PERFORMANCE OF FLAT PLATE COLLECTORS IN RELATION TO CORROSION PROBLEMS

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ABSTRACT

The performance of four types of plate collectors is discussed in terms both of instantaneous efficiency and the overall efficiency of the complete solar energy water heating system. The influence of corrosion on the durability and performance of these collectors is discussed.

INTRODUCTION

The Whillier and Hottel equation lays out a model for analysing the performance of flat plate solar collectors. However, results of instantaneous performance tests do not necessarily relate closely to the performance of an installed system.

To gain a realistic view of the relative performance of solar water heaters therefore requires consideration not only of the efficiency of the solar collector in capturing solar energy, but also the efficiency of the whole system in terms of heating water under normal operational conditions. The life span of the system is also an essential criteria for selecting a solar water heating system. Again this can only be assessed through operating the system for an extended period of time.

As part of a long-term solar energy research programme (Zingano 1983), the performance and durability of various plate collectors and solar water heaters was tested. All collectors and heating systems were available and constructed in Malawi. Instantaneous collector performance tests, details of which are not provided here, and performance of the system under typical sky conditions are discussed.

TYPES OF FLAT PLATE COLLECTORS

Four collectors were tested which fall into three categories of solar collectors:

Type A. Sandwich Type: This collector was constructed out of two plates of 0.5mm galvanised steel and separated by 4mm wide silicone rubber blocks to form the water channel. The plates were coated with a black acrylic paint and seamed on all edges. The cover was 3mm crown glass laid in sections of 230 x 225mm and 8mm above the absorber surface.

Type B. Grid Type: There were two versions of this type of collector:

Type B1: This collector was constructed out of 13mm galvanised pipes as the grid with a 19mm diameter manifold at both top and bottom. The single risers of the grid were half wrapped in 0.5mm plates of galvanised steel painted as in type A. The cover was 4mm glass fixed at 100mm above the absorber plate. Riser spacing was 100mm.

Type B2: This collector was constructed as Type B1 but the grid risers were spaced at 100mm finned in 0.5mm galvanised plates measuring 150mm across. The cover was 3mm fibreglass.

Type C. Snake Type: This collector was similar to the grid design, but the water channel was a continuous looped copper tube 19mm in diameter strapped to a 0.5mm galvanised steel plate. The cover was 4mm glass at 75mm above the absorber surface.

SOLAR WATER HEATING SYSTEMS

Five systems were tested.

System A. Collector type A was coupled to a storage tank with a built in ball valve and was a normal symphonic system.

System B. Collector type B was coupled to a similar storage tank as in A, but as a once-through system. In this arrangement the pressure of the incoming main was regulated by a pressure reducing valve. The automatic inlet regulating valve was specially developed for this purpose. It was regulated by a thermal valve which was designed to respond to radiation intensity. Thus the valve was activated at an irradiance level of $150 Wm^{-2}$. At this intensity the water trickled through the collector and dropped into the storage tank. The minimum temperature was 40°C. The water did not recirculate and therefore was not exposed to further heat losses.

System C. Collector type B1 was connected to a vertical tank and the system worked in a normal syphonic circulation.

System D. Collector type B2 was connected to a horizontal storage tank with a side make up tank and a ball valve. This was a syphonic system.

System E. Collector type C was connected to storage tank but with an option of mounting the tank horizontally or vertically. Again this system was syphonic.

TEST SITE AND SYSTEM TEST PROCEDURE

Collectors and systems were tested on the roof of a laboratory about 3m above the ground and facing north. The tests were carried out between April and July which are winter months in Malawi. For maximum normal solar insolation the collectors were fitted at 14° from horizontal. An eppley solarmeter was used to record the insolation and the ambient temperature was recorded at a nearby Stevenson Screen. The wind speed was monitored and throughout the tests this did not exceed $5 kmh^{-1}$.

Systems were left in operation for a whole day without drawing off any water. The temperature of water in the mains was recorded before sunrise each day. At that time the storage tanks were checked to make sure that they were full of water.

After sunset when exit temperature is the same or lower than the inlet temperature (Tfe Tfi) all the water in the tank was drawn off in 14.5 litre buckets. This unit was chosen because it is the volume of a common vessel used for hot baths in Malawi.

An extensive statistical survey established that what is commonly termed a "hot bath" is only 40°C. The temperature of each bucket was carefully recorded until the storage tank was completely empty.

On each day the sky conditions were recorded and the cloud cover was expressed as a fraction of eight hours. Thus 0/8 was a clear day and 8/8 represented an overcast day.

RESULTS

Instantaneous efficiency test

The results of the instantaneous performance test are shown in Figure 1. Th eX and Y intercepts of the graphs and the extracted FU values are given in Table 1.

Systems efficiency test

By extending the Whillier and Hottel equation to cover the collector, transmission pipes, and the storage tank, the final equation would be as follows (explanations of symbols are given in the appendix to this paper).

$$\eta_s = \frac{Q_u}{IA_c} = F(\tau\alpha) - \left\{\left[FU_c \frac{(T_{mc} - T_a)}{I}\right] + \left[\frac{U_t A_t}{A_c} \frac{T_{mt} - T_a}{I}\right] + \left[\frac{U_p A_p}{A_p} \frac{T_{mp} - T_a}{I}\right]\right\} \quad (1)$$

The useful energy obtained by the system was integrated as follows:

$$Q_{ut} = C_p \sum_{i=1}^{N} M_i (T_i - T_{supply}) \quad (2)$$

The average days efficiency can then be obtained from the following equation:

$$\eta_s = C_p \sum_{i=1}^{N} M_i (T_i - T_{supply})/I_{gt} A_c \quad (3)$$

The results of this test are shown on Table 2.

Relation of cloud cover to system efficiency

The results of the systems test were plotted against the cloud cover record (Figure 2). Efficiency declined as the cloud cover increased.

Rating of collector systems based on the "hot bath" (40°) temperature criteria

The minimum temperature of hot water required by a user was taken to be 40°C. As a further assessment of efficiency, the amount of water above 40°C obtained by each system was calculated. Table 3 compares the five systems in terms of the volume of water produced over 6 days by each system at or above 40°C, and expressed as a percentage of the hot water storage tank.

This merely provides a guideline to the user since the systems were being solid in these sizes. A purely scientific comparison would have taken into account the collector aperture to storage tank ratios, and then the storage tank surface area to volume ratios in order to normalise the comparison.

DISCUSSION

According to the instantaneous efficiency test alone the most efficient type of collector is the sandwich one while the snake type is the least. The former has a very short heat path, ie absorber to water while the latter has a somewhat longer path, ie absorber to pipe and then to water.

However, the sandwich type collector has the highest heat loss factor. This may be related to the design and the width of the air gap between the absorber surface and the transparent cover. In this type of collector the thermal insulation above the collector is therefore not as good as in the others.

Based on performance tests of the overall system, system B is the best while system D is the worst of the five systems. Although collector type B_2 performed better than collector type C and B_1 in the instantaneous efficiency test this did not hold true in performance testing of the system under normal operation.

Flat plate collectors and corrosion

The performance of solar collectors in terms of efficiency is only one parameter of the economic effectiveness of the device. The other parameter is the life of the device once it has been installed. Basson (1980) has outlined materials for construction of these devices which combine good performance and long life at an effective cost.

Corrosion is mainly caused by constituents present or absent in the water. Campbell and Turner (1983) have evaluated and investigated the main causes of corrosion in metals in general. Most of their findings agree with the experience of the author with installed solar collectors in Malawi. Generally, corrosion is more pronounced in the absence of furring of the water channels. The calcite deposition protects the metal from corrosion.

Dissolved salts in water form "nodules" scales at high electricity current densities but "egg shell" scales in low electricity current. Modular scales formed of temperatures above 60°C differ from those formed at room temperatures, and have more circular crystals. The principal salts in the scales are from sulphates and carbonates of sodium and calcium.

In the absence of electrolytic corrosion the presence of chlorides, chlorine, excessive dissolved oxygen and in general the elements which become cathodic stimulants lead to corrosion. In two cases the author has analysed solar collector failures and it has been found to be related to the presence of these agents and a function of the source of the water.

Solar collector corrosion is more pronounced if the source of the water is underground. This phenomenon has been attributed to the absence of a "prohibitor" (Campbell and Turner 1983). This prohibitor is now believed to be colloidal and the heavier the molecule the better is its prohibiting influence. Thus surface water is a likely medium to contain this prohibitor. This has been the observation in Malawi too. Solar collector installations drawing water from rivers have lasted longer than those drawing water from lakes and the latter in turn have lasted longer than those drawing water from boreholes. An analysis of the water has only indicated increased dissolved salts in the order of river water, lake water and ground water.

"Egg shell" scale formation is to be preferred to "nodular" scale formation. The former spreads across the metal surface better than the latter and therefore protects the metal. On the other hand the latter narrows the water channel faster and leaves pits where the metal is still exposed to the corrosive agents.

The basic construction of the collector has some effects on furring up of the water channels. Thus although the sandwich solar collectors are more efficient the scale formation narrows the passage faster and increases both the thermal and hydrolic resistances.

CONCLUSION

Generally the intrinsic efficiency of a sandwich solar collector is higher than that of a grid or snake type. However this advantage can be lost if the system installation is not the right one. In all types of solar system installations the efficiency drops inversely proportional to increased cloud cover.

To ensure an extended life of a collector it is advisable to treat all water to have a composition close to that of river water in terms of organic matter content. It is better to have wide water channels in collectors of the sandwich type and this is where the grid type has an advantage.

REFERENCES

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NOMENCLATURE

A_c	=	aperture of collector
A_p, A_t	=	surface area of transmission pipes and storage tank respectively
C_p	=	specific heat of water
F	=	drain factor
I	=	intensity of irradiance
I_{gt}	=	total global radiation on a horizontal surface
Q_u	=	useful heat gained
Q_{ut}	=	total useful heat gained
T_a	=	ambient temperature
T_i	=	initial temperature
T_{fw}, T_{fi}	=	exit and inlet temperatures respectively
T_m	=	average of exit and inlet temperatures
T_{mc}, T_{mt}, T_{mp}	=	mean water temperature in collector, storage tank and transmission pipes
T_{supply}	=	temperature of main water
U_c, U_p, U_t	=	heat loss factor for collection, transmission pipes and storage tank
$(\tau\alpha)$	=	product of absorption and transmission factors
η_s	=	system efficiency
$\bar{\eta}_s$	=	average system efficiency
η	=	collector efficiency

TABLE 1: Performance characteristics of four flat plate collectors and their apertures

Collector Type	Zero radiation efficiency (F ( ) x 100	Heat loss factor FU ($Wm^{-2}C^{-1}$)	Zero efficiency temperature (°C)	Aperture (m^2)
Type A	90	10	113.3	1.86
Type B_1	54.3	5.3	122.0	0.86
Type B_2	57.3	9.9	79.3	1.53
Type C	55.7	9.9	80.3	1.31

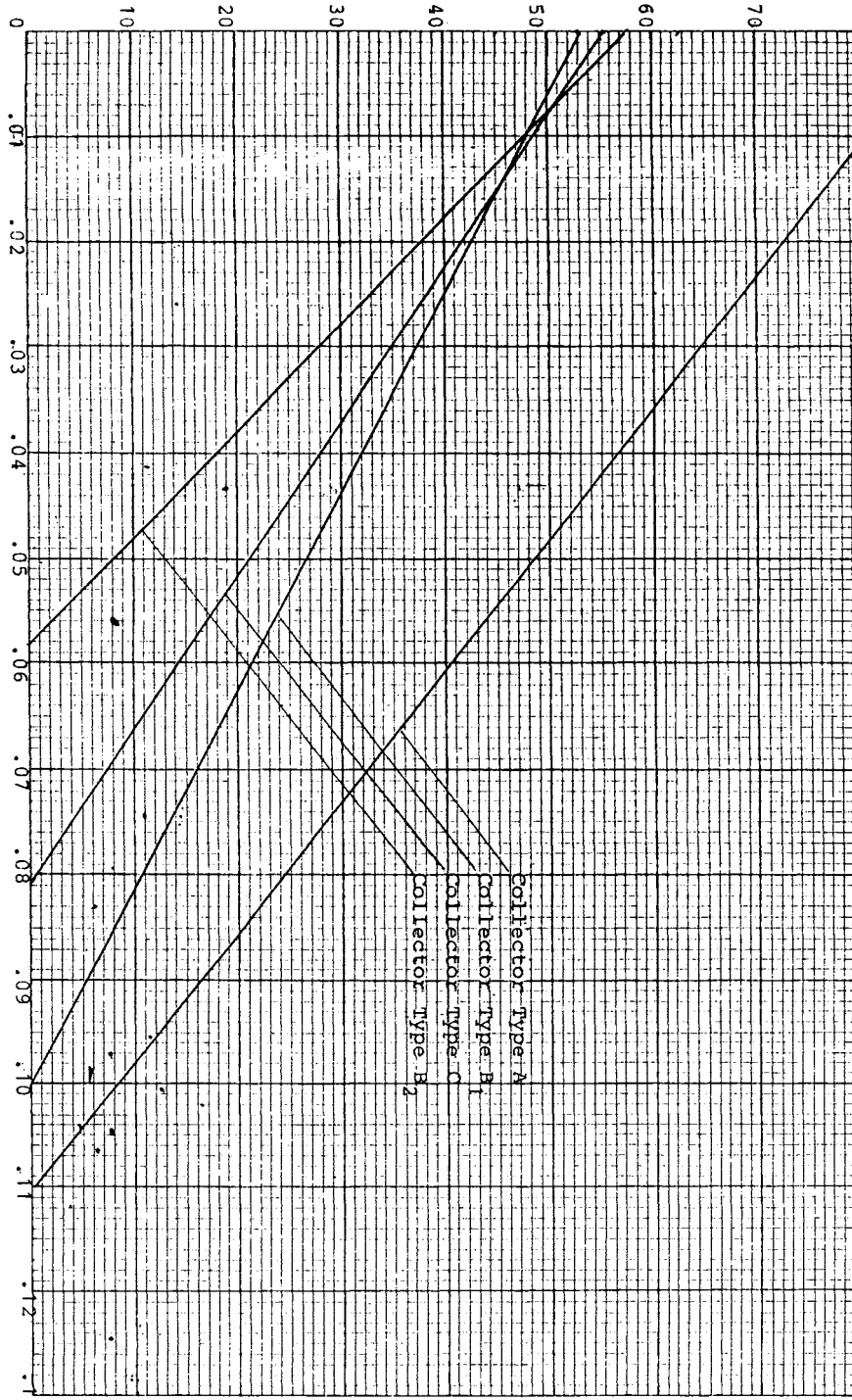
TABLE 2: Systems performance for six days

Test No.	Total irradiance 1_{gt} (MJ/M^{-2})	System efficiency A	B	C	D	E	Cloud condition
1	17.58	21	26	1.9	2.3	8.6	5/8
2	13.06	48	57	19	6.7	25	3/8
3	17.37	39	39	20	18	31	2 5/8
4	15.66	56	53	25	24	40	1/8
5	16.74	48.9	45	19	23	35	3/8

TABLE 3: Volumes of water at or above 40°C collected by systems and the volume of the hot water expressed as a volume of the storage tank

System No.	Volumes of water at or above 40°C and percentage of tank nominal capacity										Total radiation MJ/m^{-2}
Test date	A		B		C		D		E		
	Litres	%	Litres	%	Litres	%	Litres	%	Litres	%	
08.06.82	78	46	62	36	26	58	0	0	0	0	17.6
11.06.82	130	76	142	84	29	64	0	0	0	0	13.1
17.06.82	99	58	154	91	0	0	73	63	58	32	19.5
24.06.82	116	68	132	78	29	64	0	0	0	0	17.4
25.06.82	150	88	160	94	44	98	0	0	44	24	15.7
26.06.82	147	86	163	96	29	64	0	0	29	16	16.7
Total	**720**		**822**		**103**		**73**		**131**		
Rating	**2**		**1**		**4**		**5**		**3**		

FIGURE 1: Graph of efficiency for the four collectors



GRAPH OF EFFICIENCY (η) AGAINST $\frac{T_m - T_a}{T_m - T_a}$ - $\frac{°C_m^2}{W}$ FOR THE FOUR COLLECTORS

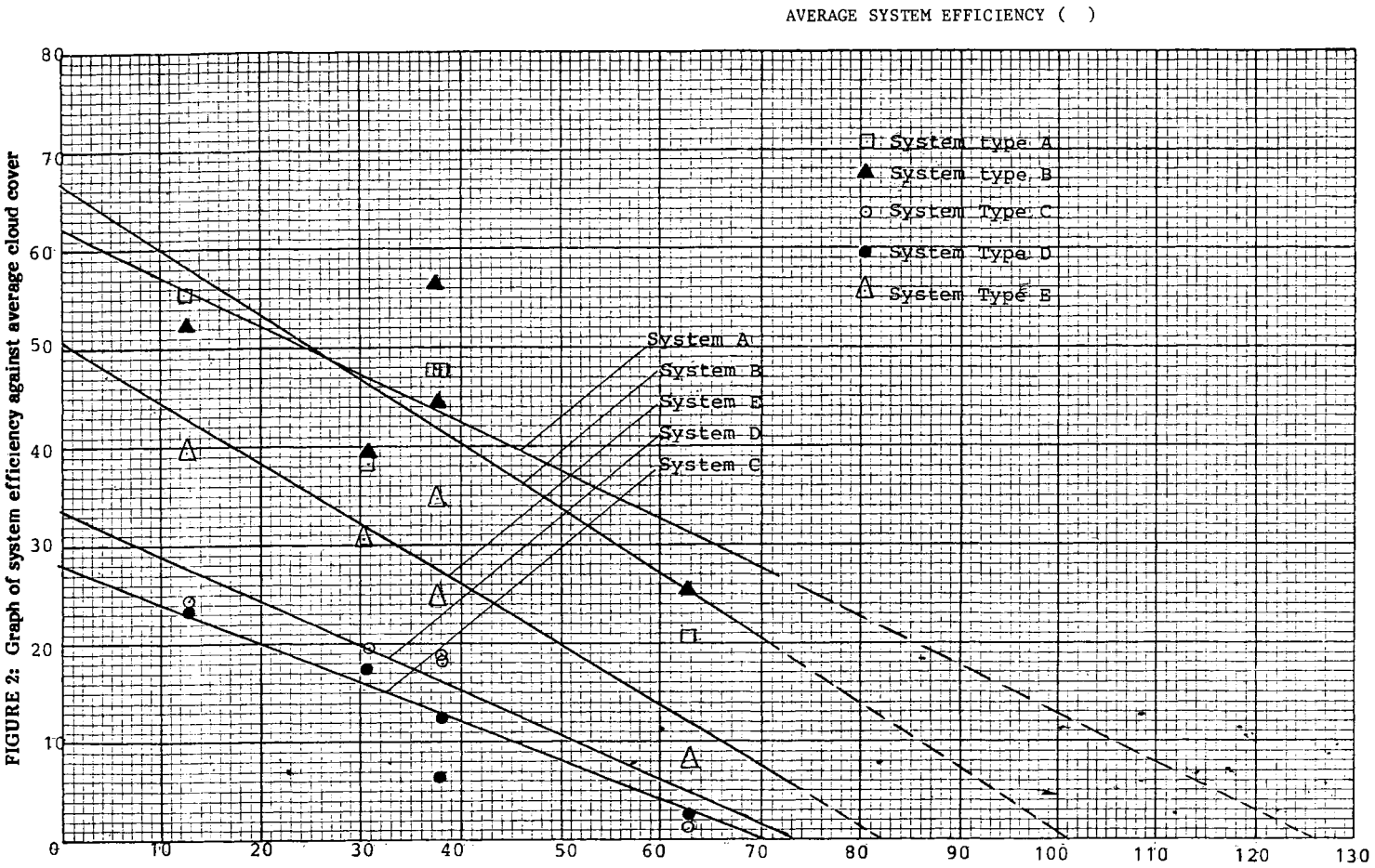


FIGURE 2: Graph of system efficiency against average cloud cover

GRAPH OF SYSTEM EFFICIENCY ( ) AGAINST AVERAGE CLOUD COVER