# Analysis of the Design Parameters of a Single-Effect Solar Still

*A Project Report*

*submitted by*


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# THESIS CERTIFICATE

This is to certify that the thesis titled **Analysis of the Design Parameters of a Single-Effect Solar Still**, submitted by **Seetharaman Subramanian**, to the Indian Institute of Technology, Madras, for the award of the degree of **Masters in Technology**, is a bona fide record of the research work done by him under our supervision. The contents of this thesis, in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma.

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# ABSTRACT

KEYWORDS: solar energy, solar still

A modern solar still is no different in theory now than the ones built hundreds of years ago. What has changed has our understanding of the design parameters that have an impact on the performance of the still. This work aims at understanding the theory behind the thermodynamics of the still, and how it leads to the various design parameters and the extent of the impact of these parameters.

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# NOTATION

| | |
|---|---|
| $C$ | Heat stored in the basin |
| $C_g$ | Heat stored in the top glass cover |
| $G_h$ | Solar radiation rate on horizontal surface, $kWm^-2$ |
| $G_r$ | Total solar radiation on horizontal surface, $kJm^-2$ |
| $G_s$ | Solar (short wave) irradiation, $Btu/hrft^2$ |
| $G_L$ | Atmospheric (long wave) irradiation, $Btu/hrft^2$ |
| $M$ | Total mass of evaporated water, $kgm^2$ |
| $\dot{m}$ | Evaporation rate, $kgm^{-2}s^{-1}$ |
| $q_k$ | Heat loss from still by conduction through base, $Btu/hr$ |
| $q_e$ | Heat transfer by evaporation |
| $q_c$ | Heat transfer by convection |
| $q_{cz}$ | Heat loss by convection to environment |
| $q_r$ | Heat transfer by radiation |
| $q_{rz}$ | Heat loss by radiation to environment |
| $T$ | Temperature, $R$ |
| $T_a$ | Temperature of ambient air, $R$ |
| $T_g$ | Temperature of glass, $R$ |
| $\alpha$ | Absorptance of still base for solar energy |
| $\alpha_{gL}$ | Absorptance of glass cover for long wave radiation |
| $\alpha_{gs}$ | Absorptance of glass cover for solar radiation |
| $\alpha_w$ | Effective absorptance of the still |
| $\eta_i$ | Internal still efficiency |
| $\eta_o$ | Overall still efficiency |
| $\tau$ | Transmittance of transparent cover plus water film for energy |
| $\theta_s$ | Time from sunrise to sunset, $hrs$ |

# CHAPTER 1

# INTRODUCTION

Potable water is highly scarce in many areas of rural India, and combined with lack of stable electricity, presents an almost insurmountable challenge for people to source drinking water. The traditional method of digging wells is not viable any more in the face of dropping water tables, and a suitable, green alternative is needed to supply the bare minimum of 5 l/day water required per person for survival (Edition, 2011).

One simple and time tested solution is harnessing the power of solar energy to evaporate and then re-condense water to purify it. It is proposed that solar stills designed specifically for this purpose will be ideally suited for this purpose. The proposition of using a solar still is not new, many researchers have been investigating the various ways in which the still can be designed in order to maximise the output. The various kinds of stills have been explored by Kumar *et al.* (2015); Abujazar *et al.* (2016); Sharshir *et al.* (2016).

The scope of this work has been limited to passive, single effect solar stills, based on the work of Pednekar *et al.* (2018) as part of his Master's thesis, where-in the various design parameters and their effect on the efficiency of the still have been explored. The underlying theory of the thermodynamic process is based on the work of Dunkle (1961), and the main aim of this project is to establish the optimal design parameters for a single effect solar still that produces an output of $5l/m^2$ per day. This is to be verified by building a prototype and then perform a DFMA analysis on it in order to achieve a pre-production prototype.

## 1.1 Design Parameters

The various design parameters that impact the performance of a solar still have been extensively tested by various authors (Garg and Mann, 1976; Riera *et al.*, 1980; Nafey *et al.*, 2000; Al-Hayeka and Badran, 2004; Tarawneh, 2007; Abujazar *et al.*, 2016;

Sharshir *et al.*, 2016; Rufuss *et al.*, 2016; Pednekar *et al.*, 2018). The main design parameters are:

- solar radiation
- wind velocity
- ambient air temperature
- brine depth
- glass angle
- size of the basin
- material of the basin
- colour of the walls of the container
- presence/absence of external condenser

## 1.2 Theoretical Model

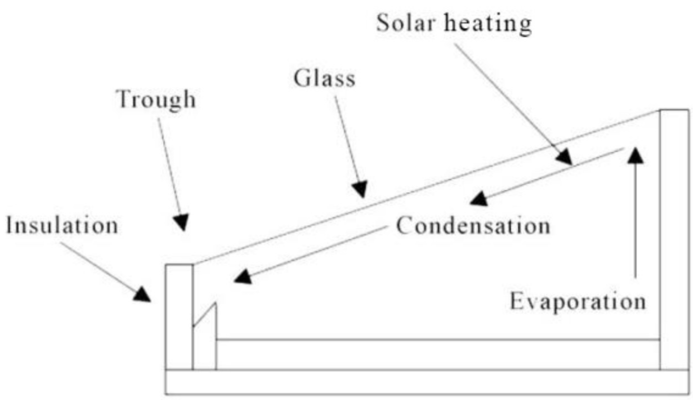


Figure 1.1: A simple schematic of a single basin solar still. Source: Pednekar *et al.* (2018)

The main body of work in establishing a mathematical model of the solar still was laid down by Dunkle (1961) and Cooper (1973). The still, whose schematic is given in Figure 1.1 is modelled as a thermal circuit shown in figure 1.2. The solar radiation incident on the top cover consists of short wave solar radiation, $G_s$, and long wave radiations $G_L$. The amount of energy that passes through the cover is $\tau G_s$, as most of the long wave rays are absorbed in the glass cover. Of this, the amount of solar energy that strikes the bottom of the still basin is $\alpha\tau G_s$; this represents the amount of solar radiation absorbed per unit area of the still. The value of $\alpha\tau$ is approximated to $0.8$ by Dunkle (1961), this value is also used in this work.

As seen in the thermal circuit in figure 1.2, of the energy impacting the bottom, $q_k$ will be lost to conduction, some will be used up in heating the water and the remainder will be lost from the water surface by convection, evaporation and radiation. This is then taken in by the lower surface of the top cover, and is then lost to the environment by convection and radiation.

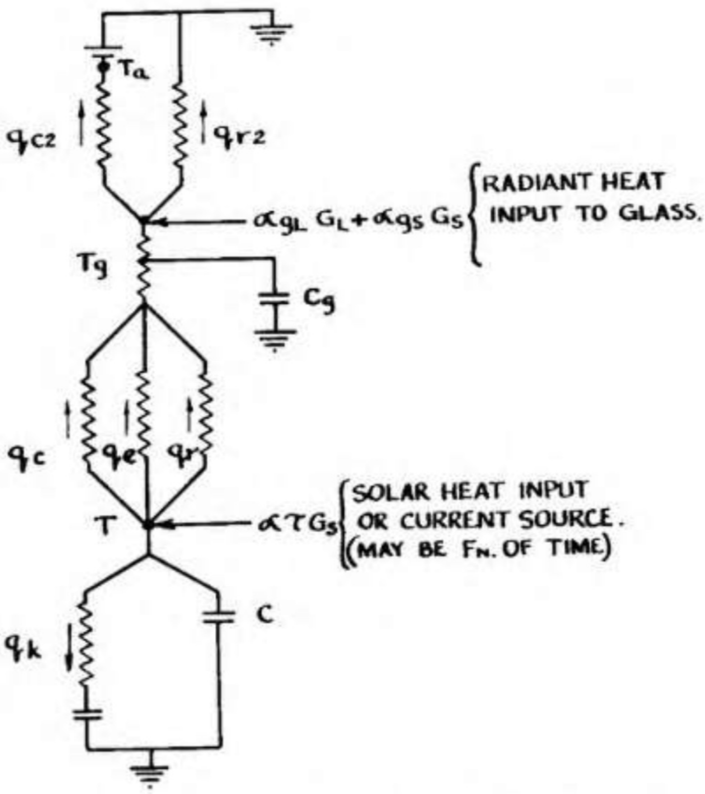


Figure 1.2: A thermal of a single basin solar still. Source: Dunkle (1961)

Based on this work, Cooper (1973) has estimated the theoretical maximum efficiency of a single-effect horizontal solar still, and has tested it against a prototype for verification and validation. He defines the efficiencies, $\eta_o$ and $\eta_i$ as

$$\eta_o = \frac{q_e}{G_h} \tag{1.1}$$

$$\eta_i = \frac{q_e}{\alpha_w G_h} \tag{1.2}$$

$$\text{thus, } \eta_o = \alpha_w \eta_i \tag{1.3}$$

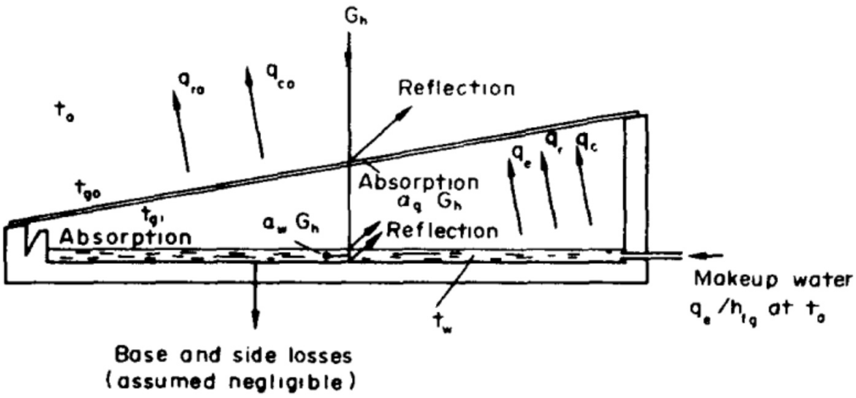


Figure 1.3: Steady state heat flows for a single-effect solar still. Source: Cooper (1973)

Though, as Dunkle (1961), Cooper (1973) was unable to find a theoretical solution for the governing set of equations, he used an iterative technique to calculate the *idealised* production rate for a given radiation rate and ambient temperature. His results are shown in the figure 1.4 below. The sharp demarcations for ambient temperatures of 20 to 50 $°C$ represents a limiting water temperature of 90 $°C$ in each case. Using this, the ideal overall efficiency is given as:

$$\eta_o = 0.727 - 2.88 \times 10^2 \frac{\theta_s}{G_r} \tag{1.4}$$

The values of $\theta_s$ and $G_r$, when assumed to be $12h$ and $30 \times 10^3 kJm^{-2}$ respectively, results in an overall efficiency $\eta_o$ of **61.2** per cent. It should be noted that it is possible to measure short-term efficiencies that are greater than this figure with real systems that have thermal lag.

When Cooper (1973) verified this experimentally, it was found that the empirical value of the overall efficiency was 51.3 per cent, whereas the ideal calculated efficiency was 57.3 per cent. The possible reasons for this discrepancy are losses from the bottom

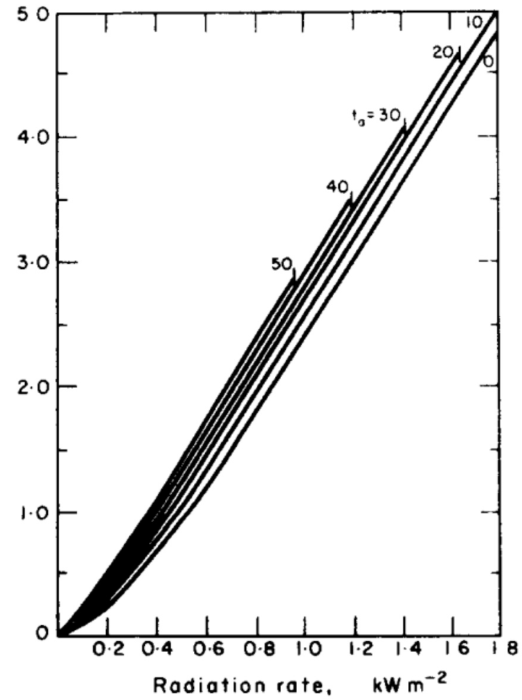


Figure 1.4: Ideal production rate as a function of radiation rate and ambient temperature. Source: Cooper (1973)

and sides of the basin, thermal lag in the system and other non-ideal conditions that are unavoidable in real-world systems.

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