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Scaling Effect of the Direct Solar Hot Water Systems on Energy Efficiency

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Abstract

Scale formation in risers and headers solar direct water systems is problem in places where hard water is being used. In this paper the effect of scaling on energy efficiency indices such as instantaneous efficiency mass flow rate and overall heat loss coefficient are improved in case of thermosyphon system and forced circulation systems due to pressure gain in the narrow region. Scale mapping is done for the entire solar hot water system for the nature of the scale growth. It is seen in the thermosiphon system the mass flow rate decreased by scaling, this affects increases the energy efficiency more than that of the heat transfer rate. The scaling effect is more predominant in thermosyphon system than the forced circulation system. The difference between mass flow rate in scale and unscaled conditions is less in forced circulation but much higher in thermosyphon system.

Keywords

Scaling Effect, Solar Hot Water Systems, Energy Efficiency

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1. Introduction

Although the direct solar hot water (SHW) systems have been available for many years, there is a continuing interest in their performance optimization. Different parameters which affect the performance of SHW system are absorber degradation, masking of the glass cover, leakage deteriorated gaskets and scaling inflow system. But the system performance degradation due to scaling still exists and its perhaps less noticeable since the system continues to operate and the degradation is a gradual and source process. In the footer there is a little scaling tendency.

Scaling is connected with the thermal decomposition of hydro carbonates, hydrolysis of carbonates and also with the decreased solubility of calcium sulphates, magnesium hydroxide and silicates of calcium and magnesium in hot water. Water's tendency to form calcium carbonate decomposition is given by the saturation ratio(S) which is the ratio of calcium concentration in the water to the calcium concentration required for calcium carbonate. In SWH i.e. absorber tubes and heat exchanger, scaling can reduce heat transfer due to the additional conductive resistance across the scaled layer, and increase the fluid pressuredrop due to narrowing of the flow passage.

Literature to date has focused on scaling effect in heat exchangers, flow systems and heat exchanger type SWH. However, information related to quantifying the effect of scaling on the performance of direct SWH systems is inadequate.

2. Solar Water Heaters

Broadly speaking, the SWH are of three categories viz. Heat exchanger type, Evacuated tube and Flat plate type. They receive both beam and diffuse solar radiation and do not require tracking of the sun. Mostly, both Heat exchanger and

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Evacuated tube types are installed in places where water hardness is considerable. The removal of scale deposited over the heat transfer surface is quite easy in both the systems. But, these systems are not as simple as FSWH. Hence FSWH is very popular due their work simplicity, robust design and low maintenance cost. Either thermosyphon or forced circulation mode is adopted in this case. In case of thermosiphon system as shown in Fig. 1(a), the water passing through the riser gets heated up and is delivered to the storage tank due thermosiphon effect. The re-circulation of the same water through absorber panel in the collector raises the temperature to around 80°C on a good sunny day. The bottom of storage tank is atleast a feet higher than the top of the collector to avoid reverse flow during the night. Thermosiphon systems still remain as one of the most interesting technologies for exploitation of solar energy. Their remarkable efficiencies, combined with simplicity of construction, autonomy in operation, absence of moving parts and thus the minimization of necessary maintenance, make them an interesting alternative to forced circulation systems.The system works on the principle that there is only water in the collector when the pump is operating. This has the benefit that the coolant used in the sytem will not have the chance to cool down during the night when temperature may drop to a level which may cause the coolant to increase in density and thus perhaps cause is not be as free flowing as it should. The only necessary feature on the drainback system is that the solar collector are elevated from the heat exchanger or drainbak tank in order for the coolant to flow out of the collector. This sytem again workson the principle that the water is circulted between the collector and the drainback tank when the designated temperature is reached between the solar collector and the hot water.

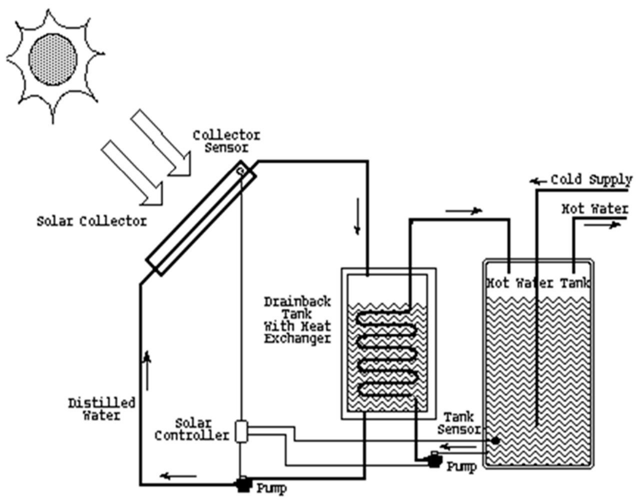

Figure 1(a). Shows Thermosiphon system.

2.1. Scaling Mechanism

Dissolved salts present in water used in SHW systems form deposits in the flow passage thus impairing heat transfer and fluid flow. The less soluble salts such as calcium carbonate precipitate is settled in the flow passage and flowing water become more concentrated. At higher water temperature, the restrictive concentration of both calcium and magnesium salts is rapidly reached with the formation of insoluble precipitates. The resultant sludge is undamaging as long as the salts form solid particles that flow easily with water. But if the precipitates adhere to metal surfaces, the resulting scale badly interferes with normal operation of the normal heater. Chemical quality of water is based on pH value, dissolved and undissolved salts and particulates. Corrosion decreases with the pH value. Undissolved particles such as sand may lead to erosion of tubes if excess in level. Scale growth rate is very sensitivity to the level of the dissolved salts and is mainly due to salts of calcium and magnesium and to lesser extent to silicates.

2.2. Scale Production & Mapping

The criteria to assess the blockage in SHW systems are listed below

- Mass flow rate measurements at the tank height level.
- Mass flow rate measurement at the absorber unit outlet.
- Calculation of all day efficiency during sunny day.
- Dismantling the absorber unit and physical inspection of risers by cutting them open.

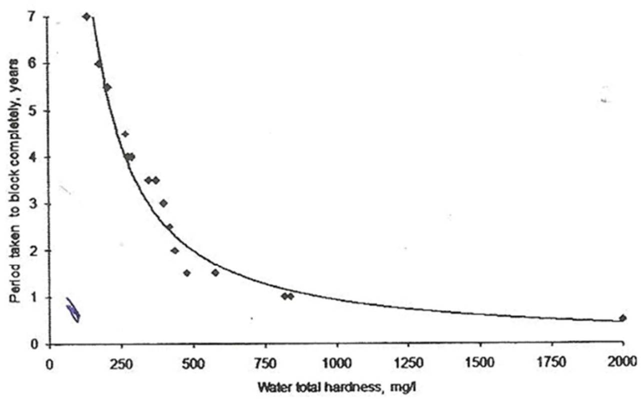

Figure 1(b). Plot of Number of Years Versus Water Hardness.

Initially the performance analysis is done for a clean SHW system considering the above criteria based on the feasibility of inspection of SHW system in field, one of the criteria to assess blockage is undertaken and compared with the clean SHW system. The cases which were giving results less than 15% of the cleaned one, were treated as major blockage and incorporated.

$$t=2354.4(Ct)^{-1.13} \quad (1)$$

$$t=308.7(Cc)^{-1.13} \quad (2)$$

‘t’ stands for time to be taken for major blockage

‘Ct’ stands for concentration of calcium in dissolved salts

‘Cc’ stands for concentration of total hardness in dissolved salts

The above equations calculate the time necessary for severe blockage separately and the minimum of this value is to be considered.

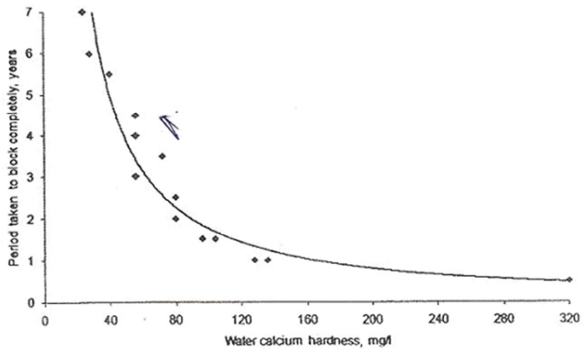

Fig. 2. Plot of number years versus water calcium hardness.

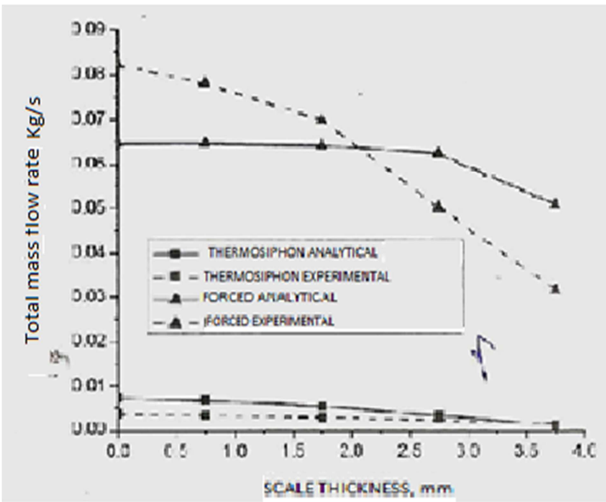

Fig. 3(a). Variation of mass flow rate.

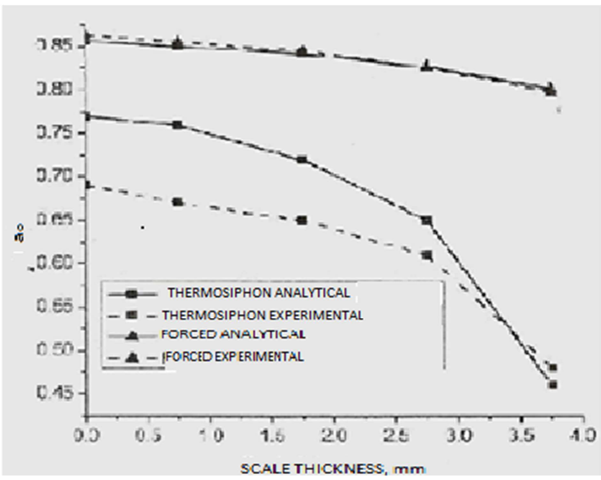

Fig. 3(b). Variation of ao.

2.3. Performance Analysis of *SHW* Systems

A SHW system is a heat exchanger that transforms incident solar radiation into the heat by accumulating it within the enclosure through green house effect. The instantaneous efficiency of a SHW system based on energy accumulation is given by

$$\eta i = Qu \div (IAp) \tag{3}$$

ηi stands for instantaneous efficiency.

Qu stands for useful rate of heat flow in SHW.

I stand for total heat flux incident on the top glass cover.

Ap stands for area of the connecting plate.

The above equation can be reformed in terms of other collector parameters, namely, collector heat removal factor and the collector efficiency factor.

$$\eta 1 = a_0 - a_1(\{T1-T2\}/I) \tag{4}$$

where $a_0=[FR\mu\beta(Ap/Ac)]$ and $a1= [FRUt(Ap/Ac)]$ this equation is referred as HWH equation.

FR=collector heat removal

μ=glass cover transmissivity

β=absorber plate absorptive

Ap=area of connecting plate

Ac=area of collector

Ut=collector heat transfer coefficient at top.

2.4. Experimental Procedure

The flow characteristics and performance deterioration studies of thermosyphon system, indoor test are performed with a copper tube at certain angle of inclination with the horizontal. Fiber glass cloth (with Teflon coating) is wrapped to a copper tube and nichrome wire winding is provided over it. Asbestos insulation with thickness of 5mm is applied over the winding to minimize the heat loss to the surrounding and to avoid electric shock. This forms part of the conventional SHW system in place of the usual nine tube array. Constant water head is maintained within the riser using a tank with an over flow arrangement. With the help of water level adjuster the level of water is brought up to the outlet of the riser such that the water levels in the tank and the riser exit are same. The heat supply to the riser is varied by adjusting the input voltage through the control panel. The control panel consists of dimmer stat, digital voltmeter and multimeter. To sense the temperature copper constantan thermocouples and 20-channel data logger with computer interface are used. All the thermocouples are calibrated for ice and steam point. A total of 5 sets of readings are taken for the each power input under each scaled condition.

Four thermocouples are fixed along the riser length at equidistance to find the temperature gradient. Three more thermocouples are positioned to measure water inlet, outlet and ambient temperature. As the mass flow rate of water is exceptionally low, the flow is measured manually using a measuring jar and stop watch.

In the beginning the water flow rate from the riser is zero as there is no thermal expansion of fluid and once the input power is supplied, slowly spills out of the riser and the state is constant once the system attains the steady state. To maintain the identical condition, everytime the new riser is inserted into the same lagging.

Artificial scaling is done in tubes by coating the inner surface with the blend of calcium carbonate scale powder and white cement for the required radial thickness. Since the percentage of composition of white cement is not substantial, the thermal conductivity of calcium carbonate scale itself is considered for the analysis. Coating is done by inserting the smooth steel rod of required flow diameter into the tubes and pouring cement liquid mixture. As the intention is to perform a comparative deterioration study, in every trail after maintaining water level, the same electrical power is supplied.

3. Data Reduction and Methodology

In the experimental analysis of the thermosiphon system, the useful output power from the riser is calculated by measuring mass flow rate and water inlet and outlet temperatures. In the forced circulation system the temperature drop is negligible if water is pumped through a riser with normal rate. Hence water flow rate is reduced by using an insert in the pump pipe line. Under this condition, the pump performance characteristics are drawn.

The assumptions made in this analysis are as follows

- Steady state heat conduction
- Thermal conductivity of scale composition is constant
- Absorber plate temperature is uniform throughout the area
- Absorber s plate effectiveness is constant
- Scale formation in risers only; no effect of scaling in headers
- Scale growth is uniform.

In the analytical, a SHW system of 1*1m^2 areas is considered for both thermosyphon and forced circulation. The effect of scaling on mass flow rate and heat transfer rate is quantified and change which is described as follows.

- Standard data are taken for a SHW system
- Pressure gain and pressure drop equations are formulated as a function of mass flow rate
- Since both the pressure gain and pressure drop are function of mass flow rate, the mass flow rate in the riser is calculated by solving the equations.
- By using the appropriate correlations, the convective coefficient of water is calculated.

The steps followed to compute mass flow rate as follows:

- Pressure gain and pressure drop equations are modified, it involves m (mass flow rate) and other standard data.
- By assuming a_0 and a_1 the flow rate is determined (a_0& a_1 are slopes).
- Convergent mass flow rate is obtained by iteration.
- In the case of scaled conditions, the scale modified flow diameter is considered.

The pressure in the system is from a water circulating pump given as below

$$\Delta Pgain = (\eta p \rho sd Pp)/m \quad (5)$$

ΔPgain=pressure change in riser(N/m^2)

ρsd=mass density of water at pump suction and delivery suction

ηp=efficiency at connecting pipe.

The steps followed to get the correct mass flow rate are given below are below.

- By considering the friction factor and standard data the pressure drop equation, which includes riser and pump suction delivery pipe length, diameter and height, is modified as a function of mass flow rate.
- Since the pressure gain is due to pump, pump power and overall efficiency are considered to formulate the pressure gain equation in terms of mass flow rate.
- Since both the pressure drop and pressure gain equations are the functions of mass flow rate, the mass flow rate is what balances the pumping with the pressure drop in the circuit.
- Convergent mass flow rate is obtained by iteration.
- In the case of scaled conditions, scale modified flow diameter is considered.

4. Results

The results are computed separately in the case of 2 m^2 thermosiphon SHW system with the standard specifications for the following conditions.

- Effect of mass flow rate neglecting thermal resistance due to scaling.
- Effect of heat transfer rate neglecting changes in mass flow rate due to scaling.
- Combined effect of mass flow rate and heat transfer.
- Steady state one dimensional heat conduction.
- Scale growth is uniform and identical in all risers.
- Heat loss from the connecting pipe and storage tank to the surrounding is negligible.
- Thermal conductivity of scale composition is constant.

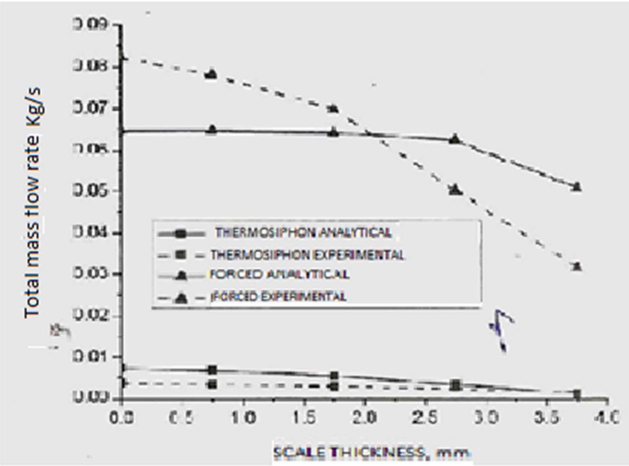

Fig. 4(a). Variation of mass flow rate.

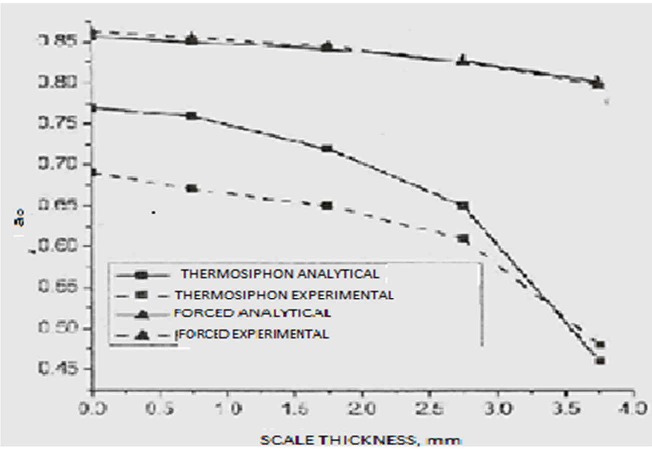

Fig. 4(b). Variation of ao.

5. Conclusions

The conclusions drawn from the field study are the following

- Time to be taken for the major blockage of SHW system is predicted using two important parameters: water total hardness and calcium hardness
- Chances of scale formation are rare in footer and lower portion of the riser due to the low temperature of water.
- The gap between experimental and analytical mass flow rates reduces with the scale thickness in the case of thermosiphon system due to the rise in the pressure gain in the narrow region subjected to higher temperature than the predicted by the standard equations.

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