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Use of Co_2 to Improve the Performance of Forced Circulation Domestic Solar Hot Water System

K. Prabu[1]*, S. Akila[2], K. Tamilarasan[1]

[1]Department of Physics, Kongu Engineering College, Perundurai, Erode – 638 052, Tamil Nadu, India
[2]Department of Chemical Engineering, Kongu Engineering College, Perundurai, Erode – 638 052, Tamil Nadu, India

Abstract: The conventional solar collector panel is filled with CO_2 gas and the experiments were conducted for forced circulation system (FCS) in the months of May, August and November 2011. The performance of FCS with CO_2 is compared with FCS without CO_2 and the hourly average efficiency is found to be comparatively high for FCS filled with CO_2. It was inferred that the daily average system efficiency was enhanced by 3.03, 3.41 and 3.66% FCS mode of operation with CO_2 filled collector panel in the months of May, August and November 2011.
Keywords: Solar hot water system, Forced circulation mode, CO_2, Efficiency.

1. Introduction

Performance enhancement of domestic hot water system is the main focus of this work due to huge demand for domestic solar hot water systems. Various techniques for improving the performance of natural circulation solar hot water systems was reported in previous studies. Jaisankar et al [1] reported that by using twisted tapes, rods and spacers, there is a possibility for enhancement of heat transfer by about 10-15%. Improvement of solar absorption efficiency by an affordable solar selection coating was reported by Enab Alshamaileh [2], who observed the tank water temperature to increase by 5 °C when compared to commercial black paint coating. A 15 °C increase in tank water temperature over conventional ones was observed by Sopian et al [3] using thermoplastic natural rubber tubing as absorber plate. Muhsin Mazman et al [4] and Ella Talmatsky and Abraham Kribus [5] have studied the use of phase change materials for enhancing solar hot water system (SHWS) performance. A photovoltaic pump operated SHWS to improve the efficiency of natural circulation system by around 5-10% was investigated by Tripanagnostopoulos [6], Chow [7], Grassie et al [8], Al-Ibrahim et al [9], Kalogirou and Tripanagnostopoulos [10]. Ramasamy and Srinivasan [11] compared the performance of natural, forced and wind assisted domestic solar hot water systems. A comparative study between the performance of forced and wind assisted domestic solar hot systems was reported by Tamilarasan et al [12]. Prabu and Tamilarasan [13] have studied the performance enhancement of natural and wind assisted solar hot water systems by filling CO_2 gas in the collector panel. Comparison of the performance of natural and forced circulation domestic solar hot water systems by the application of green-house-effect concept were analyzed by Prabu and Tamilarasan [14]. Prabu and Tamilarasan [15] have observed the desirable effects of green-house-gas on the performance of domestic solar hot water systems.

In the present study, performance of solar collector panel is verified by filling it with CO_2 for forced circulation solar hot water system (FCS-CO_2) and compare with CO_2 unfilled solar collector panel in the months of May, August and November 2011. The end results showed the increase in efficiency for forced circulation system (FCS) due to filling of CO_2 gas in the domestic solar hot water system and the same was reported in the months of May, August and November 2011.

2. Experimental Setup

Two identical standard domestic solar hot water systems were fabricated each of which consisted of a solar collector plate of 2 m^2 area, an insulated storage tank of 200 liters capacity, insulated pipes connecting collector, tank and pump, and necessary instrumentation (Table 1). A 180 W centrifugal pump was used for FCS mode. With parallel piping and valve arrangements, the system was set in FCS mode. CO_2 gas was filled in the collector panel at 1 atmospheric pressure as and when required. Experiments were conducted in both the systems simultaneously to make better comparison between the two systems operated in different modes.

Platinum RTDs were used for measuring temperatures at inlet and outlet of collector and at three levels in storage tank (1/3, 1/2 and 2/3 of tank height). The water flow rate and solar radiation (both global and diffuse) were measured using turbine type flow meter and calibrated PV type meter, respectively, with an estimated maximum error on instantaneous collector efficiency of ± 8.1%.

Experiments were conducted on a sunny day in the months of May, August and November 2011 at Perundurai (11.32°N, 77.63°E), Erode district, Tamil Nadu state, India, and were started at 8:00 a.m. with a well-mixed tank temperature of nearly 40 °C and measurements were made at one hour interval up to 4:00 p.m. The total heat gained by tank water was calculated using initial and final well mixed tank water temperatures and also from the hourly measured data. The overall heat balance made based on hourly measured data and on the initial and final temperatures of water gave similar results (deviation within ± 2.0%) in all cases.

Table 1. Details of solar hot water system

Description	Dimension
Initial tank water temperature	40 °C
Time at beginning of test	8:00 a.m.
Time at end of test	4:00 p.m.
Day of test (FCS) & (FCS-CO_2)	18 May 2011
	17 August 2011
	12 November 2011
FCS pump	180 W, Centrifugal Pump
Reading interval	1 hour
Latitude of location, Perundurai, Tamil Nadu, India	11.32°N, 77.63°E
Collector tilt, Due south	11.32°
Length of collector	2.1 m
Width of collector	1.1 m
Length of absorber plate	2.0 m
Width of absorber plate	1.0 m
Number of glass covers	1
Plate to cover spacing	0.025 m
Thickness of absorber plate	0.7 mm
Plate absorptivity / Emissivity	0.88
Outer diameter of collector tube	16.7 mm
Inner diameter of collector tube	12.7 mm
Number of tubes	8
Tube centre to centre distance	120 mm
Back insulation thickness	50 mm
Side insulation thickness	43 mm
Insulation thermal conductivity	0.04 W/m/K
Collector fluid	Water
Outer diameter of connecting pipes	55 mm
Inner diameter of connecting pipes	50 mm
Length of inlet pipe	2.1 m
Length of outlet pipe	1.9 m
Load pattern	No hot water is drawn

Diameter of storage tank	0.56 m
Height of storage tank	0.83 m
Tank insulation thickness	50 mm
Storage tank volume	0.2 mP^3

3. Results and Discussion

The global- and diffuse-radiation increased during forenoon and dropped in the afternoon. With an observed variation in ambient temperature between 22.2 and 33.5 °C, the peak values of global-radiation (Ig) were between 172 and 988 W/m^2 and those of diffuse-radiation (Id) were between 84 and 380 W/m^2.

3.1 Collector Mass Flow Rate

In FCS mode, the water was circulated through the collector pump using 180 W electrically driven centrifugal pump. It was observed that in FCS-CO_2, the circulation rate was also induced by the presence of CO_2 gas in the collector panel. An increase in circulation rate of water from the range of 99-110 kg/h for FCS to 100-111 kg/h for FCS-CO_2 was observed which could be due to the additional heat retained by CO_2 gas in the collector panel.

3.2 Mean Tank-Water Temperature

Initial temperature of water in the tank was kept close to 40 ºC at 8:00 a.m. on all the days of the experiment in order to make the comparisons easier. The water temperatures were measured at three different positions of the storage tank and an arithmetic mean was used for further calculations. Final tank water temperatures obtained in the months of May, August and November for FCS were 61.5, 55.8 and 55.3 ºC, and 62.2, 56.3 and 56.1 ºC for FCS-CO_2 modes, respectively. It was noticed that the mean tank-water temperature increases with time in all the modes of operation and highest temperature was observed in FCS-CO_2 mode in the month of May. As CO_2 retained more heat, the mean tank-water temperature was higher in FCS-CO_2 modes.

3.3 Useful Heat Gain Rate of Water

The variations are in line with the variation of incident solar radiation. The ranges of heat gain in the months of May, August and November for FCS were 114.77-873.98, 45.21-692.98 and 25.30-654.96 W, and 151.67-927.86, 82.34-735.92 and 61.38-698.37 W for FCS-CO_2 modes, respectively, which are in increasing order. Satisfactory results, in terms of relative heat gain, were obtained for FCS-CO_2 mode, which could be due to the increase in circulation rate of water caused by the presence of CO_2 gas.

3.4 Instantaneous Efficiency of the System

The instantaneous efficiency was lower at the beginning of the day, increased with time to considerable extent around 9:00-10:00 a.m. (43.01-46.10, 38.53-46.84 and 33.55-45.93%) for FCS and (47.24-48.63, 43.07-50.29 and 38.60-49.40%) for FCS-CO_2 modes in the months of May, August and November, and again decreased at about 4:00 p.m. (21.52, 5.89 and 14.41%) for FCS and (24.91, 10.73 and 19.05%) for FCS-CO_2 modes in the months of May, August and November, respectively after reaching peak values around 12:00 noon. The instantaneous efficiency obtained with FCS-CO_2 mode in the month of May was higher than that for other modes of operation chosen for this study.

3.5 Comparison

A comparison among various modes of operation is presented in Table 2. In all the cases, the initial tank water temperature was around 40 ºC. The daily average efficiency was 40.97, 36.06 and 37.01% for FCS and 44.00, 39.47 and 40.67% for FCS-CO_2 modes, in the months of May, August and November, respectively. The difference in relative performance among FCS and FCS-CO_2 modes are due to the variation in incident solar radiation and circulation rate of water through collector. The average circulation rates of water were 103.78, 104.22 and 104.78 kg/h for FCS and 104.78, 105.22 and 105.78 kg/h for FCS-CO_2 modes in the months of May, August and November, respectively. In general, the increase in water circulation rate (caused by the combined effect of centrifugal pump and CO_2 in FCS-CO_2) resulted in increased heat gain, higher final tank-water temperature and system efficiency.

Table 2. Overall performance of the system in the month of May, August and November 2011

Mode & Month	Itp* (W/m^2)	Ta* (°C)	Ttin (°C)	Ttend (°C)	Mc* (kg/h)	Qnet* (MJ/day)	Itpsum (MJ/day)	Qnetsum (MJ/day)	η (%)
FCS MAY	1381.72	30.59	39.9	61.5	103.78	18.08	44.77	18.34	40.97
$FCS-CO_2$ MAY			39.9	62.2	104.78	18.67		19.70	44.00
FCS AUGUST	1184.34	27.80	39.5	55.8	104.22	13.65	38.37	13.84	36.06
$FCS-CO_2$ AUGUST			39.5	56.3	105.22	14.06		15.15	39.47
FCS NOVEMBER	1102.12	26.48	39.8	55.3	104.78	12.98	35.71	13.21	37.01
$FCS-CO_2$ NOVEMBER			39.8	56.1	105.78	13.65		14.52	40.67

*** - Average value over the day (8:00 a.m. – 4:00 p.m.)**

4. Conclusions

In the present investigation, an attempt was made to improve the performance of domestic solar hot water system by applying the concept of green-house-effect. In order to estimate and improve the performance FCS, experiments were conducted before and after filling CO_2 gas (at 1 atm pressure) in the collector panel of FCS. The major conclusions derived from the study are:

1. The system efficiency of FCS is influenced by the variation in incident solar radiation and also by the circulation rate of water through the collector.
2. The presence of CO_2 gas in the collector panel induces the circulation rate of water in $FCS-CO_2$.
3. The sequence of the systems in the increasing order of their efficiency is $FCS-CO_2$ and FCS in the months of May, November and August, respectively.
4. The daily average system efficiency of $FCS-CO_2$ in the month of May is higher than FCS (May, August and November) and $FCS-CO_2$ (August and November), respectively.
5. With a simple retrofitting type of modification (by including a centrifugal pump and filling CO_2 in the collector panel) of NCS, it can be converted into $FCS-CO_2$ which be a better and useful alternative to NCS.

Nomenclature

Symbol	Description	Unit
NCS	: Natural circulation solar hot water system	-
FCS	: Forced circulation solar hot water system	-
$FCS-CO_2$	: Forced circulation solar hot water system with CO_2 gas filled in the collector panel	-
SHWS	: Solar hot water system	-
Itp	: Solar radiation on the collector plane	W/m^2
Itpsum	: Total solar radiation falling on the collector	MJ/day
Mc	: Mass flow rate of water across the collector	kg/h
Qnet	: Useful heat gain rate	MJ/day
Qnetsum	: Total heat gain by the tank water over the day	MJ/day
Ta	: Temperature of atmospheric air	ºC
Ttin	: Well-mixed tank water temperature at 08:00 a.m.	ºC
Ttend	: Well-mixed tank water temperature at 04:00 p.m.	ºC
η	: Daily average efficiency of the system	%

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