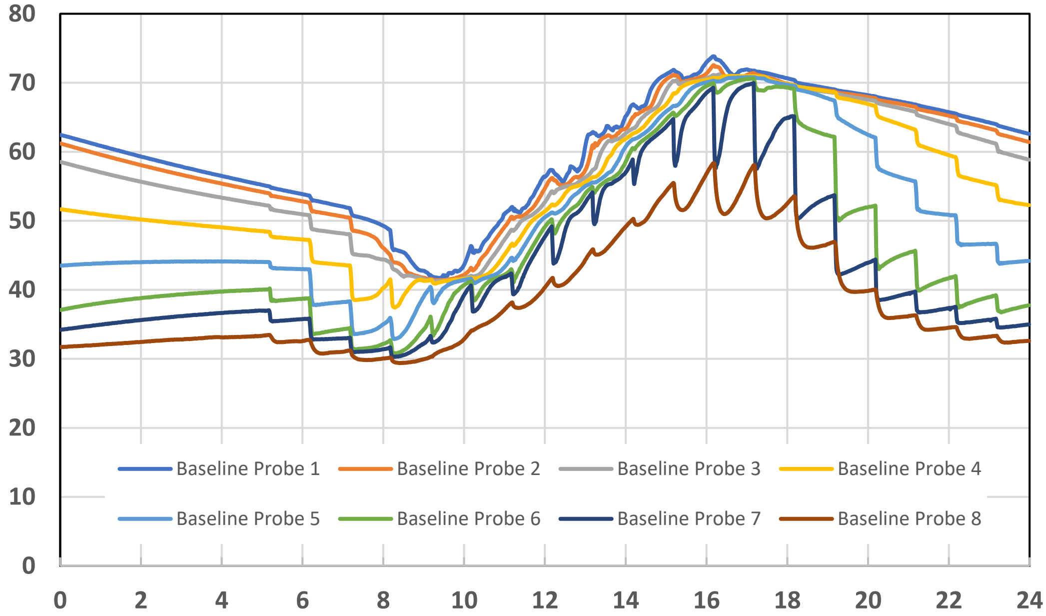

Fig. 9: Baseline thermosyphon tank temperatures (°C) vs. Time under high solar irradiance with a flow rate of 0.1 liters s^{-1} (6 liters/min).

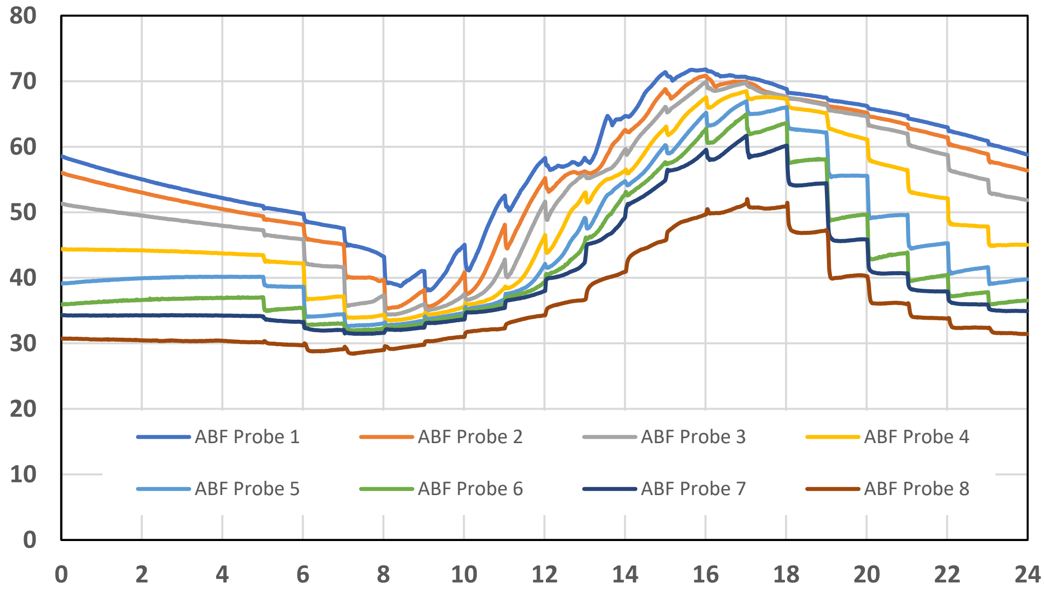

Fig. 10: ABF thermosyphon tank temperatures (°C) and the impact of backflush on tank stratification at 0.166 liters s^{-1} (10 liters/min) draw

4 Discussion

This study investigated the impact of backflushing on the energy performance of direct solar thermosyphon systems to prevent scale and fouling inside the solar collector. Analysis of the inlet and outlet temperatures as shown in Figure 3), the thermosyphon flow rate in Figures 4 and 5, and tank stratification and flow rates Figures 7 and 8. The results show a negligible impact on the energy performance of the overall system, including maintaining tank stratification and restarting of the buoyancy driven flow.

Hardwater scaling in solar thermal collectors has been known to cause a reduction in system performance due to reduced heat transfer and flow rates, and potential system failure when not addressed (Arunachala et al., 2009). Backflushing heat exchangers prevent the build-up of scale has been shown to be an effective for heat exchangers (Harrison, 2005 & Al Nasser et al.,), yet little was known on the system impact of backflushing solar thermal collectors.

This study was carried out under controlled laboratory conditions. While every effort was made to simulate typical draw patterns, further testing in ‘real world’ conditions or ‘field studies’ should be undertaken to fully understand the impact of backflushing the solar thermal collector, when a draw of hot water occurs. Despite the limitations, this initial study has yielded positive results for maintaining the performance of solar thermosyphon systems, in that no significant impact was observed on the energy output from a system using automatic backflush.

5 Conclusion

While backflushing has been shown to prevent the formation of scale in heat exchangers no work to the author’s knowledge, has been conducted on backflushing of solar thermal collectors and its impact on system performance. This is a key topic for future research, given the need of more renewable energy technologies, like solar thermal, and the simplicity and availability of direct thermosyphon systems. These systems are expected to perform reliably for several decades and, in regions with moderate to hard water, scaling will negatively impact the system’s performance over time. Backflushing these systems will help to maintain their rated energy performance.

The results of this study indicate that backflushing a solar thermal collector has little to no effect on the energy performance of a direct thermosyphon solar thermal system. Analysis of the temperatures, flow rates and flow volumes indicate that reversing the flow of water through the solar thermal collector during a draw of hot water from the storage tank has no impact on the energy production of the system compared to an identical system without a flow reversal function. Further testing under real world conditions to validate the findings and a field trial with different sized systems and anticipated draw volumes should be considered in the future to help validate these findings.

6 Acknowledgments

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7 References

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