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Performance of forced and wind assisted domestic solar hot water systems- a comparative experimental study

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Natural circulation type hot water systems are widely used in domestic applications due to cost effectiveness; however, efficiencies are lower due to lower collector flow rate under natural circulation. Forced circulation systems (FCS) offer higher efficiencies but require electricity for operation. A novel system, windmill assisted system (WAS), is fabricated and tested. Collector flow rates in WAS are observed as a function of wind velocity. Wind flow increases flow rate and thus heat collection. On test days, efficiencies of WAS and FCS modes are found close to each other. WAS appears to be a better alternative to FCS for remote areas with no electricity.

Keywords: Forced circulation system, Solar water heater, Windmill assisted system

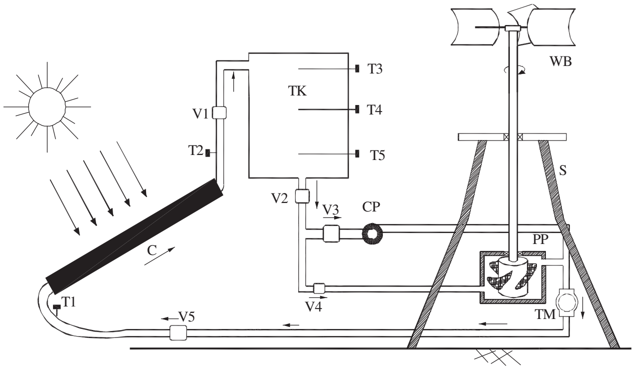
Introduction

Solar thermal technology is available for low temperature domestic hot water service[1] and for intermediate temperature applications[2]. Performance of domestic forced circulation water heaters under varying operating conditions is reported[3]. Modeling flow in natural circulation solar hot water system (SHWS) is reported[4]. Thermosyphon flows (25-40 kg/h) have been reported on a typical day. Flow rate of a commercial natural circulation domestic water heater is compared with a model developed[5]. A comparison between forced and natural circulation performance of domestic SHWS is reported[6]. Recent studies are focusing on use of better components for collectors[7-9], economic optimization[10,11] and use of solar cells for pump operation[12].

In present study, performance of a domestic solar hot water system is tested under forced circulation system (FCS) and windmill assisted system (WAS) modes.

Experimental Facility

A standard domestic SHWS (200 l) consists of a solar collector (2 m^2 collector plate area), storage tank, connecting pipes and necessary instrumentation (Fig.1, Table 1). An insulated storage tank (200 l capacity) is fabricated. Pipes with necessary insulation are used to connect collector, tank and pump. A vertical axis windmill (diam, 90 cm) driven propeller type pump is used during WAS mode. An 180 W centrifugal pump is used for forced circulation mode. With parallel piping and valve arrangements, system is set either in FCS or in WAS mode.



TK- Storage Tank, T1-T5- Resistance Temperature Detector (RTD), S- Stand, WB- Windmill blade,V1-V5-Globe Valve, C-Collector, PP – Propeller type Pump, TM-Turbine type water flow meter,CP –Centrifugal pump

Fig.1—Layout of domestic solar hot water system

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Table 1—Details of solar hot water system

Description	Dimension	Description	Dimension
Initial tank water temperature	40°C	Plate absorptivity / emissivity	0.88
Time at beginning of test	8.00 AM	Outer diameter of collector tube	16.7 mm
Time at end of test	4.00 PM	Inner diam of collector tube	12.7 mm
Days of test (FCS)	19-20 May 2005	Number of tubes	8
Days of test (WAS)	25-26 May 2005	Tube centre to centre distance	120 mm
FCS pump	180 W, centrifugal pump	Back insulation thickness	50 mm
Wind mill	Vertical axis, three bladed	Side insulation thickness	43 mm
Windmill driven pump	Propeller type	Insulation thermal conductivity	0.04 W/mK
Reading interval	1 h	Collector fluid	Water
Latitude of location, Perundurai, TN, India	11.32° N, 77.63° E	Outer diam of connecting pipes	55 mm
Collector tilt, Due south	11.32°	Inner diam of connecting pipes	50 mm
Length of collector	2.1 m	Length of inlet pipe	2.1 m
Width of collector	1.1 m	Length of outlet pipe	1.9 m
Length of absorber plate	2.0 m	Load pattern	No hot water is drawn
Width of absorber plate	1.0 m	Diam of storage tank	0.56 m
No. of glass covers	1	Height of storage tank	0.83 m
Plate to cover spacing	0.025 m	Tank insulation thickness	50 mm
Thickness of absorber plate	0.7 mm	Storage tank volume	0.2 mP^3

Temperatures are measured using platinum resistance RTDs at inlet to collector, exit of collector and at three places at storage tank (1/3, 1/2, and 2/3 height of tank). Water flow rate is measured using turbine type flowmeter. Wind velocity using turbine type anemometer and solar radiation on horizontal surface, both global and diffuse, using calibrated PV type meter are measured. Estimated maximum error on instantaneous collector efficiency is ± 8.6%.

Experiment is commenced at 8.00 AM with a well-mixed tank temperature of nearly 40°C. Measurements are made at 1 h interval up to 4.00 PM. Well-mixed tank water temperature is also measured at 8.00 AM and at 4.00 PM. Total heat gain by tank water is calculated using initial and final well mixed tank temperatures and also by summing hourly measured data. Overall heat balance calculated by both methods agreed within 4.0% in all the cases.

Results and Discussion

Global and diffuse radiations increase during forenoon and drop in afternoon (Fig. 2). Peak values varied of global radiation (950-1000 W/m$_{P}^{2}{}_{r}$) and diffuse radiation (250-380 W/m$_{P}^{2}{}_{r}$). Ambient temperature varied between 25-35°C and wind velocity between 3-7 m/s (Fig. 3).

Collector Mass Flow Rate

In case of WAS, flow rate in collector circuit depends on wind speed. Water flow rate varied between 40-160 l/h depending upon wind speed (Fig. 4). During FCS mode, flow rate is provided by 180 W electricity driven centrifugal pump. Since system is a closed loop, flow rate remains more or less constant around 110 l/h. Fluctuations in water flow rate (105-110 l/h) are due to fluctuations in supply voltage.

Mean Tank Water Temperature

Water temperatures measured at three locations of tank were averaged to get mean tank water temperature. At 8.00 AM, initial tank temperature around 40°C is maintained on all days. Temperature rises steadily with time; rate of rise is larger (about 49°C) at 11.00 AM, about 56°C at 1.00 PM, and stagnate after 2.00 PM. Final tank water temperatures with FCS mode were 60.8°C and 61.8°C. Temperatures obtained with WAS mode were 62.7°C and 63.1°C (Fig. 5). Slightly higher temperature

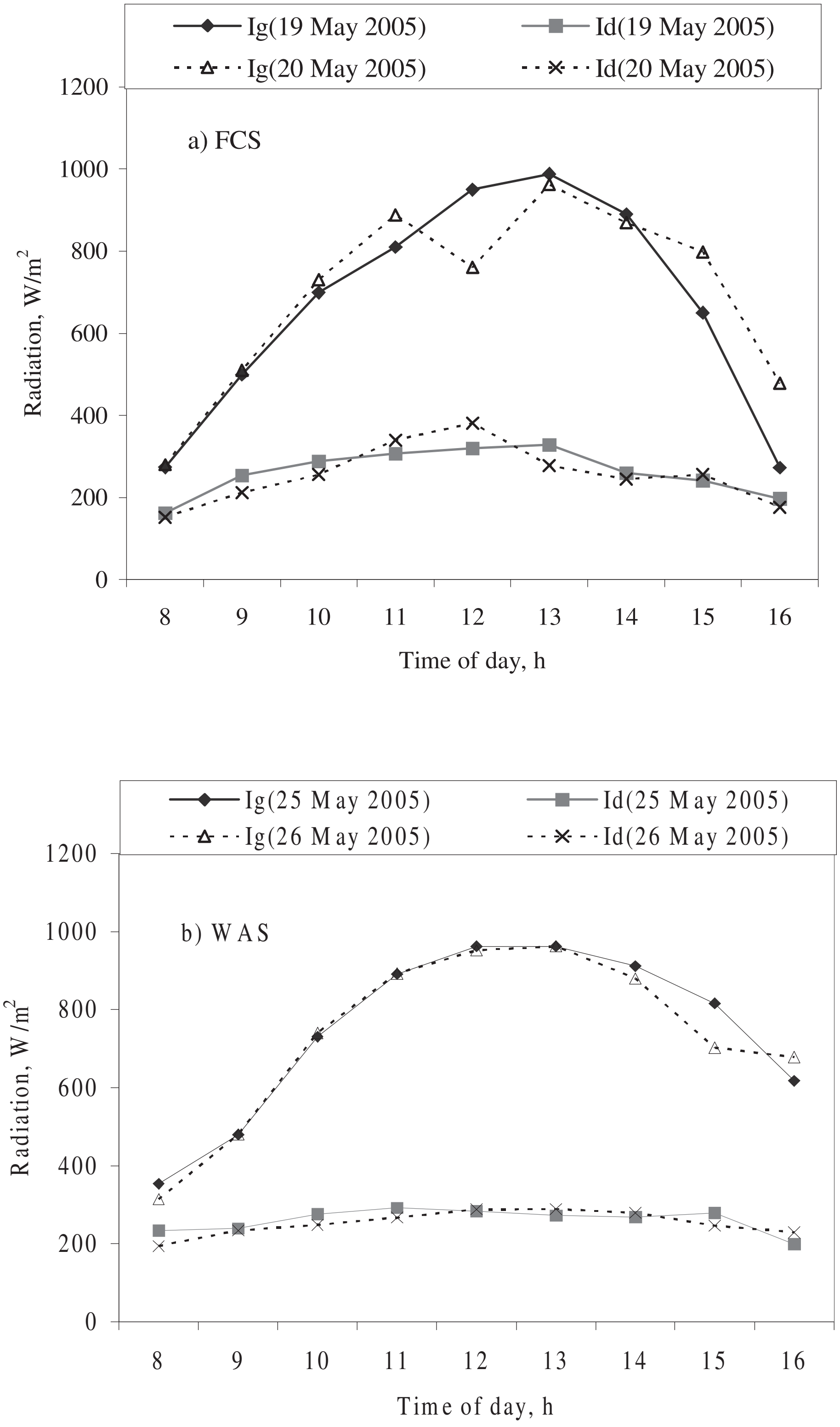

Fig. 2—Solar radiation on horizontal surface: a) FCS; b) WAS

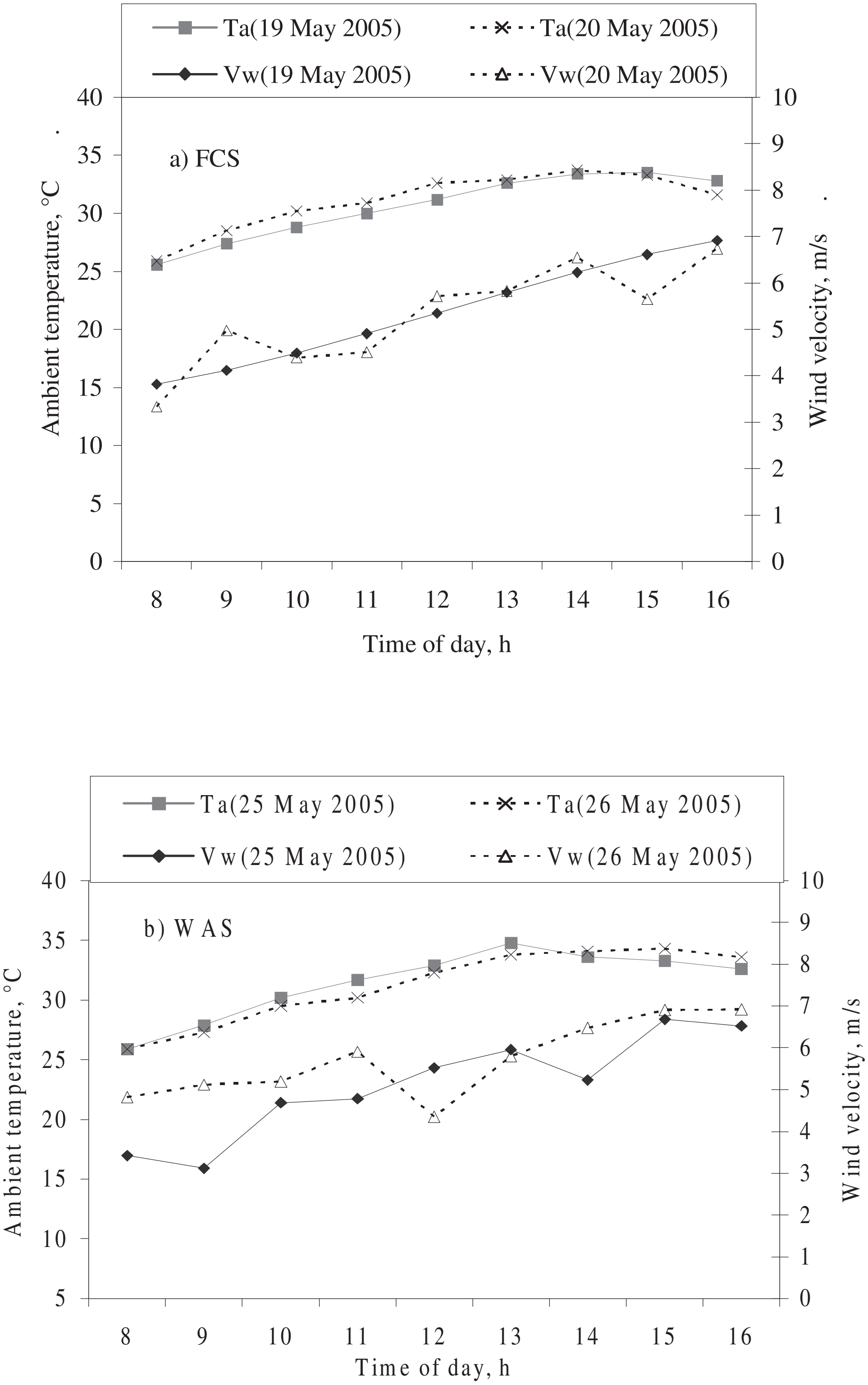

Fig. 3—Ambient temperature (Ta) and wind velocity (Vw) variation: a) FCS; b) WAS

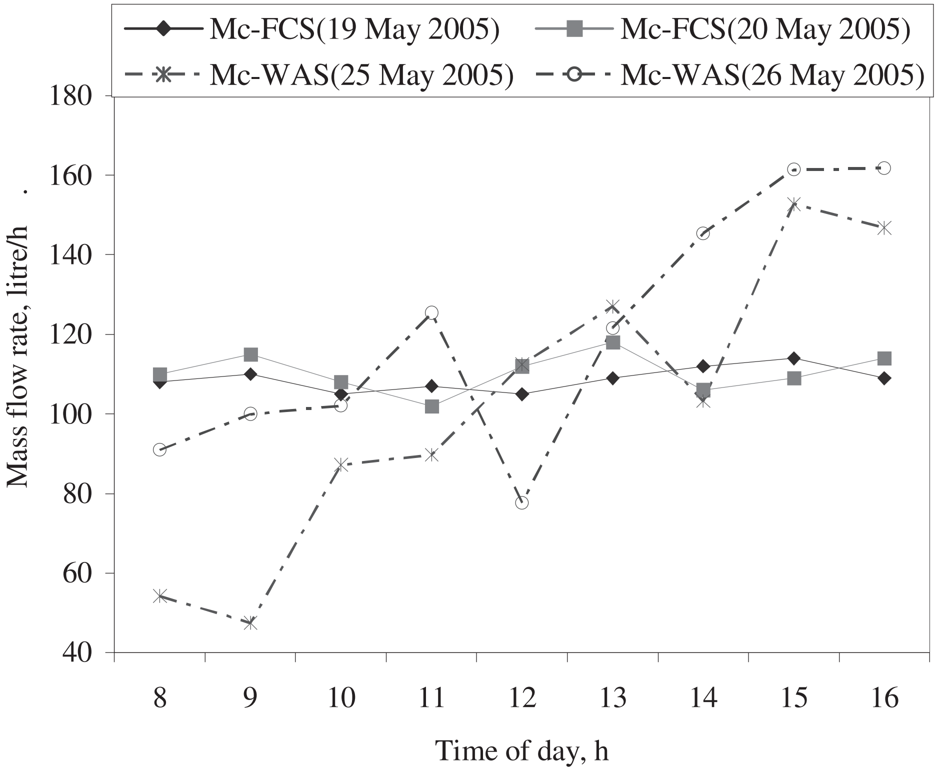

Fig. 4—Variation of mass flow rate through collector

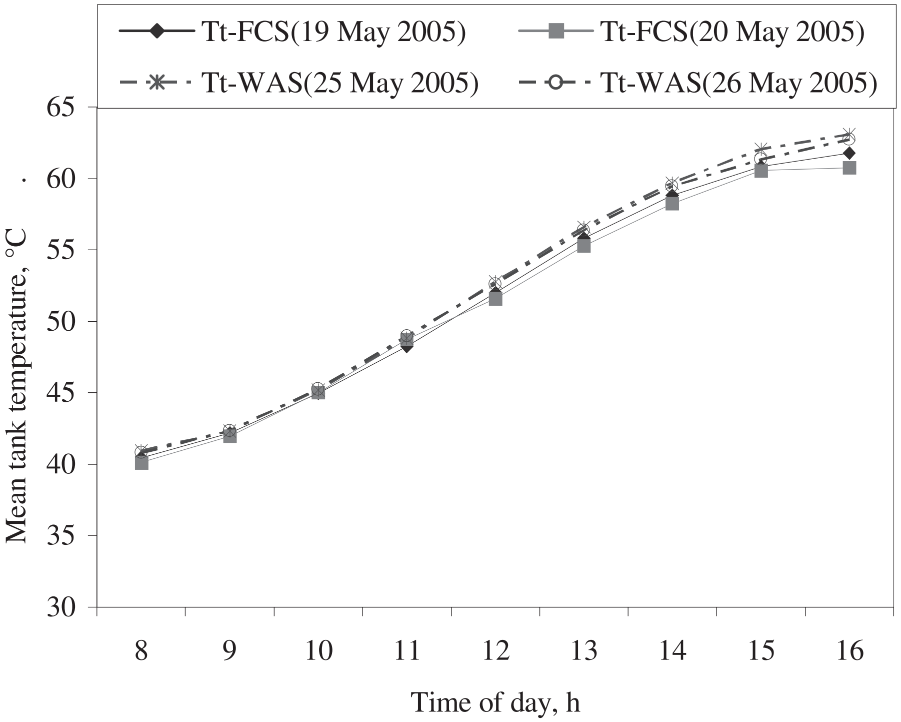

Fig. 5—Variation of mean tank water temperature of SHWS

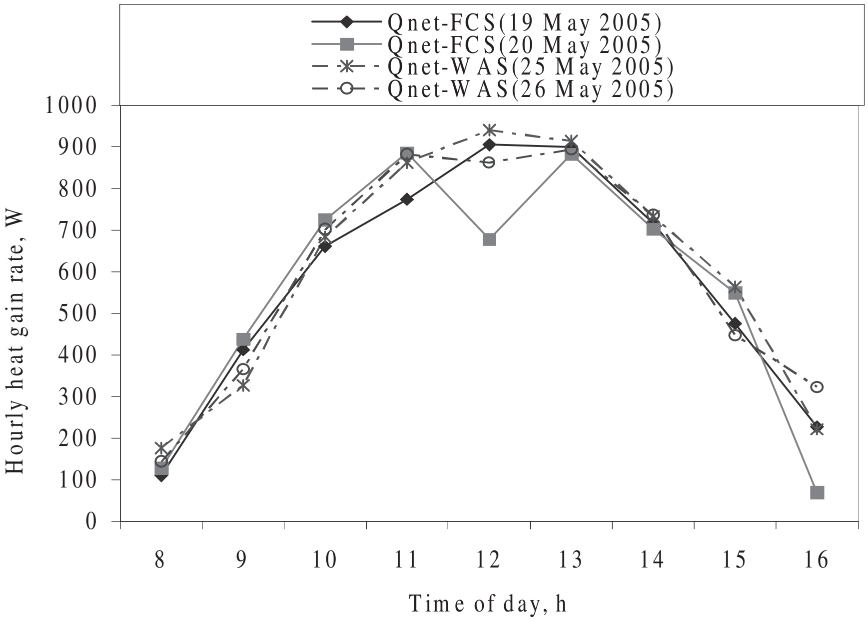

Fig. 6—Variation of hourly heat gain rate of SHWS

Table 2—Summary of overall performance over a day

Day	System	IB_{tsumB} MJ/day	QB_{csumB} MJ/day	$QB_{netsumB}$ MJ/day	System efficiency %
19 May 2005	FCS-1	44.66	19.24	18.64	41.75
20 May 2005	FCS-2	43.27	18.76	18.19	42.04
25 May 2005	WAS-1	46.20	20.09	19.51	42.22
26 May 2005	WAS-2	45.30	19.84	19.26	42.51

obtained with WAS mode might be due to better heat collection because of higher collector flow rates at higher wind velocities. Variations in collector flow rate for WAS mode do not produce any significant variations in mean tank water temperature rise.

Hourly Average Heat Gain Rate and System Efficiency

Hourly mean heat gain rates (Fig. 6) and system efficiency (Fig. 7) vary inline with solar radiation levels. It is lower at beginning of the day and attains maximum around 12.00 noon and then falls to lower value at the end of day. Maximum heat gain rates are observed with WAS (940 W) and FCS (905 W) modes at 12.00 noon. Drop in heat gain with FCS mode on 20 May 2005 at 12.00 noon is due to fall in global radiation on the same day at same time (Fig. 2).

Hourly average system efficiency varied during WAS mode (26-53%) and FCS mode (21-52%). Efficiency values obtained with FCS mode in present study agree well with earlier studies[3,5,6]. Slight drop in efficiency at 12 noon (26 May 2005) in case of WAS mode is due to lower wind velocity and in case of FCS mode is due to drop in global radiation.

Total solar radiation falling on collector plane (I_{tsum}) on all 4 days is around 43-46 MJ/day during 8.00 AM to 4.00 PM (Table 2). Total heat collected by solar collector (Q_{csum}) are around 19 MJ/day during FCS mode, and 19.25 MJ/day during WAS mode. Total heat collected by system (Q_{netsum}) is slightly less than Q_{csum} due to heat losses. Daily average system efficiency of FCS (41.9 %) and WAS (42.4 %) modes demonstrated that WAS can be a better substitute for FCS mode if sufficient

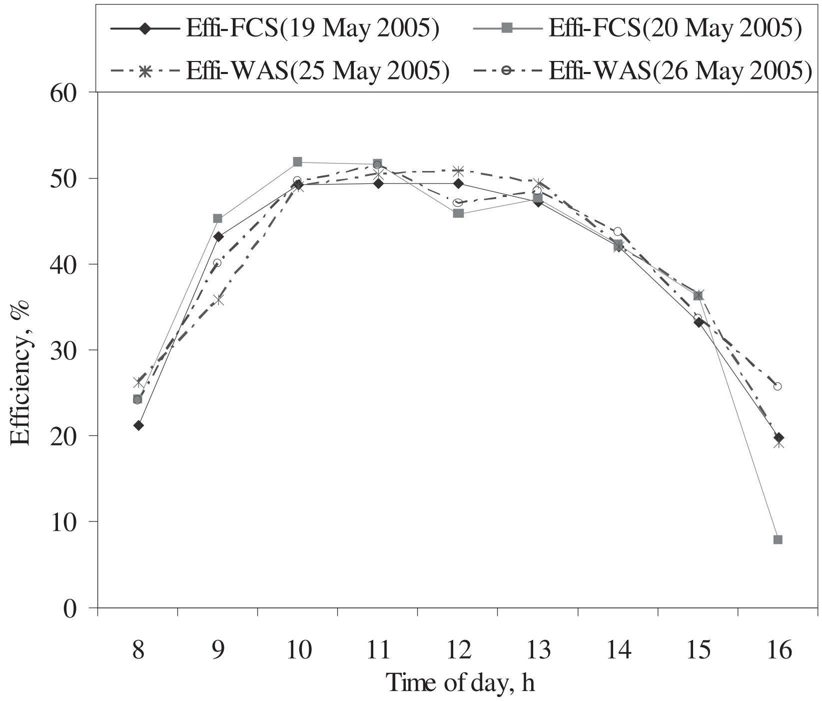

Fig. 7—Variation of hourly average efficiency of SHWS

wind velocities are prevailing at place of installation. The cost involved in making windmill assisted propeller pump is about Rs 4000. Remote areas, where electricity is not available, WAS become more beneficial.

Conclusions

Domestic solar hot water system, tested in WAS and FCS modes, indicated that hourly average efficiency of all systems varies inline with variation of solar radiation. Collector flow rates in FCS depend on pump capacity and valve settings during operation. Whereas collector flow rates in WAS are a function of wind velocity. Even if wind velocity is zero, system will operate under natural convection mode. Thus, any wind flow will increase flow rate and offer efficiencies better than natural convection mode. Efficiency of WAS and FCS modes are close to each other. WAS appears to be a better alternative to FCS, as WAS does not require electricity for its operation; especially for remote areas, where electricity is not available.

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