Assessment of Domestic Evacuated Tube Direct Solar Water Heater

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Abstract

This work presents the first assessment results of an evacuated tube solar collector at the Christchurch Polytechnic Institute of Technology. The assessment includes, a quantification of the capacity of heated water that could be supplied at different solar conditions and the realized energy savings (kWh), an interpretation of the working efficiency of the collector at different solar radiation and ambient temperatures. This paper presents a summary of the results achieved to date and outlines possible future developments that may be necessary to allow this type of direct solar water heater to be deployed in NZ conditions.

1. INTRODUCTION

The Renewable Energy Research Laboratory (RERL) at the Christchurch Polytechnic Institute of Technology (CPIT) is currently assessing the technical and economic performance of an evacuated tube solar water heater. The prototype incorporates low-cost technology applicable for remote areas region in Asia. The aim at this stage is to investigate the viability of the evacuated tube collector incorporated in this system to offer technical and economic advantages over current types of direct solar water heaters deployed in New Zealand. In addition, the work aims to outline possible future developments that may be necessary to allow this type of direct solar water heater to be deployed in NZ conditions.

Evacuated tube collectors work on the principle of using vacuum as an excellent insulating barrier, preventing heat loss primarily due to convection and conduction. Combining this feature with selective surfaces results in a high efficiency collector. The tubes are arranged in banks to make “modular” collectors.

2. COLLECTOR DESCRIPTION

The system provided for assessment consists of 16 units of Pyrex-glass 120-cm-long evacuated tube providing the heated water to a 120-litre horizontal storage tank as shown in **Figure 1**. Heated water particles in the tube move by natural convection upward to be replaced by colder water. The hot water produced will be accumulated in the storage tank. The steel mounting structure permits the solar heater to be tilted flexibly to the ground to suit geographical locations. The water cylinder is equipped with an electrical heating element to provide hot water in solar unfavorable times.

Fig. 1 The evacuated-tube thermal solar collector.

Solar heating elements: Each element is composed of two coaxial Pyrex Glass tubes, joined at the top and sealed at the bottom which contain a vacuum, the outer of **4.7**-cm and the inner **3.3-**cm diameter that contain **1.026-liters** of water. The inner tube contains the water to be solar heated and its exterior is coated with a suitably dark absorbing material for collecting the incident solar radiation and transmitting it to water. The closed volume between the outer and the inner tube being evacuated works as a thermal insulator preventing heat loss primarily due to convection and conduction. Thus the trapped solar energy absorbed and transmitted to water is prevented from escaping backward to the environment. At night or at cold weather the heated water thermally insulated by this vacuum is also then protected from being cooled or frozen. The whole Pyrex-glass tube structure is supported at the bottom on the edge of the outer tube on a horizontal PVC livelihood. **Fig.3** shows a schematic presentation of the vacuum tube heating element as fixed in a hole below the water tank sealed by a rubber ring.

Water volume in evacuated glass-tubes: 16 evacuated glass-tubes are containing 16*1.026 liters = **16.41** liter.

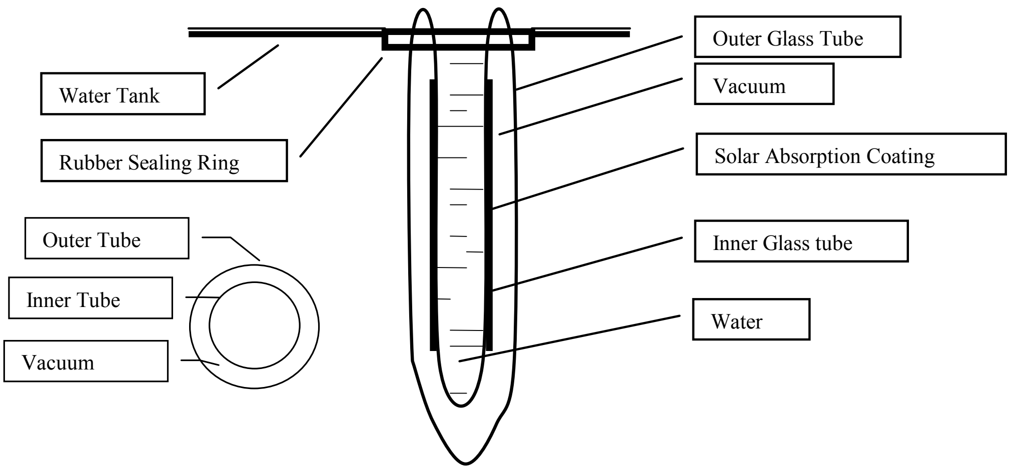

Fig. 2 Solar heating element -Vacuum Glass tube fixed below the water tank.

Hot-Water tank: Thermally isolated steel tank. Outer container made of polished steel circular cylinder of 133 cm length and 40 cm outer diameter (total volume 167048 cm3 =167 liter) with 3 cm-thick thermal insulation. **Fig. 3** shows schematically a cross-section in the water tank.

Water in/out-let: The cylinder is equipped with two circular openings at its bottom where two 1.5-cm diameter steel pipes are fixed to the tank. One pipe is used as a combined inlet for cold water and outlet for hot water as well. Two one-way valves direct the water for either allowing cold water to enter or hot water to leave the tank as required. This opening is additionally equipped with a level-setting floating valve to limit the amount of water in the cylinder to 75.5 liters and the maximum draw off to 71 liters. The second tube is a 37.5-cm long 1.5-cm Φ steel tube used for water-overflow and pressure relief conditions as well.

Total water volume heated in the system: The total water volume heated by the solar radiation in the system consists of the water contained in the tank and the total amount of water in the heating glass-tubes = **75.5 + 16*1.026 = 92** liter.

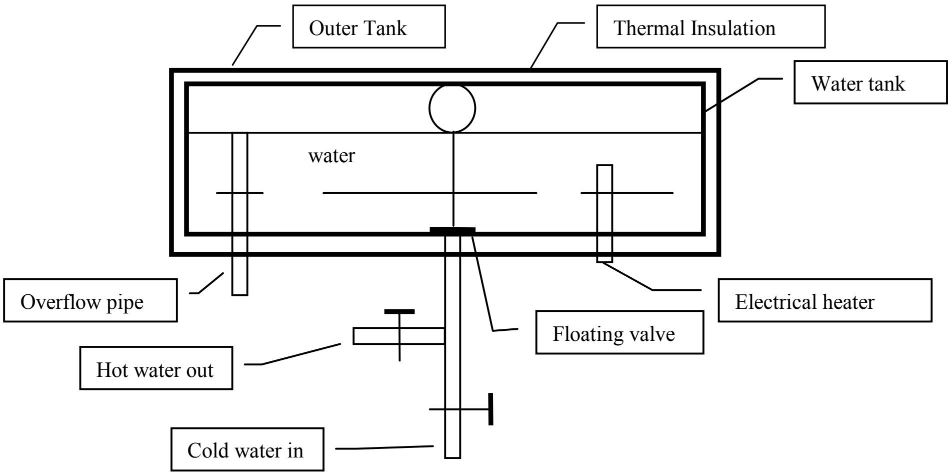

Fig. 3 Schematic cross-sections in the water tank.

Reflector surface. A reflector of polished steel with a surface area of **121x99** cm2 is placed underneath the vacuum glass tubes separated 2 cm from the tubes lowest line. The reflector surface is shaped to form parallel line parabolas between tubes to work for reflecting solar radiation to the back and sides of each tube.

Heating area. The total heating aperture area of the collector comprising the 16 Glass vacuum tubes is **121x113** cm2 = **13673 cm2**.

Supporting steel structure. The steel frame housing the 16 vacuum glass tubes is 128-cm long and 128-cm wide tilted to the ground by an angle suitable for the site geographic location. The solar collector is situated at a tilt angle which equals the site latitude (43.483 degree for Christchurch) and oriented towards North (for Southern Hemisphere).

Electrical heating element (booster). The water cylinder is equipped with a boosting electrical heating element to heat tank water electrically at solar unfavorable times. The electrical heater is situated vertically at the bottom of the water tank housed in a steel circular cylinder. The operation of the electrical boosting heater is optional. The electrical heating element hasn't been used in this test.

Working principle. The cold water approaching the inlet at the tank bottom is conveyed by gravity to the bottom of each vacuum glass tube due to its higher density. Heated water particles thrive upwards by natural convection due to reduced density whereas it will be replaced by other colder water particles. Hot water will be then further conveyed to the water tank by the same principle where warmer water is accumulated in the upper tank part and colder in the lower. This process occurs in a slow natural convection mode until all tank water is being heated.

3. TESTING

Aims:

- To assess the capability of this heater for providing a certain amount of thermal energy (kWh) in a specific time span and at different radiation conditions.
- Identify the realized savings by utilizing this heater compared to conventional types.
- To interpret the working efficiency of the collector at different solar radiation and ambient temperatures in order to allow a comparison to other heater types.
- To quantify the stream of solar heated water affordable by this heater at different solar conditions.

Approach:

- Measurement of the temperature elevation from T_1 to T_2 of a certain volume V of water being supplied to the heater in a specific period of time.
- Measurement of water flow to/from the system.
- Measurement of the intensity of incident global solar radiation in an integral (accumulated) form over the same period of time in order to allow efficiency calculations.

Fig. 4 shows the measurement set up for testing the heater.

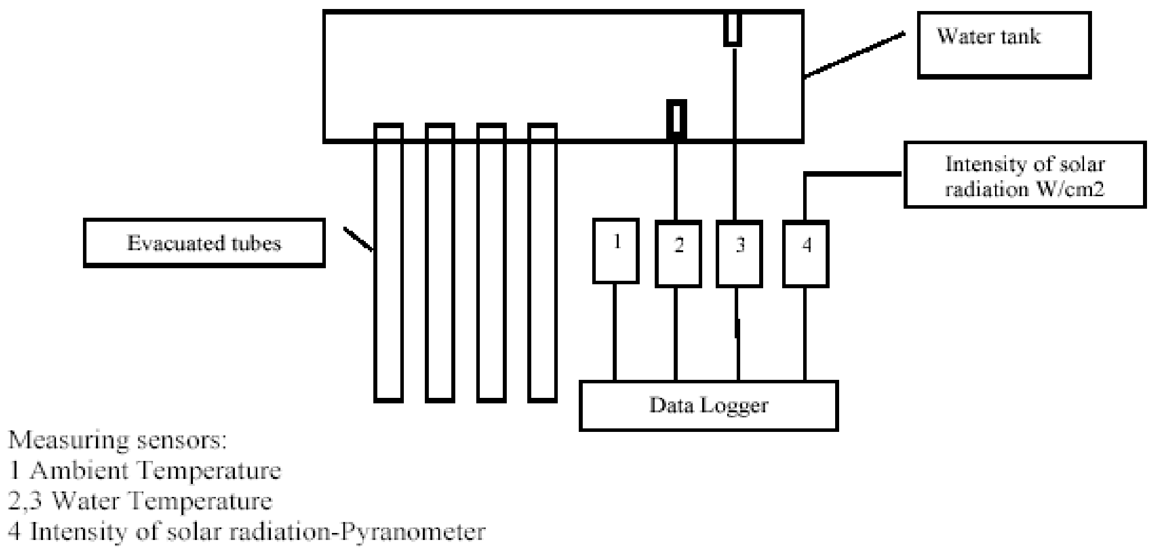

Fig. 4 **Measurement set up for testing the heater.**

3.1. Test Results

The test results are summarised in figures 5 through 8. In general, the results achieved correspond to those expected and previously published in other literature [1][2]. The measured efficiency for this evacuated tube solar water heater as shown in Figure 7 compares favourably with simplified efficiency curves as shown in unit 4 page 17 of [2].

The major difference between this trial system and other previously detailed evacuated tube solar collectors is the lower operating temperature of this unit. The system has been implemented with temperature regulating system to ensure that the operating temperature does not exceed 70^0C. Water is either discharged to a secondary storage cylinder or discharged when it exceeds this limit.

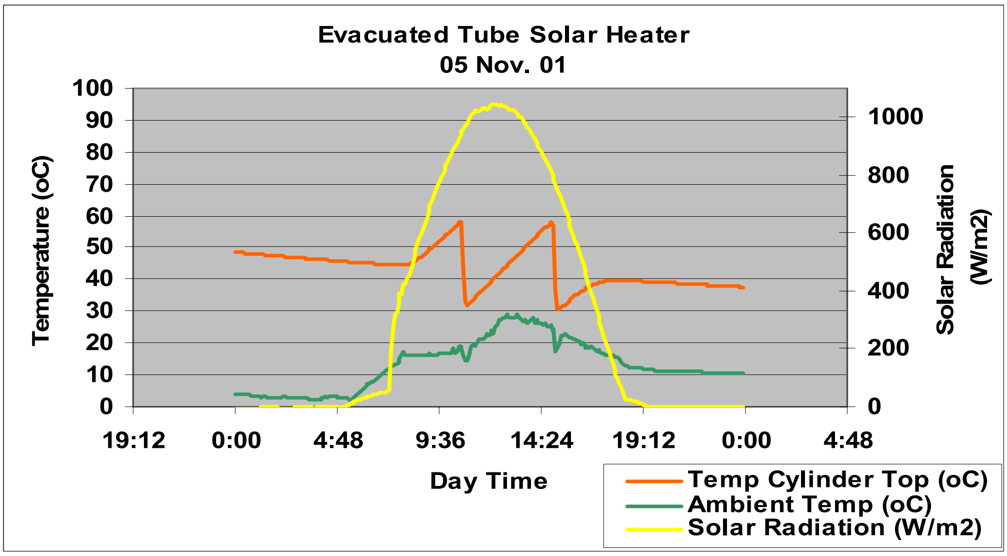

Figure 5 – Single day measurements

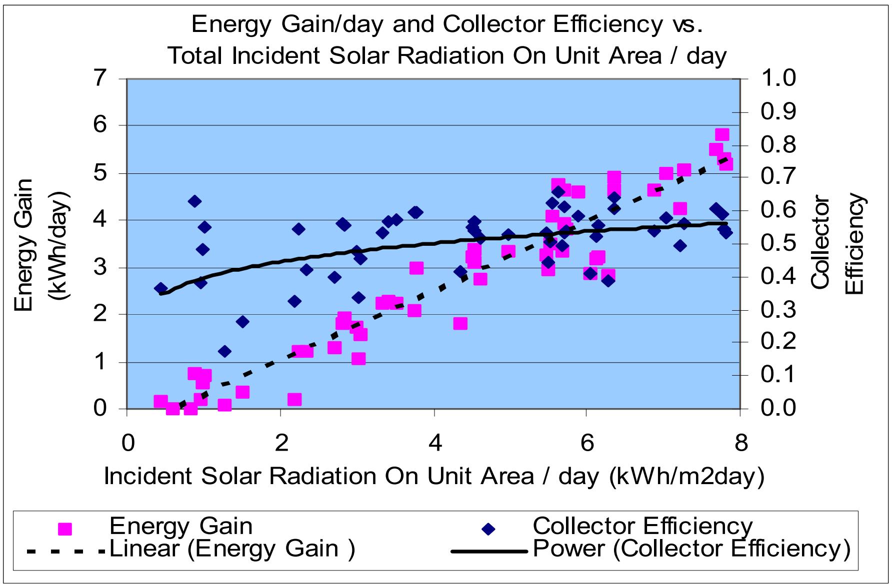

Figure 6 – Energy Gain & Collector Efficiency

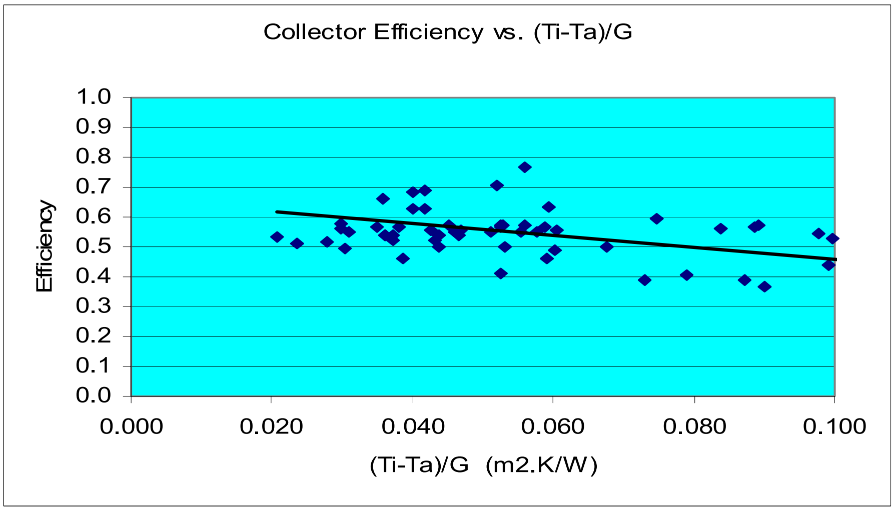

Figure 7 – Collector Efficiency

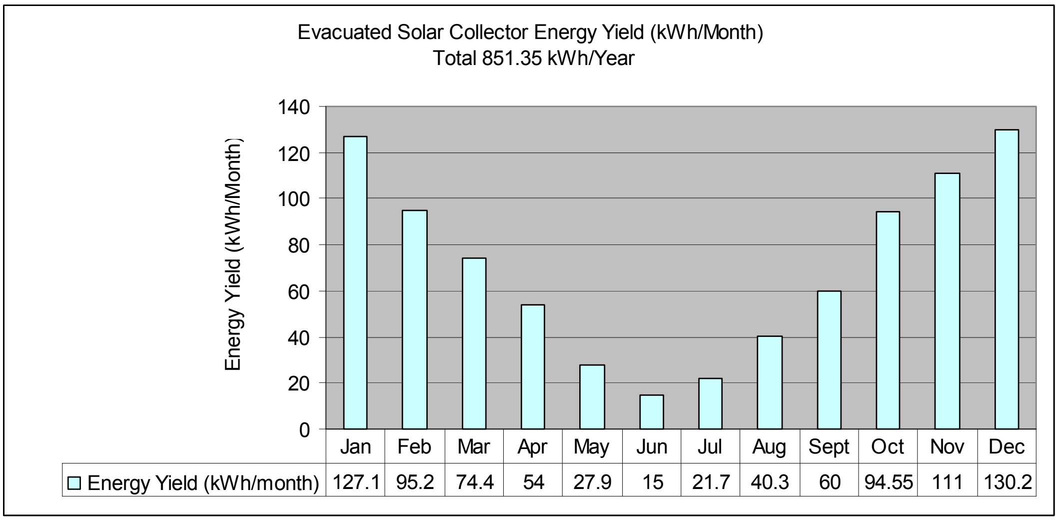

Figure 8 – Extrapolated Annual Collector Energy Yield

4. ASSESSMENT OF MODIFICATIONS

The unit as supplied is designed for stand alone use in South East Asian countries and is not suitable for use in domestic applications within New Zealand. Expected modifications required will be to allow for mains pressure operation or to allow for a larger installed capacity. Neither of these are likely to cause major engineering problems and the system as modified will compete favourably with existing systems in terms of cost and efficiency.

5. CONCLUSIONS

The evacuated tube solar water heater as supplied has been tested in New Zealand conditions. The efficiency and energy yields conform to expected parameters found in previous studies. With minor modifications, the unit is found to be suitable for use in New Zealand and would offer both financial and efficiency advantages over existing types currently in the market.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

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3. Kamel F., Wilson P., *Analysis of a Roo-top Combined Photovoltaic/Solar Thermal Plant at Christchurch*, Paper presented to Conference. ISES 2001 Solar World Congress, Adelaide, Australia 25 Nov – 2 Dec. 2001