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**PERFORMANCE OF A 2-ELEMENT PLANE REFLECTOR
AUGMENTED FLAT PLATE COLLECTOR FOR
SOLAR WATER PASTEURISATION**

BY

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BSc. (Agricultural Engineering)

**A THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR
THE AWARD OF DEGREE OF MASTER OF SCIENCE (RENEWABLE ENERGY) IN
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MARCH 2006

Ako, Elias
*Performance of a
2-element plane*



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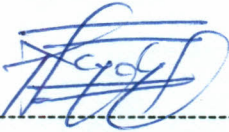
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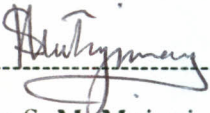
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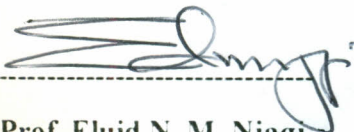
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DEDICATION

To my late father Charles Ako Osir
for his support and company during the research work.
May your soul rest in everlasting peace.

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I would like to express my sincere gratitude to my supervisors Dr. T.N. Thoruwa, Dr. S. M. Maingi and Prof. E.N.M. Njagi for their encouragement and diligent supervision while undertaking this research work.

My thanks also go to both teaching and technical staff of the Department of Engineering and Technology for their support and contribution at the various stages of this work. I wish to specifically thank Mr. Gathungu, the Chief Technician, Department of Engineering and Technology for the assistance during construction of the experimental solar water pasteurization system. Special thanks also to Njoka, Kimani, Maina and Adagala who also contributed in this study. I am also grateful to my colleague Mr. Mwangi for his support and company during the research work.

I cannot also forget to thank my parents, my late father Charles Ako and mother Margaret Ako for the foundations they laid for me. Special gratitude also goes to my wife Christine and daughters Merryl and Margaret who have been an inspiration and also without whose understanding this work would not have been accomplished.

I do also register a lot of thanks to Kenyatta University for granting me the scholarship that enabled me to undertake this study. Thanks also to Mambo and the staff Kenya Water Institute (KEWI) for their assistance in carrying out water analysis and lastly but not least I wish to thank the Almighty God for His favours and grace that have been sufficient always.

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ABSTRACT

Access to safe and adequate water supply and improved sanitation is a fundamental need and a basic human right vital for health and dignity of all people. The situation has therefore called for concerted effort which has been expressed in the global commitments reiterated in the Millenium Development Goal (MDG), to reduce to half the population of people who lack access to safe and adequate water supply by 2015 and provide safe and adequate water for all by the year 2025. There are various techniques that have been used to disinfect water and make it safe to drink. These include: chlorination, ultra-violet disinfection, use of ozone gas, pasteurization and mixed-oxidant gaseous systems which is the most recent technology. Conventional water treatment methods rely heavily on chemicals, high energy consumption, use of expensive equipments and huge capital investments. Although they are suitable where large amount of water is required, they are not suitable for most rural settings existing in Kenya today that are normally scattered making centralized system a very expensive venture. Direct application of heat is one of the oldest and most reliable method of water disinfection. This study has pursued the concept of heating water using solar thermal energy to kill disease causing organisms, mainly *E. coli* which is one of the major indicator of faecal pollution in water. The direct heating of water was investigated using a 2m² flat plate collector with a 2- element plane mirror reflector used to concentrate solar radiation from an aperture area of 4m². Two experimental collectors were investigated; one having 20mm diameter galvanized pipe with a 26 gauge stainless steel absorber sheet and the other with 18mm diameter copper pipe with a 32 gauge aluminium absorber sheet. In both investigations, collector without reflectors was used as control experiment. Thermal performance tests have been conducted using continuous flow operation at controlled flow-rate (30±3l/hr and 40±3l/hr) and using pasteurization tests with thermostatic valve installed with a valve opening temperature of 82°C. In both the experimental systems under investigation it was observed that the use of mirror increased the day average instantaneous efficiency by up to 10% during continuous flow operation and up to 100% in output of pasteurized water discharged via the thermostatic valve. Water quality tests were done for both raw and pasteurized water samples using presumptive test for total coliform and Eijkman test for confirmation of *E. coli* in water. There was no *E. coli* found in pasteurized water. Data analysis was done using both descriptive and inferential statistic. An economic analysis of the solar pasteurization system has indicated an annual saving of up to 5tonnes of wood for collector with reflectors and an aperture area of 4m² having a daily pasteurization output of up to 100liters for a day under clear sky condition with an average solar radiation of 720W/m², ambient temperature of 28°C and average wind speed less than 2m/s. Thus, the adoption of this study would not only reduce the number of cases of water borne diseases such as cholera and typhoid which have been identified as major cause of morbidity in Kenya by the Health Sub-sector Strategic Plan (1999-2004) but also lead to a reduction in environmental degradation, green-house gas emissions and health effects associated with inhaling smoke.

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LIST OF SYMBOLS AND ABBREVIATIONS

<u>Symbol</u>	<u>Description</u>	<u>Units</u>
A_c	Collector area	$[m^2]$
A_a	Aperture area	$[m^2]$
b	Exit aperture	$[m]$
C_b	Bond conductance	$[Wm^{-1}K^{-1}]$
C_i	Fuel price	$[KshMJ^{-1}]$
C_p	Specific heat capacity of water at constant pressure	$[Jkg^{-1}K^{-1}]$
C_s	Total cost of solar pasteurization system	$[Ksh]$
D	Tube diameter	$[m]$
F	Standard fin efficiency	$[Dimensionless]$
F_R	Heat transfer factor	$[Dimensionless]$
F'	Collector efficiency factor	$[Dimensionless]$
F''	Collector flow factor	$[Dimensionless]$
h_b	Convective coefficient between back cover and air	$[Wm^{-2}K^{-1}]$
h_e	Convective coefficient between collector edge and ambient air.	$[Wm^{-2}K^{-1}]$
h_w	Convective coefficient between glass cover and air	$[Wm^{-2}K^{-1}]$
h_{fi}	Heat transfer coefficient inside tube	$[Wm^{-2}K^{-1}]$
H	Height of compound parabolic collector (CPC)	$[m]$
I_{eff}	Effective solar irradiance	$[Wm^{-2}]$
I_T	Total solar radiation	$[Wm^{-2}]$
I_b	Instantaneous beam radiation on horizontal surface	$[Wm^{-2}]$

I_d	Instantaneous diffuse radiation on horizontal surface	$[\text{Wm}^{-2}]$
k	Thermal conductivity	$[\text{Wm}^{-1}\text{K}^{-1}]$
\dot{m}	Mass flow rate of water	$[\text{kgs}^{-1}]$
N	Total number of mirror elements	[Dimensionless]
Q_B	Instantaneous heat conduction through insulation	[W]
Q_E	Instantaneous plate heat loss due to edge effects	[W]
Q_T	Instantaneous rate of heat loss through glass cover	[W]
Q_u	Useful heat collected	[W]
q_u	Useful heat gain per unit length of tube	[W]
R_b	Tilt factor for beam radiation	[Dimensionless]
R_r	Tilt factor for reflected radiation	[Dimensionless]
S	Absorbed solar radiation per unit area	$[\text{Wm}^{-2}]$
SF	Annual solar fraction	[Dimensionless]
T_a	Ambient temperature	$[\text{°C}]$
T_f	Outlet temperature	$[\text{°C}]$
T_i	Inlet temperature	$[\text{°C}]$
T_m	Mean temperature	$[\text{°C}]$
T_p	Absorber plate temperature	$[\text{°C}]$
U_i	Collector heat loss factor	$[\text{WK}^{-1}\text{m}^{-2}]$
v	Wind speed	[m/s]
W	Spacing between tubes	[m]
w	Entrance size	[m]

x	Abscissa of mirror edge	[m]
y	Height or ordinate of mirror edge	[m]
η	Overall efficiency	[Dimensionless]
η_i	Instantaneous efficiency	[Dimensionless]
η_g	Efficiency of solar pasteurization system	[Dimensionless]
$(\tau\alpha)_{av}$	Transmittance absorptance product	[Dimensionless]
δ	Plate thickness	[m]
γ	Mirror angle with respect to optic axis	[Degrees]
θ	Tilt angle	[Degrees]
θ_a	Half acceptance angle	[Degrees]
ε_p	Emissivity of collector plate	[Dimensionless]
ε_g	Emissivity of glass cover	[Dimensionless]
σ	Stephen-Boltzman constant	[Wm ⁻² K ⁻⁴]

Abbreviation**Description**

APHA	American Public Health Association
ASHRAE	American Society of Heating Refrigeration and Air-conditioning Engineers
AWWA	American Water Works Association
CPC	Compound Parabolic Collector
<i>E.coli</i>	<i>Escherichia coli</i>

IDRC	International Development Research Centre
ISES	International Solar Energy Society
H ₂ O	Water
HCl	Hydrochloric acid
HOCl	Hypochlorous acid
MOGGOD	Mixed Oxidant Gases Generated On Demand
NH ₂ Cl	Chloramine
OCl ⁻	Hypochlorite ion
PV	Photo Voltaic
UNICEF	United Nations International Children's Fund
UV	Ultra-violet
WHO	World Health Organisation

CHAPTER ONE: INTRODUCTION

1.1 BACKGROUND TO THE STUDY

The most common and deadly pollutants in drinking water in developing countries are of biological origin and lead to many deaths due to waterborne diseases. In Kenya, 50% of the rural population and 25% of the urban population have no access to safe drinking water (National Development Plan, 2002-2008). The Republic of Kenya, National Health Sub-sector Strategic Plan (1999-2004), identified Typhoid and Cholera (both waterborne diseases) as major causes of morbidity in Kenya due to environmental conditions related to lack of safe drinking water, hygiene and sanitation. Boiling of water before drinking is a safe practice for physical disinfection of water as it destroys micro-organisms (Holfkes, 1983).

Kenya lies between latitudes 5°N and 4.5°S of the equator and longitudes 34°E to 43°E of Greenwich meridian and has an average insolation of 700W/m² and mean daily sunshine duration of 7 hours (National Atlas of Kenya, 1991). It is for this reason that solar energy utilization is feasible and a potential choice for water disinfection. Disinfection of drinking water is a process by which pathogenic organisms are destroyed or otherwise inactivated and can be accomplished by a number of physico-chemical treatments including direct application of thermal energy, UV radiation or addition of chemical reagents, e.g. chlorine. All these processes, though effective, have their own limitations emerging from technical, social and economic criteria. Effective microbiological purification of drinking water is an important consideration in the prevention and transmission of waterborne diseases.

Water quality studies have found that water from streams, ponds or open wells are likely to be contaminated with suspended organic and inorganic materials (Grandinetti, 1996). Microbiologically contaminated water places tremendous stress on health of many people especially in the rural areas and unplanned urban settlements which do not have treated water and therefore people drink directly from their respective sources without further treatment leading to frequent occurrences of diseases such as Cholera and Typhoid (Burriss and Jorgensen, 2001). Microbiological quality of water is the most important aspect of water supply in developing countries since most of the rural population utilize surface water or open wells for drinking water (McDonald and Kay, 1994). These surface water contain up to 1000 fecal coliform per deciliter of water as they are open to pollution from animal and human life (Feachem, 1980). Rural communities are scattered and therefore a central water supply system would be costly in terms of installation and operating costs. Disinfection using Ozone gas, UV and Mixed Oxidant Gas System are beyond the scope of rural communities because of high costs and technology associated with them.

Direct application of heat is one of the oldest and most certain method of water disinfection at household level. Biomass fuel is widely used to boil water for drinking over biomass-fuelled stoves in rural areas, this is because it is the only easily accessible fuel to the poorest population in developing countries (Smith, 1994). The depletion of this resource is of great concern due to the effects on the environment. The progressive but exponential depletion of forests and wood for water heating and cooking may lead to severe ecological damage, which if not reversed, will be expensive to restore.

Thus, with increasing global demand for energy, its increasing costs and depletion of non-renewable energy sources, solar energy has become a potential choice particularly in the rural areas as global focus on renewable energy continue to gather momentum.

1.2 STATEMENT OF THE RESARCH PROBLEM

Water intended for human consumption must be free from microorganisms that are causative agents of waterborne diseases. Most rural communities get their water from surface streams and run-off and much of it is contaminated (Grandienetti, 1996). There are about one million to a billion *E. coli* bacteria per gram of feces (Metacalf, 1994). At any given time, about half of the population in the developing world suffers from one or more of the following disease associated with water supply and sanitation such as Cholera, Ascaris, Typhoid and Hookworm (WHO, 1993-1998). The burden of diseases caused by contaminated water and lack of sanitation continues to be staggering particularly among young children in the developing countries and unsafe drinking water continues to be the major health challenges in the world today. Over 80% of all infectious disease in developing countries are transmitted through water and as a result more than four million children die each year (UNICEF, 1988). UNICEF (1989) estimated that 60% of rural families and 23% of urban families in developing countries are without safe water. WHO (1996) reports that safe water remains inaccessible for about 1.1 billion people in the world and that the hourly toll from biological contamination of drinking water is 400 deaths of children below 5 years. More than 25,000 people die daily and more than 9 million annually due to diseases associated with contaminated water. The use of wood based fuels for water pasteurization and as the main source of energy for rural

communities is a great source of concern as their depletion leads to serious potential consequences such as soil erosion, floods and desertification. It is therefore important to use alternative sources of energy, in particular solar energy. Solar energy is a promising alternative energy resource for water pasteurization since it is abundant in the tropics and the resource is not affected by the extent to which it is harnessed constructively.

1.3 JUSTIFICATION

The task of supplying safe and adequate water to the majority of the rural population is an enormous one and important in the reduction of poverty and improving health services. In view of this situation, it is logical to employ the limited resources that become available to give adequate safe water to as many people as possible. Access to safe and adequate water supply and improved sanitation is a fundamental need and a basic human right vital for health and dignity of all people (WHO, 1997). If a water source is suspected from being unsafe, the most common recommendation is to boil the water. This recommendation is seldom followed for several understandable reasons, the most important being time and amount of scarce fuel it would require. It is economically unrealistic and environmentally unsustainable to use wood fuel for boiling drinking water to rural households. With an average efficiency of 12%, a wood fuel can boil water about 3 times its weight and 1 kg of fuel wood burnt in biomass cook stoves releases 440g of CO₂ and 650g of carbon-equivalent non-CO₂ greenhouse gas emissions (Smith, 1994). The continuous use of biomass to boil water would thus lead to depletion of biomass resources and associated contribution of greenhouse gas emissions. Chlorination is widely used for water treatment, but its use has limited scope in the rural settings with

restricted financial capacity, understanding of chemicals (their uses, abuses and availability). Lack of technical knowledge in estimating the dosage and measuring the residual chlorine and chlorination by-products such as tri-halomethane has been found to be carcinogenic at high concentration (Eaton *et al.*, 1994). The use of chlorine is mainly effective when used on clean water. Water containing ammonia results in formation of chloramines and is a reaction that takes place faster than the disinfection reaction rendering chlorination uneconomical and ineffective (APHA, 1971).

Installation costs and running costs are high for a central water supply system in developing countries particularly for scattered rural settlements (Vaal, 1993), hence the need for decentralized systems. Solar water heaters have been widely used in this country. Agumba (2002), reports that there are about 7000 solar water heaters used to provide hot water in domestic households in Kenya and are situated mainly in urban areas. However, their application for water pasteurization has been almost neglected hence the need for an appropriate technology to use the solar energy for provision of safe drinking water from solar pasteurization. Solar thermal pasteurization can eliminate the need for firewood or any other sources of energy and will not only conserve the fuel already used for boiling water, but would also reduce any further demands of fuel that could arise as people resort to boiled water for health reasons.

1.4 RESEARCH OBJECTIVES

1.4.1 General Objective

The general objective of this work was to design, construct and evaluate the performance of a solar pasteurization system and test its ability to pasteurize drinking water for rural communities in Kenya. These would include boarding schools that currently have no access to safe drinking water, except through utilization of firewood for boiling water.

1.4.2 Specific Objectives

Specific objectives of this work were to:

1. Design a solar concentrating collector that utilizes solar thermal energy to pasteurize water;
2. Construct the solar collector for water pasteurization;
3. Evaluate the thermal performance of the concentrating collector for water pasteurization;
4. Investigate the effectiveness of the collector in destroying faecal coliform in contaminated water; and
5. Evaluate the economic viability of the solar pasteurization system in Kenya.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

Portable or drinking water is defined as water having quality in terms of physical, chemical and bacteriological parameters, so that it can be safely used for drinking and cooking. A daily per capita consumption of 2 liters is generally accepted for a person weighing over 60kg (WHO, 1993-1998).

The most common water pollutants are:

- (i) Biological pollutants – these are the most common and deadly pollutants in drinking water in developing countries.
- (ii) Chemical contaminants – affects colour, turbidity and odour, which have effect on the acceptability of the water (Gadgil, 1998).

The various methods that have been used for treatment of water in rural areas include pasteurisation, filtration and chlorination.

2.2 Microbiological parameters

The greatest danger to an individual health from water pollution is derived from pathogens, which are excreted in faeces and sometime in the urine of the disease carrier (both animals and human beings). Majority of waterborne diseases arise as a result of contamination of drinking water. Pathogens may be ingested directly by drinking or consuming food washed with contaminated water (Sterritt and Lester, 1994). Table 2.1 shows some common waterborne diseases and their causative pathogens.

Table 2.1 Common waterborne diseases and pathogens causing them

Disease	Causative organism
Cholera	<i>Vibrio cholerae</i>
Typhoid	<i>Salmonella typhi</i>
Paratyphoid	<i>Salmonella paratyphi</i>
Food poisoning	<i>Salmonella</i> species other than above
Bacillary dysentery	<i>Shigella</i>
Dysentery	<i>Entamoeba histolytica</i>
Bilharzia	<i>Schistosoma</i>

Source: Tebbutt (1987)

The water industry has adopted the use of indicator species of bacteria to demonstrate that any contamination has taken place. The concentration of any indicator suggests the level of risk from associated pathogens. The ideal indicator has been defined by Mallard (1982) as follows; applicable to all types of water, easily detectable by simple laboratory test in shortest time possible and harmless to man and animals with consistent characteristics. Although it is possible to examine water for specific pathogenic organisms, a much more sensitive test for routine analysis uses an indicator organism *Escherichia coli* that is a normal inhabitant of the mammalian gut. The presence of *E. coli* is an indicator of human or animal pollution and thus high possibility that pathogenic organisms are present (Tebbutt, 1987).

The coliform group is widely accepted among water analyst as the best measure of faecal contamination (APHA, 1975). The British Water Industry uses a sub-group of the total coliform flora, namely *E. coli* to indicate faecal pollution. In US, a larger sub-group, the faecal coliforms (FC) are used. Coliform group of bacteria comprises of all the aerobic and facultative anaerobic gram negative, non spore forming rod

shaped bacteria and have the property to ferment lactose with the production of acid and gas in a lactose medium within 48 hours at 37°C.

It is generally true that people in developing countries use surface or open wells for drinking water. These sources could contain more than 1000 faecal coliform per decilitre of water (Feachem, 1980). Recommended guidelines for bacteriological water quality according to WHO is that all water intended for drinking, no coliform should be detectable in any 100ml sample taken with tolerance as follows: *E.coli* should not be detectable in any 100ml sample, no sample of 100ml should contain more than 3 coliform organisms; coliform organisms should not be detectable in any two consecutive samples of 100ml from the same or closely related sampling point (Tebbutt, 1987) (Details in Appendix H).

Table 2.2 and 2.3 show excretion rates of *E. coli* by eight species of animals and concentration of faecal bacteria in untreated domestic water source typical of developing countries, respectively.

Table 2.2. Excretion rates of *E.coli* by 8 species of animals

Animal Species	Feecal Production per day (grams)	Average <i>E.coli</i> per gram feaces	Daily Load of <i>E.coli</i>
Man	150.0	13.0×10^6	1.90×10^9
Cow	23,600.0	0.23×10^6	5.40×10^9
Hog	2,700.0	3.30×10^6	8.90×10^9
Sheep	1,130.0	16.0×10^6	18.10×10^9
Ducks	336.0	33.0×10^6	11.13×10^9
Turkeys	448.0	0.30×10^6	0.13×10^9
Chickens	182.0	1.30×10^6	0.24×10^9
Gulls	15.3	0.10×10^6	0.04×10^9

E. coli concentration 100ml⁻¹ - Sewage – 3.4×10^5 – 2.8×10^7

Source: White and Godfrey (1985)

Table 2.3. Reported concentration of faecal bacteria in untreated domestic water sources

Source	Feacal Organisms of water *	Coliforms MPN/100ml	<i>Streptococci</i> MPN/100ml of waater
Spring	0		0
Dams	0-2		0-14
Wells	11-350		50-90
Large rivers	10-100,000		10-10,000

* When a single value is given it is geometric mean. Source: Feachem (1980)

The standard test for the coliform group of bacteria may be carried out either by multiple-tube fermentation technique, that is presumptive test and confirmatory test or by membrane filter technique (Adams, 1990).

2.3 Water disinfection methods

2.3.1 Filtration

This is a process whereby water is purified by passing through a porous material or medium. It is a simple and effective technique for purifying surface water. Two types of filtration processes mainly used in water treatment are slow sand and rapid sand processes. Slow sand filtration is most commonly used and consists of layers of fine sand filter 0.6-0.9m thick BS no. 52 mesh (0.3mm) supported on layers of coarse gravel of BS no. 10 mesh (1.6mm). Perforated pipes at the base of the filter collects the filtered water and filtration rate is 0.1-0.3 m³/m²/h so a very large surface area is required and is controlled by gravity alone (Twart *et al.*, 1994).

Rapid sand filters utilises a filter medium normally within the range of 0.5-1.5mm and have a filtration rate ranging between 5-10m³/m²/h (about 50 times that of slow sand

filters) and are mainly used for water that has been previously treated by coagulation or sedimentation. However the method is less effective than slow sand filters in retaining very small solids. Rapid sand filters have a higher loading rate and thus smaller and compact compared to slow sand filters. Both methods are expensive to operate since dirt layers collect on the surface and impedes drainage forcing it to be removed mechanically by skimming back-washing for slow sand and rapid sand respectively. After 2 to 3 months sand removed by skimming operations is replaced to maintain the required depth. This makes sand filtration labour intensive and operationally expensive (Duncan, 1988).

2.3.2 Water pasteurisation

Boiling is the oldest method to obtain water free from biological contaminants. Biomass fuel is widely used to boil drinking water using biomass stoves. Biomass fuels are generally polluting and expensive when purchased (owing to low efficiency of cook stoves) but it is the only accessible fuel in developing countries (Smith, 1994). Holding water at 70°C for 6 minutes is sufficient to pasteurise the water and render it safe for human consumption (Feachman and Bradley, 1998). One way to provide clean drinking water is to heat-pasteurise it by heating the water to 65°C for 30 minutes or at 82°C for 15 seconds or an intermediate temperature for an intermediate time and it's not necessary to boil water (Andreatta, 1994). WHO recommends a vigorous boiling of water for a minute for disinfection at sea level, adding an extra minute of boiling for each 100 metres increase in altitude to account for the progressively lower boiling point of water at higher altitudes (WHO, 1993-1998).

The process of pasteurisation and its use in milk is well known. Most milk is pasteurised at 71.7°C (161°F) for 15 seconds or alternatively at 62.8°C (140°F) for 30 minutes. Some bacteria are heat resistant and can survive in milk during pasteurisation, but these do not cause disease in people but however they spoil the milk, and hence pasteurised milk is kept refrigerated (Ciochetti and Metacalf, 1994).

Weber and Walter (1972) also reported that commercial pasteurization of milk (63°C for 30 minutes or 72°C for 15 seconds) kills or inactivates all vegetative *tubercle bacilli* (*Mycobacterium tuberculosis*). Some thermophilic cells survive up to 80°C and boiling kills all vegetative microorganisms in 10 minutes (Ciochetti and Metacalf, 1994).

Koottatep (1988) performed an experiment to disinfect water using 2 types of flat plate collectors, with glass tubes and copper tubes respectively. A temperature range of 51°C-60°C was achieved using glass tube collector with 50-67% inactivation of coliform present. Higher temperatures above 60°C were attained using the copper tube collector ensuring 100% faecal coliform inactivation of natural water. It was also established that at below 50°C, only 16% of the faecal coliforms could be inactivated. Retention time of 15 and 20 minutes ensured complete disinfection in copper and glass tubes respectively.

Most micro-organisms in actively growing state are killed by exposure to temperature at 70°C for 1 to 5 minutes. Some are killed in 10 minutes at temperatures as low as 54°C (Weber and Walter, 1972). Boiling water is not necessary to kill pathogens, but reaching water pasteurisation temperature is critical. Andreatta (1994), developed a

water pasteurisation indicator (WAPI) which is a polycarbonate tube, sealed at both ends and partially filled with blue Soya bean fat that melts at 69°C (Figure 2.1).

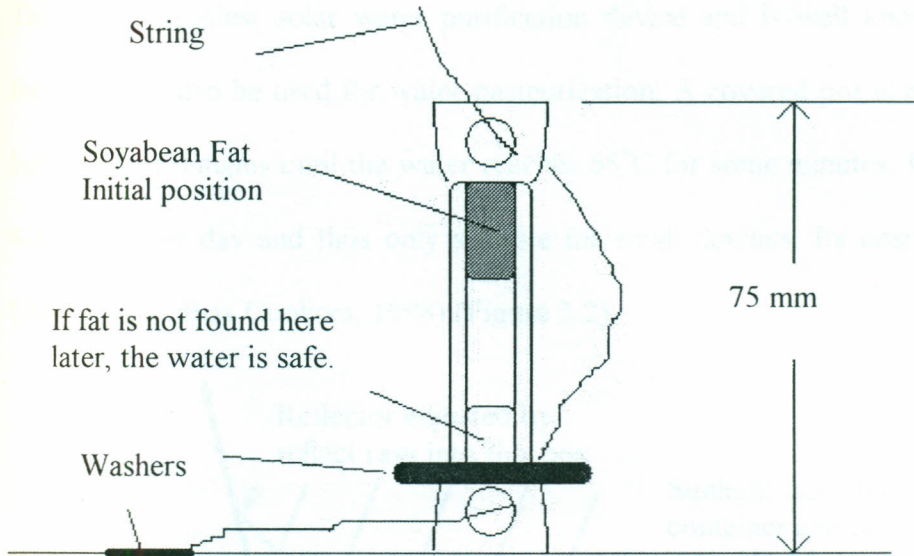


Figure 2.1 Water pasteurization indicator

2.3 Solar water treatment devices

Accra *et al.* (1984) established that exposure of drinking water for a few hours of sunshine in a transparent material reduced the amount of coliform bacteria in water. It was established that 99.9% of coliform bacteria were killed by sunlight in 95 minutes compared to 630 minutes under normal room conditions. Investigations into possible re-growth of the bacteria showed that inactivated coliform bacteria failed to re-grow after 5 days under ordinary room conditions hence disinfected water through solar radiation may safely be stored in the home provided the water does not get re-contaminated. Bacteria in water with suspended solids tend to survive longer when exposed since the presence of suspended solid materials enhance bacterial survival.

2.3.3.1 Solar box cooker

This is the simplest solar water purification device and is well known for cooking food. It can also be used for water pasteurization. A covered pot is placed inside the box where it remains until the water reaches 65°C for some minutes. It can pasteurize 4-12 litres per day and thus only suitable for small families. Its cost is of the order US\$20 (Solar Box Cookers, 1998) (Figure 2.2).

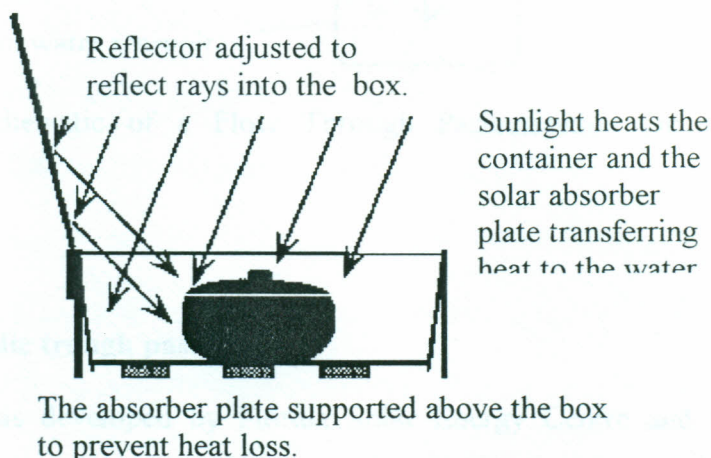


Figure 2.2 Solar box cooker used for water pasteurisation

2.3.3.2 Flow through pasteurization devices

In order to produce more water, PAX world service produced a flow through unit consisting of 15m of black tubing coiled within a standard solar box cooker. One end of the tubing is connected to a thermostatic valve and the other end to a storage tank containing pre-filtering material. Small amount of water within the tubing allows rapid heating of the water to valve opening temperature of 83.5° C. As the pasteurized water drains, contaminated water from the storage tank automatically refills the tubing. It yields 16-24 litres a day and the cost is of the order US\$150. Four to five times water output was achieved over a flow through unit with a heat exchanger and a

2.3.3.4 Solar PV Pasteuriser

Conventional technology also can treat water in remote areas, by combining PV cells that produce electricity with compact, sturdy equipment for UV light disinfection and may be preferred where chlorination is unavailable or unwanted. Gadgil and Shown (1995) produced a UV system for field use. This system provided water for a large village with UV light running on electricity. The system makes use of both filtration and UV light for disinfection with a 2m² PV panels or a 12V car battery providing electricity. The price of the system excluding storage tank is of the order US\$800 and is capable of disinfecting 16 litres per minute.

PV cells can also provide power for mixed-oxidant disinfection system. These systems use sodium chloride (table salt) to produce a highly active oxidant mixture. Venczel and Sobsey (1997), examined the effectiveness of this system in the laboratory and in a village in Bolivia and concluded that on-site production of mixed-oxidant disinfectants can provide inexpensive and effective disinfection where conventional treatment and distribution are unavailable. The disadvantages of this system are the pressurised raw water required for its operation, the high installation costs and the requirement of a highly skilled labour force.

2.3.3.5 The Solar Puddle

This is a low cost large area device and is essentially a puddle in a greenhouse and is a useful pasteurizer where water delivered per unit cost is an important figure of merit. A shallow pit about 1m² by 0.1m deep is dug and insulated with native materials (paper, straw, grass or leaves). Over these are layers of clear and then black plastic with edges extending out and over the sides of the pit. A drain siphon is installed in

the lowest part of the trough and weighted down with rocks. Water is added to a depth of 0.025m to 0.075m. A layer of clear plastic is laid over the water with edges extending over the edges of the pit. Spacers are placed on this plastic layer and a final layer of plastic placed on top of the spacers which should be at least 0.05m apart. Water needs to be added on each day. On a sunny day the device produces about 70 litres of water a day and the cost is of the order US\$40 (Andreatta, 1994) (Figure 2.4).

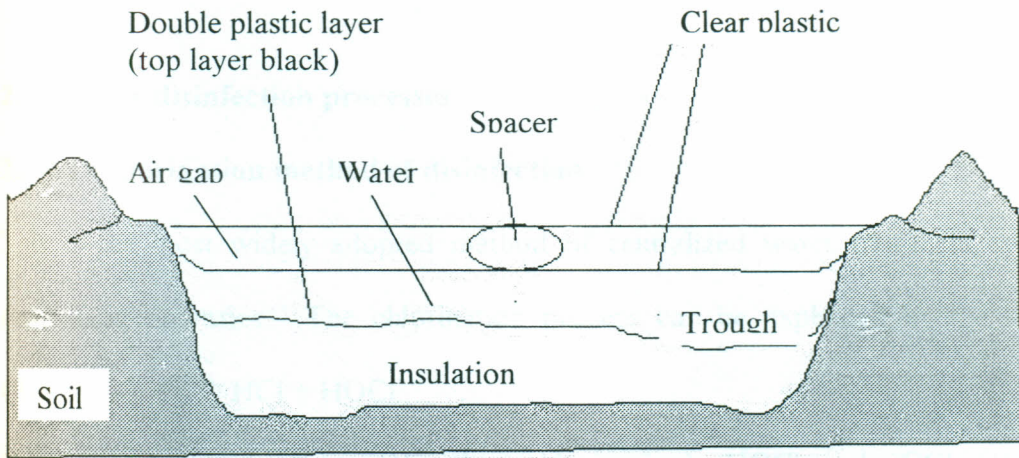


Figure 2.4 Schematic Section of a Solar Puddle

The major disadvantages of the solar puddle are the degradation of the top plastic layers which weaken under combined effect of the sun and heat hence requiring frequent replacements thus increasing its long term cost, the formation of condensation in the top layer of the plastic reduces its performance.

2.3.3.6 The Solar still

A solar still usually consists of a large flat surface mounted on legs. A short wall is built around the top of the table and lined with impermeable material (ideally black, high-temperature silicone rubber) to make a small pool of water on the top of the table. A pane of glass is mounted at slight angle above the table. As the water is heated, it forms vapour which condenses on the pane. Gravity pulls the condensate to the lower edge of the pane, which overhangs the pool, and drips into a trough, and

then through a hose or a tube into a collection jug. On a clear day a still of 1m by 2m produces about 12liters of water a day. The major drawbacks of solar still technology is that it is viable only for the production of relatively small quantities of fresh water about 2-3 litres/m²/day and requires large areas of land because of the low productivity. Solar stills are considered more economical in the case of seawater desalination (Parker, 1991).

2.3.4 Other disinfection processes

2.3.4.1 Chlorination method of disinfection

This is the most widely adopted method of centralized water treatment system in developing countries. The chlorination process can be explained by the reaction,



HOCl readily breaks into OCl^- (hypochlorite ion). HOCl and OCl^- act as the disinfectant (Pontius, 1990). Chlorination process is rendered ineffective when water is rich in organic acids and ammonia.

Chlorine reacts with ammonia to form chloramines as explained by the reaction below.



The germicidal action of NH_2Cl (chloramine) is $1/10 - 1/1000$ of HOCl and requires a contact time a 100 times longer than HOCl (Gray, 1994). Chlorine purifies water by damaging the cell structure of bacterial pollutants thereby destroying them and the amount of chlorine required to do this is called the chlorine demand of the water. Le Chavallier (1990) has outlined that chlorine is not an aggressive disinfectant as there are a number of pathogenic micro-organisms which are resistant to chlorination.

Cairncross and Feachem (1993) have outlined that chlorine should not be used; when a regular supply of chlorine compounds cannot be guaranteed, when chlorine may react with other chemicals or impurities in water creating undesirable or dangerous by-products and if careful monitoring cannot be provided as the chlorine demand of water varies with the amount of impurities in the water and thus varies with the water source. Turbidity of the water source also determines the amount of chlorine dose required to disinfect a water supply.

The chlorination process

While chlorination remains the most widely used water disinfection process, studies have revealed problems associated with tri-halomethanes and traces of chloroform as by-product of long contact period of chlorine. These by-products are carcinogenic. All forms of chlorine are harmful to health and inhaling and contact with the skin should be avoided (Twart *et al.*, 1994). Minimum contact time for chlorination is 10-15 minutes and application can be as chlorine gas or hypochlorite compound (Gray, 1994).

2.3.4.2 Ozone method of disinfection

Ozone method of water disinfection is the next widely used disinfection method after chlorination and is extensively limited to industrialised countries with high integrity piped network (Gadgil, 1998). Ozone is a gas (O_3) with powerful oxidizing effect causing rapid and effective disinfection of clear water. Its disadvantages are that it must be manufactured on site, its costly and complicated, it leaves no persistent residual in water and may cause unwanted precipitation of iron and manganese. It is not suitable for turbid water although it improves palatability (Rice *et al.*, 1997). When water containing bromides is oxidized especially using Ozone gas or

Hydrogen-peroxide, bromate is formed which is considered carcinogenic (Bull and Kopfler, 1991). Removal of bromide after oxidation requires membrane filtration and is extremely costly. The use of Ozone is not generally recommended for developing countries because of high installation, operation and maintenance cost, Ozonation requires continuous supply of power and need of importation of equipment and spare parts. The concentration of ozone produced by a modern plant is of the order 15-20 grams per cubic metre of air and can be introduced to the water through perforated pipes or ceramic. The operational energy requirement is equivalent to 27 watts hour per gramme of ozone with costs of the order 3 times that of chlorination (Schulz and Okun, 1992).

2.3.4.3 UV disinfection method

The germicidal effect occurs because UV light causes severe damage to the DNA of the micro-organism and to be effective UV energy must reach the nucleic acid within the largest organism to induce structural changes that will prevent replication of the pathogen (Kruithof *et al.*, 1991). The dose to inactivate 90% of *E.coli* is $3000\mu\text{W}/\text{cm}^2$ (Gadgil, 1998). The degree to kill micro-organisms depends upon wavelength, product intensity and radiation at time of exposure. UV radiation lies between 15 and 400nm (nanometer) wavelength. Peak disinfection is achieved at 260nm. UV is an appropriate method for point-of-use disinfection system under circumstances where disinfection is protected from recontamination. UV disinfection plants are designed to operate with pressurised raw water and thus expensive and beyond means of rural communities (Schulz and Okun, 1992).

2.3.4.4 Mixed Oxidant Gaseous Systems On Demand (MOGSOD)

MOGSOD is the most recent technology for drinking water disinfection. Its basic concept is to electrically produce the mixed oxidant gases on demand on electrochemical cell that use brine (NaCl) as the source of chlorine. Separation of brine in electrochemical cell is based on either a membrane or density gradients in the salt solution. It requires skilled manpower and has high operating costs thus inappropriate for developing countries (Venczel and Sosbey, 1997).

2.3.5 Bottled water

This is a generic term which describes all waters sold in containers and given the generic nature, bottled water is only safe if it is true to the standard particular to its stated category as covered by specific and general directives. Kenya Bureau of Standards Specifications for Drinking Water and the Water Act Cap 372 outlines the Scientific Standard for Bottled Water which falls into two categories, namely; natural mineral waters and other types of bottled water with the later conforming to higher standards laid down for drinking water. Natural water must be collected under conditions which guarantee its original bacteriological purity and must contain 200-1500mg per litre of dissolved solids both organic and inorganic, (Akumu, 2004). During processing of bottled water, besides the basic decantation and filtration, the products are subjected to more elaborate processing including UV radiation or Ozone treatment. Excess minerals are further removed by means of ion exchange singly or in combination with reverse osmosis after which the water is bottled under sanitary conditions with rigorous quality control program at processing point and in the distribution system (Hutton, 1987).

Over the past few years, increased public awareness on environmental issues has caused more concern about water quality; this is reflected by increased sales of bottled water in urban areas in the past few years. Out of the 60 brands of bottled water in the Kenyan market, only 6 have been certified by Kenya Bureau of Standards (Akumu, 2004). Manufacturers take advantage of the public perception of drinking water that it is largely based on the physical characteristic i.e. the appearance rather than quality in relation to the prescribed standard (Gray, 1994).

2.4 Project strategies and way forward

Disinfection using Ozone, UV, and Mixed Oxidant Gas Systems are beyond the scope of rural communities because of the high costs and technology associated with them. Solar water pasteurizers are feasible application for provision of safe drinking water from a dubious quality water source and is effective in inactivating disease causing bacteria and does not require an additional input of external energy. It isn't necessary to boil water to disinfect it, but can be heated to a pasteurising temperature where it's held for some time. Therefore in this study, water pasteurisation using solar energy was chosen for use in Kenya. More over, Kenya receives an average insolation of 700W/m^2 and over 80% of the population live in rural areas. Most people live in scattered rural settings that make a central water supply expensive.

The following strategies were adopted in developing the solar water pasteurisation system for rural community use in Kenya:

1. Use of locally available material as much as possible for the construction of the solar water pasteurizer. Consideration in the selection of the materials also included low cost, easy handling during fabrication and ability to withstand local environmental and operating conditions.

2. Improvement on the flow through pasteurisation device and to incorporate it to a flat-plate collector with a 2-element plane mirror reflector to enhance the performance by increasing the magnitude of solar radiation incident on the absorber surface of the collector with the overall objective of increasing the pasteurised water output at much lower costs.
3. Use of the motor vehicle thermostatic valve to regulate the pasteurisation discharge temperature as the use of water pasteurisation indicator (WAPI) is not practical in the case of self discharge of pasteurised water.

Indicator. Thermal loss rate constant, k .

Relations are also given

Energy Available

Incident on a unit area perpendicular to the beam outside the atmosphere is known as solar constant or 'solar flux' (Duffie and Beckwith, 1991).

As the earth's surface is usually lower than the solar constant due to the atmospheric resistance, some energy is absorbed by air to heat it. Radiation incident from the sun also depends on the position of the sun which varies with time of geographical location, season and day of the year.

Lord-Walton's solar constant (Duffie and Beckwith, 1991) is given by the equation that expresses the useful heat collected, Q_u , per unit area of collector.

For any variables, the incident solar radiation normal to the collector surface is I_0 . Hence, to vary the mean temperature, T_m , of the fluid to avoid the heat temperature, T_a , as

$$Q_u = A_c \left[I_0 (1 - \rho_a) - U_L (T_m - T_a) \right] \quad (1.1)$$

CHAPTER 3: THEORY

3.1 Introduction

In order to design and assess the thermal performance of the 2-element plane reflector flat-plate collector for solar water pasteurization, it is necessary to have an adequate understanding of the various aspects that make up the system. This chapter gives the background of theory used in the design and thermal performance assessment of the solar water pasteurization system. These include: the solar energy available; radiation augmentation; linear solar concentrators and optimal geometry of a composite plane mirror concentrator. Thermal test data conversion, Instantaneous and theoretical efficiency calculations are also given.

3.2 Solar Energy Available

The solar radiation on a unit area perpendicular to the beam outside the earth's surface, also known as solar constant is 1353 w/m^2 (Duffie and Beckman, 1991). The solar intensity on the earth's surface is usually lower than the solar constant due to the losses in the atmosphere resulting from scattering or absorption by air molecules, clouds and particulate matter. Solar intensity also depends on the position of the sun in the sky, which varies according to geographical location, season and time of the day. The Hottel-Whillier-Bliss equation (Duffie and Beckman, 1991) is one of the basic equation that expresses the useful heat collected, Q_u per unit area in terms of two operating variables, the incident solar radiation normal to the collector, I and the temperature difference between the mean temperature, T_m of the heat removal fluid and the ambient temperature, T_a as

$$Q_u = F_R [(\tau\alpha)I_T - U_L(T_m - T_a)] \text{-----} (3.1)$$

Where F_R is a factor related to the design of the collector plate and effectiveness of the heat removal fluid. The transmittance-absorbance product $(\tau\alpha)$ is actually some 5% greater than the direct product of the transmittance through covers and collector absorbance. The heat loss coefficient U_L rises rapidly with increasing wind velocity if there are no covers. Thus three design factors define F_R , $(\tau\alpha)$ and U_L define the thermal performance of the collector.

In a typical high temperature tube design the rate of energy loss by combined thermal conduction and natural convection is of the same order of magnitude of thermal radiation and can be approximated to 6% of the total energy absorbed by the collector (Ratzel *et al.*, 1979).

The flux I_T falling on a tilted surface at any instant is given by

$$I_T = I_b R_b + I_d R_d + (I_b + I_d) R_r \quad \text{-----}(3.2)$$

To determine the flux, S absorbed in the absorber plate, each of the above term is multiplied by the transmissivity-absorbance product, $(\tau\alpha)$. Thus,

$$S = I_b R_b (\tau\alpha)_b + \{I_d R_d + (I_b + I_d) R_r\} (\tau\alpha)_d \quad \text{-----} (3.3)$$

3.3 Solar concentrators

Concentration of solar radiation is achieved by either using a reflecting arrangement of mirrors or a refracting arrangement of lenses. The optical system directs the solar radiation onto an absorber of a smaller area. This reduces thermal losses and weight in comparison with a flat plate collector of an equivalent aperture area. Solar

concentrator types range from inexpensive and reliable static booster reflectors to more advanced concentrating systems such as multiple stage concentrators that track the sun continuously (Sukhatme, 1992). Other examples of solar concentrators are Fresnel lens, Cylindrical parabolic, Compound parabolic, Parabolic dish concentrators and Flat plate collectors with plane mirror reflectors.

3.3.1 Radiation Augmentation

It is possible to increase the radiation incident on the absorber plate by use of plane reflectors. A flat-plate collector with plane reflectors is a simple non-imaging concentrating collector and represent an effective means of getting slightly higher temperatures than are obtainable with flat-plate collectors alone. It is possible to have north facing and south facing reflectors which may reflect the radiation in a specular or diffuse manner. Concentration ratios obtained are low and normally range from one to four (Sukhatme, 1992). An advantage associated with this type of concentrating collector is that diffuse component of the incoming radiation is not entirely wasted. Details of reflector materials for solar concentrators are given in Appendix B.

3.3.2 Linear solar concentrator with flat absorber

A flat plate collector with plane reflectors is a simple non-imaging concentrating collector and represents an effective means of getting slightly higher temperatures than are obtainable with a flat-plate collector alone (Sukhatme, 1992). Non-imaging concentrating collectors have the advantage of utilising both beam and diffuse component of solar radiation. Even on a clear sky condition the diffuse component can represent up to 20% of the total irradiance (Boes *et al.*, 1979). Winston (1984) has given the procedure for obtaining the best mirror profile for a given acceptance angle

for linear concentrator and shown that it would tend to a compound parabolic in shape for a flat horizontal absorber. Design consisting of plane mirror elements simplifies the fabrication problem with some loss in concentration (Mullick *et al.*, 1986). The widths of the elements however have to be selected carefully in order to yield maximum concentration. The widths of the elements are functions of their angles of inclination, which have to be ascertained by applying Winston's edge ray principle (Winston and Welford, 1978) to the upper edge of each element. An optimisation procedure for a two-element concentrator has been proposed by Mannan and Banerrot (1986). Mullick *et al.* (1988) have proposed an optimisation procedure for designing a multi-element concentrator based on the use of discrete maximum principle to yield optimal angles and widths of the reflector elements for any given number of elements and any height of the concentrator less than the maximum. Reflectors are assumed to be perfectly specular for this analysis and the concentrator assumed long compared to their width. Mullick *et al.* (1988) has also reported that optimal designs tend to compound parabolic collector (CPC) as the number of mirror elements increases.

3.3.3 Optimal geometry of composite plane mirror solar concentrator

The optimal geometry of an east-west aligned linear concentrator with a flat absorber tend to a compound parabolic concentrator (CPC) as the number of mirror elements increase. Winston (1984) has shown that for maximizing concentration on a flat horizontal absorber, the reflector should start at edge A , of the absorber and the slope of the mirror at any point P on the reflector AB should be such that a ray incident at an angle θ_m from the optic axis should arrive at the opposite edge O , of the absorber (Figure 3.1). The principle can be extended to the case of a reflector composed of flat

mirror elements by applying the same condition of the upper edge of any mirror element to find its slope.

Figure 3.2 depicts one side, AB of such a reflector consisting of N plane mirror elements and a flat absorber OA .

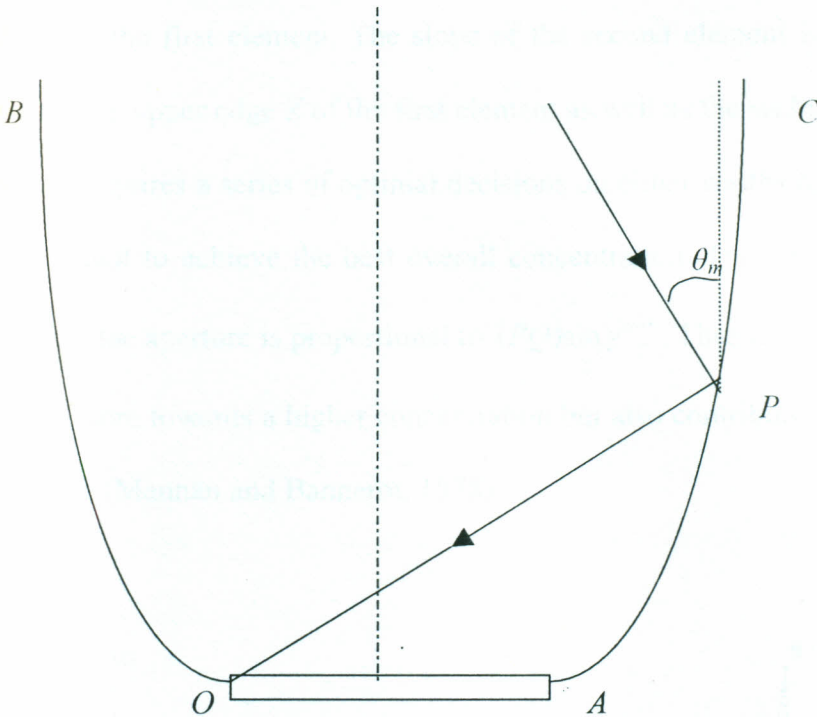


Figure 3.1 Sectional view of a compound parabolic concentrator

The slope of the n^{th} mirror element, PQ should be such that a ray striking the upper element edge, P of the element at an angle θ_m from the optic axis is reflected onto edge O of the absorber. Other rays at an angle θ_m (or less than θ_m) from the optic axis striking the element PQ are directed on the absorber OA after one or more reflections.

The angle TPO made by the ray reflected from P is

$$\angle TPO = \theta_m + 2\gamma^{n-1} = \tan^{-1}\left(\frac{OT}{PT}\right) = \tan^{-1}\left(\frac{x^{n-1}}{y^{n-1}}\right) \text{----- (3.4)}$$

and the mirror slope is

$$\gamma^{n-1} = \frac{1}{2} \left[\tan^{-1} \left(\frac{x^{n-1}}{y^{n-1}} \right) \right] - \theta_m \quad \text{-----(3.5)}$$

The slope of the first element is a function of the location of the point Z and hence width AZ of the first element. The slope of the second element is a function of the location of the upper edge Z of the first element as well as the width ZW of the second element. It requires a series of optimal decisions on either widths or the slope of all N mirror element to achieve the best overall concentration. The contribution of mirror PQ towards the aperture is proportional to $(PQ)\sin\gamma^{n-1}$. Thus mirrors of larger widths contribute more towards a higher concentration but also contribute to the height of the concentrator (Mannan and Bannerot, 1978)

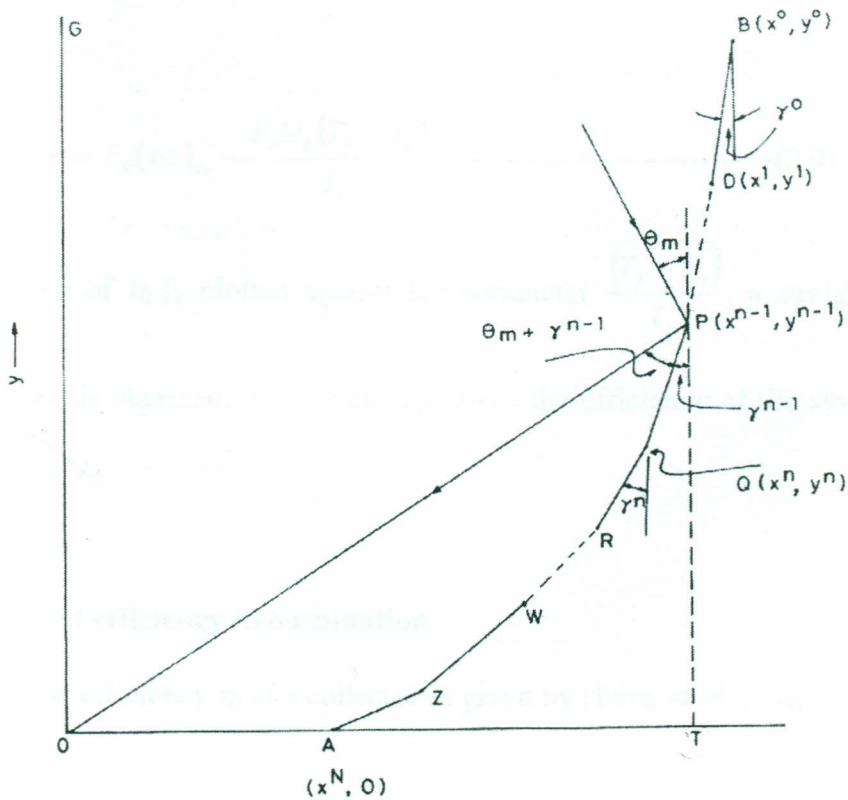


Figure 3.2 Geometry of a N -element seasonally adjusted concentrator

3.4 Determination of collector instantaneous efficiency

When the system is operated under steady state conditions, the instantaneous efficiency, η_i is defined by the relationship

$$\eta = \frac{\text{Useful heat gain}}{\text{Radiation incident on collector}} = \frac{Q_u}{A_c I_T} = \dot{m} c_p \frac{(T_o - T_a)}{A_c I_T} \quad \text{-----(3.6)}$$

Substituting equation (3.1) into (3.4) then

$$\eta_i = F_R \left[\frac{S}{I_T} - \frac{U_L (T_f - T_a)}{I_T} \right] \quad \text{-----(3.7)}$$

$$\text{When we put } S = I_T (\tau\alpha)_{av} \quad \text{-----(3.8)}$$

Where $(\tau\alpha)_{av}$ is the average transmissivity-absorbance product for the beam, diffuse and reflected radiation, then

$$\eta_i = F_R (\tau\alpha)_{av} - \frac{F_R U_L (T_f - T_a)}{I_T} \quad \text{-----(3.9)}$$

When a graph of η_i is plotted against the parameter $\frac{(T_f - T_a)}{I_T}$, a straight line with negative slope is obtained. The y -intercept gives the efficiency of the system and the slope gives $F_R U_L$.

3.5 Theoretical efficiency determination

The theoretical efficiency η_t of a collector as given by Harns *et al.* (1985)

$$\eta_t = \left[(\tau\alpha)_{av} - U_L \frac{(T_p - T_a)}{I_T} \right] \quad \text{-----(3.10)}$$

$$\text{Where } (\tau\alpha)_{av} = 0.95 - \frac{0.115}{\cos\theta} \text{-----(3.11)}$$

θ is the collector tilt angle with respect to the horizontal.

U_L is the average heat loss rate given by Okujagu and Adjepong (1989)

as

$$U_L = \frac{(Q_B + Q_E + Q_T)}{(T_p - T_a)A_c} \text{-----(3.12)}$$

$$\text{and } Q_B = A_c \frac{(T_p - T_a)}{\left(\frac{\delta}{k} + \frac{1}{h_b}\right)} \text{-----(3.13)}$$

h_b is the convective coefficient and has been estimated by Okujagu and Adjepong (1989), to be between 12.5 to 25W/m²K

$$Q_E = h_e A_c (T_p - T_a) \text{-----(3.14)}$$

h_e is the convective coefficient between edges of collector plate and ambient air and usually taken as 0.5W/m²K.

Q_T the instantaneous rate of energy transfer through the transparent cover to the surrounding air and given by

$$Q_T = \frac{A_c(T_p - T_a)}{\left[\frac{c/T_p}{(T_p - T_a)} / \left\{ (N - f)^{0.33} + \frac{1}{h_w} \right\} \right]} + \frac{\sigma A_c (T_p^4 - T_a^4)}{\left[\frac{1}{\left\{ (\varepsilon_p + 0.005N) + 1 - \varepsilon_p \right\}} \right]} + \left[\frac{(2N + f - 1)}{\varepsilon_g} \right] - N \text{-----(3.15)}$$

h_w is given by Kreith and Kreider (1981), as $h_w = 5.7 + 3.8v$ W/m^2K --- (3.16)

where v is the wind speed in m/s.

3.6 Temperature distribution between tubes

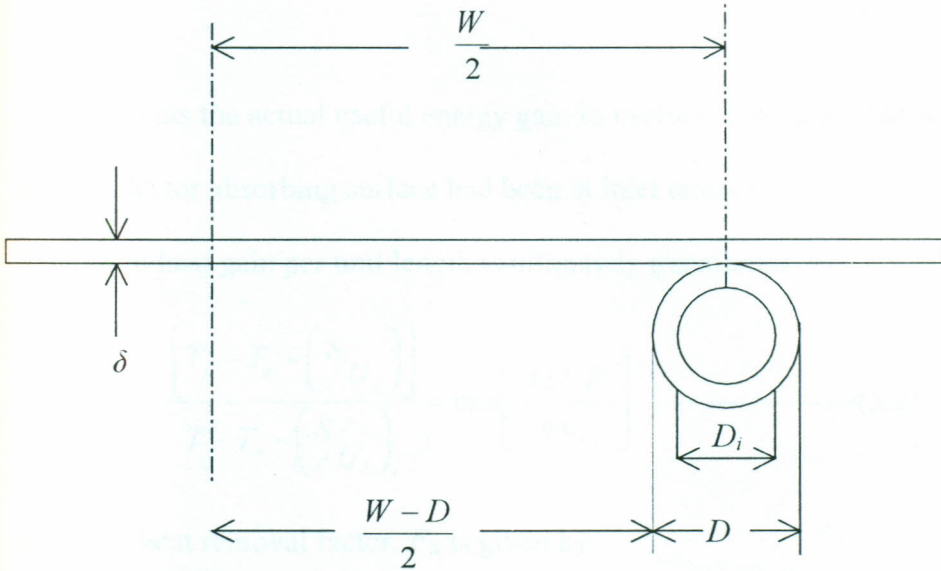


Figure 3.3 Sheet and tube dimensions

This is derived with the assumption that the temperature gradient in the flow direction is negligible. Considering a distance W between tubes, tube diameter D and absorber plate thickness δ , the heat for the tube per unit length in the direction of flow, q_u is given by

$$q_u = WF' [S - U_L(T_f - T_a)] \text{-----(3.17)}$$

and

$$F' = \frac{1/U_L}{W \left[\frac{1}{U_L} [D + (W - D)F] + \frac{1}{C_b} + \frac{1}{\pi D_i h_{fi}} \right]} \text{-----(3.18)}$$

where F is the standard fin efficiency and is given by the expression

$$F = \tanh\left[\frac{m(W - D)}{2}\right] \text{-----}(3.19)$$

and

$$m = \left[\frac{U_L k}{\delta}\right]^{0.5} \text{-----}(3.20)$$

F' represents the actual useful energy gain to useful energy gain that would result if the collector absorbing surface had been at inlet temperature.

The useful heat gain per unit length is ultimately transferred to the fluid and

$$\frac{\left[T_f - T_a - \left(\frac{S}{U_L}\right)\right]}{T - T_a - \left(\frac{S}{U_L}\right)_i} = \exp\left[\frac{A_c U_L F'}{m c_p}\right] \text{-----}(3.21)$$

Collector heat removal factor, F_R is given by

$$F_R = \frac{\dot{m} c_p (T_f - T_i)}{A_c [S - U_L (T_i - T_a)]} = \frac{\dot{m} c_p}{A_c U_L} \left[1 - \exp\left(\frac{A_c U_L F'}{\dot{m} c_p}\right)\right] \text{---}(3.22)$$

where $\frac{\dot{m} c_p}{A_c U_L F'}$ is the collector capacitance rate (mass flow-rate).

The maximum possible useful heat gain in the collector is at inlet temperature and heat losses to the surrounding are maximum, then

$$Q_u = A_c F_R [S - U_L (T_i - T_a)] \text{-----}(3.23)$$

and the collector flow factor, F'' is given by the expression

$$F'' = \frac{F_R}{F'} = \frac{\dot{m}c_p}{A_c U_L F'} \left[1 - \exp\left(\frac{A_c U_L F'}{\dot{m}c_p}\right) \right] \text{-----}(3.24)$$

The mean plate temperature can be used to calculate the useful heat gain,

$$Q_u = A_c F_R [S - U_L (T_p - T_a)] \text{-----}(3.25)$$

and

$$T_p = T_i + \frac{Q_u (1 - F_R)}{A_c U_L F_R} \text{-----}(3.26)$$

An estimate of T_p is made U_L value calculated from

$$Q_L = U_L A_c (T_p - T_a) \text{-----}(3.27)$$

and mean fluid temperature $T_m = T_i + \frac{Q_u (1 - F')}{A_c U_L F_R} \text{-----}(3.28)$

3.7 Thermal test data conversion

If test data are plotted as η_i versus $\frac{(T_m - T_a)}{I_T}$ then the equation of the straight line is

$$\eta_i = F_{av}(\tau\alpha) - F_{av} U_L \frac{(T_m - T_a)}{I_T} \text{-----}(3.29)$$

Where F_{av} is approximately the same as F' . It would be equal to F' if the fluid temperature rise through the collector were linear with the distance. If the flow-rate of the fluid is known, the intercept $F_{av}(\tau\alpha)$ and the slope $-F_{av} U_L$

of the curve of the equation above are related to $F_R U_L$ and $F_R(\tau\alpha)$ by the equation given by Beckman *et al.* (1977).

$$F_R(\tau\alpha) = F_{av}(\tau\alpha) \left[1 + \frac{A_c F_{av} U_L}{2\dot{m}c_p} \right]^{-1} \text{-----(3.30)}$$

$$F_R U_L = F_{av} U_L \left[1 + \frac{A_c F_{av} U_L}{2\dot{m}c_p} \right]^{-1}$$

3.8 Natural circulation system

Norton and Probert (1986) have reviewed the theory of operation of natural circulation system. If it is assumed that there is constant temperature increase of water flowing through the collector, it is possible to calculate the flow-rate which will produce this temperature difference at the estimated collector gain.

From the basic collector equations

$$Q_u = A_c F_R [S - U_L(T_i - T_a)] \text{-----(3.31)}$$

and

$$Q_u = \dot{m}c_p(T_f - T_i) \text{-----(3.32)}$$

solving for flow-rate

$$\dot{m} = A_c F_R \left[\frac{S - U_L(T_i - T_a)}{c_p \Delta T} \right] \text{-----(3.33)}$$

Substituting for F_R in the above equation

$$\dot{m} = \frac{U_L F' A_c}{c_p \ln \left[1 - \frac{U_L(T_f - T_i)}{S - U_L(T_i - T_a)} \right]} \text{-----(3.34)}$$

CHAPTER 4: MATERIALS AND METHODS

4.1 Introduction

Two experimental solar flat plate collectors were designed, constructed and tested in the study. One was constructed using 20mm diameter galvanized steel pipe with 26 gauge stainless steel absorber plate and the other was constructed using 18mm copper pipe with 32 gauge aluminium absorber plate. In both cases experiments were performed with reflectors in position and without reflectors for the control experiments. Details of the constructed systems are shown in Figures 4.1 and in Appendix D.

4.2 Design procedure

The design parameters were as follows: drinking water requirements, 2liters per person per day (WHO, 1993-1998); design consideration of 100 people; daily drinking water requirement for 100 people, 200liters per day; desired pasteurization temperature, (T_o) 82°C; average inlet water temperature, (T_i) 22°C; specific heat capacity of water at constant pressure, (C_p) 4200J/KgK; anticipated day average insolation, (I) 800W/m²; assumed collector day average efficiency, 0.5.

Daily energy load required to pasteurize 200liters of water is given by the relationship, $Q_L = mC_p\Delta T = 50.4\text{MJ/day}$.

Required solar energy collection area is given by $A_c = \frac{mC_p\Delta T}{I_{av}\eta t} = 4.13\text{m}^2$

For the prototype, a standard collector absorber area of 1m x 2m (2m²) was considered so as to supply about 100liters of pasteurized water per day.

Parallel piping configuration was chosen using 20mm diameter pipe with a manifold header having a greater diameter of 25mm. This was to encourage a uniform flow

distribution in the parallel risers. A pipe (tube) spacing of 175mm was chosen based on the recommended spacing range of 150mm – 180mm, typical for domestic solar water heating for optimal effectiveness of the collector relative to cost (Ghamar and Worth, 1992; Gillet and Moon, 1985).

Number of parallel risers at spacing of 175mm = 5.

Absorber plate thickness = 0.5mm

Value of heat transfer coefficient, h_f was taken to be $300\text{W/m}^2\text{K}$. Values ranging $200 < h_f < 400\text{W/m}^2\text{K}$ has been recommended for parallel riser tube with sandwich absorber (Gillet and Moon, 1985).

Value of collector heat loss coefficient, U_L was taken as $8\text{W/m}^2\text{K}$, this has also been recommended by Gillet and Moon (1985), for a single glazed collector with absorber painted malt black.

Using equations 3.19 and 3.20 the standard fin efficiency, F was calculated and found to be 0.7. This was used to calculate the collector efficiency factor, F' using equation 3.18 and found to be 0.697 (the value of bond conductance, C_b was assumed to be 0).

The dimensionless mass flow-rate of the collector was found using equation 3.22 and found to be 3.12. This was used to calculate the collector flow factor, F'' using equation 3.24 and calculated to be 0.855.

Heat removal factor, F_R was then calculated from the relationship $F_R = F'F'' = 0.696$

Using equations 3.33 and 3.34 the theoretical flow-rate was calculated to be 30l/hr.

4.3 Construction of the solar pasteurisation system

Important general consideration in selection of materials for construction of the solar collector included local availability, low cost, easy handling during fabrication, weatherability and long service life (i.e. ability to withstand environmental and

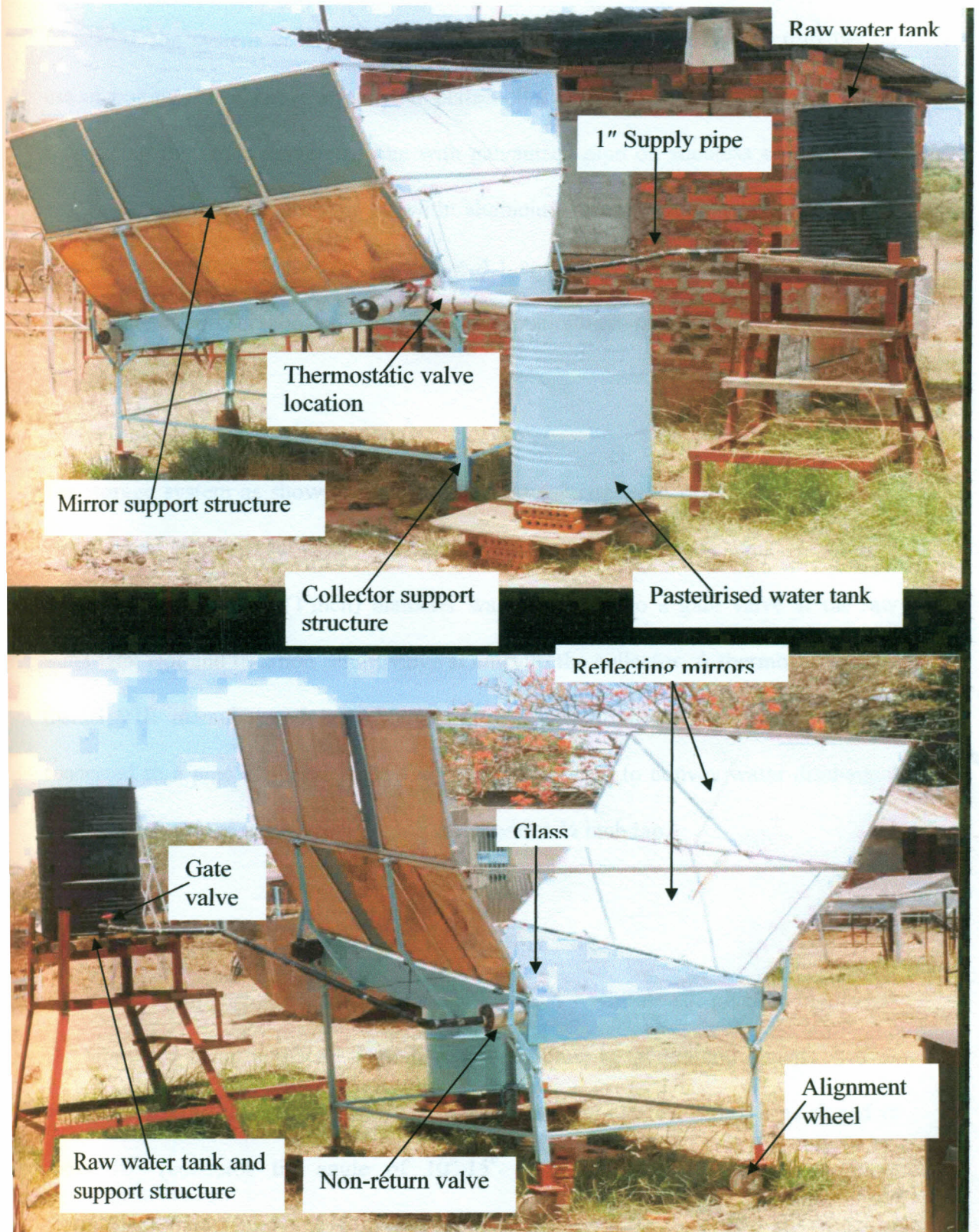


Figure 4.2 Photograph of the experimental set up

operating conditions). Ease of transportation was also taken into consideration by fabricating the system in sub-assemblies that could be easily assembled together by use of bolting. Two experimental flat plate collectors as shown in Figure 4.1 were constructed for the experiments; one with galvanized pipe on stainless steel absorber and the other with copper pipes with aluminium absorber plate. Details of the collector components are shown in Figure 4.1 and in Appendix D. Figure 4.2 gives the schematic representation of the solar pasteurization system.

4.3.1 Piping and water storage

The storage system as shown in Figures 4.1 and 4.2 consisted of two 250liter tanks, for raw and pasteurized water respectively. From the raw water tank, galvanized supply pipe of 25.4mm (1 inch) diameter was connected to a gate valve at the raw water tank exit and to a non return valve at entry to the collector. A thermostatic valve (model 97E manufactured by *KUZEH*, Japan) was fitted on the outlet pipe and connected to a pipe of diameter 25.4mm which was used to convey water discharged onto the pasteurized water storage tank fitted with a $\frac{3}{4}$ inch tap.

4.3.2 Construction of collector support structure

The collector support structure as shown in Figure 4.1 with details given in Figure 4.3 was fabricated from mild-steel angle-line of size 50mm by 50mm and dimensioned to accommodate the collector of size 1000mm by 2000mm (1m by 2m). It was sloped at about 10° (collector tilt angle of 10° - 15° below the latitude angle has been recommended by Gillet and Moon, 1985). A commercially available ply-wood of thickness 13mm and dimensions 995mm by 1995mm was bolted on the stand and was

used to hold the bottom insulation. It was also ensured that the support structure was capable of withstanding both lateral and wind uplifting wind forces and the load imposed by the presence of both reflector and collector mountings. A 20 by 20mm square hollow section was used to reinforce the collector structure.

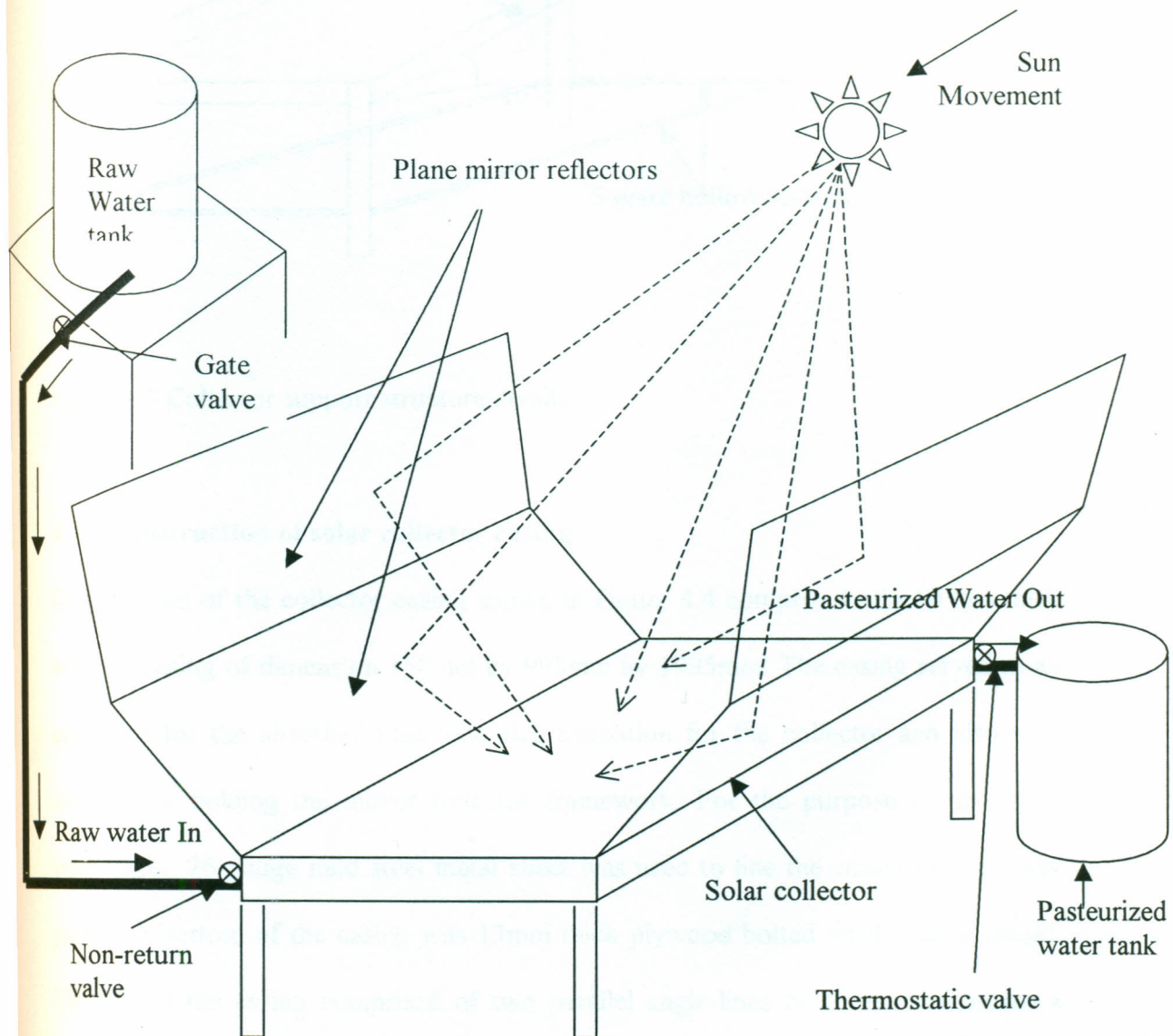


Figure 4.2 Schematic diagram of the experimental set-up

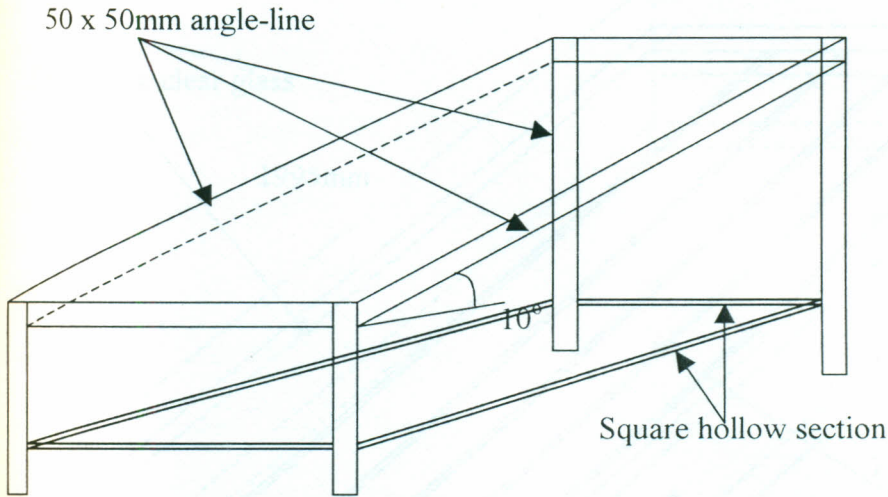


Figure 4.3 Collector support structure details.

4.3.3 Construction of solar collector casing

Construction of the collector casing shown in Figure 4.4 comprised of a 50 mm thick wooden casing of dimension 150mm by 995mm by 1995mm. The casing served as an enclosure for the absorber assembly, side insulation for the collector and also as a support for holding the mirror reflector framework. For the purpose of making it water tight, 26 gauge mild steel metal sheet was used to line the casing on the outer part. The bottom of the casing was 13mm thick plywood bolted on the stand (base). The top of the casing comprised of two parallel angle-lines of dimensions 50mm x 50mm x 1995mm bolted on the wood casing and was used to support the framework for holding the reflecting mirrors. The top of the casing was glazed by a transparent heat tempered glass of thickness 5mm. Glass satisfied the cover desirable properties

of high optical transmittance, low reflectivity and low absorbance of solar radiation (see Appendix B). The absorber and collector cover were designed to permit differential thermal expansion.

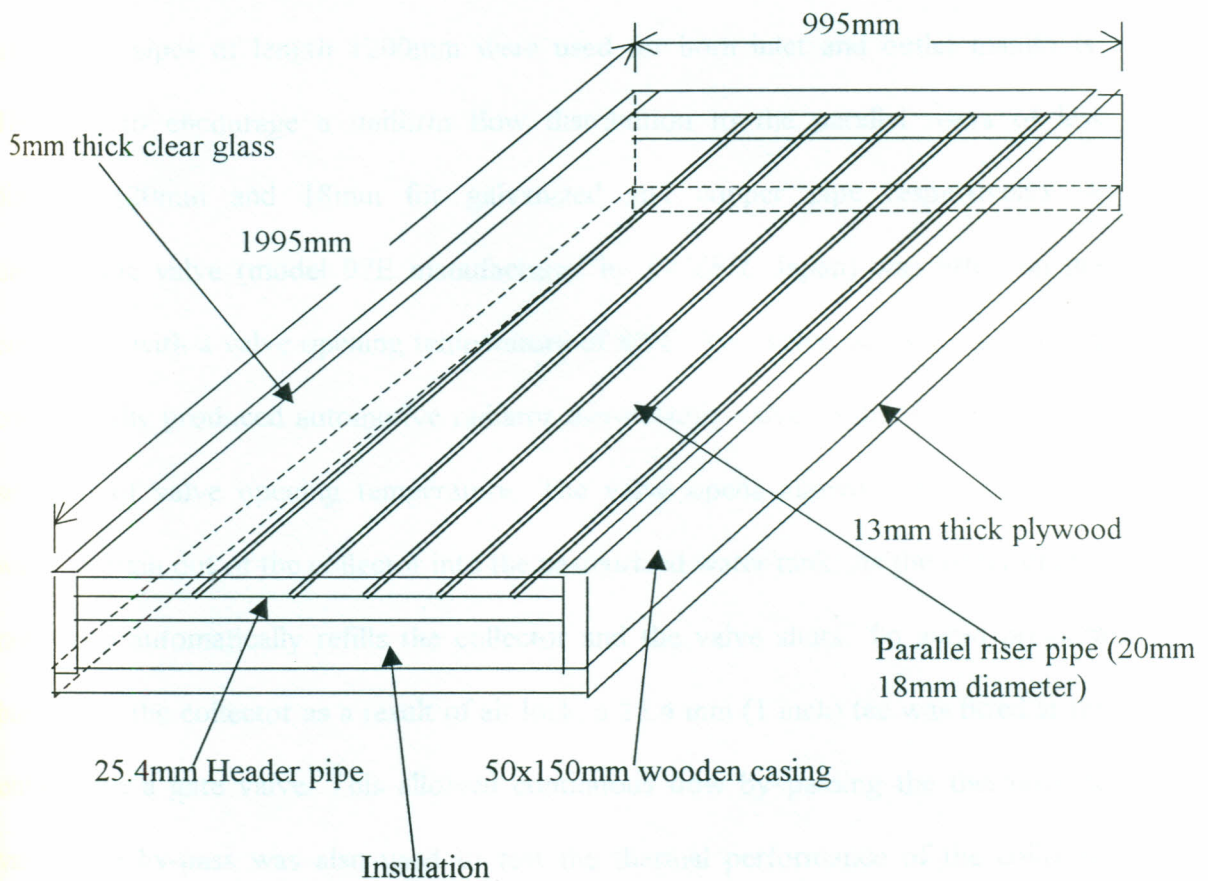


Figure 4.4 Collector casing and absorber assembly

4.3.4 Construction of solar absorber assembly

The absorber assembly shown in Figure 4.4 comprised of 20mm (3/4 inch) diameter galvanized pipes (risers) running parallel to the slope with a 26 gauge mild steel absorber plate and 18mm diameter copper pipe with a 32 gauge aluminium absorber sheet respectively for the two experimental collectors (see also items 2 and 3 in Appendix D). In both cases the absorber surface was painted malt black. To ensure satisfactory paint adhesion a thin layer of red-oxide primer was applied before the malt black paint. Rigorous effort was made during construction to have a good

thermal contact between the pipe and the absorber plate by folding to half the outside diameter of the pipe with brazing used for bonding in the case of galvanized pipe collector and binding wire for the copper collector. 25.4mm (1 inch) diameter galvanized pipes of length 1200mm were used for both inlet and outlet manifolds. This was to encourage a uniform flow distribution to the parallel risers of less diameter (20mm and 18mm for galvanized and copper pipe respectively). A thermostatic valve (model 97E manufactured by *KUZEH*, Japan) was fitted on the outlet pipe with a valve opening temperature of 82°C. This valve was selected from a commercially produced automotive radiator thermostatic valve so that there is limited selection of valve opening temperature. The valve opens allowing the pasteurised water to drain out of the collector into the pasteurized water tank. As the water drains, raw water automatically refills the collector and the valve shuts. To avoid pressure build up in the collector as a result of air lock, a 25.4 mm (1 inch) tee was fitted at the outlet with a gate valve. This allowed continuous flow by-passing the thermostatic valve. The by-pass was also used to test the thermal performance of the collector under a continuous flow operation.

4.3.5 Construction of solar reflector assembly

The reflector assembly shown in Figure 4.5 consisted of the mirror support structure and 3mm thick commercially available specular flat mirrors manufactured by *Impala* glass. Mirrors were chosen as they have the desired characteristic property of high optical reflectivity of about 0.95. The mirrors were supported by a 20mm by 20mm angle line frame with dimensions 3mm by 610mm by 1995mm with bolting provision to hold the mirrors in position. Two frames on either sides of the collector were supported by a 6mm thick flat bar. Hinges were used to adjust the mirrors to the

desired angle derived from Winston's edge ray principle (Winston and Welford, 1978) to the upper edge of each element. Using equations 3.4 and 3.5 angles of 120° and 165° were arrived at for the lower and upper elements respectively. Templates corresponding to these angles were then marked and cut from sheet metal and used to adjust the mirror frames to the required tilt angle.

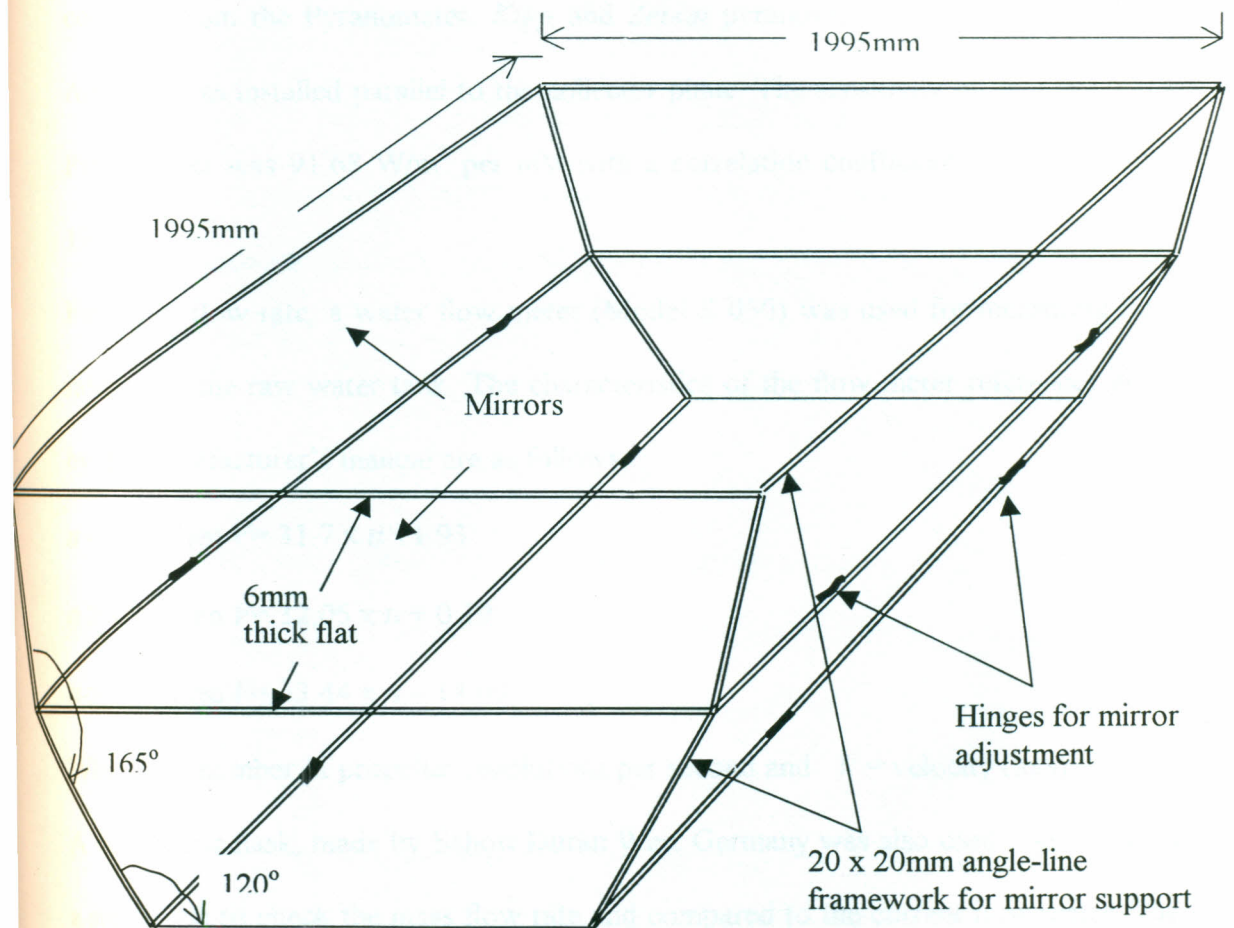


Figure 4.5 Solar reflector assembly details

4.4 EXPERIMENTATION

4.4.1 Calibration of Instruments

Calibration of all instruments were carried out before the onset of the experiments with systematic re-calibration performed at regular intervals against standard scales or as per manufacturer's instruction.

Data logger (Model FLUKE 2286 series) made in USA was programmed to record temperature from T-type Thermocouple and solar radiation intensity incident on the collector from the Pyranometer. *Kipp* and *Zenon* pyranometer (CN27-277) made in Australia was installed parallel to the collector plane. The sensitivity of the CN27-277 Pyranometer was 91.68 W/m^2 per mV with a correlation coefficient of 0.99 (Odote, 1994).

For water flow rate, a water flow meter (Model S 050) was used for measuring flow rates from the raw water tank. The characteristics of the flow meter references given by the manufacturer's manual are as follows:

$$n < 1.98 \text{ then } V = 31.7 \times n + 1.93$$

$$n \geq 1.98 \text{ then } V = 32.05 \times n + 0.19$$

$$n > 1.98 \text{ then } V = 33.44 \times n - 14.09$$

Where n = number of propeller revolutions per second and V = velocity (m/s).

A volumetric flask, made by Schott Duran West Germany was also used together with a stopwatch to check the mass flow rate and compared to the current flow meter. The gate valve located at the exit of the raw water tank was adjusted every 15 minutes to maintain the flow-rate within ± 3 litres/hour as a result of drop in water head in the tank. Wind velocity was measured in a 15 minute interval using a VELOCICALC portable air velocity meter model 8357 with a sensitivity of 0.05 m/s connected to a portable printer model 8925 both manufactured by TSI, USA.

4.4.2 Thermal Performance Tests

4.4.2.1 Continuous Flow Tests

Thermal performance tests using continuous flow of water was conducted according to ASHRAE Standard 93-77 (Sukhante, 1992). All experiment were performed using a continuous flow operation under outdoor conditions without and with the reflecting mirrors in position using flow-rates 30 ± 3 l/hr and 40 ± 3 l/hr arbitrarily chosen. All experiments were carried out under clear sky condition and every experiment measurements were recorded at a 15 minute interval during the effective sunshine period 0900 hours to 1700 hours local time with the collector aligned in the East-West direction to prevent shadowing as the sun moves across the sky.

Thermocouples of Cu-Ni (Copper-Nickel) type with temperature range of -185°C to 300°C and sensitivity 0.1°C were installed for temperature measurements. These thermocouples were also glued on the absorber plate on three locations as indicated in the Figure 4.6.

The following seven primary experimental variables were measured and recorded simultaneously at a 15minute interval with eight runs of each experiment done for comparison and to check repeatability of the experiments.

Variable	Instrument
1. Collector fluid inlet temperature	Thermocouple
2. Collector fluid outlet temperature	Thermocouple
3. Ambient temperature	Thermocouple
4. Absorber plate temperature	Thermocouple
5. Fluid flow-rate	Flow meter
6. Solar radiation	Pyranometer

7. Surrounding air speed

Wind anemometer

For 15minute segment, instantaneous efficiency η_i was calculated using equation

(3.6). A standard plot of instantaneous efficiency η_i versus $\frac{\Delta T_m}{I_T}$ curve was estimated

by performing linear regression on all test data points of the form $y = a + bx$.

Regression analysis was used to obtain the values of a and b , where the slope $b = F_R U_L$

and the y-intercept, $a = F_R (\tau\alpha)_{av}$ of the system. t-statistics was then used to analyse

values of the regression parameters at 0.01 significant level (Rai, 1987).

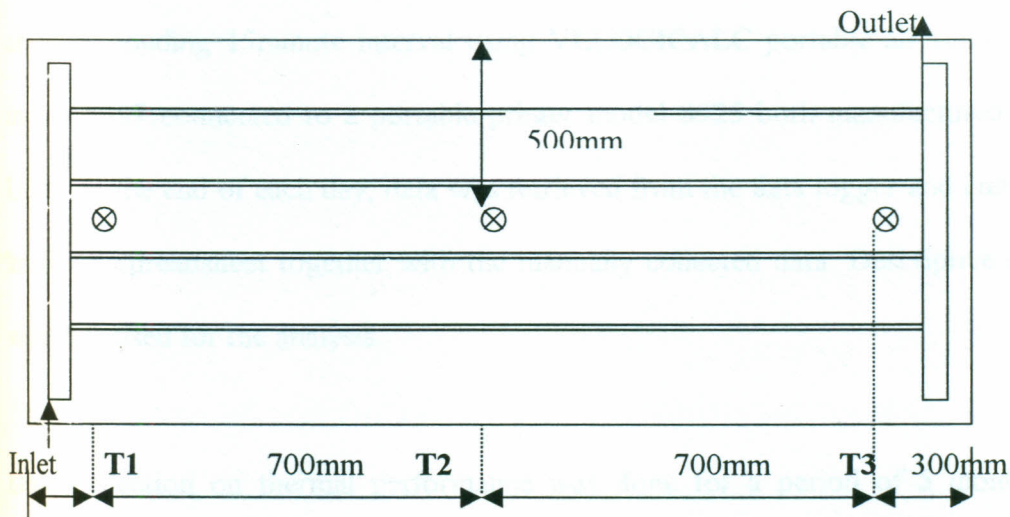


Figure 4.6 Temperature measurement points on absorber plate (indicated by ⊗)

4.4.2.2 Solar pasteurization tests

These tests were performed with the thermostatic valve in place so that the water discharge temperature is regulated. The tests were also performed under very clear sky conditions during the effective sunshine hours of 0900 – 1700 hours. Tests were performed with both galvanized pipe collector and the copper pipe collector. In each case tests were done with reflectors in position and also without reflectors for the

purpose of control. Nine runs of each experiment were performed for comparisons and to check repeatability.

A 10liter bucket was used to collect each batch of water discharged and a 1 liter graduated flask used to measure the volume of water discharged. The measured water was then poured back into the pasteurized water tank. Volume, average temperature and time of each batch discharged were recorded manually. The average temperature of each discharge was measured using a portable digital thermometer. Amount of solar radiation, ambient, inlet, outlet and average absorber temperatures were recorded using FLUKE 2286 series data logger. Similarly, wind speed was recorded at corresponding 15minute interval using VELOCICALC portable air velocity meter model 8357 connected to a portable printer model 8925 both manufactured by TSI, USA. At the end of each day, data was retrieved from the data logger and entered into an Excel spreadsheet together with the manually collected data. Descriptive statistics was then used for the analysis.

Data collection on thermal performance was done for a period of 5 months from October 2004 to February 2005. The raw data collected is given in Appendix H.

4.4.3 Water Quality Testing

4.4.3.1 Sampling procedure

Sampling was done from three randomly selected sites along Kamiti River next to Kenyatta University in accordance to procedure for sampling water from a water course or reservoir (WHO, 1997). Water was collected into sterilized 20litre containers with the cap carefully unscrewed while holding the container by the lower

part, it was submerged with the mouth facing upwards and towards the current and then carefully capped with the foil protective cover put in place. Raw water samples from each site was also collected in 300ml sterile water bottles and the remaining poured into the raw water tank (also pre-cleaned) of the solar pasteurizer. Care was taken not to mix samples from different sites by draining any water left in the collector before adding raw water from a different site. Pasteurized water samples from each site were collected in 300ml sterile bottles. The bottles were labeled with the following information: site of sampling, date of sampling, time of sampling, name of person taking the samples (WHO, 1997). All samples were placed in an insulated cool box and sent to the laboratory within six hours of collection. Multiple-tube fermentation technique was used for both presumptive coliform test and *Eijkman* test for confirmation of *E. coli* in water.

4.4.3.2 Presumptive coliform test

All water samples were subjected to presumptive coliform test (WHO, 1997), which detects presence of coliform bacteria in water. The bottles containing the samples were vigorously shaken to achieve homogeneous dispersion of bacteria. With a sterile 10ml pipette, 10ml of water sample was inoculated into each of the five McCartney bottles containing 10ml of McConkey broth purple (double strength). 50ml of sample was added to a tube containing 50ml McConkey broth purple (double strength) and 1ml of water sample into each of five tubes containing 5ml McConkey broth purple (single strength). Durham tubes were inserted in each bottle making sure that each tube was inverted and filled completely with the solution by gently shaking the bottles to distribute the sample evenly ensuring that the samples are devoid of any air bubbles.

4.4.3.2 Methyl red test for confirmation of coliforms in water

The tubes were incubated at 36-38°C for 24 hours after which each tube was examined for presence of gas and for fermentation (change of medium colour from purple to yellow). The number of positive tubes was recorded and negative tubes re-incubated for a further 24 hour period after which they were checked for fermentation and gas production as described above. Acid and gas production at the end of 24 or 48 hours of incubation was presumed to be due the presence of coliforms because coliform organisms are able to ferment lactose at 35-37°C with production of gas and acid within 24-48 hours. The number of positive tubes after 48 hours was recorded and results interpreted using McCrady's most probable number (mpn) probability tables. Negative reaction was indicated by either no growth or growth without gas. This excludes the coliform group of bacteria.

4.4.3.3 Eijkman test for confirmation of *E. coli* in water

All tubes positive for presumptive coliform test were subjected to the Eijkman test. Unlike other coliforms, *E.coli* is capable of fermenting lactose with subsequent production of gas and indole from tryptophan at 43.5-44°C (WHO, 1997). *E.coli* is an indicator of recent faecal contamination of either human or animal origin and should not be detected in water used for drinking (See Appendix H).

A drop of broth was transferred from each presumptive positive tube into a bottle containing 5ml single strength McConkey broth and to a bottle containing Tryptone water respectively. A different pipette was used for each positive bottle. The sub-cultured samples were incubated for 24 hours at 43.5-44.5°C. At the end of the 24 hours of incubation, each tube was examined for fermentation and gas production

(positive test) and results recorded. To each of the Tryptone water tubes, a drop of Kovacs reagent was added and gently mixed. The presence of indole was indicated by a red colour in the Kovacs reagent, forming a film over the aqueous phase of the medium. Confirmatory tests positive for indole, fermentation and gas production indicated the presence of *E.coli* while growth and gas production in the absence of indole production confirmed thermo-tolerant coliforms (WHO, 1997).

McCrary (mpn) probability tables were used to interpret the results and counts were expressed per 100ml (see Appendix G).

CHAPTER 5: RESULTS AND DISCUSSIONS

5.1 Introduction

Data collected during the experiment were; solar radiation (I), ambient temperature (T_a), absorber plate temperature (T_p), inlet temperature (T_i), outlet temperature (T_o), flow-rate (\dot{m}), volume of pasteurized water and water quality parameters.

About 90 tests were conducted under various weather conditions to determine the thermal performance of the collector with reflectors in position and when without reflectors using two different flow-rates for the continuous flow tests and similarly for the pasteurization tests. Selected experiments conducted during clear sky condition are analyzed and presented. This is because clear sky days have a reasonably constant solar radiation and experiments done on different days can easily be compared. Data was retrieved from a diskette in the data logger and entered into excel spreadsheet computer application software and analyzed. An average of six best runs of each experimental data obtained are shown in Tables 5.1 and 5.2. These were used to compare the thermal performance.

5.2 Solar radiation and distribution for a clear day

Figure 5.1 shows the average time series variation of solar radiation and ambient temperature distribution for a clear sky condition. The maximum solar radiation and ambient temperature recorded was 900.7W/m^2 and 34.1°C and average 719W/m^2 and 32.1°C respectively. The ambient temperature increased progressively within the day due to the continuous accumulation of heat on the earth's surface with time during the effective sunshine period. Solar radiation was highest at mid-day (900.7W/m^2) when the radiation was perpendicular to a given horizontal surface with the sun overhead.

Table 5.1 Summarized results of thermal performance using continuous flow tests.

Date and time	Experimental system	Test No.	Flow Rate (l/h)	Day Av. Rad. I (W/m ²)	Day Av. Amb. Temp T_a (°C)	Day Av. Wind vel. v (m/s)	Day Av. Inlet temp T_i (°C)	Day Av. Outlet temp. T_o (°C)	Day Av. Abs. Plate Temp. T_p (°C)				Day Av. Inst. Eff.
									T_{p1}	T_{p2}	T_{p3}	T_{pav}	
29-09-04 9am-5pm	G.I. pipe collector - no reflector	1	30±3	636.5 ±154.3	28.2 ±4.5	1.4 ±0.6	24.9 ±6.2	50.5 ±9.3	50.7 ±12.2	61.2 ±9.2	74.6 ±16.4	62.3 ±11.7	0.35 ±0.1
30-09-04 9am-5pm	G.I. pipe collector - no reflector	2	40±3	647.8 ±212.2	28.0 ±3.7	1.5 ±0.6	25.9 ±5.8	46.0 ±7.7	43.9 ±8.4	53.3 ±8.9	66.4 ±12.2	54.5 ±8.9	0.33 ±0.05
05-10-04 9am-5pm	G.I. pipe collector - no reflector	3	40±3	598.9 ±185.8	27.9 ±5.1	1.8 ±0.7	26.4 ±5.3	46.0 ±9.0	48.9 ±11.4	55.9 ±12.9	69.9 ±12.1	55.9 ±11.9	0.33 ±0.11
06-10-04 9am-5pm	G.I. pipe collector - no reflector	4	30±3	700.7 ±203.3	28.7 ±5.1	1.3 ±0.6	25.6 ±3.7	49.1 ±10.1	50.7 ±10.0	57.4 ±8.6	71.4 ±16.1	60.0 ±11.0	0.34 ±0.05
07-10-04 9am-5pm	G.I. pipe collector - no reflector	5	40±3	643.2 ±207.6	28.3 ±4.4	1.1 ±0.4	24.6 ±3.7	47.2 ±6.8	45.6 ±6.3	51.4 ±8.1	70.0 ±14.3	55.5 ±9.4	0.32 ±0.07
08-10-04 9am-5pm	G.I. pipe collector with reflector	6	40±3	712.5 ±181.0	29.8 ±4.6	1.2 ±0.8	25.1 ±6.8	56.2 ±9.9	53.5 ±11.2	62.4 ±10.5	90.7 ±21.4	68.9 ±11.0	0.45 ±0.03
09-10-04 9am-5pm	G.I. pipe collector with reflector	7	30±3	699.9 ±171.6	32.0 ±2.4	1.1 ±0.6	27.7 ±4.5	63.5 ±12.3	57.6 ±8.0	70.2 ±14.2	105.6 27.9	77.8 ±16.3	0.53 ±0.09
10-10-04 9am-5pm	G.I. pipe collector with reflector	8	30±3	714.0 ±163.2	31.1 ±2.4	1.7 ±0.8	27.0 ±3.5	59.8 ±10	55.7 ±8.5	64.7 ±10.2	92.0 ±17.5	69.9 ±11.9	0.46 ±0.07
11-10-04 9am-5pm	G.I. pipe collector with reflector	9	40±3	711.1 ±184.9	30.6 ±2.8	1.3 ±0.5	29.1 ±3.9	56.2 ±11.1	49.2 ±9.4	63.1 ±14.2	90.7 ±21.0	68.7 ±14.2	0.45 ±0.08
14-10-04 9am-5pm	G.I. pipe collector with reflector	10	40±3	655.03 ±218.0	29.4 4.0	1.1 ±0.5	25.9 5.9	47.8 ±8.1	45.1 ±8.9	52.4 ±8.4	69.0 ±15.4	55.5 ±10.7	0.4 ±0.1
02-02-05 9am-5pm	Cu collector – no reflector	33	30±3	683.75 ±157.2	27.1 ±4.0	1.7 ±0.5	23.9 ±4.5	54.7 ±9.8	52.4 ±8.9	62.7 ±11.4	72.3 ±12.9	62.5 ±11.0	0.39 ±0.05
03-02-05 9am-5pm	Cu collector - no reflector	34	40±3	671.7 ±161.5	28.2 ±4.5	1.8 ±0.6	23.9 ±5.4	51.9 ±10.9	49.1 ±8.3	61.5 ±13.5	71.2 ±15.4	60.6 ±12.4	0.36 ±0.05

04-02-05 9am-5pm	Cu collector - no reflector	35	30±3	705.0 ±137.8	28.5 ±4.5	2.1 ±0.8	24.4 ±5.4	53.5 ±9.9	50.5 ±9.1	57.2 ±10.3	71.7 ±14.3	60.5 ±11.2	0.35 ±0.03
05-02-05 9am-5pm	Cu collector - no reflector	36	30±3	696.9 ±163.9	27.4 ±3.9	2.2 ±0.8	23.8 ±4.1	56.9 ±9.9	53.5 ±9.1	63.0 ±10.1	72.8 ±13.2	62.5 ±10.2	0.41 ±0.07
06-02-05 9am-5pm	Cu collector - no reflector	37	40±3	706.0 ±180.9	27.1 ±4.4	2.0 ±0.9	23.7 ±5.3	52.7 ±11.7	50.3 ±11.3	59.8 ±13.7	70.1 ±13.1	60.0 ±12.7	0.32 ±0.05
07-02-05 9am-5pm	Cu collector - no reflector	38	40±3	717.7 ±160.8	28.9 ±3.2	1.6 ±0.6	24.6 ±3.8	50.9 ±7.9	50.3 ±10.9	57.9 ±10.0	68.9 ±13.4	58.8 ±10.4	0.31 0.07
09-02-05 9am-5pm	Cu collector – with reflectors	40	40±3	721.6 ±162.7	29.3 ±4.5	2.2 ±1.0	25.3 ±5.7	57.3 ±12.9	53.0 ±11.4	62.1 ±13.1	81.1 ±21.2	65.1 ±15.1	0.38 ±0.07
10-02-05 9am-5pm	Cu collector – with reflectors	41	30±3	724.8 ±165.3	29.1 ±4.5	2.6 ±1.0	24.3 ±7.0	64.7 ±16.6	55.4 ±17.5	65.0 ±19.2	83.4 ±25.9	67.9 ±20.8	0.47 ±0.07
11-02-05 9am-5pm	Cu collector – with reflectors	42	30±3	721.6 ±155.2	29.1 ±3.9	2.7 ±1.1	24.7 ±5.4	61.7 ±17.2	57.5 ±15.8	66.4 ±17.2	84.7 ±24.9	69.7 ±19.2	0.52 0.20
12-02-05 9am-5pm	Cu collector – with reflectors	43	30±3	728.7 ±152.1	28.4 ±4.9	2.9 ±1.2	24.2 ±6.0	60.1 ±14.7	56.6 ±14.3	64.9 ±16.2	81.3 ±22.1	67.6 ±17.5	0.52 ±0.19
13-02-05 9am-5pm	Cu collector – with reflectors	44	40±3	701.62 ±164.1	27.4 ±4.9	2.9 ±1.3	23.7 ±4.9	55.9 ±13.2	55.2 ±12.0	61.1 ±12.4	73.8 ±17.3	63.4 ±13.8	0.40 ±0.07
14-02-05 9am-5pm	Cu collector – with reflectors	45	40±3	753.8 ±176.4	30.3 ±4.1	2.3 ±1.0	26.0 ±5.7	57.2 ±13.6	55.1 ±13.1	61.6 ±11.8	76.6 ±16.7	64.4 ±13.9	0.38 ±0.05
15-02-05 9am-5pm	Cu collector – with reflectors	46	30±3	724.8 ±165.3	29.1 ±4.5	2.6 ±1.0	26.6 ±5.6	61.9 ±16.8	57.4 ±15.6	67.4 ±17.0	85.0 ±23.9	69.8 ±18.8	0.52 ±0.19

Table 3.2. Summarized results of thermal performance using pasteurization tests.

Date and time	Experimental system	Test No.	Day Av. Wind vel. v (m/s)	Day Av. Rad. I (W/m^2)	Day Av. Amb. Temp T_a ($^{\circ}C$)	Day Av. Inlet temp T_i ($^{\circ}C$)	Day Av. Abs. Plate Temp. T_p ($^{\circ}C$)	Day Av. Discharge Temp. T_d ($^{\circ}C$)	Day total No. of Valve Opening (Batches)	Day total Vol. of pasteurized water discharged (Litres)
23-12-04 9am-5pm	G.I. pipe collector with reflectors	16	1.8 ± 0.9	716.3 ± 128.2	28.3 ± 4.3	26.2 ± 5.7	73.6 ± 13.8	83.7 ± 0.2	23	74.6
24-12-04 9am-5pm	G.I. pipe collector with reflectors	17	1.0 ± 0.6	741.5 ± 144.7	30.2 ± 4.1	27.6 ± 4.3	72.9 ± 14.3	83.9 ± 0.6	24	79.1
26-12-04 9am-5pm	G.I. pipe collector with reflectors	19	2.0 ± 1.0	700.14 ± 137.5	28.0 ± 4.3	25.1 ± 3.5	72.7 ± 15.0	83.3 ± 1.1	19	67.6
27-12-04 9am-5pm	G.I. pipe collector with reflectors	20	1.8 ± 1.2	691.4 ± 135.3	27.8 ± 4.5	25.2 ± 5.1	72.5 ± 15.5	84.0 ± 1.2	18	62.6
03-01-05 9am-5pm	G.I. pipe collector with reflectors	22	1.7 ± 0.8	693.6 ± 133.4	27.7 ± 3.3	24.3 ± 3.6	73.4 ± 13.8	83.3 ± 1.0	18	65.4
04-01-05 9am-5pm	G.I. pipe collector with reflectors	23	1.5 ± 0.8	706.5 ± 141.7	28.0 ± 4.5	26.0 ± 5.1	72.3 ± 15.0	83.7 ± 0.9	18	67.4
05-01-05 9am-5pm	G.I. pipe collector – no reflectors	24	1.0 ± 0.7	673.7 ± 153.8	28.3 ± 4.6	26.4 ± 5.1	70.2 ± 15.0	83.5 ± 0.9	10	38.3
06-01-05 9am-5pm	G.I. pipe collector – no reflectors	25	1.0 ± 0.5	678.9 ± 166.1	29.0 ± 4.4	27.0 ± 5.7	70.1 ± 15.7	83.7 ± 1.1	10	37.7
07-01-05 9am-5pm	G.I. pipe collector – no reflectors	26	1.4 ± 0.7	675.05 154.4	28.9 ± 4.3	26.6 ± 4.2	69.5 ± 15.8	83.3 ± 0.6	9	36.4
08-01-05 9am-5pm	G.I. pipe collector – no reflectors	27	1.4 ± 0.6	720.4 ± 169.5	28.0 ± 3.7	25.5 ± 4.7	70.5 ± 14.1	83.3 ± 0.9	10	39.4
12-01-05 9am-5pm	G.I. pipe collector – no reflectors	29	1.8 ± 0.9	677.7 ± 151.3	28.4 ± 3.8	25.7 ± 4.3	71.0 ± 14.7	83.6 ± 1.1	9	36.9
18-01-05 9am-5pm	G.I. pipe collector – no reflectors	30	1.4 ± 0.7	716.0 ± 167.7	27.9 ± 4.2	24.8 ± 4.6	69.8 ± 16.1	83.7 ± 0.9	10	41.7

9am-5pm	collector - with reflectors		±1.0	±189.9	±4.0	±4.6	±14.8	±1.9	24	84.5
18-02-05 9am-5pm	Copper pipe collector - with reflectors	50	1.8 ±1.0	734.8 ±175.3	29.8 ±4.8	25.9 ±5.8	77.0 ±15.8	83.1 ±0.9	25	90.1
19-02-05 9am-5pm	Copper pipe collector with reflectors	51	2.1 ±1.1	714.8 ±169.3	28.6 ±4.9	24.4 ±5.0	76.3 ±4.5	83.1 ±0.9	25	90.1
20-02-05 9am-5pm	Copper pipe collector - with reflectors	52	1.8 ±0.9	747.3 ±173.6	28.8 ±4.8	24.5 ±5.3	77.7 ±13.3	83.8 ±0.8	27	95.2
21-02-05 9am-5pm	Copper pipe collector - with reflectors	53	2.3 ±1.0	754.1 ±171.1	30.1 ±4.2	25.4 ±5.4	79.2 ±14.9	83.4 ±0.6	27	93.9
22-02-05 9am-5pm	Copper pipe collector - with reflectors	54	2.3 ±1.2	751.4 ±169.1	29.5 ±5.0	25.6 ±6.0	79.4 ±13.3	83.6 ±0.9	26	89.4
23-02-05 9am-5pm	Copper pipe collector- no reflectors	55	1.7 ±0.8	743.7 ±176.5	30.0 ±4.7	24.9 ±6.1	74.7 ±13.8	83.8 ±0.4	14	47.9
24-02-05 9am-5pm	Copper pipe collector- no reflectors	56	1.7 ±0.6	705.0 ±167.7	30.9 ±4.2	25.0 ±6.0	73.6 15.1	83.7 ±1.0	13	45.0
26-02-05 9am-5pm	Copper pipe collector- no reflectors	58	2.1 ±0.9	751.8 ±167.8	30.2 ±4.6	26.1 ±6.4	74.2 ±14.7	83.5 ±1.0	14	49.3
27-02-05 9am-5pm	Copper pipe collector- no reflectors	59	1.6 ±0.5	700.5 ±171.5	29.2 ±4.4	25.4 ±6.2	73.4 ±11.9	83.6 ±0.7	14	47.6
28-02-05 9am-5pm	Copper pipe collector- no reflectors	60	1.8 ±0.6	708.4 ±157.9	30.1 ±3.6	24.6 ±5.3	73.4 ±12.9	83.5 ±0.7	14	46.6

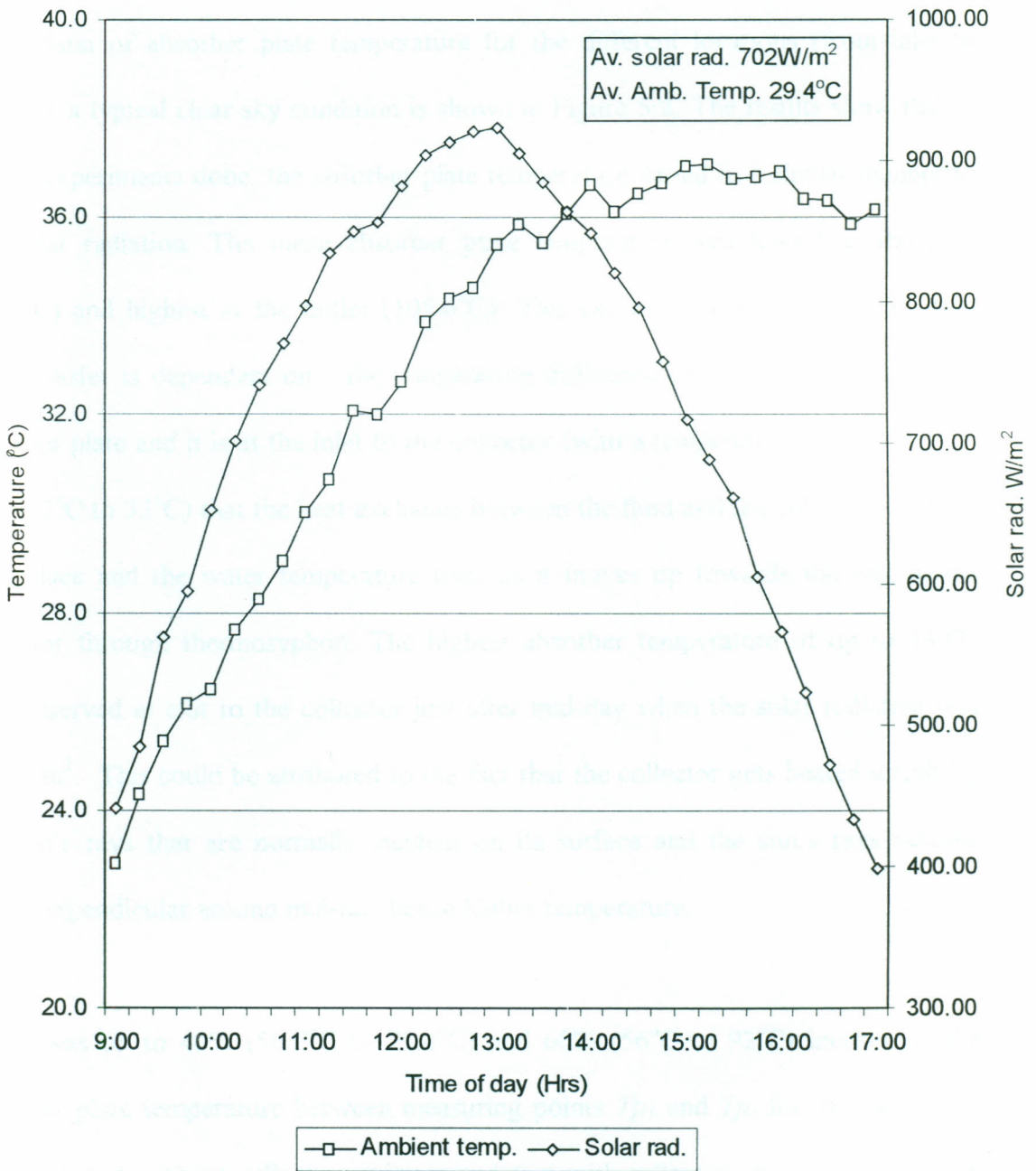


Figure 5.1 Average solar radiation and ambient temperature for clear sky condition at Kenyatta University

5.3 Temperature distribution on absorber plate

Temperature variations on absorber plate were monitored using thermocouples that were fixed onto the absorber plate on different locations (see Figure 4.6). A comparison of absorber plate temperature for the different locations (from inlet to exit) for a typical clear sky condition is shown in Figure 5.2. The results show that in all the experiments done, the absorber plate temperature varied in a similar manner to the solar radiation. The mean absorber plate temperature was lowest at the inlet (57.6°C) and highest at the outlet (105.6°C). This can be explained by the fact that heat transfer is dependent on the temperature difference between the fluid and the absorber plate and it is at the inlet to the collector (with a temperature range observed from 15°C to 33°C) that the heat exchange between the fluid and the collector starts to take place and the water temperature rises as it moves up towards the exit of the collector through thermosyphon. The highest absorber temperature of up to 140°C was observed at exit to the collector just after mid-day when the solar radiation was $900\text{W}/\text{m}^2$. This could be attributed to the fact that the collector gets heated mainly by the sun's rays that are normally incident on its surface and the sun's rays become more perpendicular around mid-day hence higher temperature.

There was up to 40% (50.7°C to 71.4°C) and 60% (56°C to 92°C) increase in the absorber plate temperature between measuring points T_{p1} and T_{p3} for the galvanized pipe collector with no reflecting mirrors and that with reflecting mirrors respectively and similarly 38% (53°C to 72°C) and 50% (57°C to 85°C) for the copper pipe collector without mirrors and with mirrors respectively. The higher absorber plate temperatures of 92°C and 85°C realized for the galvanized pipe collector and copper pipe collector respectively may be attributed to the fact that the reflectors concentrated additional solar radiation from a larger aperture area of 4m^2 compared to

the 2m^2 area in the absence of reflectors. This resulted in an increase in radiation per unit surface area of the absorber plate.

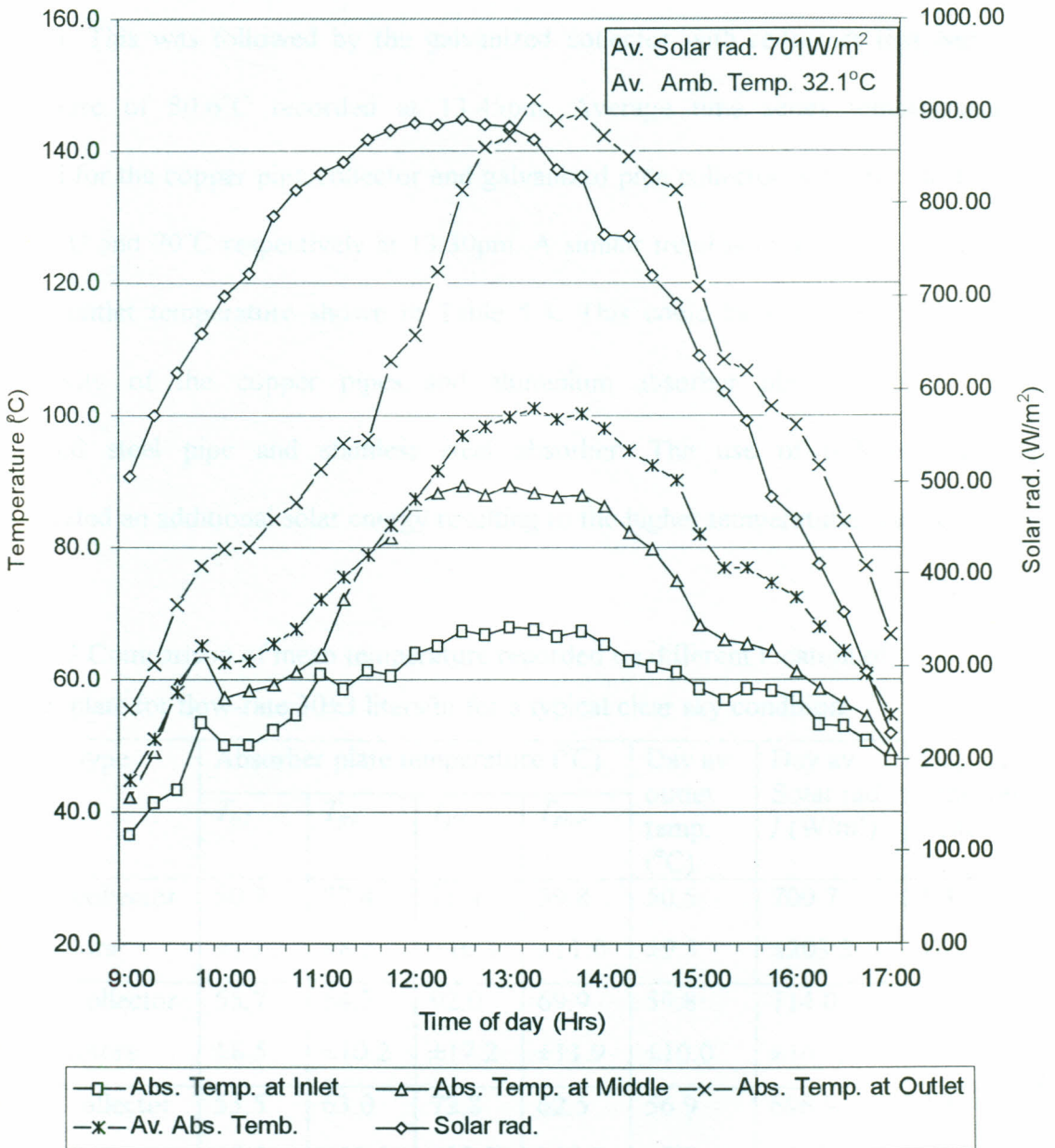


Figure 5.2 Typical variations in average absorber plate temperature for flat plate collector with reflecting mirrors in position

Figure 5.3 shows the average time series variations of the collector absorber temperature variations for the different experimental systems under investigation. The highest average solar radiation recorded was 923W/m^2 at 12.45pm. Copper pipe collector with reflector recorded the highest absorber plate temperature of 88.7°C at 13.30pm. This was followed by the galvanized collector with reflectors that had a temperature of 80.6°C recorded at 13.45pm. Average time series temperatures recorded for the copper pipe collector and galvanized pipe collector without reflectors were 75°C and 70°C respectively at 13.30pm. A similar trend is reflected in the daily average outlet temperature shown in Table 5.3. This could be explained by better conductivity of the copper pipes and aluminium absorber plate compared to galvanized steel pipe and stainless steel absorber. The use of reflectors also concentrated an additional solar energy resulting to the higher temperatures realized.

Table: 5.3 Comparison of mean temperature recorded on different location of absorber plate for flow-rate 30 ± 3 liters/hr for a typical clear sky condition.

Collector type	Absorber plate temperature ($^\circ\text{C}$)				Day av. outlet temp. ($^\circ\text{C}$)	Day av. Solar rad. I (W/m^2)	Day av. wind vel. v (m/s)
	T_{p1}	T_{p2}	T_{p3}	T_{pav}			
G.I. pipe collector No reflectors	50.7 ± 10.0	57.4 ± 8.6	71.4 ± 16.1	59.8 ± 11.0	50.5 ± 9.3	700.7 ± 203.3	1.3 ± 0.6
G.I. pipe collector With reflectors.	55.7 ± 8.5	64.7 ± 10.2	92.0 ± 17.2	69.9 ± 11.9	59.8 ± 10.0	714.0 ± 163.2	1.3 ± 0.5
Cu. pipe collector No reflectors	53.5 ± 9.1	63.0 ± 10.1	72.8 ± 13.2	62.5 ± 10.2	56.9 ± 9.9	696.9 ± 163.9	2.2 ± 0.8
Cu. pipe collector With reflectors.	57.4 ± 15.6	67.4 ± 17.0	85.0 ± 23.9	69.8 ± 18.8	64.7 ± 16.6	724.8 ± 165.3	2.3 ± 1.0

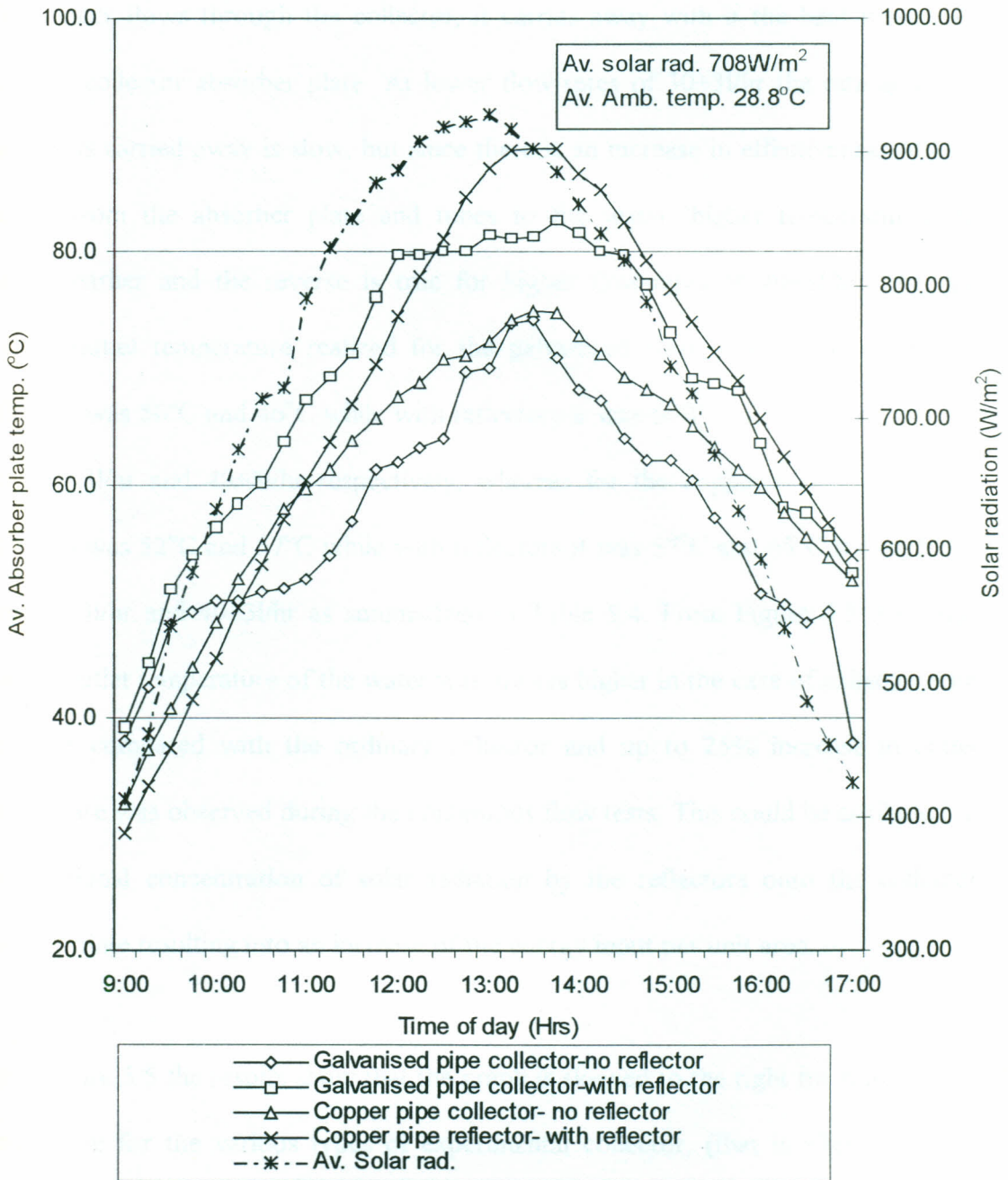


Figure 5.3 Comparisons of average collector absorber temperatures with local time for the different experimental collectors for a typical clear sky condition

5.4 Effects of flow-rate on outlet temperature

When water flows through the collector, it carries away with it the heat it receives from the collector absorber plate. At lower flow-rates of $30\pm 3\text{l/hr}$ the rate at which this heat is carried away is slow, but since there is an increase in effectiveness of heat transfer from the absorber plate and tubes to the water, higher temperatures are reached earlier and the reverse is true for higher flow-rates of $40\pm 3\text{l/hr}$. The day average outlet temperature realized for the galvanized steel pipe collector without reflectors was 50°C and 46°C while with reflectors it was 60°C and 56°C for the flow-rates $30\pm 3\text{l/hr}$ and $40\pm 3\text{l/hr}$ respectively, whereas for the copper collector without reflectors was 52°C and 57°C while with reflectors it was 57°C and 65°C for the flow-rates $30\pm 3\text{l/hr}$ and $40\pm 3\text{l/hr}$ as summarized in Table 5.4. From Figure 5.5 it is clear that the outlet temperature of the water was always higher in the case of collector with reflectors compared with the ordinary collector and up to 25% increase in outlet temperature was observed during the continuous flow tests. This could be attributed to the additional concentration of solar radiation by the reflectors onto the collector absorber plate resulting into an increase of the energy input per unit area.

From Figure 5.5 the results show that the graph is skewed to the right for water outlet temperature for the various types of experimental collector, (that is after 12.30pm) whereas in Figure 5.6 a maximum solar radiation of 922W/m^2 was observed at 12.30pm. This could be explained by the collector orientation along the east-west direction with the slope facing west; it was after 12.30pm that the sun's rays become more perpendicular to the collector absorber surface (see Figure 5.4) and the incident angle is small resulting to the highest temperatures of 81°C and 68°C for the copper

pipe collector and 71°C and 62°C for galvanized pipe collector with and without reflectors respectively.

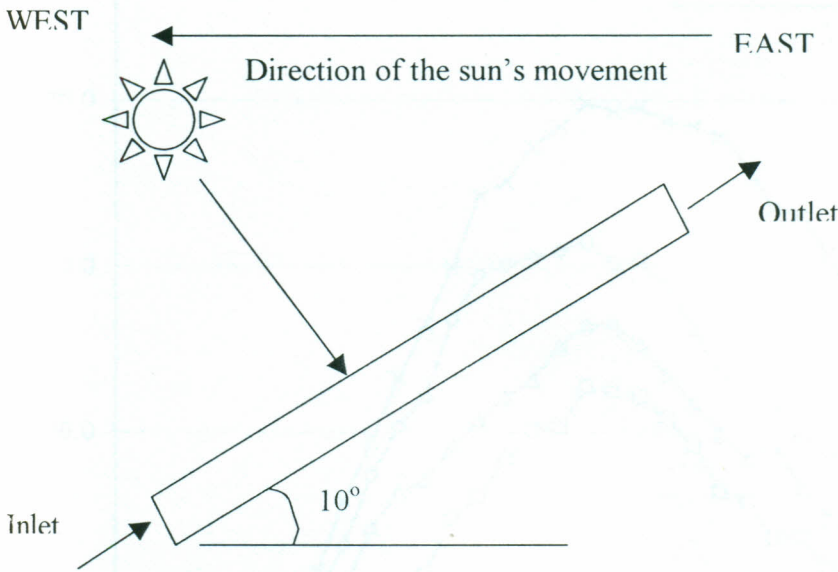


Figure 5.4 Schematic illustration of collector orientation and the sun's position in the sky relative to the collector at maximum outlet temperature

Table 5.4 Comparison of average outlet temperature and instantaneous efficiency at different flow-rates recorded for a typical clear sky condition

Collector type	Flow-rate (l/hr)	Daily av. Outlet Temp. (°C)	Daily av. Solar rad. I (W/m ²)	Daily av. Wind vel. v (m/s)	Daily av. Inst. eff. (%)
G.I. pipe collector No reflectors	30±3	50.5 ±10.1	700.7 ±203.3	1.3 ±0.6	0.35 ±0.05
	40±3	46.0 ±7.7	647.8 ±212.2	1.8 ±0.7	0.33 ±0.05
G.I. pipe collector With reflectors	30±3	59.8 ±10.0	714.0 ±163.2	1.7 ±0.8	0.46 ±0.07
	40±3	56.2 ±11.1	711.1 ±184.9	1.3 ±0.5	0.42 ±0.08
Cu. pipe collector No reflectors	30±3	56.9 ±9.9	696.9 ±163.9	2.2 ±0.8	0.41 ±0.07
	40±3	51.9 ±10.9	671.7 ±161.5	1.8 ±0.6	0.36 ±0.05
Cu. pipe collector With reflectors	30±3	64.7 ±16.6	724.8 ±165.3	2.2 ±1.0	0.52 ±0.09
	40±3	57.3 ±13.6	753.8 ±176.4	2.9 ±1.3	0.38 ±0.05

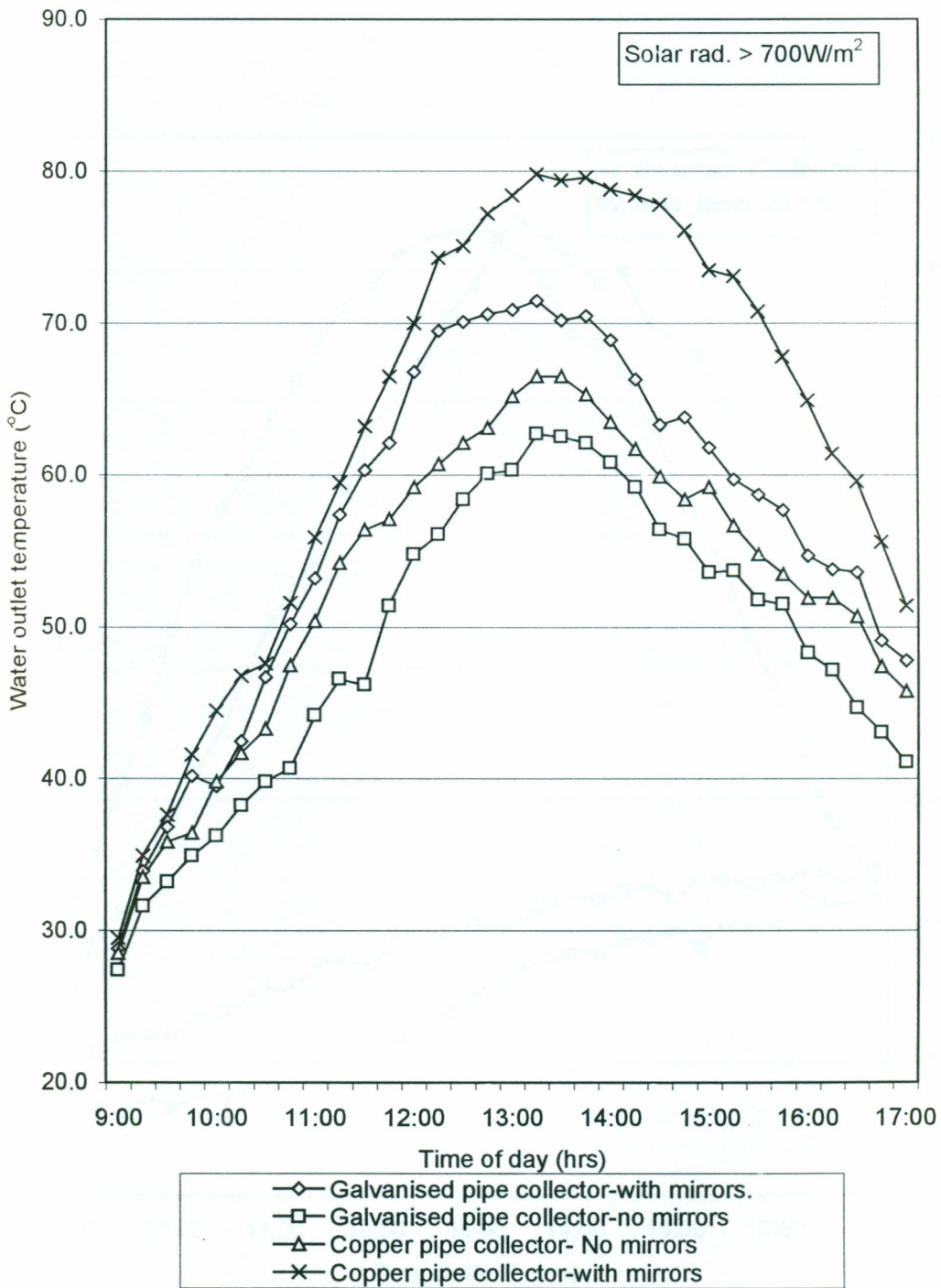


Figure 5.5 Comparison of average collector water outlet temperature with local time for the different experimental collectors at flow-rate (30±3l/hr.) for a typical clear sky condition ($I > 700\text{W/m}^2$)

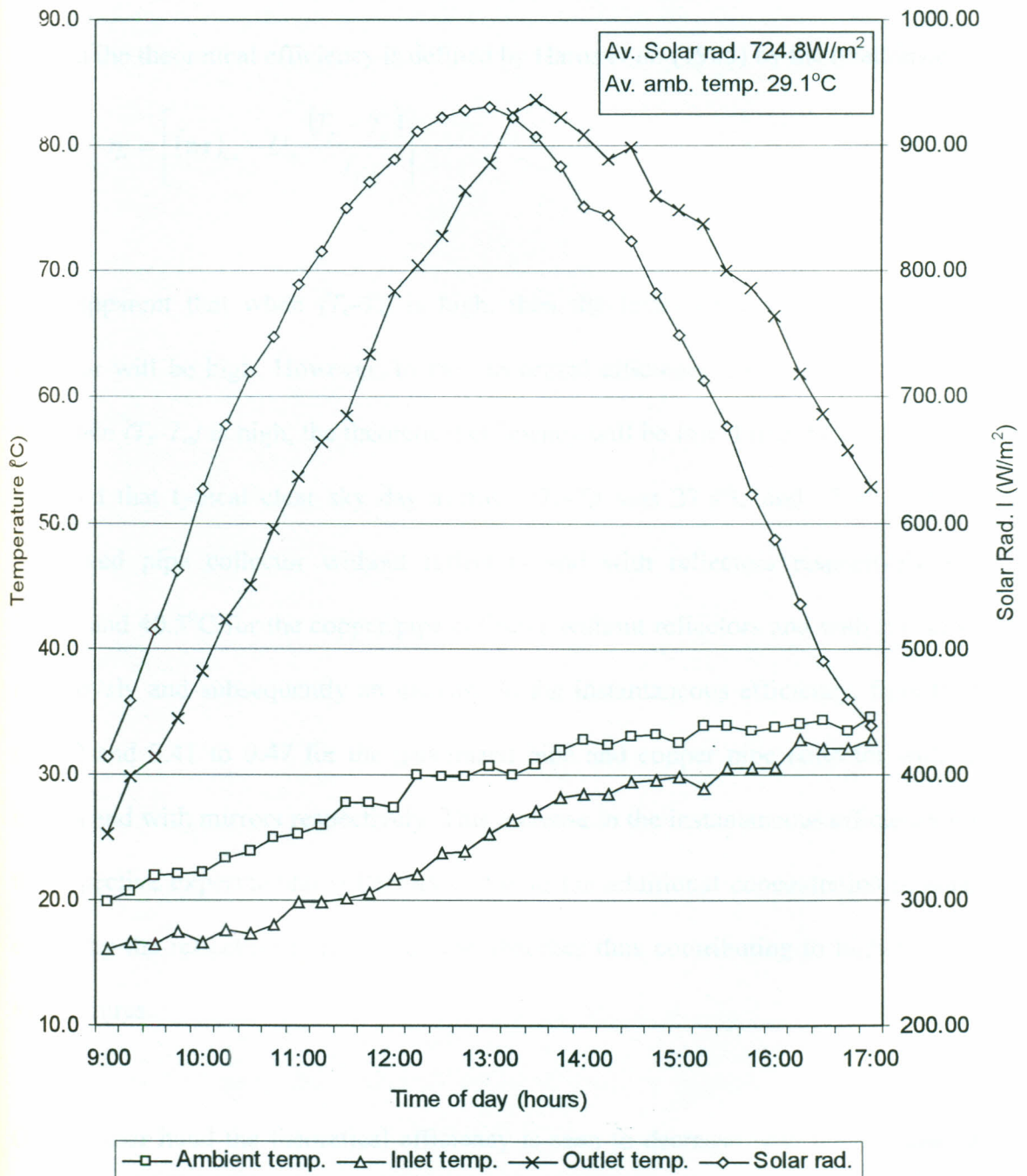


Figure 5.6 Variation of water outlet, inlet (flow-rate $30 \pm 3 l/hr$) and ambient temperature with solar radiation for copper pipe collector with reflectors for a typical clear sky condition

5.5 Collector instantaneous efficiency

Collector instantaneous efficiency is defined by the relationship

$$\eta = \frac{\text{Useful heat gain}}{\text{Radiation incident on collector}} = \frac{Q_u}{A_c I_T} = \dot{m} c_p \frac{(T_o - T_a)}{A_c I_T}$$

and the theoretical efficiency is defined by Harns *et al.* (1985) by the relationship

$$\eta_t = \left[(\tau\alpha)_{av} - U_L \frac{(T_p - T_a)}{I_T} \right]$$

It is apparent that when $(T_o - T_i)$ is high, then the instantaneous efficiency of the collector will be high. However, in the theoretical efficiency equation it is apparent that when $(T_p - T_a)$ is high, the theoretical efficiency will be low. From Table 5.5 it was observed that typical clear sky day average $(T_o - T_i)$ was 27.9°C and 35.9°C for the galvanized pipe collector without reflectors and with reflectors respectively and 32.5°C and 40.5°C for the copper pipe collector without reflectors and with reflectors respectively and subsequently an increase in the instantaneous efficiency, from 0.34 to 0.52 and 0.41 to 0.47 for the galvanized pipe and copper pipe collector without mirrors and with mirrors respectively. This increase in the instantaneous efficiency for the respective experimental collectors is due to the additional concentration of solar energy by the reflecting mirrors onto the absorber thus contributing to higher outlet temperatures.

On the other hand the theoretical efficiency is seen to decrease with the increase in values of $(T_p - T_a)$ and the experimental collectors with reflectors registering higher values of 45.7°C and 48.8°C for the galvanized pipe and copper pipe respectively and 32.7°C and 36.6°C for the respective collectors without reflectors. The efficiencies obtained from experimental observations were found to be less than the theoretical

values calculated analytically and could be due to: transient effects that may decrease the amount of useful energy delivered; efficiency decreases with increasing angles of incidence and the efficiency decreases with increasing ratio of diffuse to beam radiation.

Table.5.5 Day average values of (T_o-T_i) , (T_p-T_a) and the instantaneous and theoretical efficiencies for a typical clear sky condition and flow-rate of $30\pm 3l/hr$

Collector type	Day av. (T_o-T_i) ($^{\circ}C$)	Day av. (T_p-T_a) ($^{\circ}C$)	Day av. amb. temp. ($^{\circ}C$)	Day av. Solar rad. I (W/m^2)	Av. Inst. eff.	Av. Theoretical eff.
G.I. pipe collector No reflectors	27.9 ± 8.5	32.7 ± 8.9	27.9 ± 5.1	700.7 ± 203.2	0.33 ± 0.05	0.49
G.I. pipe collector With reflectors.	35.9 ± 11.8	45.7 ± 15.2	32.0 ± 2.4	699.9 ± 171.7	0.52	0.64
Cu. pipe collector No reflectors	32.5 ± 7.9	36.6 ± 8.6	28.4 ± 3.9	696.8 ± 163.8	0.41 ± 0.07	0.54
Cu. pipe collector With reflectors.	40.4 ± 13.9	48.8 ± 17.7	29.1 ± 4.5	724.8 ± 165.3	0.47 ± 0.07	0.68

It was also observed that the instantaneous efficiency decreased with increase in flow-rate (see Table 5.4), 46% to 42% and 52% to 38% for the galvanized and copper pipe collectors respectively with increase in flow-rates from $30\pm 3l/hr$ to $40\pm 3l/hr$. This could be explained by the reduced heat transfer efficiency with increased flow-rate. As the flow-rate was increased from $30\pm 3l/hr$ to $40\pm 3l/hr$ the contact time of the fluid in the pipes (galvanized steel or copper), which acted as heat transfer medium was reduced and the temperature rise (T_o-T_i) was lower for flow-rate of $40\pm 3l/hr$ compared to the flow-rate of $30\pm 3l/hr$, hence the decreased values of instantaneous efficiency since it's a direct function of (T_o-T_i) .

Figure 5.7 illustrates typical average time series variation of instantaneous efficiency for a clear sky condition. Instantaneous efficiency was found to be above 50% between 12.00pm and 2.00pm for the collectors with reflectors. This could be because during this period solar radiation was highest (above 860W/m^2) and incident to the collector. The collector was placed facing west at 10° (see Figure 5.4) and thus it was at 1.30 pm when the sun's rays were most perpendicular to the collector surface with an instantaneous efficiency value of 56% being attained for the copper pipe collector with reflectors and solar radiation of 902W/m^2 recorded.

5.6 Thermal performance using pasteurization tests

Warm up time was the time taken for water in the collector to be heated to the thermostatic valve opening temperature (82°C). It was observed that the warm up time varied for the different collectors (see Table 5.6). The long warm up time of up to 3 hours and 2 hours for the galvanized pipe collector without reflectors and that with reflectors respectively, was due to the large angle of incidence causing transient effects on the collector as a result of closed loop and insufficient radiation to overcome thermal and optical losses. Less warm up time was observed for collector with reflectors and can be explained by the concentration of additional solar radiation by the reflectors onto the absorber plate resulting into higher energy input per unit area of the absorber. For the copper pipe collector a less warm up time of 2 hours 30minutes and 1 hour 45minutes was observed for collector without reflectors and with reflectors respectively. This could be explained by the better conductivity of copper hence better heat transfer to the water.

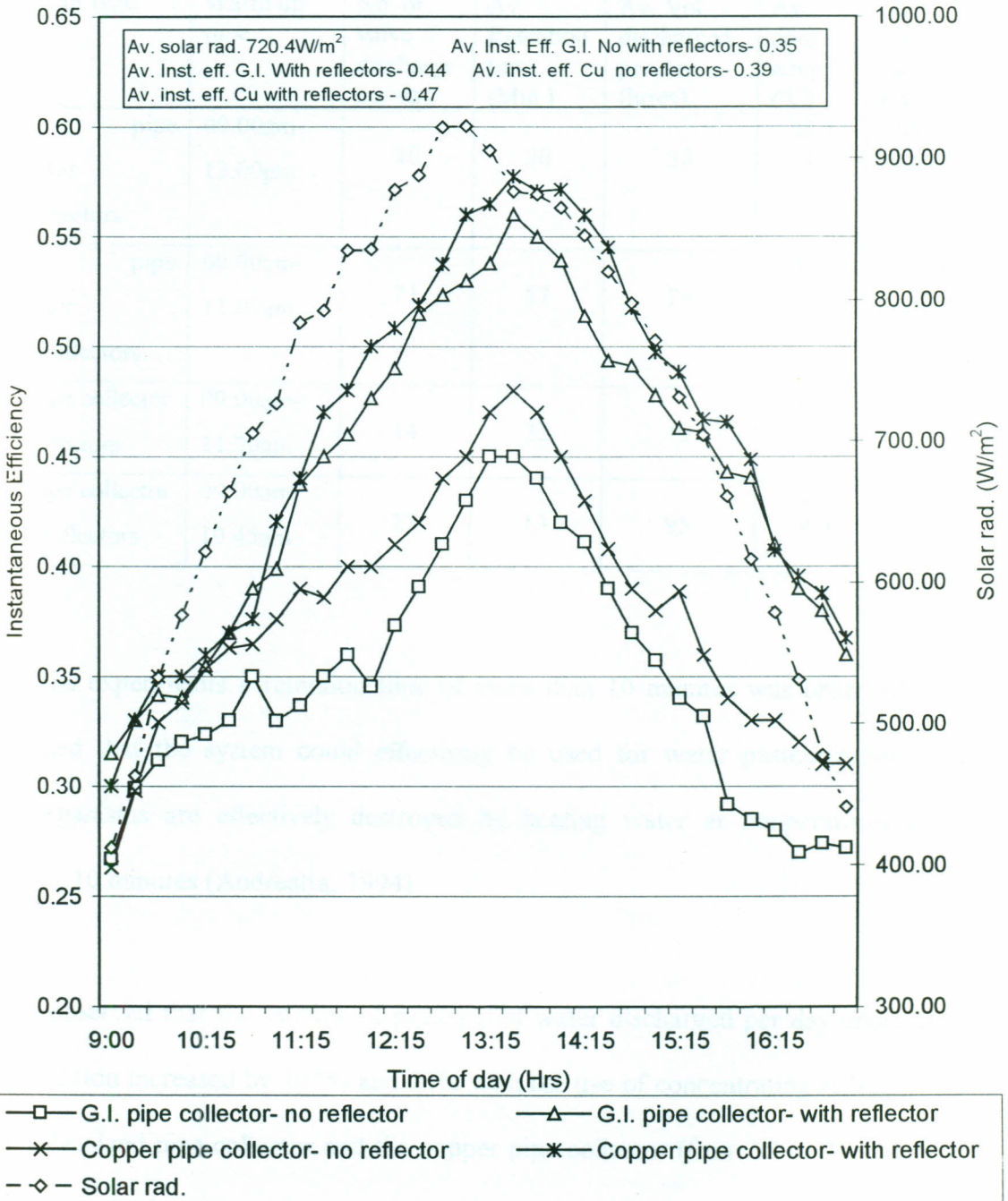


Figure 5.7 Comparison of average collector instantaneous efficiency with local time for the different experimental collectors for typical clear sky condition during a continuous flow operation

Table 5.6 Comparison of the warm up time, average retention time and volume of pasteurized water per day for the different experimental collectors

Collector type	Warm up time	No. of valve discharge per day	Av. Retention time (Min.)	Av. Vol. discharged per day (litres)	Av. amb. temp. (°C)	Av. solar rad. I (W/m^2)
G.I. pipe collector No reflectors	09.00am- 12.00pm	10	30	38	28.3 ±4.6	720.4 ±169.5
G.I. pipe collector With reflectors.	09.00am- 11.00am	21	17	79	30.2 ±4.1	741.5 ±144.7
Cu. pipe collector No reflectors	09.00am- 11.30am	14	22	49	30.2 ±4.6	751.8 ±167.8
Cu. pipe collector With reflectors	09.00am- 10.45am	27	13	95	28.8 ±4.8	747.3 ±173.6

In all the experiments a retention time of more than 10 minutes was observed. This confirmed that the system could effectively be used for water pasteurization since microorganisms are effectively destroyed by heating water at temperatures above 75°C for 10 minutes (Andreatta, 1994).

It was observed that the volume of pasteurized water discharged per day under clear sky condition increased by 107% and 94% with the use of concentrating reflectors for both galvanized pipe collector and the copper pipe collector (from 38 to 79 and 49 to 95 liters per day for galvanized pipe collector and the copper pipe collector respectively). This could be explained by the higher energy input per unit area on the absorber with the use of reflectors; this could have far exceeded the thermal and optical energy losses by conduction, convection and radiation allowing the water to reach discharge temperature in 13 and 17 minutes and 22 and 30 minutes for the

copper and galvanized pipe collectors with reflectors and without reflectors respectively. The higher conductivity of copper and aluminium ensured a more rapid heat transfer to the water compared to the galvanized pipe collector and stainless less absorber.

The number of valve openings shown in Table 5.6 is an indication of the number of batches collected as the system operated in an automatic batch process where by water was filled in the collector from the raw water tank and heated until it reached valve opening temperature. This was then discharged creating space for another batch. The discharge temperature for each batch ranged from 92°C to 75°C at the time the valve closed giving an average discharge temperature of 83.5°C per batch. The volume of each batch was governed by the volume of water that could be held in the header pipe and the parallel riser pipes. The galvanized pipe collector consisted of 1"(25.4mm) diameter header and 3/4"(20mm) risers with a capacity of 4.2 liters whereas the copper pipe risers were of diameter 18mm with a capacity of 3.6 liters.

In all experiments it was observed that the first discharge after the warm up time exceeded the capacity within the collector with up to 5.8 liters being discharged in the case of galvanized pipe collector and 4.2 liters for the case of copper collector (see Table 5.7). This could be attributed to the high absorber plate temperatures realized during the warm up time before the first discharge allowing a part of the new batch entering the collector to instantly attain the valve opening temperature range. Higher absorber temperatures above 90°C were observed before the first discharge for the galvanized collector; this could be because the galvanized pipe was not as effective as the copper pipe in transferring heat to the water due to its lower conductivity.

Table 5.7 Comparison of collector batch capacity and volume of first batch discharged

Collector Type	Warm up Time	Batch capacity (liters)	Volume of first Discharge (liters)	Av. absorber temp. At first discharge. (°C)
G.I. pipe collector No reflectors	09.00am- 12.00pm	4.2	5.8	89.4
G.I. pipe collector With reflectors.	09.00am- 11.00am	4.2	6.1	92.6
Cu. pipe collector No reflectors	09.00am- 11.30am	3.6	3.8	83.1
Cu. pipe collector With reflectors	09.00am- 10.45am	3.6	4.1	86.0

5.7 Water Quality Analysis

In this section, results of the bacteriological water analysis using the presumptive coliform test for total coliforms and Eijkman test for the confirmation of *E. coli* in water are presented and discussed. A total number of 30 samples for both raw and pasteurized water were analyzed using multiple tube technique for the two tests mentioned. Descriptive statistics has been used for the analysis of data. Summarized results for the laboratory analysis of the samples are given in Table 5.8.

Water sample positivity was high for the raw water with all samples (15/15) testing positive for total coliforms and 87% (13/15) testing positive for *E. coli* (see Table 5.8). A maximum total coliform count greater than 180/100ml of sample of raw water was recorded for both total coliform and *E. coli*.

Table 5.8 Total coliform and *E.coli* counts obtained from raw and pasteurized water samples

Water sample type	Total no. of samples taken	No. positive for Total coliforms	No. positive for <i>E. coli</i>	Maximum count of Total coliforms MPN/100ml	Maximum count of <i>E. coli</i> MPN/100ml
Raw Water	15	15	13	>180	>180
Pasteurized water	15	2	0	3	<1
Total	30	17	13	-	-

The presence of *E.coli* was an indication of recent faecal contamination of either human or animal origin. This contamination could be due to the run-off caused by rainfall in the up-stream areas where there are slums without sanitary facilities or raw sewage discharged into the river and also semi-intensive livestock production systems which may increase the chances of faecal contamination (see Tables 2.1 and 2.2). The high positivity for the raw water collected from River Kamiti confirms the high prevalence of waterborne diseases resulting from drinking untreated surface water that is open to pollution and is typical of developing countries (Feachem, 1980).

For the pasteurized water, there was no *E. coli* detected in all the 15 samples taken indicating that the solar pasteurizer was effective in destruction of disease causing bacteria. Two samples of pasteurized water tested positive for total coliforms with a low count of 2 /100ml and 4/100ml of the pasteurized water sample. This could be attributed to contamination during sampling or presence of thermo-tolerant coliforms and these don't cause diseases to people (Ciochetti and Metcalf, 1994).

5.8 Economic evaluation of the solar pasteurization system

5.8.1 Introduction

Economic and financial considerations are important factors to be considered when examining and evaluating the viability of investment in renewable energy projects. Life Cycle Savings (LCS) and the Life Cycle Cost (LCC) have been adopted in this analysis. These methods are considered to be some of the most complete approaches to economic appraisal of solar energy systems (Duffie and Beckman, 1991). LCC is defined as the sum of all costs associated with an energy delivery system over its lifetime or over a selected period of analysis and LCS is defined as the difference in the present worth between LCC of the conventional or alternative fuel-only system and the LCC of the solar energy system.

Charcoal and firewood were chosen as the alternative source of fuel as these are the most widely used sources of energy in the rural areas. Over 70% of energy utilized in Kenya is derived from biomass (National Development Plan, 2002). Detailed description of the LCC methodology is given in Appendix E.

5.8.2 Life cycle costing of the experimental systems

The LCC of the four experimental systems were computed for solar water pasteurization and tabulated. Life span 20years for the solar pasteurizer has been considered as this corresponds to the useful lifetime of most domestic hot water heating systems. A discount rate of 10% was also chosen, as this is usually considered typical for developing countries (Garg and Prakash, 1997). Table 5.9 and Figure 5.8 shows the LCC comparisons of the different systems investigated.

Table 5.9 Life cycle cost comparisons for the different systems investigated.

Item / Experimental setup	Galvanized pipe collector- No reflector	Galvanized pipe collector- with reflector	Cu. pipe collector – No reflector	Cu. pipe collector – with reflector
Capital costs. (Kshs)				
4mm glass (1mx2m)	2200	2200	2200	2200
1" Galvanized supply pipe 6m	2000	2000	2000	2000
Collector support structure	9000	9000	9000	9000
Insulation (20kg. Cotton)	500	500	500	500
3/4" Galvanized pipe (Risers) 10m	3000	3000	-	-
16 gauge stainless steel absorber	3000	3000	-	-
18mm copper pipe (Risers) 10m	-	-	10000	10000
32 gauge aluminium absorber	-	-	3000	3000
Mirror support structure	-	6000	-	6000
Mirror reflectors (3x600x2000)	-	7000	-	7000
2 storage tanks	5000	5000	5000	5000
Installation and accessories (10% of total capital)	2470	3770	3170	4470
Total Capital Cost (Ksh)	24110	41470	34870	49170
Other costs				
Operational and Maintenance cost (2% of capital)	494	794	634	894
Replacement costs (10% of capital)	2470	3770	3170	3170
Total Life Cycle Cost (LCC)	27074	46034	38674	54534

5.8.3 Costing for a pasteurization system using alternative fuel

The alternative fuel considered in this study was charcoal although firewood is the most widely used source of energy in the rural areas. The reason being charcoal has a more standardized pricing compared to firewood and charcoal being derived from wood, it is possible to estimate the quantity of firewood from that of charcoal using the ratio of 3:1 for the conversion process using traditional earth kilns that are common in developing countries. Details for the calculations using alternative fuel is given Appendix F.

5.8.4 Comparisons of LCC of the different experimental systems

The copper pipe collector with reflectors had the highest LCC of Ksh.54534 (USD\$720) followed by the galvanized pipe collector with reflectors with an LCC of Ksh.46034 (US\$ 606) then the copper pipe collector without reflectors with Ksh. 38674 (US\$ 508) and lastly the galvanized pipe collector without reflectors had the lowest LCC of Ksh.27034 (US\$ 356).

If the energy load for the pasteurization system was to be supplied using charcoal as the alternative fuel source then 4.5kg would be required per day to heat 100 liters of water from 23°C to 83°C at a cost of Ksh.112.50 or at an annual cost of Ksh.41,052.50 (US\$ 540). Although such a system utilizing charcoal has a low initial cost, the long term cost is comparatively high because of continuous purchase of fuel. The hidden or indirect cost due to destruction of the environment, greenhouse gas emissions and health effects associated with inhaling smoke are also disadvantages of using firewood or charcoal.

Considering the LCC of the collectors with reflectors as shown in Table 5.9 then the payback period would be less than two years with an annual saving of about 5 tonnes of wood (see Appendix F).

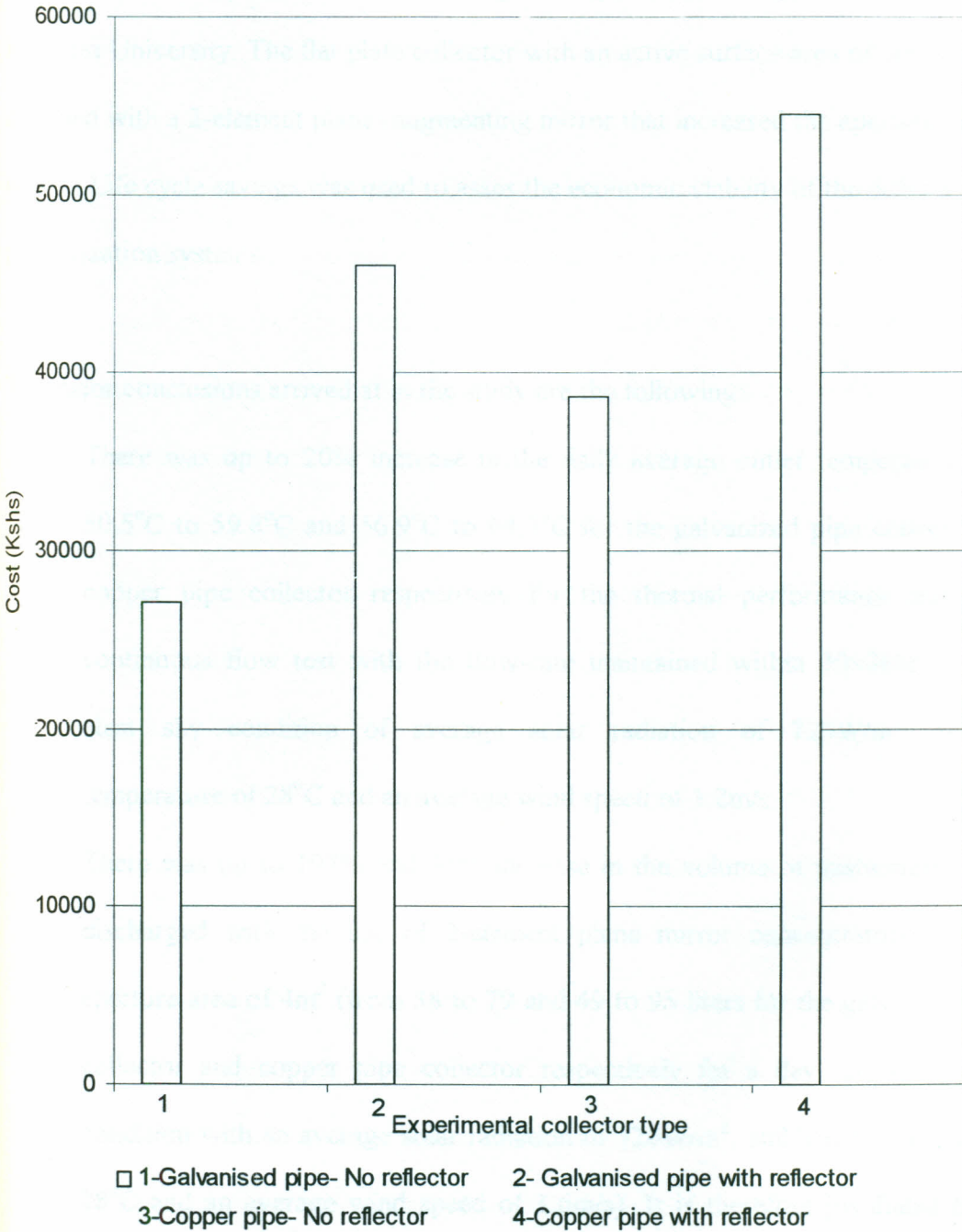


Figure 5.8 Comparison of the LCC of the different experimental solar pasteurization systems

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

A flat plate collector integrated with a 2-element plane augmenting mirrors was designed, constructed and tested at the Engineering and Technology workshop at Kenyatta University. The flat plate collector with an active surface area of 2m^2 was designed with a 2-element plane- augmenting mirror that increased the aperture area to 4m^2 . Life cycle savings was used to assess the economic viability of the different pasteurization systems.

The major conclusions arrived at in the study are the following:

1. There was up to 20% increase in the daily average outlet temperature from 50.5°C to 59.8°C and 56.9°C to 64.7°C for the galvanized pipe collector and copper pipe collector respectively for the thermal performance test using continuous flow test with the flow-rate maintained within $30\pm 3\text{l/hr}$ under a clear sky condition of average solar radiation of 720W/m^2 , ambient temperature of 28°C and an average wind speed of 1.2m/s .
2. There was up to 107% and 94% increase in the volume of pasteurized water discharged with the use of 2-element plane mirror concentrators from an aperture area of 4m^2 (from 38 to 79 and 49 to 95 liters for the galvanized pipe collector and copper pipe collector respectively for a day under clear sky condition with an average solar radiation of 720W/m^2 , ambient temperature of 28°C and an average wind speed of 1.6m/s). It is therefore justifiable to use concentrators for flat plate collectors for solar water pasteurization as the enhancement of solar radiation by plane mirror reflectors is of great

importance due to its potential application on various solar thermal devices.

3. There was up to 28% and 20% increase in the volume of pasteurized water with the use of copper pipe and aluminium absorber plate compared to that with galvanized steel pipe and stainless steel absorber plate (from 38 to 49 and 79 to 95 liters for collector without reflectors and that with reflectors under the clear sky conditions stated above). This was due to the higher conductivity of copper and aluminium compared to steel (see Appendix C).
4. The experimental solar pasteurization system was 100% effective in the destruction *E. coli* in water. The maximum *E. coli* count in the raw water was greater than 180 and there was no *E. coli* detected in the pasteurized water samples and thus in conformity with WHO requirement that no *E. coli* should be detected in drinking water (see Appendix H).
5. Economic analysis has also shown that a solar pasteurization system with an output of 100 liters per day at a discharge temperature of 83°C could save up to 100 tonnes of wood during the estimated useful life span of 20 years. The adoption of this system would also contribute towards environmental conservation through minimizing the use of biomass to boil drinking water and also reducing the amount of greenhouse gas emissions that result from combustion of biomass and the health effects associated with it.
6. The payback period for the collector with reflectors would be under 2 years as the cost of such a collector is in the order of Kshs. 50,000.00 and when considering the annual energy load to pasteurize 100 liters of drinking water (for a community of about 50 people) to be supplied by charcoal then the annual cost would be in the order of KShs. 40,000.00 for a rate of KShs. 25 per kilogram of charcoal (see Appendix F).

From the results obtained and discussed in this study, it is concluded that solar water pasteurization is viable in the tropics as the sun's energy is free, sustainable and not affected by how much the resource is constructively tapped. The adoption of the system by rural communities would go along way in improving the health of those in rural areas that are currently without safe drinking water and the system has the advantage of being easily decentralized. It does not require expensive equipments and huge capital investments and could also play a major role towards achieving the Millenium Development Goal (MDG) of providing safe and adequate water to all by the year 2025.

6.2 Recommendations for further work

The results obtained in this work can further be improved and complemented with the following research suggestions:

1. More work should be done to determine the optimum spacing of the parallel riser pipe so as to achieve the optimum batch of pasteurized water since the study has shown that water is heated in the collector in batches. The spacing used in the experimental collector is that recommended for continuous flow operation for a domestic solar water heater which is based on the optimal spacing relative to material cost (Ghamari and Worth, 1992).
2. Develop suitable models and standardized methods of assessing and predicting the thermal performance under various conditions for the 2-element plane-augmenting flat plate collector with a thermostatic valve for solar water pasteurization.
3. From literature *E. coli* is the major cause of waterborne diseases cannot

- survive above 65°C. In the experimental investigations, automotive thermostatic valve with an opening temperature of 82°C was used and the copper pipe collector with reflectors realized an output of up to about 100 liters of pasteurized water/day. Further investigations needs to be carried out using electronically operated thermostatic valve with a pre-set opening temperature of about 70°C. This would probably double the amount of pasteurized water collected for a similar collector used in the current study.
4. Further work can also be carried by pre-heating the raw water with the pasteurized water discharged from the collector via a heat exchanger to recover the energy that goes to waste in the pasteurized water storage tank. This is because drinking water is normally required cold. The pre-heating would raise the collector inlet water temperature and hence improve the collector performance.
 5. Although the investigations in this study have shown that the copper pipe collector has better thermal performance compared to the galvanized pipe collector, more investigations should be carried out on suitability for its use in pasteurizing water for human consumption, this is because the concentration of copper ions in water may be above the WHO recommended values.
 6. Further tests be carried out on all other aspects of drinking water quality parameters not within the scope of this study. This study was mainly concerned with bacteriological aspect of drinking water quality as this is the most common and deadly pollutant in drinking water in developing countries.

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APPENDICES

Appendix A

Method of least squares

The least square method is used to estimate the regression coefficients a and b where the joint distribution of x and y is not known in the relationship

$y = a + bx$. The exact relationship between x_i and y_i is given by the equation

$y_i = a + bx_i + \varepsilon_i$. Where ε_i denotes the vertical deviation from the point (x_i, y_i) to the line. The least square method requires that the sum of square of derivatives (errors) is minimized.

$$\sum y_i = na + b \sum x_i \quad \text{and} \quad \sum x_i y_i = a \sum x_i + b \sum x_i^2$$

Solving the 2 equations above then $b = \frac{S_{xy}}{S_x^2}$ -----(a)

$$a = \frac{\sum y}{n} - b \left(\frac{\sum x}{n} \right) \text{ -----(b)}$$

Sum of square of errors is given by $S_x^2 = \sum x_i^2 - \frac{1}{n} (\sum x_i)^2$ -----(c)

And $S_{xy} = \sum xy - \frac{1}{n} (\sum x)(\sum y)$ -----(d)

Using equations a, b, c and d above and inserting in the following values for collector with reflectors, $n=33$, $\Sigma x=0.671$, $\Sigma x^2=0.0133$, $\Sigma xy=0.387$, $\Sigma y=18.07$ and $\Sigma y^2=9.378$ then the regression equation is $y = 0.66 - 5.7x$.

Similarly for collector without reflectors $n=33$, $\Sigma x=0.543$, $\Sigma x^2=0.0096$, $\Sigma xy=0.264$ and $\Sigma y=14.98$. Thus the regression equation becomes $y=0.51 - 2.59x$.

Appendix B

Solar Reflector Materials

B-1 Reflector materials for use in solar concentrators

In many solar energy applications, it is cost effective to use reflectors to increase the irradiance on the receiver and thereby increase the heat production. Kwan and Bannerot (1984) have outlined that reflectors for solar energy application should fulfill the following requirements: reflect as much as possible the useful incident solar radiation onto the absorber; the reflector material and its support structure be inexpensive compared to the thermal absorber onto which the reflector concentrates radiation; high reflectance be maintained during the entire lifetime of the solar collector; the surface be easily cleaned without damaging the optical properties; the construction be mechanically strong to resist strong winds, vibrations etc.; be easy to mount and visual appearance of the reflector should be aesthetical and the concentrator aperture should not be shaded by objects in the surrounding; the reflector material be environmentally benign and without any hazardous compounds; and the reflectance be highly specular and radiation shouldn't be scattered in other directions other than that of specular beam.

B-2 Durability of reflector materials

Reflectors must be sturdy and durable in order to withstand many years of exposure to outdoor environmental conditions. Loss of specular and total solar reflectivity can result from erosion or oxidation of the surface, dirt accumulation on reflector and action of cleaning agents. While degradation caused by accumulation of dust on the reflecting surface is essentially reversible, surface oxidation is not (Tabor, 1978).

Aluminium has good mechanical properties but poor long-term stability of optical properties; especially the specular reflectance is a major drawback due to formation of aluminium oxide (Al_2O_3), a polymer that reduces reflectance of aluminium surface. The degradation of silver is not as rapid as that of aluminium due to limited corrosion resistance of free electron-like metals and are often used in back-surface mirrors, evaporated on the back of a glass or a polymer that protects the metal from oxidation. Front surface mirrors have the advantage of being bendable and light in weight but are more susceptible to chemical attack (Kwan and Bannerot, 1984).

Appendix C

Table C-1 Properties of selected solar collector materials

Material	Density (Kg/m ³)	Specific heat (kJ/kg°C)	Thermal conductivity (W/m °C)
Aluminium	2707	0.996	204
Iron	7897	0.452	73
Steel	7833	0.465	54
Copper	8954	0.383	386
Brass (70/30)	8522	0.385	111
Silver	10524	0.234	419
Tin	7304	0.226	64
Zinc (pure)	7144	0.384	112
Glass	2550	0.84	1.0
Wood	600	2.2	0.15
Glass fibre	42	-	0.04

Source: Gillet and Moon (1985)

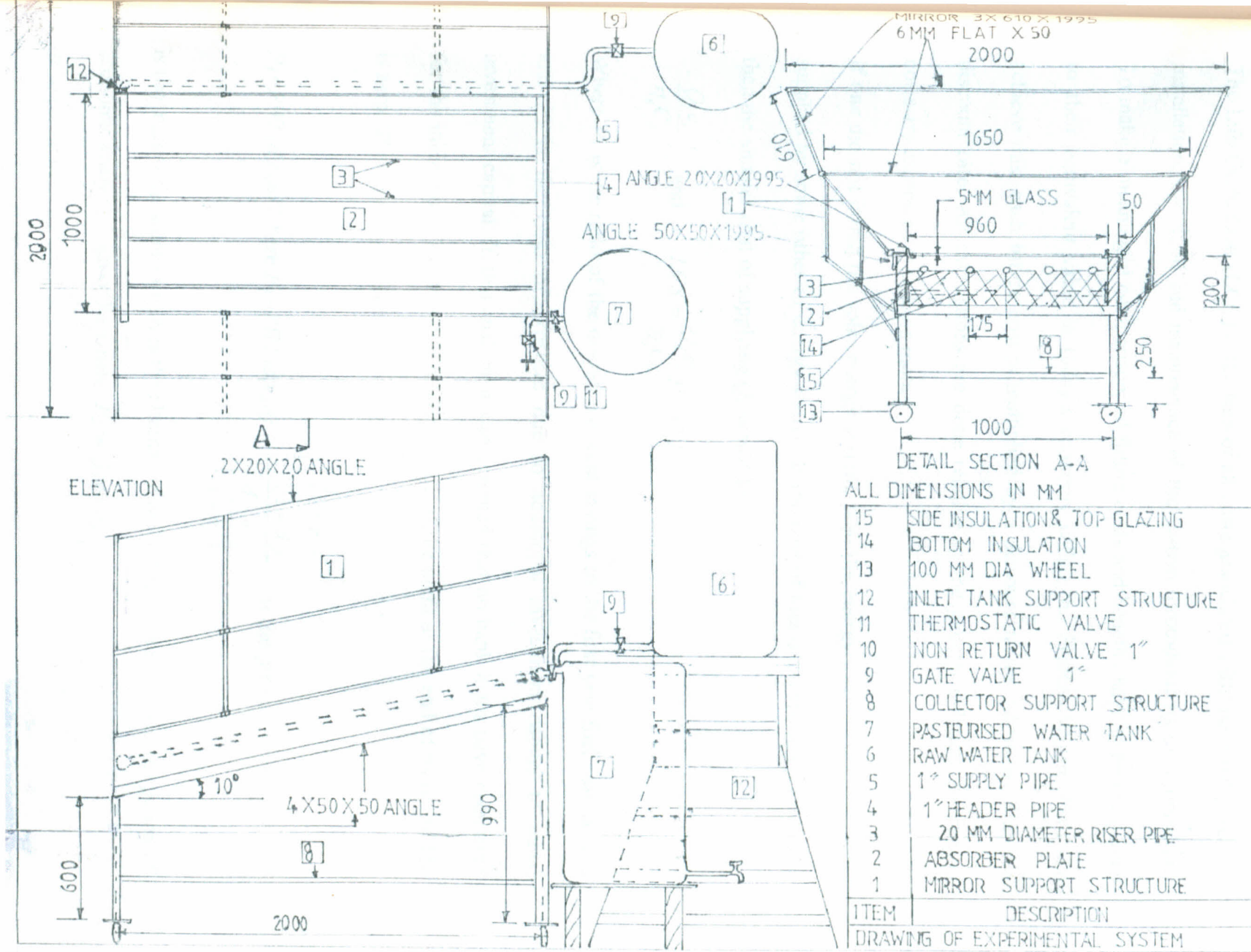


Figure D-1 Drawing of experimental system

Appendix E

Life Cycle Costing and Discounting Methodology

The Life Cycle Cost (LCC) is the sum of all costs associated with the initial purchase, installation, operation and maintenance of the system throughout its operational life.

To make a meaningful comparison, all future costs and benefits have to be discounted to their equivalent value in today's economy called the Present Worth (PW). To achieve this, each future cost is multiplied by a discount factor calculated from the discount rate. All calculations are done relative to the general inflation, so that all costs are expressed in today's money.

If one did not install the solar energy system, then the energy load Q_L would have to be supplied by some other of energy source. If the cost of fuel is c_i with an efficiency η_g , then the annual cost of supplying Q_L would be

$$\frac{Q_L c_i}{\eta_g C_v} \quad \text{and} \quad LCS = \frac{Q_L c_i}{\eta_g C_v} P_1 - C_s P_2$$

Where P_1 is the ratio of the overall fuel cost savings to the first year fuel cost savings and P_2 is the ratio of expenses due to additional investment capital to initial investment capital. In this analysis it was assumed that no bank loans have been used for the initial costs and that the residual value of the plant at the end of its useful life is zero. Therefore parameter P_1 becomes:

$$P_1 = PWF(d, e_i, n) \quad \text{Where} \quad P_1 = PWF(d, e_i, n) = \frac{1 - \left(\frac{1 + e_i}{1 + d} \right)^n}{\left(\frac{d - e_i}{1 + e_i} \right)} \quad \text{is the present worth factor, } d$$

is the market discount rate, e_i is the alternative fuel inflation rate and n is the period of economic analysis (years). Parameter P_2 is given by:

$$P_2 = 1 - M.PWF(d, g, n)$$

Where $PWF(d, g, n) = \frac{1 - \left(\frac{1+g}{1+d}\right)^n}{\left(\frac{d-g}{1+g}\right)}$ where g is the general inflation rate M is the

ratio of first year maintenance to the initial investment.

Appendix F

Costing for a pasteurization system using alternative fuel

The following have been considered in the calculations that follow:

1. Daily collector output of pasteurized water of 100 liters
2. Average inlet temperature of 23°C and thermostatic valve discharge temperature of 83°C
3. Charcoal of calorific value of 28MJ/kg and cost of Ksh 25/kg
4. Institutional stove efficiency of 20%
5. For every 1kg of charcoal 3Kg of wood is required

The daily energy load required to raise the temperature of 100liters of water from 23°C to 83°C is given by

$$Q_L = \dot{m}C_p(T_o - T_i) = 100 \times 4200 \times 60 = 25.2\text{MJ}$$

$$\text{Quantity of charcoal required to meet the energy load} = \frac{25.2}{28 \times 0.2} = 4.5\text{kg}$$

$$\text{Daily cost of charcoal to meet energy load} = 25 \times 4.5 = \text{Kshs } 112.50$$

$$\text{Annual cost for daily water pasteurization} = 112.50 \times 365 = \text{Kshs } 42,062.50 \text{ (USD540)}$$

$$\text{Equivalent amount of wood required to meet the daily energy load} = 4.5 \times 3 = 13.5\text{kg}$$

$$\text{Equivalent amount of wood required to meet the annual energy load} = 5 \text{ tonnes}$$

Considering a lifespan of 20 years then an equivalent of 100tonnes of wood would be required to meet the energy load for this period.

Appendix G

Table G-1 Most Probable Number (MPN) of Coliforms by McCrady's Table

Number of tubes giving positive tests			
1x50 ml	5x10 ml	5x1 ml	MPN/100 ml
0	0	0	<1
0	0	1	1
0	0	2	2
0	1	1	2
0	1	2	3
0	2	0	2
0	2	1	3
0	2	2	4
0	3	0	3
0	3	1	5
0	4	0	5
1	0	0	1
1	0	1	3
1	0	2	4
1	0	3	6
1	1	0	3
1	1	1	5
1	1	2	7
1	1	3	9
1	2	0	5
1	2	1	7
1	2	2	10
1	2	3	12
1	3	0	8
1	3	1	11
1	3	2	14
1	3	3	18
1	3	4	21
1	4	0	13
1	4	1	17
1	4	2	22
1	4	3	28
1	4	4	35
1	4	5	43
1	5	0	24
1	5	1	35
1	5	2	54
1	5	3	92
1	5	4	161
1	5	5	>180

Source: WHO (1997)

Appendix H

Table H-1 Classification of drinking water according to bacteriological tests

Class	Grade	Presumptive coliform count (per 100 ml)	<i>E. Coli.</i> count (per 100 ml)
I	Excellent	0	0
II	Satisfactory	1-3	0
III	Suspicious	4-10	0
IV	Unsatisfactory	>10	0, 1 or more

Source: WHO (1997)

RAW DATA SHEETS

Time (Hrs.)	Solar Rad. (mV)	Solar rad. I (W/m ²)	Wind vel. v (m/s)	T _a (°C)	T _i (°C)	T _o (°C)	T _{p1} (°C)	T _{p2} (°C)	T _{p3} (°C)	T _{p-av} (°C)	(T _{p-av} -T _a) (°C)	(T _o -T _i) (°C)	T _m (°C)	(T _m -T _a) (°C)	(T _m -T _a)/I m ² °C/W	(T _o -T _i)/I m ² °C/W	Th _{eff}
9:01	5.17	473.99	1.2	18.7	14.3	28.2	25.8	42.5	36.8	35.0	16.3	13.9	21.3	2.6	0.01	0.03	0.26
9:16	5.62	515.24	0.6	20.2	14.8	32.4	26.7	48.2	41.7	38.9	18.7	17.6	23.6	3.4	0.01	0.03	0.30
9:31	6.12	561.08	1.1	20.3	14.8	35.9		54.2	64.2	59.2	38.9	21.1	25.4	5.1	0.01	0.04	0.33
9:46	6.87	629.84	2.2	21.4	16.1	38.7	30.1	56.4	67.3	51.3	29.9	22.6	27.4	6.0	0.01	0.04	0.31
10:01	7.59	695.85	0.7	21.7	16.9	42.5	32.9	62.5	68.5	54.6	32.9	25.6	29.7	8.0	0.01	0.04	0.32
10:16	7.68	704.10	1.9	21.9	17.7	45.8	34.1	69.2	69.4	57.6	35.7	28.1	31.8	9.9	0.01	0.04	0.35
10:31	8.32	762.78	1.2	22.9	18.1	47.1	38.8	56.4	74.2	56.5	33.6	29.0	32.6	9.7	0.01	0.04	0.33
10:46	8.42	771.95	2.8	23.3	19.1	49.9	43.2	59.9	72.4	58.5	35.2	30.8	34.5	11.2	0.01	0.04	0.35
11:01	8.43	772.86	0.6	24.8	19.7	52.5	45.5	56.8	82.3	61.5	36.7	32.8	36.1	11.3	0.01	0.04	0.37
11:16	8.28	759.11	0.4	26.7	19.8	53.5	52.1	60.1	82.8	65.0	38.3	33.7	36.7	10.0	0.01	0.04	0.39
11:31	8.13	745.36	1.2	26.5	21.7	55.8	56.6	63.9	82.2	67.6	41.1	34.1	38.8	12.3	0.02	0.05	0.40
11:46	8.23	754.53	2.4	27.1	21.9	57.3	57.5	64.5	85.6	69.2	42.1	35.4	39.6	12.5	0.02	0.05	0.41
12:01	8.03	736.19	0.6	27.8	22.5	58.5	59.8	69.2	93.2	74.1	46.3	36.0	40.5	12.7	0.02	0.05	0.43
12:16	8.27	758.19	2.7	28.5	24.7	60.5	62.4	70.1	92.1	74.9	46.4	35.8	42.6	14.1	0.02	0.05	0.41
12:31	8.42	771.95	1.4	28.1	24.7	61.7	58.8	64.4	92.3	71.8	43.7	37.0	43.2	15.1	0.02	0.05	0.42
12:46	8.42	771.95	1.3	30.1	24.5	63.9	56.4	66.4	94.5	72.4	42.3	39.4	44.2	14.1	0.02	0.05	0.45
13:01	5.85	536.51	1.7	29.8	26.7	61.8	64.8	68.3	90.7	74.6	44.8	35.1	44.3	14.5	0.03	0.07	0.57
13:16	9.03	827.87	1.8	29.8	27.6	62.7	65.3	71.9	98.9	78.7	48.9	35.1	45.2	15.4	0.02	0.04	0.37
13:31	9.33	855.37	2.1	30.4	27.1	62.6	66.3	76.8	88.9	77.3	46.9	35.5	44.9	14.5	0.02	0.04	0.36
13:46	9.86	903.96	1.3	32.1	26.9	61.2	67.5	76.6	95.4	79.8	47.7	34.3	44.1	12.0	0.01	0.04	0.33
14:01	6.88	630.76	2.1	31.6	26.8	62.8	71.4	78.9	96.5	82.3	50.7	36.0	44.8	13.2	0.02	0.06	0.50
14:16	4.47	409.81	1.6	30.4	28.2	52.7	62.9	67.4	80.5	70.3	39.9	24.5	40.5	10.1	0.02	0.06	0.52
14:31	9.47	868.21	0.5	32.8	27.8	49.9	58.3	60.2	75.7	64.7	31.9	22.1	38.9	6.1	0.01	0.03	0.22
14:46	4.23	387.35	1.3	32.4	28.6	54.4	60.4	66.2	78.6	68.4	36.0	25.8	41.5	9.1	0.02	0.07	0.58
15:01	6.34	581.25	1.8	33	30.8	52.7	58.2	62.1	70.215	63.5	30.5	21.9	41.8	8.8	0.02	0.04	0.33
15:16	5.86	537.24	1.5	32.5	30.8	53.4	59.4	64.2	75.9	66.5	34.0	22.6	42.1	9.6	0.02	0.04	0.37
15:31	6.55	600.50	1.8	32.9	31.4	48.5	52.3	58.8	71.6	60.9	28.0	17.1	40.0	7.1	0.01	0.03	0.25
15:46	5.88	539.08	0.9	32.7	32.2	47.9	52.9	55.8	66.3	58.3	25.6	15.7	40.1	7.3	0.01	0.03	0.25
16:01	4.87	446.48	1.5	32.5	33.2	43.2	45.4	48.8	54.5	49.6	17.1	10.0	38.2	5.7	0.01	0.02	0.20
16:16	4.60	421.73	1.3	32.5	33.3	43.1	45.2	48.1	52.8	48.7	16.2	9.8	38.2	5.7	0.01	0.02	0.20
16:31	4.20	385.06	2.0	32.4	33.6	42.1	44.7	47.6	51.3	47.9	15.5	8.5	37.9	5.5	0.01	0.02	0.19
16:46	4.90	449.23	0.8	32.8	33.5	42.8	45.3	48.9	54.1	49.4	16.6	9.3	38.2	5.4	0.01	0.02	0.18
17:01	4.80	440.06	0.7	33	33.3	42.3	44.9	48.6	52.4	48.6	15.6	9.0	37.8	4.8	0.01	0.02	0.18
Average		636.53	1.4	28.3	24.9	50.6	51.4	61.0	74.4	62.4	34.1	25.6	37.7	9.5	0.01	0.04	0.35
Std. deviation		154.34	0.6	4.5	6.2	9.3	12.2	9.2	16.4	11.7	10.9	9.7	6.2	3.6	0.00	0.01	0.11

(Hrs.)	(mV)	I (W/m ²)	v (m/s)	(°C)	T_1 (°C)	T_0 (°C)	T_{p1} (°C)	T_{p2} (°C)	T_{p3} (°C)	$T_{p.av}$ (°C)	$(T_{p.av} - T_a)$ (°C)	$(T_0 - T_1)$ (°C)	T_m (°C)	$(T_m - T_a)$ (°C)	$(T_m - T_a)/I$ m ² °C/W	$T_{h,eff}$
9:00	5.44	498.9	1.1	20.3	16.4	27.8	23.9	30.3	44.2	32.8	12.5	11.4	22.1	1.8	0.004	0.24
9:15	6.01	551.1	0.9	21.5	16.2	29.7	25.3	38.6	48.2	37.4	15.9	13.5	23.0	1.5	0.003	0.26
9:30	6.54	599.6	0.8	21.2	16.6	31.1	27.2	43.6	51.3	40.7	19.5	14.5	23.9	2.7	0.004	0.25
9:45	7.33	672.2	0.8	21.5	16.2	34.9	29.1	56.2	62.1	49.1	27.6	18.7	25.6	4.1	0.006	0.29
10:00	6.60	604.6	1.7	21.6	19.3	38.6	32.5	59.1	66.9	52.8	31.2	19.3	29.0	7.4	0.012	0.33
10:15	8.70	797.9	1.2	24.1	19.6	41.6	33.6	62.4	69.1	55.0	30.9	22	30.6	6.5	0.008	0.29
10:30	7.17	657.3	1.8	24.4	19.9	44.4	44.4	69.7	75.4	63.2	38.8	24.5	32.2	7.8	0.012	0.39
10:45	7.95	728.5	1.2	24.4	21.5	46.7	44.6	46.6	60.5	50.6	26.2	25.2	34.1	9.7	0.013	0.36
11:00	10.55	967.6	0.8	25.0	20.2	48.2	39.5	46.9	70.8	52.4	27.4	28	34.2	9.2	0.010	0.30
11:15	9.88	905.5	2.0	27.0	20.6	44.8	43.1	51.4	75.5	56.7	29.7	24.2	32.7	5.7	0.006	0.28
11:30	7.28	667.7	1.5	25.5	22.3	44.9	51.8	58.6	72.8	61.1	35.6	22.6	33.6	8.1	0.012	0.35
11:45	8.64	792.0	0.5	27.5	23.9	43.8	47.7	50.9	63.9	54.2	26.7	19.9	33.9	6.3	0.008	0.26
12:00	5.69	521.7	1.8	28.4	24.9	43.8	46.1	48.2	54.7	49.7	21.3	18.9	34.4	6.0	0.011	0.38
12:15	6.69	613.3	1.6	27.4	25.1	46.9	41.5	45.1	52.3	46.3	18.9	21.8	36.0	8.6	0.014	0.37
12:30	10.30	944.0	1.4	29.2	24.1	50.2	43.4	51.7	81.8	59.0	29.8	26.1	37.2	8.0	0.008	0.29
12:45	10.79	988.9	2.7	29.7	25.3	57.6	52.4	66.5	84.8	67.9	38.2	32.3	41.5	11.8	0.012	0.34
13:00	8.79	806.2	2.2	29.4	26.3	58.3	50.6	64	72.1	62.2	32.8	32	42.3	12.9	0.016	0.42
13:15	10.55	967.4	1.7	30.2	26.5	59.2	52.4	65.2	85.8	67.8	37.6	32.7	42.9	12.7	0.013	0.35
13:30	10.17	932.7	1.7	29.4	27.8	59.5	58.6	68	90.2	72.3	42.9	31.7	43.7	14.3	0.015	0.36
13:45	6.46	592.6	2.7	28.4	28.1	52.8	51.7	53.4	66.9	57.3	28.9	24.7	40.5	12.1	0.020	0.44
14:00	4.63	424.3	2.4	30.3	29.3	46.5	45.9	49.9	60.9	52.2	21.9	17.2	37.9	7.6	0.018	0.42
14:15	9.46	867.7	1.5	29.3	29.6	52.8	41.6	52.3	79.1	57.7	28.4	23.2	41.2	11.9	0.014	0.28
14:30	8.28	758.9	0.5	32.3	29.5	51.7	45.8	54.6	81.4	60.6	28.3	22.2	40.6	8.3	0.011	0.31
14:45	7.92	726.0	0.7	30.9	30.1	47.6	49.8	52.2	64.6	55.5	24.6	17.5	38.9	8.0	0.011	0.25
15:00	7.88	722.7	1.6	30.8	30.2	49.7	49.2	61.2	80.6	63.7	32.9	19.5	40.0	9.2	0.013	0.28
15:15	6.14	562.6	0.9	32.0	31.4	51.7	51.4	63.3	74.6	63.1	31.1	20.3	41.6	9.6	0.017	0.38
15:30	5.10	467.9	2.9	32.0	32.1	48.8	50.7	58.7	67.4	58.9	26.9	16.7	40.5	8.5	0.018	0.37
15:45	4.31	395.0	2.4	31.9	33.6	46.4	48.3	56	67.2	57.2	25.3	12.8	40.0	8.1	0.021	0.34
16:00	3.52	322.7	1.3	31.1	33	43.9	47.8	48.9	57.2	51.3	20.2	10.9	38.5	7.4	0.023	0.35
16:15	3.22	295.2	1.5	31.3	33.8	41.9	43.3	43.9	49.1	45.4	14.1	8.1	37.9	6.5	0.022	0.29
16:30	4.06	372.2	1.0	31.9	33.5	46.7	44.7	49.8	60.1	51.5	19.6	13.2	40.1	8.2	0.022	0.37
16:45	3.53	324.0	1.7	31.2	33.6	44.3	46.4	48.7	50.1	48.4	17.2	10.7	39.0	7.8	0.024	0.35
17:00	3.58	327.8	1.2	31.3	33.8	42	43.5	44.2	49.8	45.8	14.5	8.2	37.9	6.6	0.020	0.26
Average		647.8	1.5	28.0	25.9	46.0	43.9	53.3	66.4	54.5	26.6	20.1	36.0	8.0	0.012	0.33
Std. Deviation		211.2	0.6	3.7	5.8	7.7	8.4	8.9	12.4	8.7	7.7	6.9	5.9	3.0	0.014	0.05

Time (Hrs)	Solar rad. (mV)	Solar rad. I (W/m ²)	Wind vel. v (m/s)	T _a (°C)	T ₁ (°C)	T _o (°C)	T _{p1} (°C)	T _{p2} (°C)	T _{p3} (°C)	T _{p.av} (°C)	(T _{p.av} -T _a) (°C)	(T _o -T ₁) (°C)	T _m (°C)	(T _m -T _a) (°C)	(T _m -T _a)/I m ² C/W	Ther.
9:00	5.6	511.0	1.0	20.4	14.3	28.8	33.1	47.8	53.7	44.9	24.5	14.5	21.6	1.2	0.002	0.30
9:15	6.7	612.8	0.9	19.6	15.4	32.9	43.4	48.9	59.7	50.7	31.1	17.5	24.2	4.6	0.007	0.30
9:30	7.3	672.7	0.5	21.5	17.1	35.7	41.4	46.4	57.9	48.6	27.1	18.6	26.4	4.9	0.007	0.29
9:45	6.9	629.9	0.6	21.2	19.2	38.9	43.7	47.9	58.2	49.9	28.7	19.7	29.1	7.9	0.012	0.33
10:00	6.6	601.1	1.3	24.2	19.5	42.2	42.4	50.2	60.8	51.1	26.9	22.7	30.9	6.7	0.011	0.40
10:15	6.9	629.5	0.8	23.1	21.4	39.6	42.9	46.5	52.8	47.4	24.3	18.2	30.5	7.4	0.012	0.30
10:30	5.5	506.3	0.5	23.8	22.6	42.8	45.6	48.6	54.7	49.6	25.8	20.2	32.7	8.9	0.018	0.42
10:45	6.6	604.8	0.7	25.6	22.8	43.7	44.2	50.9	53.8	49.6	24.0	20.9	33.3	7.7	0.013	0.36
11:00	5.9	540.4	0.8	27.6	22.8	42.9	43.5	50.2	52.6	48.8	21.2	20.1	32.9	5.3	0.010	0.39
11:15	6.4	585.8	1.2	25.7	23.4	40.1	43	47.2	49.1	46.4	20.7	16.7	31.8	6.1	0.010	0.30
11:30	9.7	890.8	1.0	27.2	23.5	42.6	41.9	48.8	50.2	47.0	19.8	19.1	33.1	5.9	0.007	0.22
11:45	7.5	689.7	0.8	28.5	24.6	52.5	51.4	62.3	66.8	60.2	31.7	27.9	38.6	10.1	0.015	0.42
12:00	11.6	1060.2	0.7	30.1	25	57.6	54.1	70.7	72.9	65.9	35.8	32.6	41.3	11.2	0.011	0.32
12:15	7.7	707.7	1.1	27.9	26.5	53.2	53.1	67.8	68.2	63.0	35.1	26.7	39.9	12.0	0.017	0.40
12:30	9.7	890.9	0.5	29.3	25.2	57.4	54.3	70.9	72.4	65.9	36.6	32.2	41.3	12.0	0.013	0.38
12:45	10.1	922.4	0.8	30.2	26.2	63.2	65.9	79.2	81.2	75.4	45.2	37.0	44.7	14.5	0.016	0.42
13:00	6.5	595.0	1.4	30.7	27.5	64.5	69.8	81.9	83.8	78.5	47.8	37.0	46.0	15.3	0.026	0.65
13:15	9.0	826.5	1.7	30.5	27.7	65.7	74.7	82.9	85.7	81.1	50.6	38.0	46.7	16.2	0.020	0.48
13:30	7.2	662.8	1.0	31.1	28.2	59.4	71.6	74.8	76.5	74.3	43.2	31.2	43.8	12.7	0.019	0.49
13:45	8.6	788.5	0.6	30.8	28.2	60.4	68.9	75.2	78.8	74.3	43.5	32.2	44.3	13.5	0.017	0.43
14:00	5.6	516.3	2.2	30.8	30.9	52.2	66.1	68.1	71.5	68.6	37.8	21.3	41.6	10.8	0.021	0.43
14:15	7.6	697.3	1.3	32.8	31	52.8	58.2	64.8	68.7	63.9	31.1	21.8	41.9	9.1	0.013	0.33
14:30	5.6	510.0	1.2	31.6	31.6	47.8	51.9	56.4	58.9	55.7	24.1	16.2	39.7	8.1	0.016	0.33
14:45	6.7	614.8	1.6	31.7	30.4	44.7	47.3	52.6	54.1	51.3	19.6	14.3	37.6	5.9	0.010	0.24
15:00	4.3	392.2	0.8	31.8	31.4	44.2	47	50.6	52.1	49.9	18.1	12.8	37.8	6.0	0.015	0.34
15:15	5.8	534.3	1.5	32.8	31.6	39.9	42.1	46.5	47.9	45.5	12.7	8.3	35.8	3.0	0.006	0.16
15:30	5.0	459.0	2.3	31.4	32.6	41.2	43.4	46.8	48.2	46.1	14.7	8.6	36.9	5.5	0.012	0.20
15:45	5.2	472.2	1.2	32.1	31.6	38.7	37.3	44.4	47.3	43.0	10.9	7.1	35.2	3.1	0.006	0.16
16:00	3.4	313.6	0.5	32.6	31.4	38.6	38.9	42.2	46.8	42.6	10.0	7.2	35.0	2.4	0.008	0.24
16:15	3.7	338.2	1.8	32.1	31.4	38.6	39.2	43.5	47.3	43.3	11.2	7.2	35.0	2.9	0.009	0.22
16:30	3.9	357.6	1.9	32.5	31.6	39.2	38.8	43.2	48.1	43.4	10.9	7.6	35.4	2.9	0.008	0.22
16:46	3.4	310.8	1.7	32.6	31.8	38.8	37.5	43.2	48.6	43.1	10.5	7.0	35.3	2.7	0.009	0.24
17:00	3.5	316.3	0.9	32.2	31.9	38.6	37.6	43.1	48.8	43.2	11.0	6.7	35.3	3.1	0.010	0.22
Average		598.8	1.1	28.7	26.4	46.0	48.9	55.9	59.9	54.9	26.3	19.7	36.2	7.5	0.013	0.33
Std. Deviation		185.82	0.5	4.1	5.3	9.7	11.4	12.9	12.1	11.9	11.8	9.7	6.1	4.2	0.022	0.11

Time (Hrs)	Solar rad. (mV)	Solar rad. I (W/m ²)	Wind vel. v (m/s)	T _a (°C)	T _i (°C)	T _o (°C)	T _{p1} (°C)	T _{p2} (°C)	T _{p3} (°C)	T _{p,av} (°C)	(T _{p,av} -T _a) (°C)	(T _o -T _i) (°C)	T _m (°C)	(T _m -T _a) (°C)	(T _m -T _a)/I m ² °C/W	Th _{eff}
9:00	5.65	518.18	2.0	18.9	13.2	29.4	21.6	38.9	47.8	36.1	17.2	16.2	21.3	2.4	0.005	0.27
9:15	6.02	551.47	1.9	20.2	14.5	31.6	29.3	45.1	52.3	42.2	22.0	17.1	23.1	2.9	0.005	0.27
9:30	5.77	528.81	1.1	19.8	14.9	33.2	38.9	46.8	53.7	46.5	26.7	18.3	24.1	4.3	0.008	0.30
9:45	4.99	457.21	1.9	19.8	15.2	33.9	39.1	49.2	54.3	47.5	27.7	18.7	24.6	4.8	0.010	0.36
10:00	8.91	816.78	0.9	19.7	15.3	36.2	39.7	52.0	56.9	49.5	29.8	20.9	25.8	6.1	0.007	0.22
10:15	8.71	798.72	0.7	21.0	15.6	38.2	48.3	63.0	65.4	58.9	37.9	22.6	26.9	5.9	0.007	0.25
10:30	5.63	516.34	1.3	22.0	16.1	38.8	58.1	60.1	63.3	60.5	38.5	22.7	27.5	5.5	0.011	0.38
10:45	8.16	748.02	0.9	21.4	16.8	39.7	39.2	43.8	51.2	44.7	23.3	22.9	28.3	6.9	0.009	0.27
11:00	7.50	687.78	1.3	23.8	17.9	41.2	45.6	48.6	52.2	48.8	25.0	23.3	29.6	5.8	0.008	0.30
11:15	9.55	875.91	1.5	24.6	17.6	44.6	48.9	52.3	55.4	52.2	27.6	27.0	31.1	6.5	0.007	0.27
11:30	9.79	897.91	0.5	26.1	17.8	47.2	48.1	54.3	57.6	53.3	27.2	29.4	32.5	6.4	0.007	0.29
11:45	8.48	777.26	2.3	24.4	19.2	49.4	52.2	58.6	60.5	57.1	32.7	30.2	34.3	9.9	0.013	0.34
12:00	9.89	907.08	0.8	27.5	19.9	50.8	51.7	59.3	61.2	57.4	29.9	30.9	35.4	7.8	0.009	0.30
12:15	10.28	942.38	1.3	28.2	19.8	53.1	52.8	61.2	78.5	64.2	36.0	33.3	36.5	8.3	0.009	0.31
12:30	10.75	985.28	2.3	27.8	21.5	54.4	52.9	65.3	85.7	68.0	40.2	32.9	38.0	10.2	0.010	0.29
12:45	10.56	968.23	2.5	28.8	22.6	60.1	55.6	66.7	92.7	71.7	42.9	37.5	41.4	12.6	0.013	0.34
13:00	10.81	991.15	0.7	30.1	22.2	61.3	56.1	65.8	90.8	70.9	40.8	39.1	41.8	11.7	0.012	0.35
13:15	10.38	951.82	0.8	30.1	21.8	63.7	55.9	68.0	94.3	72.7	42.6	41.9	42.8	12.7	0.013	0.39
13:30	8.09	742.06	1.0	31.5	22.3	60.8	58.2	66.1	91.2	71.8	40.3	38.5	41.6	10.1	0.014	0.45
13:45	10.11	926.52	0.9	30.8	24.2	65.9	64.8	73.5	97.1	78.5	47.7	41.7	45.1	14.3	0.015	0.39
14:00	10.19	934.13	1.1	32.1	23.6	63.1	62.9	69.6	91.3	74.6	42.5	39.5	43.4	11.3	0.012	0.37
14:15	8.35	765.34	1.3	31.1	23.9	60.0	66.5	66.6	83.0	72.0	40.9	36.1	42.0	10.9	0.014	0.41
14:30	8.58	786.98	1.3	31.4	25.7	58.4	62.6	68.1	91.8	74.2	42.8	32.7	42.1	10.7	0.014	0.36
14:45	6.83	625.99	2.3	31.8	26.7	55.8	59.5	62.9	88.7	70.4	38.6	29.1	41.3	9.5	0.015	0.41
15:00	7.36	674.95	1.0	31.9	27.4	55.6	57.8	59.9	89.2	69.0	37.1	28.2	41.5	9.6	0.014	0.37
15:15	6.77	620.86	1.3	32.9	27.5	54.7	56.3	59.4	87.8	67.8	34.9	27.2	41.1	8.2	0.013	0.38
15:30	6.57	602.15	0.7	33.1	26.4	53.8	56.2	56.9	79.4	64.2	31.1	27.4	40.1	7.0	0.012	0.40
15:45	5.32	487.46	0.6	33.2	28.4	50.5	56.4	57.7	73.4	62.5	29.3	22.1	39.5	6.3	0.013	0.40
16:00	5.70	522.76	1.5	33.6	28.9	50.3	50.8	56.8	75.1	60.9	27.3	21.4	39.6	6.0	0.011	0.36
16:15	4.77	437.50	1.1	32.5	30.2	49.2	54.7	54.7	61.5	57.0	24.5	19.0	39.7	7.2	0.016	0.38
16:30	4.34	397.80	1.9	33.0	30.6	45.7	46.2	49.3	57.2	50.9	17.9	15.1	38.2	5.2	0.013	0.33
16:45	3.48	318.59	0.7	33.8	31.4	45.1	43.9	47.7	63.6	51.7	17.9	13.7	38.3	4.5	0.014	0.38
17:00	3.92	359.39	2.3	33.7	31.3	45.1	43.2	47.4	63.2	51.3	17.6	13.8	38.2	4.5	0.013	0.34
Average		700.69	1.3	27.9	22.1	49.1	50.7	57.4	71.7	60.0	32.1	27.0	35.6	7.7	0.011	0.34
Std. Deviation		203.27	0.57	5.1	5.5	10.1	10.0	8.6	16.1	11.0	8.7	8.5	7.0	3.0	0.015	0.05

Time (Hrs)	Solar rad. (mV)	Solar rad. I (W/m ²)	Wind vel. v (m/s)	T _a (°C)	T _i (°C)	T _o (°C)	T _{p1} (°C)	T _{p2} (°C)	T _{p3} (°C)	T _{p.av} (°C)	(T _{p.av} -T _a) (°C)	(T _o -T _i) (°C)	T _m (°C)	(T _m -T _a) (°C)	(T _m -T _a)/I m ² °C/W	Th _{eff}
9:00	6.10	559.52	1.1	19.8	18.2	35.4	34.5	38.9	49.5	41.0	21.2	17.2	26.8	7.0	0.013	0.27
9:15	5.52	505.98	1.3	19.8	18.4	39.7	40.5	42.6	48.6	43.9	24.1	21.3	29.1	9.3	0.018	0.37
9:30	5.04	461.98	1.0	21.4	20.2	40.5	41.1	44.5	49.3	45.0	23.6	20.3	30.4	9.0	0.019	0.38
9:45	4.99	457.57	1.4	21.5	20.8	41.2	43.8	46.2	52.7	47.6	26.1	20.4	31.0	9.5	0.021	0.39
10:15	4.70	430.44	0.9	21.7	21.1	37.9	38.2	41.7	51.9	43.9	22.2	16.8	29.5	7.8	0.018	0.34
10:30	5.39	494.52	0.5	23.9	22.1	37.2	38.2	39.4	50.1	42.6	18.7	15.1	29.7	5.8	0.012	0.27
10:45	5.55	509.01	0.9	24.2	21.2	39.6	38.1	41.2	58.1	45.8	21.6	18.4	30.4	6.2	0.012	0.32
11:00	5.57	510.93	0.9	24.2	22.8	40.1	39.7	43.5	57.3	46.8	22.6	17.3	31.5	7.3	0.014	0.30
11:15	6.65	609.49	0.8	25.3	23.2	43.1	40.3	44.7	58.2	47.7	22.4	19.9	33.2	7.9	0.013	0.29
11:30	5.54	507.54	1.3	26.1	22.3	44.4	41.2	45.4	61.4	49.3	23.2	22.1	33.4	7.3	0.014	0.38
11:45	9.68	887.83	1.3	27.5	22.1	46.2	44.3	48.4	73.3	55.3	27.8	24.1	34.2	6.7	0.007	0.24
12:00	10.48	960.35	1.0	26.8	21.5	50.8	49.1	63.3	85.4	65.9	39.1	29.3	36.2	9.4	0.010	0.27
12:15	5.87	538.34	1.2	26.7	22.6	47.8	51.4	56.5	80.7	62.9	36.2	25.2	35.2	8.5	0.016	0.41
12:30	5.71	523.86	0.9	27.6	23.5	49.6	43.5	49.8	62.4	51.9	24.3	26.1	36.6	9.0	0.017	0.44
12:45	12.14	1112.63	0.5	28.8	22.7	52.2	42.6	49.5	72.4	54.8	26.0	29.5	37.5	8.7	0.008	0.23
13:00	11.40	1045.06	0.7	29.2	22.5	55.2	44.3	54.9	83.1	60.8	31.6	32.7	38.9	9.7	0.009	0.27
13:15	11.35	1040.48	0.5	28.6	23.1	57.7	49.9	57.7	82.8	63.5	34.9	34.6	40.4	11.8	0.011	0.29
13:30	6.34	580.88	0.9	31.2	23.9	58.4	53.4	62.8	91.2	69.1	37.9	34.5	41.2	10.0	0.017	0.52
13:45	7.66	702.64	1.7	30.2	24.1	58.1	61.2	69.5	94.3	75.0	44.8	34.0	41.1	10.9	0.016	0.42
14:00	7.44	682.28	1.0	30.4	25.6	52.5	54.9	59.7	79.4	64.7	34.3	26.9	39.1	8.7	0.013	0.34
14:15	6.80	623.06	0.5	31.3	26.8	51.8	50.8	56.4	81.8	63.0	31.7	25.0	39.3	8.0	0.013	0.35
14:30	10.26	940.27	1.1	33.5	26.3	59.3	54.4	66.6	95.4	72.1	38.6	33.0	42.8	9.3	0.010	0.31
14:45	9.30	852.72	0.9	32.3	25.8	52.5	49.9	58.8	83.9	64.2	31.9	26.7	39.2	6.9	0.008	0.27
15:00	8.43	773.23	1.4	31.6	27.8	54.4	53.6	59.7	81.5	64.9	33.3	26.6	41.1	9.5	0.012	0.30
15:15	8.68	795.42	0.5	32.8	27.3	52.6	50.2	58.4	84.5	64.4	31.6	25.3	40.0	7.2	0.009	0.28
15:30	5.13	470.14	1.0	31.9	28.5	48.2	48.2	53.9	74.1	58.7	26.8	19.7	38.4	6.5	0.014	0.37
15:45	7.40	678.34	0.8	32.7	28.9	47.6	40.6	52.8	73.9	55.8	23.1	18.7	38.3	5.6	0.008	0.24
16:00	5.30	486.09	1.2	32.2	29.9	44.2	42.9	49.2	64.5	52.2	20.0	14.3	37.1	4.8	0.010	0.26
16:15	6.27	574.93	2.1	33.2	30.6	42.3	39.1	47.3	59.9	48.8	15.6	11.7	36.5	3.3	0.006	0.18
16:30	5.34	489.66	1.1	33.4	30.8	45.1	41.8	49.6	72	54.5	21.1	14.3	38.0	4.6	0.009	0.26
16:45	4.44	406.97	2.4	33.6	29.7	42.4	38.6	44.9	58.6	47.4	13.8	12.7	36.1	2.5	0.006	0.27
17:00	4.04	370.11	1.0	33.4	31.4	43.1	42.6	47.3	67.9	52.6	19.2	11.7	37.3	3.9	0.010	0.28
Average		643.20	1.1	28.3	24.6	47.2	45.1	51.4	70.0	55.5	27.2	22.7	35.9	7.6	0.012	0.32
Std. Deviation		207.67	0.43	4.42513	3.6893	6.8213	6.34026	8.183	14.3215	9.4	7.5	6.9	4.3	2.2	0.011	0.07

Time (Hrs)	Solar rad. (mV)	Solar rad. I (W/m ²)	Wind vel. v (m/s)	T _a (°C)	T _i (°C)	T _o (°C)	T _{p1} (°C)	T _{p2} (°C)	T _{p3} (°C)	T _{p,av} (°C)	(T _{p,av} -T _a) (°C)	(T _o -T _i) (°C)	T _m (°C)	(T _m -T _a) (°C)	(T _m -T _a)/I (m ² °C/W)	Th _{eff}
9:00	5.61	514.23	1.0	26.9	21.3	38.7	36.5	42.2	55.6	44.8	17.9	17.4	30.0	3.1	0.006	0.35
9:15	6.23	570.80	1.9	28.6	21.8	43.5	41.5	49.1	62.2	50.9	22.3	21.7	32.7	4.1	0.007	0.40
9:30	6.74	617.65	0.6	27.8	21.2	45.6	43.5	59.1	71.2	57.9	30.1	24.4	33.4	5.6	0.009	0.41
9:45	7.19	659.45	0.4	28.5	21.9	48.6	53.5	64.2	77.1	64.9	36.4	26.7	35.3	6.8	0.010	0.42
10:00	7.65	700.89	0.7	28.6	22.1	50.6	50.2	57.3	79.8	62.4	33.8	28.5	36.4	7.8	0.011	0.43
10:15	7.90	724.46	1.9	29.1	22.0	51.8	50.1	58.4	79.9	62.8	33.7	29.8	36.9	7.8	0.011	0.43
10:30	8.58	786.61	1.1	31.0	22.5	52.2	52.3	59.1	84.3	65.2	34.2	29.7	37.4	6.4	0.008	0.40
10:45	8.89	815.22	1.5	29.8	23.0	55.6	54.7	61.1	86.9	67.6	37.8	32.6	39.3	9.5	0.012	0.42
11:00	9.09	833.55	0.7	30.7	23.7	57.1	60.9	63.7	91.9	72.2	41.5	33.4	40.4	9.7	0.012	0.42
11:15	9.21	844.37	1.0	28.9	24.1	66.8	58.6	72.2	95.7	75.5	46.6	42.7	45.5	16.6	0.020	0.53
11:30	9.48	869.40	2.7	30.5	25.4	69.2	61.5	78.9	96.4	78.9	48.4	43.8	47.3	16.8	0.019	0.53
11:45	9.59	879.21	2.2	30.5	25.9	70.2	60.6	81.5	108.1	83.4	52.9	44.3	48.1	17.6	0.020	0.53
12:00	9.68	887.37	0.6	29.8	26.9	73.8	63.9	86.4	112.0	87.4	57.6	46.9	50.4	20.6	0.023	0.55
12:15	9.66	885.45	0.5	32.2	25.8	75.5	65.2	88.2	121.6	91.7	59.5	49.7	50.7	18.5	0.021	0.59
12:30	9.72	891.50	0.2	32.4	26.1	78.6	67.2	89.3	134.2	96.9	64.5	52.5	52.4	20.0	0.022	0.62
12:45	9.65	884.62	1.1	33.8	26.5	77.8	66.8	87.8	140.7	98.4	64.6	51.3	52.2	18.4	0.021	0.61
13:00	9.63	882.60	1.1	34.1	26.7	79.3	67.9	89.3	142.3	99.8	65.7	52.6	53.0	18.9	0.021	0.62
13:15	9.47	868.21	1.0	33.7	27.8	79.4	67.5	88.3	147.5	101.1	67.4	51.6	53.6	19.9	0.023	0.62
13:30	9.12	836.21	1.2	33.8	29.1	78.9	66.5	87.5	144.6	99.5	65.7	49.8	54.0	20.2	0.024	0.62
13:45	9.05	829.52	1.4	33.1	28.9	79.1	67.2	87.9	145.6	100.2	67.1	50.2	54.0	20.9	0.025	0.63
14:00	8.76	802.93	0.7	33.0	30.6	76.9	65.4	86.2	142.3	98.0	65.0	46.3	53.8	20.8	0.026	0.60
14:15	8.34	764.24	0.6	32.8	30.5	75.1	62.9	82.3	139.1	94.8	62.0	44.6	52.8	20.0	0.026	0.61
14:30	7.88	722.71	1.6	34.8	31.4	73.6	61.9	79.6	135.7	92.4	57.6	42.2	52.5	17.7	0.024	0.61
14:45	7.54	691.18	1.4	33.6	31.1	71.5	61.2	74.8	134.2	90.1	56.5	40.4	51.3	17.7	0.026	0.61
15:00	6.94	636.17	1.2	33.9	31.3	66.3	58.5	68.3	119.3	82.0	48.1	35.0	48.8	14.9	0.023	0.58
15:15	6.53	598.49	0.3	35.0	31.2	63.5	56.8	65.8	108.4	77.0	42.0	32.3	47.4	12.4	0.021	0.57
15:30	6.17	566.03	0.6	34.1	31.7	63.0	58.7	65.3	106.9	77.0	42.9	31.3	47.4	13.3	0.023	0.58
15:45	5.37	491.86	1.6	34.6	33.1	60.6	58.4	64.1	101.3	74.6	40.0	27.5	46.9	12.3	0.025	0.59
16:00	5.01	459.13	1.3	34.5	33.7	59.3	57.2	61.2	98.6	72.3	37.8	25.6	46.5	12.0	0.026	0.58
16:15	4.88	447.22	0.4	33.9	33.7	58.1	53.2	58.5	92.3	68.0	34.1	24.4	45.9	12.0	0.027	0.57
16:30	4.60	421.91	1.0	34.3	34.1	55.9	52.9	56.2	83.9	64.3	30.0	21.8	45.0	10.7	0.025	0.54
16:45	4.12	377.81	2.2	34.3	34.5	52.3	50.6	54.5	77.2	60.8	26.5	17.8	43.4	9.1	0.024	0.49
17:00	3.68	337.75	1.1	34.0	35.2	48.2	47.9	49.3	66.9	54.7	20.7	13.0	41.7	7.7	0.023	0.40
Average		699.96	1.1	32.0	27.7	63.5	57.6	70.2	105.6	77.8	45.8	35.8	45.6	13.6	0.019	0.53
Std. Deviation		171.66	0.59	2.4	4.5	12.3	8.0	14.2	27.9	16.3	15.2	11.8	7.1	5.6	0.033	0.09

Time (Hrs)	Solar rad. (mV)	Solar rad. (W/m ²)	Wind vel. v (m/s)	T _a (°C)	T _i (°C)	T _o (°C)	T _{p1} (°C)	T _{p2} (°C)	T _{p3} (°C)	T _{p.av} (°C)	(T _{p.av} -T _a) (°C)	(T _o -T _i) (°C)	T _m (°C)	(T _m -T _a) (°C)	(T _m -T _a)/I (m ² C/W)	Th _{eff}
9:00	5.75	526.88	0.9	27.1	21.6	37.7	29.6	39.2	49.7	39.5	12.4	16.1	29.7	2.6	0.005	0.32
9:15	5.85	536.24	1.3	26.5	22.3	40.9	34.5	42.4	50.2	42.4	15.9	18.6	31.6	5.1	0.010	0.36
9:30	7.48	685.40	0.8	27.2	23.1	45.4	37.8	46.1	63.6	49.2	22.0	22.3	34.3	7.1	0.010	0.34
9:45	6.89	631.97	1.6	26.8	22.8	46.5	40.4	54.1	66.4	53.6	26.8	23.7	34.7	7.9	0.012	0.39
10:00	7.89	723.36	1.5	26.3	22.9	49.7	41.6	62.1	79.2	61.0	34.7	26.8	36.3	10.0	0.014	0.39
10:15	8.99	823.74	2.2	28.4	24.8	51.2	42.1	69.1	84.7	65.3	36.9	26.4	38.0	9.6	0.012	0.34
10:30	9.35	857.12	0.8	28.8	25.9	56.9	45.6	70.2	86.5	67.4	38.6	31.0	41.4	12.6	0.015	0.38
10:45	9.44	865.64	0.6	27.4	26.2	61.5	51.2	77.4	96.6	75.1	47.7	35.3	43.9	16.5	0.019	0.43
11:00	9.15	838.51	2.2	27.7	26.9	64.3	53.2	79.6	104.5	79.1	51.4	37.4	45.6	17.9	0.021	0.47
11:15	9.55	875.64	0.8	27.7	27.1	67.4	54.1	81.8	107.2	81.0	53.3	40.3	47.3	19.6	0.022	0.48
11:30	9.59	879.39	1.7	29.2	27.6	71.2	54.8	85.9	108.6	83.1	53.9	43.6	49.4	20.2	0.023	0.52
11:45	8.17	749.39	1.2	28.6	26.9	73.6	56.4	90.1	117.1	87.9	59.3	46.7	50.3	21.7	0.029	0.65
12:00	9.97	913.96	1.3	28.1	27.5	75.1	60.2	88.6	118.7	89.2	61.1	47.6	51.3	23.2	0.025	0.55
12:15	10.00	917.17	1.7	30.0	27.3	71.3	68.4	71.2	112.6	84.1	54.1	44.0	49.3	19.3	0.021	0.50
12:30	9.97	913.87	1.7	30.2	28.4	72.9	63.9	77.3	118.3	86.5	56.3	44.5	50.7	20.5	0.022	0.51
12:45	9.98	915.24	1.4	29.4	28.1	72.5	70.5	88.5	124.8	94.6	65.2	44.4	50.3	20.9	0.023	0.51
13:00	9.74	893.24	1.2	29.7	29.1	70.5	62.4	69.5	112.9	81.6	51.9	41.4	49.8	20.1	0.023	0.49
13:15	9.43	864.27	0.5	31.7	30.1	68.6	52.5	63.2	110.2	75.3	43.6	38.5	49.4	17.7	0.020	0.47
13:30	9.32	854.00	1.1	29.7	30.9	67.5	52.3	60.1	111.3	74.6	44.9	36.6	49.2	19.5	0.023	0.45
13:45	8.98	823.56	1.4	32.5	31.4	68.6	51.9	60.4	110.3	74.2	41.7	37.2	50.0	17.5	0.021	0.47
14:00	8.71	798.72	1.0	32.8	31.9	65.4	52.9	62.4	109.6	75.0	42.2	33.5	48.7	15.9	0.020	0.44
14:15	8.34	764.34	0.5	33.2	32.1	62.8	53.6	61.8	106.4	73.9	40.7	30.7	47.5	14.3	0.019	0.42
14:30	8.04	737.47	1.8	33.5	32.3	58.6	52.4	59.1	103.2	71.6	38.1	26.3	45.5	12.0	0.016	0.37
14:45	7.60	697.13	0.5	33.7	32.2	56.1	49.8	58.3	102.4	70.2	36.5	23.9	44.2	10.5	0.015	0.36
15:00	7.13	653.31	1.6	34.0	32.8	54.8	48.4	57.5	99.8	68.6	34.6	22.0	43.8	9.8	0.015	0.35
15:15	6.95	637.27	1.1	33.9	32.6	53.4	46.5	55.2	100.1	67.3	33.4	20.8	43.0	9.1	0.014	0.34
15:30	7.04	645.43	1.3	33.9	32.9	53.2	46.0	54.8	97.2	66.0	32.1	20.3	43.1	9.2	0.014	0.33
15:45	5.93	543.75	1.5	33.5	33.0	51.3	41.9	51.7	79.9	57.8	24.3	18.3	42.2	8.7	0.016	0.35
16:00	5.16	473.25	0.7	33.9	33.2	50.3	42.9	52.8	79.4	58.4	24.5	17.1	41.8	7.9	0.017	0.38
16:15	5.10	467.29	1.2	33.6	33.6	49.9	43.6	51.2	78.5	57.8	24.2	16.3	41.8	8.2	0.017	0.37
16:30	4.13	378.18	0.4	33.2	34.0	46.2	42.6	49.5	70.2	54.1	20.9	12.2	40.1	6.9	0.018	0.34
16:45	3.47	318.22	0.8	33.6	34.1	44.8	40.8	47.2	68.3	52.1	18.5	10.7	39.5	5.9	0.018	0.35
17:00	2.86	261.93	1.6	33.5	34.2	42.1	39.4	45.6	62.9	49.3	15.8	7.9	38.2	4.7	0.018	0.32
Average		711.06	1.2	30.6	29.1	58.2	49.2	63.1	93.7	68.7	38.1	29.2	43.7	13.1	0.018	0.45
Std. Deviation		184.91	0.5	2.8	3.9	11.1	9.4	14.2	21.0	14.0	14.5	11.6	6.0	6.0	0.032	0.08

Date: 10 - 10 - 04 Test No. 8 Flow-rate: 30 ± 3l/hr

Time (Hrs)	Solar rad. (mV)	Solar rad. (W/m ²)	Wind vel. v (m/s)	T _a (°C)	T _i (°C)	T _o (°C)	T _{p1} (°C)	T _{p2} (°C)	T _{p3} (°C)	T _{p.av} (°C)	(T _{p.av} -T _a) (°C)	(T _o -T _i) (°C)	T _m (°C)	(T _m -T _a) (°C)	(T _m -T _a)/I (m ² °C/W)	Th _{eff}
9:00	5.66	519.09	0.8	26.4	21.3	38.8	34.3	41.2	53.8	43.1	16.7	17.5	30.1	3.7	0.007	0.35
9:15	6.33	580.06	0.6	26.2	21.5	41.9	39.5	46.9	60.3	48.9	22.7	20.4	31.7	5.5	0.009	0.37
9:30	6.89	631.49	0.3	27.4	22.3	44.8	42.1	47.5	70.1	53.2	25.8	22.5	33.6	6.2	0.010	0.37
9:45	7.32	670.91	0.5	28.9	22.8	46.2	43.3	48.2	68.6	53.4	24.5	23.4	34.5	5.6	0.008	0.37
10:00	7.88	722.71	0.7	26.9	22.7	48.5	44.9	51.1	75.1	57.0	30.1	25.8	35.6	8.7	0.012	0.37
10:15	8.30	761.22	0.5	28.2	23.4	50.5	46.5	54.3	78.5	59.8	31.6	27.1	37.0	8.8	0.011	0.37
10:30	8.67	794.87	0.7	28.0	23.6	54.7	49.7	58.8	82.3	63.6	35.6	31.1	39.2	11.2	0.014	0.41
10:45	9.06	830.71	0.5	28.4	23.6	58.2	53.3	60.4	87.3	67.0	38.6	34.6	40.9	12.5	0.015	0.44
11:00	9.00	825.21	0.3	29.5	23.5	60.2	54.8	62.3	89.7	68.9	39.4	36.7	41.9	12.4	0.015	0.47
11:15	9.28	850.42	0.9	29.7	24.4	62.4	57.9	65.4	91.3	71.5	41.8	38.0	43.4	13.7	0.016	0.47
11:30	9.40	862.16	0.6	32.0	23.8	63.3	56.6	64.1	89.2	70.0	38.0	39.5	43.6	11.6	0.013	0.48
11:45	9.53	873.71	1.5	29.5	24.8	67.1	63.2	73.1	95.0	77.1	47.6	42.3	46.0	16.5	0.019	0.51
12:00	9.83	900.94	0.7	30.3	25.7	68.8	63.6	71.7	98.2	77.8	47.5	43.1	47.3	17.0	0.019	0.50
12:15	9.72	891.50	1.2	31.3	26.7	69.5	65.3	73.4	101.7	80.1	48.8	42.8	48.1	16.8	0.019	0.50
12:30	9.71	890.40	0.5	30.4	26.4	70.1	66.8	76.2	110.3	84.4	54.0	43.7	48.3	17.9	0.020	0.51
12:45	9.68	887.37	0.6	30.6	26.9	70.6	66.9	80.4	113.6	87.0	56.4	43.7	48.8	18.2	0.020	0.52
13:00	9.69	888.29	0.6	31.6	27.5	70.9	62.4	72.1	115.5	83.3	51.7	43.4	49.2	17.6	0.020	0.51
13:15	9.40	861.61	1.6	31.5	27.1	71.5	65.4	76.9	121.3	87.9	56.4	44.4	49.3	17.8	0.021	0.54
13:30	9.38	859.87	1.7	30.8	26.9	70.2	64.6	74.8	119.6	86.3	55.5	43.3	48.6	17.8	0.021	0.53
13:45	9.13	836.95	0.4	32.4	28.4	70.5	66.2	78.2	119.8	88.1	55.7	42.1	49.5	17.1	0.020	0.53
14:00	9.25	847.95	2.1	32.4	28.2	68.9	63.6	72.5	117.1	84.4	52.0	40.7	48.6	16.2	0.019	0.50
14:15	8.79	805.96	0.6	31.5	29.5	66.3	62.2	68.9	101.3	77.5	46.0	36.8	47.9	16.4	0.020	0.48
14:30	8.23	754.43	1.7	32.8	29.6	63.3	56.8	64.4	102.3	74.5	41.7	33.7	46.5	13.7	0.018	0.47
14:45	7.67	702.73	1.5	34.0	29.8	63.8	58.6	67.2	104.3	76.7	42.7	34.0	46.8	12.8	0.018	0.51
15:00	7.27	666.42	1.6	34.1	29.8	61.8	51.7	62.5	98.4	70.9	36.8	32.0	45.8	11.7	0.018	0.50
15:15	6.12	561.45	0.5	33.4	31.5	58.7	51.6	58.9	88.7	66.4	33.0	27.2	45.1	11.7	0.021	0.51
15:30	6.25	573.37	1.0	33.4	30.9	56.1	55.2	61.5	87.8	68.2	34.8	25.2	43.5	10.1	0.018	0.46
15:45	5.67	519.83	1.4	34.6	29.5	54.1	54.9	62.1	91.2	69.4	34.8	24.6	41.8	7.2	0.014	0.50
16:00	5.28	483.80	0.7	33.8	30.7	53.7	54.3	59.5	91.1	68.3	34.5	23.0	42.2	8.4	0.017	0.50
16:15	4.99	457.30	2.4	34.5	30.5	50.8	53.1	58.5	89.4	67.0	32.5	20.3	40.7	6.2	0.013	0.46
16:30	4.96	454.73	0.9	33.6	32.1	48.6	52.5	55.6	83.5	63.9	30.3	16.5	40.4	6.8	0.015	0.38
16:45	4.52	414.03	0.8	33.3	33.1	46.1	50.7	52.9	75.1	59.6	26.3	13.0	39.6	6.3	0.015	0.33
17:00	4.16	381.48	1.7	33.3	33.3	45.8	45.8	47.2	65.7	52.9	19.6	12.5	39.6	6.3	0.016	0.34
Average		714.03	1.0	31.1	27.0	58.7	55.1	62.7	92.0	69.9	38.9	31.7	42.9	11.8	0.016	0.46
Std. Deviation		163.25	0.55	2.5	3.5	9.8	8.5	10.2	17.5	11.9	9.4	9.9	5.4	4.5446	0.004	0.06

Time of day	Solar rad. (mV)	Solar rad. (W/m ²)	Amb. Temp. Ta (°C)	Inlet Temp. Ti (°C)	Av. abs.plate temp. T _{pav} (°C)	Av. discharge Temp. (°C)	Wind vel. v (m/s)	No. of valve discharge/15min.	Pasteurised water discharged/15min.(litres)	Cumulative vol. Of discharged water (litres)
9:00	4.771	437.41	21.2	14.1	29.7	—	2.9	0	0.00	0.00
9:15	5.584	511.94	21.7	14.3	35.1	—	3.6	0	0.00	0.00
9:30	6.158	564.57	22	15.1	39.7	—	1.3	0	0.00	0.00
9:45	6.855	628.47	22.6	14.7	43.8	—	0.3	0	0.00	0.00
10:00	6.988	640.66	22.6	16.1	49.2	—	4.1	0	0.00	0.00
10:15	7.0136	643.01	23.4	16.3	55.6	—	4.4	0	0.00	0.00
10:30	7.515	688.98	24.7	15.9	62.1	—	4.9	0	0.00	0.00
10:45	7.75	710.52	25.5	18.2	69.9	—	1.9	0	0.00	0.00
11:00	8.01	734.36	26.1	18.1	75.8	—	5.2	0	0.00	0.00
11:15	8.338	764.43	27	18.4	81.2	86.1	0.6	1	5.60	5.60
11:30	8.729	800.27	26.8	21.1	79.6	—	1.1	0	0.00	5.60
11:45	9.088	833.19	27.4	21.6	83.1	85.5	3.4	1	5.10	10.70
12:00	9.678	887.28	28.7	22.5	77.4	—	1.4	0	0.00	10.70
12:15	9.709	890.12	28.3	22.9	82.4	84.9	3.5	1	4.80	15.50
12:30	9.846	902.68	29	22.9	72.9	—	1.5	0	0.00	15.50
12:45	7.777	713.00	29.3	24.6	79.9	84.8	1.3	1	4.65	20.15
13:00	9.316	854.09	30.4	25.6	73.6	—	1.0	0	0.00	20.15
13:15	8.54	782.95	30.2	25.9	83.7	84.7	1.1	1	4.50	24.65
13:30	9.631	882.97	31.4	26.9	80.8	83.9	0.5	1	3.90	28.55
13:45	9.309	853.45	30.8	27.2	84.2	83.4	1.9	1	3.70	32.25
14:00	9.323	854.73	31.8	27.5	76.1	82.9	1.1	1	3.70	35.95
14:15	8.546	783.50	31.6	27.8	80.2	82.7	0.6	1	3.60	39.55
14:30	9.508	871.69	32.1	28.4	74.9	82.9	1.4	1	3.70	43.25
14:45	8.908	816.69	32.8	29.6	81.1	82.9	1.5	1	3.60	46.85
15:00	7.623	698.88	32.6	32.8	83.5	—	2.2	0	0.00	46.85
15:15	7.838	718.59	32.8	31.7	79.5	83.1	2.7	1	2.80	49.65
15:30	7.469	684.76	32.6	31.8	82.2	82.6	2.2	1	2.70	52.35
15:45	6.982	640.11	32.1	30.9	77.8	82.7	1.4	1	2.70	55.05
16:00	6.549	600.41	33.4	33.7	82.3	—	3.0	0	0.00	55.05
16:15	5.923	543.02	32.9	33.1	78.6	83.1	1.5	1	2.80	57.85
16:30	5.498	504.06	32.7	33.7	84.4	—	2.4	0	0.00	57.85
16:45	4.906	449.78	33.2	34.1	75.8	82.5	2.8	1	2.85	60.70
17:00	4.497	412.28	33.2	33.9	79.6	—	1.8	0	0.00	60.70
Sum								16	60.70	
Average		706.15	28.9	24.6	72.0	83.7	2.1			
Std. Deviation		141.77	3.9	6.7	15.2	0.4	1.3			

Time of day (Hrs)	Solar rad. (mV)	Solar rad. (W/m ²)	Amb. Temp. Ta (oC)	Inlet Temp. Ti (oC)	Av. Abs. Plate temp. Tpav. (oC)	Av. discharge Temp. (oC)	Wind vel. (m/s)	No. of valve discharge/15min.	Pasteurised water discharged/15min.(litres)	Cumulative vol. Of discharged water (litres)
9:00	5.48	502.22	20.4	19.3	28.9	—	1.10	0	0.00	0.00
9:15	6.22	570.07	21.6	20.1	34.7	—	1.63	0	0.00	0.00
9:30	6.78	621.77	21.9	21.1	41.6	—	2.61	0	0.00	0.00
9:45	7.05	646.16	22.4	20.5	46.9	—	1.60	0	0.00	0.00
10:00	6.45	590.88	22.3	21.2	51.4	—	5.63	0	0.00	0.00
10:15	7.10	650.74	23.8	22.1	56.4	—	3.55	0	0.00	0.00
10:30	7.49	686.41	22.5	21.6	62.6	—	0.95	0	0.00	0.00
10:45	7.78	713.36	23.0	22.7	69.1	—	2.13	0	0.00	0.00
11:00	8.05	738.39	23.8	22.9	73.4	—	1.97	0	0.00	0.00
11:15	8.53	781.76	24.2	22.8	76.8	—	1.20	0	0.00	0.00
11:30	8.61	789.36	24.8	21.9	79.7	86.1	2.92	1	5.80	5.80
11:45	8.76	803.03	25.1	22.6	83.5	—	1.40	0	0.00	5.80
12:00	8.96	821.73	26.1	23.4	84.0	85.3	1.60	1	5.10	10.90
12:15	9.36	857.67	27.2	23.1	86.4	—	1.70	0	0.00	10.90
12:30	9.54	874.63	28.9	23.6	83.1	84.4	1.20	1	4.70	15.60
12:45	9.04	828.79	28.1	23.9	84.1	83.6	1.10	1	4.40	20.00
13:00	9.53	873.44	28.3	24.1	79.6	83.3	1.54	1	4.20	24.20
13:15	9.45	866.10	28.7	25.3	73.4	82.7	0.89	1	4.15	28.35
13:30	9.62	881.96	29.4	25.9	76.8	82.9	2.05	1	4.40	32.75
13:45	9.39	860.97	30.4	26.8	82.4	82.7	2.99	1	3.70	36.45
14:00	8.90	815.86	30.4	26.3	84.6	82.6	2.10	1	3.90	40.35
14:15	8.67	795.23	30.1	26.2	77.6	—	1.40	0	0.00	40.35
14:30	8.39	769.38	30.9	26.7	81.3	83.1	1.60	2	5.55	45.90
14:45	7.91	724.91	31.3	27.2	78.7	82.6	2.10	1	2.60	48.50
15:00	7.69	704.74	32.1	27.3	80.5	82.7	1.10	1	2.90	51.40
15:15	7.29	668.16	32.5	27.8	83.8	82.2	2.56	2	5.20	56.60
15:30	7.01	642.86	32.4	28.5	78.9	82.4	0.90	1	2.70	59.30
15:45	6.78	621.96	33.1	28.9	83.7	82.6	3.07	1	2.55	61.85
16:00	6.07	556.86	32.9	29.9	77.1	—	1.95	0	0.00	61.85
16:15	5.75	527.25	33.4	30.6	82.1	83.5	2.66	1	2.90	64.75
16:30	5.13	470.50	33.3	30.8	79.8	—	2.08	0	0.00	64.75
16:45	4.85	444.83	34.1	31.4	83.7	83.8	3.01	1	2.80	67.55
17:00	4.39	402.66	33.8	31.9	74.1	—	1.98	0	0.00	67.55
Sum								19	67.55	
Average		700.14	28.0	25.1	72.7	83.3	2.0			
Std. Deviation		137.47	4.3	3.5	15.7	1.1	1.0			

Time of day	Solar rad. (mV)	Solar rad. (W/m ²)	Amb. Temp (°C)	Inlet Temp. (°C)	Av. abs. plate temp. T _{pav.} (°C)	Av. discharge Temp. (°C)	Wind vel. v (m/s)	No. of valve discharge/15min.	Pasteurised water discharged/15min.(litres)	Cumulative vol. of discharged water (litres)
9:00	5.69	521.57	19.6	16.3	30.2	—	1.4	0	0.00	0.00
9:15	6.25	573.37	20.7	17.9	35.7	—	1.6	0	0.00	0.00
9:30	6.80	622.97	21.4	17.7	40.4	—	1.4	0	0.00	0.00
9:45	7.19	659.45	22.5	18.4	46.8	—	2.2	0	0.00	0.00
10:00	7.58	695.30	22.7	19.6	50.5	—	1.7	0	0.00	0.00
10:15	7.38	676.97	22.9	19.8	55.8	—	1.8	0	0.00	0.00
10:30	7.90	724.64	23.2	20.1	62.7	—	0.7	0	0.00	0.00
10:45	8.01	734.17	23.6	20.1	68.8	—	0.9	0	0.00	0.00
11:00	8.07	739.86	23.7	21.2	74.6	86.2	0.8	1	5.90	5.90
11:15	8.52	780.75	24.0	20.9	77.5	—	0.8	0	0.00	5.90
11:30	8.78	804.49	24.6	21.4	81.2	85.4	0.8	1	5.10	11.00
11:45	8.87	813.29	24.3	22.2	83.4	—	1.7	0	0.00	11.00
12:00	9.06	830.25	24.7	21.8	81.9	85.5	1.8	1	4.70	15.70
12:15	9.11	834.84	25.6	22.8	83.6	—	2.0	0	0.00	15.70
12:30	9.13	837.41	25.9	23.2	84.9	84.7	0.1	1	4.30	20.00
12:45	9.26	848.96	26.6	24.0	81.2	—	0.5	0	0.00	20.00
13:00	9.10	834.20	27.6	25.4	86.1	84.7	1.6	1	4.20	24.20
13:15	8.33	763.88	29.1	26.7	80.9	83.5	2.2	1	3.80	28.00
13:30	8.98	823.65	30.4	26.9	79.9	83.4	1.7	1	3.60	31.60
13:45	8.87	813.57	30.5	27.5	72.7	—	3.4	0	0.00	31.60
14:00	8.59	787.71	30.4	27.3	78.6	83.5	0.5	2	5.90	37.50
14:15	8.87	812.74	31.6	28.4	83.5	—	0.7	0	0.00	37.50
14:30	8.50	779.65	31.7	28.2	84.1	83.2	0.4	2	5.80	43.30
14:45	8.21	752.97	31.2	29.4	77.4	84.6	4.8	1	2.80	46.10
15:00	7.68	703.92	32.8	29.5	81.2	83.5	2.5	1	2.80	48.90
15:15	7.13	653.22	32.2	30.8	78.3	82.8	1.2	1	2.70	51.60
15:30	6.69	613.25	32.8	31.2	82.9	83.5	2.6	1	2.55	54.15
15:45	5.90	540.64	33.8	30.8	73.8	—	0.5	0	0.00	54.15
16:00	5.36	491.22	33.6	31.4	79.6	83.5	1.5	1	2.80	56.95
16:15	5.22	478.48	33.6	32.1	82.1	—	4.8	0	0.00	56.95
16:30	4.86	445.29	33.2	33.1	75.3	83.1	3.8	1	2.90	59.85
16:45	4.60	421.54	33.8	32.8	80.6	—	2.9	0	0.00	59.85
17:00	4.38	401.38	33.1	33.2	74.7	83.0	3.5	1	2.70	62.55
Sum								18	62.55	
Average		691.38	27.8	25.2	72.5	84.0	1.8			
Std. Deviation		135.13	4.5	5.1	15.0	1.0	1.2			

Time of day (Hrs)	Solar rad. (mV)	Solar rad. (W/m ²)	Amb. Temp. T _a (°C)	Inlet Temp. T _i (°C)	Av. abs. plate Temp. T _{pav} (°C)	Av. discharge Temp. (°C)	Wind vel. (m/s)	No. of valve discharge/15min.	Pasteurised water scharged/15min. (litre)	Cumulative vol. Of discharged water (litres)
9:00	4.547	416.87	19.7	16.8	27.5	—	0.8	0	0.0	0.0
9:15	4.841	443.82	20.3	17.2	32.8	—	0.6	0	0.0	0.0
9:30	5.389	494.06	20.2	17.9	40.2	—	0.5	0	0.0	0.0
9:45	5.785	530.37	21.4	19.2	43.5	—	0.7	0	0.0	0.0
10:00	6.499	595.83	20.9	19.8	49.4	—	0.5	0	0.0	0.0
10:15	6.809	624.25	21.8	20.1	54.9	—	0.1	0	0.0	0.0
10:30	7.254	665.05	22.5	20.6	60.3	—	0.3	0	0.0	0.0
10:45	7.58	694.93	23.5	21.4	65.4	—	0.9	0	0.0	0.0
11:00	7.906	724.82	24.6	22.4	71.9	—	0.6	0	0.0	0.0
11:15	8.245	755.90	26.5	23.5	75.7	—	0.5	0	0.0	0.0
11:30	8.502	779.46	26.0	22.9	79.7	—	0.3	0	0.0	0.0
11:45	8.713	798.81	27.4	24.2	71.9	85.7	0.6	1	6.0	6.0
12:00	8.98	823.29	28.1	25.0	77.7	—	0.3	0	0.0	6.0
12:15	9.089	833.28	28.6	25.6	82.1	—	0.7	0	0.0	6.0
12:30	9.185	842.08	28.4	25.9	74.2	84.2	0.6	1	5.5	11.5
12:45	9.32	854.46	28.7	27.1	79.9	—	1.6	0	0.0	11.5
13:00	9.284	851.16	29.9	26.8	77.9	83.8	0.2	1	4.4	15.9
13:15	9.281	850.88	31.0	27.8	83.1	—	2.1	0	0.0	15.9
13:30	8.985	823.74	30.8	29.1	81.5	—	2.7	0	0.0	15.9
13:45	9.033	828.15	32.4	29.3	74.5	83.9	2.3	1	4.7	20.6
14:00	8.751	802.29	31.9	28.9	80.1	—	1.7	0	0.0	20.6
14:15	8.918	817.60	31.1	29.9	79.8	83.5	1.1	1	4.5	25.1
14:30	8.659	793.86	32.5	30.1	83.4	—	1.5	0	0.0	25.1
14:45	8.497	779.00	32.2	30.4	82.1	84.5	0.8	1	4.2	29.3
15:00	7.766	711.99	32.2	30.9	74.6	—	2.4	0	0.0	29.3
15:15	7.184	658.63	31.9	30.9	77.8	82.8	0.9	1	3.8	33.1
15:30	6.763	620.03	32.9	31.5	79.9	—	0.9	0	0.0	33.1
15:45	6.284	576.12	32.7	32.6	83.1	83.5	0.4	1	3.6	36.7
16:00	5.845	535.87	33.1	32.4	69.7	—	0.9	0	0.0	36.7
16:15	5.125	469.86	32.7	32.9	78.9	83.0	1.5	1	3.8	40.5
16:30	4.845	444.19	32.8	33.0	70.4	—	1.8	0	0.0	40.5
16:45	4.478	410.54	33.1	32.8	72.9	—	1.2	0	0.0	40.5
17:00	4.149	380.38	32.9	33.5	79.5	82.5	1.0	1	3.8	44.3
Sum								10	44.3	
Average		673.68	28.3	26.4	70.2	83.7	1.0			
Std. Deviation		153.78	4.6	5.1	15.0	0.9	0.7			

Time of day (Hrs)	Solar rad. (mV)	Solar rad. (W/m ²)	Amb. Temp. T _a (°C)	Inlet Temp. T _i (°C)	Av. Abs. Plate temp. T _{pav.} (°C)	Av. discharge Temp. (°C)	Wind vel. (m/s)	No. of valve discharge/15min.	Pasteurised water discharged/15min.(litres)	Cumulative vol. of discharged water (litres)
9:00	4.38	401.56	19.6	15.9	29.6	—	1.8	0	0.0	0.0
9:15	4.82	442.17	20.6	16.6	34.1	—	1.4	0	0.0	0.0
9:30	5.38	493.51	21.6	16.8	38.2	—	0.7	0	0.0	0.0
9:45	5.83	534.22	21.9	17.7	43.8	—	0.2	0	0.0	0.0
10:00	6.25	572.91	22.8	19.2	47.4	—	0.4	0	0.0	0.0
10:15	6.80	623.61	22.9	19.7	52.5	—	1.7	0	0.0	0.0
10:30	7.04	645.52	24.0	20.3	55.5	—	0.5	0	0.0	0.0
10:45	7.44	681.73	24.3	20.9	59.8	—	1.0	0	0.0	0.0
11:00	7.80	714.74	25.6	22.4	65.4	—	0.6	0	0.0	0.0
11:15	8.15	747.56	25.4	23.4	71.5	—	0.3	0	0.0	0.0
11:30	8.48	777.08	27.5	25.5	76.1	—	1.2	0	0.0	0.0
11:45	8.80	807.15	27.4	25.8	79.9	85.5	0.2	1	6.2	6.2
12:00	8.98	822.83	28.7	26.4	84.6	—	0.5	0	0.0	6.2
12:15	9.32	854.46	29.3	27.1	85.2	—	2.5	0	0.0	6.2
12:30	9.45	866.19	30.8	28.4	71.9	84.7	1.9	1	5.3	11.5
12:45	9.76	894.52	30.1	28.7	77.7	—	0.1	0	0.0	11.5
13:00	10.83	993.26	31.4	29.3	73.5	84.3	0.6	1	4.6	16.1
13:15	9.98	914.78	31.9	29.7	79.9	—	1.3	0	0.0	16.1
13:30	9.16	839.97	31.0	29.7	72.2	84.5	1.0	1	3.8	19.9
13:45	8.91	816.50	32.0	30.6	74.2	—	0.7	0	0.0	19.9
14:00	8.72	799.08	31.7	31.2	81.4	—	1.4	0	0.0	19.9
14:15	8.47	776.90	32.3	31.2	86.1	83.5	1.6	1	4.2	24.1
14:30	8.00	733.07	32.2	32.1	85.3	—	0.6	0	0.0	24.1
14:45	7.65	701.44	32.1	32.0	76.3	83.1	0.1	1	3.7	27.8
15:00	7.29	668.16	32.8	31.7	77.8	—	0.6	0	0.0	27.8
15:15	6.85	627.73	32.8	32.1	70.2	—	0.5	0	0.0	27.8
15:30	6.54	599.86	32.8	32.7	79.8	83.3	0.4	1	4.1	31.9
15:45	6.10	558.79	33.0	32.9	82.9	—	0.5	0	0.0	31.9
16:00	5.58	511.67	32.9	33.0	83.7	82.5	0.3	1	3.7	35.6
16:15	5.08	466.01	33.9	32.9	82.2	—	2.0	0	0.0	35.6
16:30	4.75	435.66	33.9	32.7	80.8	82.8	1.0	1	3.2	38.8
16:45	4.42	405.32	33.7	33.4	73.2	—	2.6	0	0.0	38.8
17:00	4.20	384.87	32.9	33.2	79.4	82.7	2.1	1	2.9	41.7
Sum								10	41.7	
Average		670.09	29.0	27.1	70.1	83.7	1.0			
Std deviation		166.09	4.4	5.7	15.7	1.0	0.5			

Time of day (Hrs)	Solar rad. (mV)	Solar rad. (W/m ²)	Amb. Temp. T _a (°C)	Inlet Temp. T _i (°C)	Average plate temp T _{pav} (°C)	Average discharge Temp. (°C)	Wind vel. (m/s)	No. of valve discharge/15min.	Pasteurised water discharged/15min. (litres)	Cumulative vol. Of discharged water (litres)
9:00	4.322	396.24	20.1	18.4	28.5	-	1.3	0.0	0.0	0.0
9:15	4.913	450.42	20.7	19.1	32.7	-	0.5	0.0	0.0	0.0
9:30	5.361	491.50	21.6	20.2	35.6	-	1.4	0.0	0.0	0.0
9:45	5.804	532.11	21.4	20.2	42.5	-	1.4	0.0	0.0	0.0
10:00	6.412	587.85	22.4	21.1	47.5	-	2.1	0.0	0.0	0.0
10:15	6.854	628.37	23.5	22.1	51.4	-	0.8	0.0	0.0	0.0
10:30	7.386	677.15	23.7	21.8	55.8	-	2.2	0.0	0.0	0.0
10:45	7.521	689.53	25.3	23.2	61.2	-	1.6	0.0	0.0	0.0
11:00	8.188	750.68	25.4	22.9	67.7	-	1.4	0.0	0.0	0.0
11:15	8.531	782.12	27	24.2	71.9	-	0.6	0.0	0.0	0.0
11:30	8.748	802.02	27.9	25.7	76.1	-	1.3	0.0	0.0	0.0
11:45	8.916	817.42	28	24.9	79.2	85.5	1.1	1.0	6.4	6.4
12:00	9.086	833.00	28.9	25.7	65.7	-	1.4	0.0	0.0	6.4
12:15	9.311	853.63	28.1	25.9	75.3	-	1.0	0.0	0.0	6.4
12:30	9.505	871.42	30	26.8	81.1	84.2	0.6	1.0	5.4	11.8
12:45	9.354	857.57	29.9	27.2	76.6	-	1.7	0.0	0.0	11.8
13:00	9.247	847.76	30.4	26.9	75.7	84.1	1.5	1.0	4.2	16.0
13:15	9.337	856.02	29.7	27.4	79.8	-	1.9	0.0	0.0	16.0
13:30	9.124	836.49	31.4	27.8	70.8	83.5	0.7	1.0	3.8	19.8
13:45	8.898	815.77	31.4	27.9	80.8	-	0.9	0.0	0.0	19.8
14:00	8.674	795.23	32.1	28.5	85.5	-	1.0	0.0	0.0	19.8
14:15	8.546	783.50	33	27.9	86.9	83.6	3.3	1.0	4.2	24.0
14:30	8.232	754.71	31.9	28.5	76.1	-	3.9	0.0	0.0	24.0
14:45	7.883	722.71	32.9	28.9	79.7	83.3	1.1	1.0	3.6	27.6
15:00	7.549	692.09	32.9	29.9	83.3	-	0.6	0.0	0.0	27.6
15:15	7.106	651.48	32.9	30.7	78.1	-	0.8	0.0	0.0	27.6
15:30	6.853	628.28	32.7	30.8	83.5	83.0	0.7	1.0	4.1	31.7
15:45	6.43	589.50	33.1	29.9	78.2	-	1.6	0.0	0.0	31.7
16:00	5.941	544.67	32.8	31.1	82.9	-	1.1	0.0	0.0	31.7
16:15	5.495	503.78	33.4	31.4	80.4	82.8	2.3	1.0	3.9	35.6
16:30	4.915	450.61	33.2	32.4	69.6	-	1.3	0.0	0.0	35.6
16:45	4.556	417.69	33.3	33.8	76.4	-	1.4	0.0	0.0	35.6
17:00	3.986	365.44	33.2	33.8	75.8	83.5	0.7	1.0	3.8	39.4
Sum								9.0	39.4	
Average		675.05	28.9	26.6	69.5	83.7	1.4			
Std deviation		154.43	4.3	4.2	15.8	0.8	0.7			

Time of day (Hrs)	Solar rad. (mV)	Solar rad. (W/m ²)	Amb. Temp. T _a (°C)	Inlet Temp. T _i (°C)	Av. abs. plate temp T _{pav} . (°C)	Av. discharge Temp. (°C)	Wind vel. v (m/s)	No. of valve discharge/15min.	Pasteurised water scharged/15min.(litre)	Cumulative vol. Of discharged water (litres)
9:00	4.862	445.75	22.1	18.4	31.5	—	1.2	0	0	0
9:15	5.582	511.76	22.1	18.9	36.4	—	0.8	0	0	0
9:30	6.084	557.78	23	19.2	40.3	—	1.3	0	0	0
9:45	6.682	612.61	22.9	19.9	45.6	—	1.6	0	0	0
10:00	7.154	655.88	23.1	19.9	51.9	—	1.1	0	0	0
10:15	7.653	701.63	24.4	21.2	57.5	—	2.2	0	0	0
10:30	7.982	731.79	24.4	20.7	61.3	—	2.4	0	0	0
10:45	8.324	763.14	25.9	21.5	67.1	—	1	0	0	0
11:00	8.871	813.29	25.2	21.9	72.3	—	0.7	0	0	0
11:15	9.251	848.13	25.9	22.5	79.8	—	1.8	0	0	0
11:30	9.457	867.02	25.7	23.1	69.6	86.5	0.5	1	6.4	6.4
11:45	10.875	997.02	25.9	23.1	74.4	—	1.4	0	0	6.4
12:00	11.086	1016.36	26.9	24.7	79.9	—	1.6	0	0	6.4
12:15	10.987	1007.29	26.7	23.9	76.4	87	0.7	1	5.9	12.3
12:30	9.781	896.72	26.9	24.9	68.9	—	1.9	0	0	12.3
12:45	9.59	879.21	27.7	24.9	78.5	85.5	0.8	1	4.5	16.8
13:00	9.312	853.72	27.9	26.1	70.2	—	2.4	0	0	16.8
13:15	9.141	838.05	28.3	26.3	78.9	—	0.9	0	0	16.8
13:30	9.065	831.08	28.5	26.9	80.2	85	0.7	1	4.6	21.4
13:45	9.175	841.16	28.9	27.1	77.7	—	2.3	0	0	21.4
14:00	8.979	823.19	29.1	27.8	84.9	83.5	1.7	1	3.7	25.1
14:15	8.681	795.87	29.1	27.8	81.7	—	2.1	0	0	25.1
14:30	8.296	760.58	30.1	29.1	86.3	83	2.8	1	3.6	28.7
14:45	8.052	738.21	29.7	28.7	78.2	—	0.8	0	0	28.7
15:00	7.743	709.88	30.7	29.1	79.3	83	1.2	1	3.7	32.4
15:15	7.373	675.96	30.3	28.9	82.1	—	1.4	0	0	32.4
15:30	6.924	634.79	31.7	30.1	70.6	82.5	0.6	1	3.5	35.9
15:45	6.771	620.77	32.6	30.7	76.7	—	0.9	0	0	35.9
16:00	6.294	577.03	33.9	30.1	81.9	83	1.3	1	3.55	39.45
16:15	5.597	513.13	37.7	31.1	75.6	—	1.8	0	0	39.45
16:30	4.956	454.37	32.9	32.6	80.1	—	0.8	0	0	39.45
16:45	4.585	420.35	32.7	33.1	72.2	84.5	0.9	1	3.9	44.35
17:00	4.152	380.66	32.1	33.3	77.7	—	2.1	0	0	
Sum								10	43.35	
Average		720.43	28.0	25.7	70.5	83.2	1.4			
Std. deviation		169.53	3.7	4.3	14.1	0.6	0.6			

Time of day (Hrs)	Solar rad. (mV)	Solar rad. (W/m ²)	Amb. Temp T _a (°C)	Inlet Temp. T _i (°C)	Av. abs. plate temp. T _{pav} (°C)	Av. discharge Temp. (°C)	Wind vel. v (m/s)	No. of valve discharge/ 15min.	Pasteurised water discharged/ 15min.(litres)	Cumulative vol. of discharged water (litres)
9:00	4.00	366.54	19.2	15.9	30.5	--	2.5	0	0.00	0.00
9:15	4.78	437.86	20.4	16.4	33.9	--	0.8	0	0.00	0.00
9:30	5.86	536.97	20.7	16.9	39.9	--	2.5	0	0.00	0.00
9:45	6.01	551.23	22.6	18.9	44.8	--	2.4	0	0.00	0.00
10:00	5.91	541.46	22.9	19.5	49.6	--	0.6	0	0.00	0.00
10:15	6.70	614.07	24	20.2	56.8	--	2.4	0	0.00	0.00
10:30	7.42	680.45	25.5	22.1	60.8	--	3.0	0	0.00	0.00
10:45	7.86	720.24	25.4	22.8	67.4	--	3.6	0	0.00	0.00
11:00	8.26	757.37	25.3	22.9	72.8	--	2.7	0	0.00	0.00
11:15	8.31	761.40	26.9	24.1	78.6	--	2.4	0	0.00	0.00
11:30	8.37	767.18	27.9	24.1	82.2	--	0.8	0	0.00	0.00
11:45	8.53	782.21	28.1	25.9	76.5	85.5	0.6	1	5.70	5.70
12:00	8.55	784.05	28.4	24.7	79.9	--	0.4	0	0.00	5.70
12:15	9.09	833.74	29.1	25.7	82.4	--	0.2	0	0.00	5.70
12:30	9.57	877.56	29.7	26.1	74.7	84.5	2.2	1	4.90	10.60
12:45	9.61	880.77	29.8	26.3	80.6	--	0.9	0	0.00	10.60
13:00	9.48	868.94	29.6	25.9	73.9	84.4	1.7	1	4.10	14.70
13:15	9.31	853.63	29.5	27.3	79.5	--	1.7	0	0.00	14.70
13:30	9.35	857.30	29.9	27.8	75.2	84.1	2.4	1	3.80	18.50
13:45	9.00	824.75	30.4	28.3	80.1	--	1.8	0	0.00	18.50
14:00	8.86	812.65	31	27.9	74.1	83.5	1.3	1	3.70	22.20
14:15	8.52	781.21	30.9	28.3	81.4	--	2.4	0	0.00	22.20
14:30	8.33	763.42	31.6	28.5	83.8	83.2	2.5	1	3.60	25.80
14:45	7.87	721.34	31.3	28.9	73.2	--	0.8	0	0.00	25.80
15:00	7.78	713.45	30.9	18.5	79.9	--	2.5	0	0.00	25.80
15:15	7.29	668.44	31.1	28.9	77.1	82.5	2.2	1	4.10	29.90
15:30	6.88	630.30	31.7	29.9	80.5	--	0.9	0	0.00	29.90
15:45	6.08	557.78	32.8	29.7	84.1	82.5	1.1	1	3.60	33.50
16:00	6.13	561.91	32.5	30.6	76.1	--	2.1	0	0.00	33.50
16:15	5.78	529.91	31.9	29.9	80.2	83.0	2.8	1	3.55	37.05
16:30	5.24	480.49	32.3	31.4	70.4	--	2.1	0	0.00	37.05
16:45	4.78	438.32	32.3	32.5	78.6	--	1.1	0	0.00	37.05
17:00	4.25	389.73	32.7	33.1	83.1	82.7	2.3	1	3.95	41.00
Sum								10	41.00	
Average		677.17	28.4	25.5	71.0	83.6	1.8			
Std. deviation		151.32	3.8	4.7	14.7	1.0	0.9			

Time of day	Solar rad. (mV)	Solar rad. (W/m ²)	Amb. Temp (°C)	Inlet Temp. (°C)	Average plate temp. T _{pav.} (°C)	Average discharge Temp. (°C)	Wind vel. (m/s)	No. of valve discharge/ 15min.	Pasteurised water charged/ 15min.(litre)	Cumulative vol. of discharged water (litres)
9:00	4.251	389.73	19.7	16.9	27.1	-	0.4	0	0.00	0.00
9:15	4.982	456.75	20.4	17.8	31.7	-	1.2	0	0.00	0.00
9:30	5.521	506.17	20.7	18.1	37.6	-	1.4	0	0.00	0.00
9:45	6.214	569.70	21.3	19.1	40.2	-	1.8	0	0.00	0.00
10:00	7.052	646.53	21.3	19.9	45.6	-	0.6	0	0.00	0.00
10:15	7.941	728.03	21.7	19.9	50.7	-	1.6	0	0.00	0.00
10:30	8.687	796.42	22.0	20.1	56.6	-	0.6	0	0.00	0.00
10:45	8.838	810.27	22.3	20.7	62.3	-	2.1	0	0.00	0.00
11:00	9.238	846.94	22.1	20.7	68.6	-	2.1	0	0.00	0.00
11:15	9.321	854.55	22.5	21.5	73.1	-	1.8	0	0.00	0.00
11:30	9.122	836.30	23.9	20.9	80.1	85.5	2.0	1	6.10	6.10
11:45	9.627	882.60	24.8	22.1	72.9	-	1.1	0	0.00	0.00
12:00	9.713	890.49	25.0	23.1	79.8	-	1.6	0	0.00	0.00
12:15	9.743	893.24	26.6	23.9	83.8	85.1	1.9	1	5.50	11.60
12:30	9.916	909.10	26.9	23.9	77.7	-	1.3	0	0.00	11.60
12:45	9.933	910.66	27.9	24.1	84.1	84.5	0.6	1	4.50	16.10
13:00	10.528	965.21	27.9	24.9	73.9	-	0.4	0	0.00	16.10
13:15	9.584	878.66	27.8	24.5	79.2	83.5	0.7	1	4.10	20.20
13:30	9.285	851.25	28.4	26.1	82.1	-	0.8	0	0.00	20.20
13:45	9.627	882.60	28.6	25.8	78.3	83.7	1.8	1	3.80	24.00
14:00	8.802	806.97	29.9	26.3	82.5	-	1.2	0	0.00	24.00
14:15	8.531	782.12	31.0	26.8	77.2	83.3	1.5	1	3.70	27.70
14:30	8.356	766.08	31.0	27.3	83.3	-	1.4	0	0.00	27.70
14:45	8.105	743.07	29.9	27.3	78.8	83.1	1.8	1	3.65	31.35
15:00	7.664	702.64	30.9	27.9	84.1	-	2.3	0	0.00	31.35
15:15	7.216	661.56	30.9	29.1	72.4	83.5	2.7	1	3.70	35.05
15:30	6.937	635.98	31.1	29.9	79.6	-	2.2	0	0.00	35.05
15:45	6.465	592.71	31.4	29.3	75.1	82.6	1.0	1	3.50	38.55
16:00	6.101	559.34	31.6	31.3	82.4	-	0.8	0	0.00	38.55
16:15	5.741	526.33	31.4	30.9	70.5	82.5	1.7	1	2.90	41.45
16:30	5.263	482.51	32.1	32.3	75.8	-	1.3	0	0.00	41.45
16:45	4.998	458.22	32.3	32.9	81.6	-	1.0	0	0.00	41.45
17:00	4.412	404.49	32.3	32.5	74.1	83.5	1.4	1	3.40	44.85
Sum								11	44.85	
Average		715.98	26.9	24.8	69.8	83.7	1.4			
Std. deviation		167.77	4.2	4.6	16.1	0.9	0.6			

Thermal performance of copper pipes on aluminium absorber with reflectors in position

Date: 10 - 02 - 05 Test No.

Flow-rate: 30 ± 3 litres/hr.

Time of day	Solar rad.	Solar rad.	T _a	T _i	T _o	T _{p1}	T _{p2}	T _{p3}	T _{p.av.}	(T _{p.av.} -T _a)	(T _o -T _i)	T _m	(T _m -T _a)	(T _m -T _a)/I	Wind vel.	Th _{eff.}
(Hrs)	(mV)	I (W/m ²)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(m ² °C/W)	(m/s)	
9:00	4.52	414.03	19.8	14.1	29.3	15.4	21.7	25.7	20.9	1.1	15.2	21.7	1.9	0.005	1.4	0.32
9:15	5.00	457.94	20.7	14.7	33.8	21.9	26.7	33.8	27.5	6.8	19.1	24.3	3.6	0.008	2.0	0.36
9:30	5.61	514.42	21.9	14.5	35.3	25.6	29.7	39.4	31.6	9.7	20.8	24.9	3.0	0.006	3.4	0.35
9:45	6.13	562.27	22.0	15.5	37.4	29.9	34.3	46.8	37.0	15.0	21.9	26.5	4.5	0.008	2.7	0.34
10:00	6.84	627.09	22.2	14.7	42.2	31.8	39.7	51.1	40.9	18.7	27.5	28.5	6.3	0.010	1.7	0.38
10:15	7.39	677.88	23.3	15.6	47.3	36.4	45.5	57.8	46.6	23.3	31.7	31.5	8.2	0.012	2.2	0.41
10:30	7.86	720.24	23.8	15.4	51.1	38.9	49.5	60.9	49.8	26.0	35.7	33.3	9.5	0.013	2.8	0.43
10:45	8.16	747.83	25.0	17.0	56.5	43.5	51.2	67.1	53.9	28.9	39.5	36.8	11.8	0.016	1.9	0.46
11:00	8.61	789.55	25.3	17.8	58.7	46.9	56.4	69.8	57.7	32.4	40.9	38.3	13.0	0.016	1.8	0.45
11:15	8.89	815.22	26.0	17.9	62.4	53.9	60.1	73.3	62.4	36.4	44.5	40.2	14.2	0.017	3.1	0.48
11:30	9.28	850.79	27.7	18.1	64.5	55.8	62.4	76.9	65.0	37.3	46.4	41.3	13.6	0.016	2.2	0.48
11:45	9.50	871.33	27.8	18.6	66.4	57.5	65.1	78.9	67.2	39.4	47.8	42.5	14.7	0.017	2.0	0.48
12:00	9.70	889.66	27.4	20.7	71.4	62.4	72.8	90.2	75.1	47.7	50.7	46.1	18.7	0.021	0.7	0.50
12:15	9.94	910.84	29.9	21.1	73.5	64.5	75.6	98.8	79.6	49.7	52.4	47.3	17.4	0.019	1.2	0.50
12:30	10.07	922.76	29.8	23.7	77.8	68.7	80.2	105.6	84.8	55.0	54.1	50.8	21.0	0.023	2.1	0.51
12:45	10.13	928.54	29.8	23.8	82.4	72.8	87.7	109.8	90.1	60.3	58.6	53.1	23.3	0.025	1.8	0.55
13:00	10.16	931.10	30.7	25.2	85.7	76.0	89.1	111.5	92.2	61.5	60.5	55.5	24.8	0.027	2.4	0.57
13:15	10.07	922.76	29.9	26.4	87.5	77.1	89.7	114.8	93.9	64.0	61.1	57.0	27.1	0.029	2.3	0.58
13:30	9.89	906.90	30.8	27.0	87.6	79.9	90.1	119.4	96.5	65.7	60.6	57.3	26.5	0.029	2.0	0.58
13:45	9.63	883.06	31.9	28.2	85.2	76.8	87.5	112.8	92.4	60.5	57.0	56.7	24.8	0.028	1.7	0.56
14:00	9.29	852.07	32.8	28.4	83.9	74.8	86.9	110.2	90.6	57.8	55.5	56.2	23.4	0.027	5.4	0.57
14:15	9.21	844.46	32.3	29.4	81.9	76.8	85.8	113.8	92.1	59.8	52.5	55.7	23.4	0.028	2.2	0.54
14:30	8.98	823.38	33.0	30.4	78.9	74.7	81.2	110.1	88.7	55.7	48.5	54.7	21.7	0.026	4.2	0.52
14:45	8.53	782.21	33.1	30.5	77.0	67.7	78.5	106.2	84.1	51.0	46.5	53.8	20.7	0.026	3.7	0.52
15:00	8.17	749.12	32.4	30.8	75.9	66.9	77.8	104.4	83.0	50.6	45.1	53.4	21.0	0.028	3.8	0.53
15:15	7.77	712.72	33.8	30.9	73.8	64.8	74.4	101.5	80.2	46.4	42.9	52.4	18.6	0.026	2.3	0.53
15:30	7.38	676.69	33.9	31.5	71.1	62.4	72.4	99.2	78.0	44.1	39.6	51.3	17.4	0.026	3.8	0.51
15:45	6.79	622.69	33.5	32.5	68.7	58.4	69.8	94.2	74.1	40.6	36.2	50.6	17.1	0.027	2.6	0.51
16:00	6.41	587.49	33.7	33.5	63.4	54.8	65.7	88.7	69.7	36.0	29.9	48.5	14.8	0.025	3.3	0.45
16:15	5.84	535.69	34.0	32.8	59.9	51.8	63.8	78.2	64.6	30.6	27.1	46.4	12.4	0.023	2.9	0.44
16:30	5.35	490.03	34.3	33.1	56.7	49.5	60.2	69.4	59.7	25.4	23.6	44.9	10.6	0.022	4.8	0.42
16:45	5.01	459.50	33.4	33.1	54.8	45.6	58.9	66.6	57.0	23.6	21.7	44.0	10.6	0.023	3.7	0.41
17:00	4.79	438.69	34.6	33.8	51.9	44.1	56.2	64.7	55.0	20.4	18.1	42.9	8.2	0.019	2.6	0.36
Average		724.82	29.1	24.3	64.7	55.4	65.0	83.4	67.9	38.8	40.4	44.5	15.4	0.021	2.6	0.47
Std deviation		165.32	4.5	7.0	16.6	17.5	19.2	25.9	20.8	17.7306	13.9	10.6	7.1	0.007	1.0	0.07

Time of day	Solar rad.	Solar rad.	T _a	T _i	T _o	T _{p1}	T _{p2}	T _{p3}	T _{p.av.}	(T _{p.av.} -T _a)	(T _o -T _i)	T _m	(T _m -T _a)	(T _m -T _a)/I	Wind vel.	Th _{eff}
(Hrs)	(mV)	I (W/m ²)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(m ² °C/W)	v (m/s)	
9:00	4.45	408.07	19.2	15.7	26.4	24.6	30.4	36.1	30.4	11.2	10.7	21.1	1.9	0.005	1.2	0.23
9:15	5.01	459.59	19.6	17.2	29.7	29.4	37.7	41.2	36.1	16.5	12.5	23.5	3.9	0.008	0.9	0.24
9:30	5.65	518.27	19.8	17.5	36.9	34.9	42.8	48.9	42.2	22.4	19.4	27.2	7.4	0.014	1.9	0.33
9:45	6.27	574.56	20.8	18.4	41.6	38.7	47.6	55.6	47.3	26.5	23.2	30.0	9.2	0.016	1.3	0.35
10:00	6.77	621.04	21.8	18.8	45.5	44.6	52.1	62.5	53.1	31.3	26.7	32.2	10.4	0.017	1.7	0.38
10:15	7.27	666.42	22.3	19.6	50.2	48.5	56.8	69.3	58.2	35.9	30.6	34.9	12.6	0.019	2.1	0.40
10:30	7.64	700.07	22.8	19.8	53.6	53.4	59.6	74.9	62.6	39.8	33.8	36.7	13.9	0.020	1.4	0.42
10:45	8.16	748.11	23.8	19.4	59.2	57.5	66.8	81.6	68.6	44.8	39.8	39.3	15.5	0.021	2.1	0.47
11:00	8.48	777.81	23.5	20.4	60.4	58.4	68.7	78.4	68.5	45.0	40.0	40.4	16.9	0.022	2.5	0.45
11:15	8.66	793.49	24.5	19.8	59.4	56.4	70.5	79.9	68.9	44.4	39.6	39.6	15.1	0.019	1.9	0.44
11:30	8.88	814.39	24.8	21.3	60.9	58.6	71.4	81.6	70.5	45.7	39.6	41.1	16.3	0.020	0.8	0.43
11:45	8.98	823.01	25.7	20.8	62.2	59.7	73.1	84.9	72.6	46.9	41.4	41.5	15.8	0.019	2.1	0.44
12:00	9.23	846.02	27.1	21.1	63.7	62.4	72.1	84.6	73.0	45.9	42.6	42.4	15.3	0.018	0.9	0.44
12:15	9.30	852.53	26.9	21.5	63.2	64.2	71.8	83.2	73.1	46.2	41.7	42.4	15.5	0.018	2.5	0.43
12:30	9.44	865.46	27.1	21.7	63.3	58.6	74.4	85.5	72.8	45.7	41.6	42.5	15.4	0.018	1.6	0.42
12:45	9.62	882.24	27.4	23.9	62.9	59.2	72.4	82.5	71.4	44.0	39.0	43.4	16.0	0.018	2.5	0.39
13:00	9.53	873.34	27.9	25.1	63.7	56.1	70.1	81.2	69.1	41.2	38.6	44.4	16.5	0.019	2.3	0.39
13:15	9.30	852.44	29.1	24.8	63.4	57.8	73.5	79.2	70.2	41.1	38.6	44.1	15.0	0.018	0.8	0.40
13:30	9.05	829.89	29.1	24.9	62.3	59.8	70.2	81.7	70.6	41.5	37.4	43.6	14.5	0.017	1.4	0.39
13:45	8.98	823.56	29.3	25.9	63.5	58.6	72.1	83.8	71.5	42.2	37.6	44.7	15.4	0.019	1.9	0.40
14:00	8.67	794.77	29.5	25.9	63.3	56.1	73.4	85.1	71.5	42.0	37.4	44.6	15.1	0.019	2.1	0.41
14:15	8.35	765.71	29.9	26.1	62.7	56.2	72.4	80.5	69.7	39.8	36.6	44.4	14.5	0.019	1.6	0.42
14:30	8.22	753.33	29.7	26.3	58.7	55.2	70.4	78.5	68.0	38.3	32.4	42.5	12.8	0.017	2.3	0.38
14:45	7.79	713.91	30.5	27.8	59.8	56.5	69.8	80.4	68.9	38.4	32.0	43.8	13.3	0.019	1.9	0.39
15:00	7.94	727.66	30.6	27.5	57.5	56.8	68.9	79.4	68.4	37.8	30.0	42.5	11.9	0.016	2.7	0.36
15:15	7.25	664.50	32.1	28.6	56.7	54.8	66.4	75.1	65.4	33.3	28.1	42.7	10.6	0.016	1.4	0.37
15:30	6.88	631.13	30.9	28.7	56.4	54.3	63.3	71.8	63.1	32.2	27.7	42.6	11.7	0.018	2.2	0.38
15:45	6.31	578.68	31.1	29.1	53.7	52.1	61.7	68.9	60.9	29.8	24.6	41.4	10.3	0.018	1.8	0.37
16:00	5.70	522.39	30.9	29.5	51.9	51.8	58.7	66.9	59.1	28.2	22.4	40.7	9.8	0.019	1.2	0.38
16:15	5.28	483.80	31.1	29.6	50.9	49.8	55.3	64.7	56.6	25.5	21.3	40.3	9.2	0.019	1.7	0.39
16:30	4.70	430.80	31.3	30.4	49.7	47.6	53.8	62.8	54.7	23.4	19.3	40.1	8.8	0.020	1.6	0.39
16:45	4.38	401.19	31.7	31.4	47.3	48.4	51.3	59.7	53.1	21.4	15.9	39.4	7.7	0.019	0.9	0.35
17:00	3.99	365.71	31.6	31.5	45.5	48.9	50.6	56.7	52.1	20.5	14.0	38.5	6.9	0.019	1.4	0.33
Average		683.75	27.1	23.9	54.7	52.4	62.7	72.3	62.5	35.4	30.8	39.3	12.3	0.018	1.7	0.39
Std. deviation		157.25	4.0	4.5	9.8	8.9	11.4	12.9	11.0	9.7	9.5	6.0	3.8	0.003	0.5	0.05

Time of day	Solar rad.	Solar rad.	T _a	T _i	T _o	T _{p1}	T _{p2}	T _{p3}	T _{p.av.}	(T _{p.av.} -T _a)	(T _o -T _i)	T _m	(T _m -T _a)	(T _m -T _a)/I	Wind vel.	T _{heff}
(Hrs)	(mV)	I (W/m ²)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(m ² °C/W)	v (m/s)	
9:00	4.14	379.83	19.2	16.6	28.5	25.8	34.4	39.7	33.3	14.1	11.9	22.6	3.4	0.009	1.3	0.27
9:15	4.80	439.88	20.5	16.8	33.5	31.9	37.9	43.4	37.7	17.2	16.7	25.2	4.7	0.011	1.7	0.33
9:30	5.27	483.34	20.8	17.2	35.8	33.6	40.3	46.1	40.0	19.2	18.6	26.5	5.7	0.012	1.7	0.34
9:45	5.78	529.82	21.3	17.2	36.4	35.4	42.6	48.2	42.1	20.8	19.2	26.8	5.5	0.010	0.5	0.32
10:00	6.52	597.30	22.3	17.9	39.8	37.5	45.4	50.9	44.6	22.3	21.9	28.9	6.6	0.011	3.0	0.32
10:15	6.99	640.38	22.6	17.8	41.7	39.9	45.2	56.1	47.1	24.5	23.9	29.8	7.2	0.011	2.8	0.33
10:30	7.48	685.95	23.8	18.4	43.3	42.1	48.1	59.9	50.0	26.2	24.9	30.9	7.1	0.010	1.6	0.32
10:45	7.90	724.55	24.1	18.9	47.5	46.4	53.2	63.7	54.4	30.3	28.6	33.2	9.1	0.013	2.0	0.35
11:00	8.27	758.19	25.6	19.7	50.4	50.5	56.7	68.1	58.4	32.8	30.7	35.1	9.5	0.012	2.5	0.35
11:15	8.60	788.26	25.9	20.2	54.2	54.8	63.4	71.8	63.3	37.4	34.0	37.2	11.3	0.014	2.2	0.38
11:30	8.88	814.39	26.2	20.9	56.4	56.6	65.8	75.9	66.1	39.9	35.5	38.7	12.5	0.015	2.4	0.38
11:45	9.22	845.01	26.4	20.8	57.1	57.8	67.1	77.8	67.6	41.2	36.3	39.0	12.6	0.015	2.4	0.38
12:00	9.43	864.45	27.6	21.7	59.2	58.8	68.2	79.8	68.9	41.3	37.5	40.5	12.9	0.015	1.2	0.38
12:15	9.63	883.06	28.4	21.9	60.7	57.8	66.9	81.4	68.7	40.3	38.8	41.3	12.9	0.015	2.8	0.38
12:30	9.56	876.00	28.6	22.4	62.1	58.9	68.7	85.2	70.9	42.3	39.7	42.3	13.7	0.016	3.0	0.40
12:45	9.75	894.06	28.9	23.1	63.1	58.6	69.7	87.8	72.0	43.1	40.0	43.1	14.2	0.016	2.4	0.39
13:00	9.64	883.98	29.2	24.4	64.2	59.7	70.4	89.4	73.2	44.0	39.8	44.3	15.1	0.017	2.6	0.39
13:15	9.62	881.78	29.5	25.1	65.5	61.4	73.4	90.2	75.0	45.5	40.4	45.3	15.8	0.018	2.0	0.40
13:30	9.56	876.09	30.1	25.3	64.5	59.8	71.7	92.4	74.6	44.5	39.2	44.9	14.8	0.017	0.9	0.39
13:45	9.31	853.91	31.1	26.1	62.3	58.6	69.4	89.9	72.6	41.5	36.2	44.2	13.1	0.015	3.7	0.37
14:00	9.23	846.57	32.3	26.8	63.5	56.8	65.7	87.2	69.9	37.6	36.7	45.2	12.9	0.015	3.9	0.38
14:15	8.97	822.28	31.8	27.4	61.7	54.2	64.8	84.7	67.9	36.1	34.3	44.6	12.8	0.016	2.2	0.36
14:30	8.75	802.48	32.4	28.9	59.9	53.3	62.6	79.8	65.2	32.8	31.0	44.4	12.0	0.015	3.7	0.34
14:45	8.56	784.87	32.5	28.1	58.4	52.4	64.1	79.2	65.2	32.7	30.3	43.3	10.8	0.014	2.1	0.34
15:00	8.15	747.38	32.7	28.3	59.2	53.6	65.8	78.7	66.0	33.3	30.9	43.8	11.1	0.015	2.1	0.36
15:15	7.75	710.43	33.4	29.4	59.7	54.2	66.7	75.5	65.5	32.1	30.3	44.6	11.2	0.016	1.1	0.37
15:30	7.43	681.55	33.5	30.5	57.8	53.9	64.6	74.1	64.2	30.7	27.3	44.2	10.7	0.016	0.7	0.35
15:45	6.92	634.61	32.9	31.3	56.5	53.1	62.6	74.4	63.4	30.5	25.2	43.9	11.0	0.017	1.0	0.35
16:00	6.57	602.06	33.1	31.5	56.9	51.9	60.7	72.6	61.7	28.6	25.4	44.2	11.1	0.018	2.0	0.37
16:15	6.07	556.86	33.1	31.9	52.9	51.1	57.2	68.7	59.0	25.9	21.0	42.4	9.3	0.017	2.0	0.33
16:30	5.62	515.24	33.9	32.1	51.7	48.9	54.8	65.5	56.4	22.5	19.6	41.9	8.0	0.016	2.7	0.33
16:45	5.02	460.51	33.8	33.5	50.4	49.7	53.9	64.7	56.1	22.3	16.9	42.0	8.2	0.018	2.2	0.32
17:00	4.62	423.10	33.5	33.9	49.8	47.3	52.7	62.4	54.1	20.6	15.9	41.9	8.3	0.020	0.9	0.33
Average		705.70	28.5	24.4	53.5	50.5	59.2	71.7	60.5	32.0	29.0	38.9	10.4	0.015	2.1	0.35
Std. Deviation		157.18	4.5	5.4	9.9	9.0	10.5	14.3	11.2	8.8	8.3	6.8	3.1	0.003	0.8	0.03

Time of day	Solar rad.	Solar rad.	T _a	T _i	T _o	T _{p1}	T _{p2}	T _{p3}	T _{p.av.}	(T _{p.av.} -T _a)	(T _o -T _i)	T _m	(T _m -T _a)	(T _m -T _a)/I	Wind vel.	Th _{eff.}
(Hrs)	(mV)	I (W/m ²)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(m ² °C/W)	v (m/s)	0.27
9:00	4.99	457.21	19.8	15.8	29.7	33.9	37.4	38.4	36.6	16.8	13.9	22.8	3.0	0.006	1.0	0.32
9:15	5.45	500.02	20.7	16.7	34.8	38.7	44.7	46.3	43.2	22.5	18.1	25.8	5.1	0.010	3.4	0.33
9:30	5.98	548.61	20.9	17.2	38.2	41.6	46.2	49.4	45.7	24.8	21.0	27.7	6.8	0.012	1.8	0.35
9:45	6.49	595.19	21.3	17.9	41.8	44.5	48.3	53.7	48.8	27.5	23.9	29.9	8.6	0.014	2.8	0.36
10:00	6.75	618.93	20.9	18.4	43.9	46.2	52.6	57.6	52.1	31.2	25.5	31.2	10.3	0.017	3.0	0.37
10:15	7.06	647.08	21.6	18.9	46.4	47.9	54.1	58.2	53.4	31.8	27.5	32.7	11.1	0.017	0.9	0.37
10:30	7.65	701.72	21.9	19.1	48.7	48.8	57.2	62.4	56.1	34.2	29.6	33.9	12.0	0.017	1.9	0.37
10:45	8.25	755.90	22.5	19.1	50.8	50.1	57.9	63.7	57.2	34.7	31.7	35.0	12.5	0.016	2.1	0.34
11:00	8.76	802.75	22.8	20.9	52.4	52.2	59.1	64.7	58.7	35.9	31.5	36.7	13.9	0.017	2.2	0.53
11:15	6.23	570.89	23.5	19.8	54.7	53.6	60.7	65.9	60.1	36.6	34.9	37.3	13.8	0.024	4.2	0.37
11:30	8.85	811.55	23.9	21.1	55.8	55.8	61.7	67.4	61.6	37.7	34.7	38.5	14.6	0.018	0.5	0.54
11:45	6.47	593.08	24.2	21.1	57.8	55.1	63.9	68.7	62.6	38.4	36.7	39.5	15.3	0.026	2.5	0.35
12:00	9.76	894.43	25.4	21.5	57.3	56.4	64.1	69.4	63.3	37.9	35.8	39.4	14.0	0.016	1.9	0.39
12:15	9.04	828.42	25.9	21.9	58.4	57.1	65.3	71.4	64.6	38.7	36.5	40.2	14.3	0.017	2.5	0.30
12:30	11.73	1075.50	26.1	22.9	59.7	56.5	67.8	74.9	66.4	40.3	36.8	41.3	15.2	0.014	1.9	0.29
12:45	11.39	1044.14	26.1	23.5	58.5	56.2	66.7	76.4	66.4	40.3	35.0	41.0	14.9	0.014	1.7	0.39
13:00	9.51	871.42	26.2	23.5	62.1	58.8	69.7	79.1	69.2	43.0	38.6	42.8	16.6	0.019	3.2	0.54
13:15	7.36	674.40	26.3	24.3	65.6	60.1	72.9	83.4	72.1	45.8	41.3	45.0	18.7	0.028	0.8	0.45
13:30	8.78	805.13	26.5	26.1	67.9	62.9	75.2	87.6	75.2	48.7	41.8	47.0	20.5	0.025	2.4	0.42
13:45	9.34	856.20	28.1	25.9	67.4	65.3	77.7	90.8	77.9	49.8	41.5	46.7	18.6	0.022	3.2	0.43
14:00	9.25	847.76	27.9	26.2	68.2	64.7	76.8	92.4	78.0	50.1	42.0	47.2	19.3	0.023	2.2	0.45
14:15	8.90	816.32	29.1	26.8	68.9	63.5	77.9	90.4	77.3	48.2	42.1	47.9	18.8	0.023	3.8	0.45
14:30	8.46	775.98	28.9	26.9	66.4	62.8	75.7	88.6	75.7	46.8	39.5	46.7	17.8	0.023	2.5	0.46
14:45	8.31	762.14	29.6	26.7	66.6	60.4	72.8	86.7	73.3	43.7	39.9	46.7	17.1	0.022	1.2	0.48
15:00	7.96	729.50	29.4	27.1	67.2	59.8	72.3	82.4	71.5	42.1	40.1	47.2	17.8	0.024	2.4	0.47
15:15	7.77	712.72	30.2	27.9	65.8	58.1	70.8	79.8	69.6	39.4	37.9	46.9	16.7	0.023	1.5	0.47
15:30	7.32	671.37	29.8	27.6	63.7	58.4	68.7	77.5	68.2	38.4	36.1	45.7	15.9	0.024	1.8	0.48
15:45	6.69	612.88	30.7	27.8	61.5	58.2	65.4	74.2	65.9	35.2	33.7	44.7	14.0	0.023	1.9	0.49
16:00	6.25	572.82	31.5	28.5	60.7	56.7	65.6	74.8	65.7	34.2	32.2	44.6	13.1	0.023	1.9	0.48
16:15	5.83	534.86	31.4	28.6	57.7	54.4	63.9	72.1	63.5	32.1	29.1	43.2	11.8	0.022	2.3	0.46
16:30	5.19	476.19	31.7	28.4	53.2	49.8	58.4	68.5	58.9	27.2	24.8	40.8	9.1	0.019	2.7	0.42
16:45	4.78	438.51	32.2	28.9	49.7	46.6	56.8	65.3	56.2	24.0	20.8	39.3	7.1	0.016	2.0	0.38
17:00	4.29	392.85	32.9	29.8	46.8	43.9	52.1	60.7	52.2	19.3	17.0	38.3	5.4	0.014	1.1	0.41
Average		696.86	26.4	23.5	56.0	53.9	63.0	71.0	62.6	36.3	32.5	39.8	13.4	0.019	2.2	0.41
Std. deviation		163.86	3.9	4.1	10.2	7.6	10.1	13.2	10.2	8.6	7.9	6.7	4.4	0.005	0.8	0.07

Time of day	Solar rad.	Solar rad.	T _a	T _i	T _o	T _{p1}	T _{p2}	T _{p3}	T _{p.av}	(T _{p.av} -T _a)	(T _o -T _i)	T _m	(T _m -T _a)	Wind vel.	(T _m -T _a)/I	Th _{eff}
(Hrs)	(mV)	I (W/m ²)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	v (m/s)	(m ² °C/W)	
9:00	4.54	416.14	19.2	14.4	27.4	24.5	30.6	41.5	32.2	13.0	8.2	20.9	1.7	2.9	0.004	0.11
9:15	5.15	471.69	20.4	14.9	29.5	28.9	33.5	44.6	35.7	15.3	9.1	22.2	1.8	3.6	0.004	0.11
9:30	5.77	528.54	20.8	15.3	32.5	30.2	36.1	49.1	38.5	17.7	11.7	23.9	3.1	1.3	0.006	0.13
9:45	6.15	563.56	21.5	16.7	35.7	33.6	39.2	51.2	41.3	19.8	14.2	26.2	4.7	0.3	0.008	0.14
10:00	6.65	610.04	21.5	16.9	38.3	36.8	42.9	53.3	44.3	22.8	16.8	27.6	6.1	4.1	0.010	0.16
10:15	7.01	643.04	22.1	16.7	40.1	39.2	47.7	56.2	47.7	25.6	18.0	28.4	6.3	4.4	0.010	0.16
10:30	7.87	721.89	22.3	17.2	42.9	42.2	50.4	58.9	50.5	28.2	20.6	30.1	7.8	4.9	0.011	0.16
10:45	8.69	796.61	22.5	17.2	45.3	44.7	50.5	61.6	52.3	29.8	22.8	31.3	8.8	1.9	0.011	0.16
11:00	6.51	596.47	23.4	18.4	46.1	43.2	53.7	64.3	53.7	30.3	22.7	32.3	8.9	5.2	0.015	0.22
11:15	9.49	870.23	23.7	18.7	47.9	46.1	56.7	68.9	57.2	33.5	24.2	33.3	9.6	0.6	0.011	0.16
11:30	7.47	685.22	24.6	19.2	52.2	50.5	58.6	73.1	60.7	36.1	27.6	35.7	11.1	1.1	0.016	0.23
11:45	6.97	638.55	24.8	20.8	56.4	53.9	60.8	75.3	63.3	38.5	31.6	38.6	13.8	3.4	0.022	0.28
12:00	11.12	1019.02	24.9	21.1	59.2	56.5	65.2	77.4	66.4	41.5	34.3	40.2	15.3	1.4	0.015	0.19
12:15	7.81	716.20	25.4	21.9	62.9	58.2	68.2	79.7	68.7	43.3	37.5	42.4	17.0	3.5	0.024	0.30
12:30	10.76	986.57	26.7	22.4	64.5	62.8	70.2	82.2	71.7	45.0	37.8	43.5	16.8	1.5	0.017	0.22
12:45	8.93	818.79	25.9	23.2	65.9	61.1	73.8	81.7	72.2	46.3	40.0	44.6	18.7	1.3	0.023	0.28
13:00	11.17	1023.61	26.9	24.1	67.4	63.8	76.7	83.2	74.6	47.7	40.5	45.8	18.9	1.0	0.018	0.23
13:15	11.52	1055.79	27.4	25.1	68.8	64.5	78.7	84.5	75.9	48.5	41.4	47.0	19.6	1.1	0.019	0.23
13:30	7.69	704.84	28.2	25.3	68.2	66.7	78.2	87.4	77.4	49.2	40.0	46.8	18.6	0.5	0.026	0.33
13:45	10.63	974.74	28.6	25.7	67.6	67.1	79.7	88.3	78.4	49.8	39.0	46.7	18.1	1.9	0.019	0.23
14:00	9.84	902.22	28.8	25.7	66.4	65.4	76.1	85.9	75.8	47.0	37.6	46.1	17.3	1.1	0.019	0.24
14:15	8.67	794.77	30.1	26.4	64.2	62.8	74.5	84.4	73.9	43.8	34.1	45.3	15.2	0.6	0.019	0.25
14:30	9.23	846.11	29.6	26.9	62.1	60.9	72.1	81.7	71.6	42.0	32.5	44.5	14.9	1.4	0.018	0.22
14:45	8.84	810.18	30.6	27.1	59.4	58.9	72.7	80.1	70.6	40.0	28.8	43.3	12.7	1.5	0.016	0.20
15:00	7.96	729.50	31.1	26.9	58.5	56.4	70.2	80.8	69.1	38.0	27.4	42.7	11.6	2.2	0.016	0.22
15:15	6.63	607.93	31.8	28.1	55.6	52.8	67.1	77.9	65.9	34.1	23.8	41.9	10.1	2.7	0.017	0.23
15:30	7.60	696.40	33.4	27.8	54.3	50.5	63.7	75.1	63.1	29.7	20.9	41.1	7.7	2.2	0.011	0.17
15:45	6.75	619.02	32.5	29.2	55.1	48.9	59.1	71.2	59.7	27.2	22.6	42.2	9.7	1.4	0.016	0.21
16:00	6.28	575.48	32.3	29.7	52.7	47.5	56.6	67.8	57.3	25.0	20.4	41.2	8.9	3.0	0.015	0.20
16:15	5.85	536.24	33.1	29.8	50.2	46.6	54.8	64.3	55.2	22.1	17.1	40.0	6.9	1.5	0.013	0.18
16:30	5.50	503.78	33.5	29.8	48.8	45.7	53.7	62.2	53.9	20.4	15.3	39.3	5.8	2.4	0.012	0.17
16:45	4.88	447.77	32.5	30.5	46.6	44.9	51.1	60.7	52.2	19.7	14.1	38.6	6.1	2.8	0.014	0.18
17:00	4.41	404.13	33.7	33.1	45.4	43.2	48.7	58.7	50.2	16.5	11.7	39.3	5.6	2.2	0.014	0.17
Average		706.52	27.1	23.2	52.7	50.3	59.8	70.1	60.0	33.0	25.6	37.9	10.9	2.1	0.015	0.20
Std. Deviation		180.95	4.4	5.3	11.7	11.5	13.7	13.1	12.7	11.2	10.1	7.6	5.3	1.3	0.005	0.05

Time of day	Solar rad.	Solar rad.	T _a	T _i	T _o	T _{p1}	T _{p2}	T _{p3}	T _{p.av.}	(T _{p.av.} -T _a)	(T _o -T _i)	T _m	(T _m -T _a)	(T _m -T _a)/I	Wind vel.	Th _{eff}
(Hrs)	(mV)	I (W/m ²)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(m ² °C/W)	v (m/s)	
9:00	4.90	449.05	20.1	16.2	25.3	29.7	34.1	37.1	33.6	13.5	9.1	20.8	0.6	0.001	1.4	0.18
9:15	5.68	520.83	21.8	17.8	28.4	32.6	38.5	40.7	37.3	15.5	10.6	23.1	1.3	0.002	1.9	0.18
9:30	6.20	568.05	22.6	19.9	31.9	35.1	39.4	44.7	39.7	17.1	12.0	25.9	3.3	0.006	2.8	0.18
9:45	6.89	631.58	23.7	19.9	33.5	38.1	42.5	47.7	42.8	19.1	13.6	26.7	3.0	0.005	1.0	0.19
10:00	7.25	665.05	24.9	21.3	35.8	41.1	46.8	54.7	47.5	22.6	14.5	28.6	3.7	0.005	0.7	0.19
10:15	6.38	584.55	25.6	20.6	40.9	44.7	51.1	58.7	51.5	25.9	20.3	30.8	5.2	0.009	1.0	0.30
10:30	7.66	702.09	26.7	21.4	44.3	46.9	53.1	63.4	54.5	27.8	22.9	32.9	6.2	0.009	1.6	0.29
10:45	9.45	866.74	27.7	21.6	46.5	48.7	56.4	68.1	57.7	30.0	24.9	34.1	6.4	0.007	1.9	0.25
11:00	8.83	809.17	27.4	22.3	48.5	50.9	59.7	70.1	60.2	32.8	26.2	35.4	8.0	0.010	2.1	0.28
11:15	8.93	818.34	28.2	22.2	51.2	50.7	59.4	69.8	60.0	31.8	29.0	36.7	8.5	0.010	2.6	0.31
11:30	9.27	849.78	28.9	22.9	52.1	51.8	61.2	72.1	61.7	32.8	29.2	37.5	8.6	0.010	1.9	0.30
11:45	8.68	795.32	28.4	22.9	53.4	53.2	62.5	74.8	63.5	35.1	30.5	38.2	9.8	0.012	2.2	0.34
12:00	9.88	905.71	28.9	23.6	54.4	53.8	64.7	77.2	65.2	36.3	30.8	39.0	10.1	0.011	0.7	0.30
12:15	8.90	815.68	28.8	23.1	55.2	55.9	66.6	79.4	67.3	38.5	32.1	39.2	10.4	0.013	1.2	0.34
12:30	8.11	743.07	28.9	23.7	57.4	57.7	69.1	82.5	69.8	40.9	33.7	40.6	11.7	0.016	1.1	0.40
12:45	10.24	938.62	29.4	24.5	60.3	58.9	70.7	85.1	71.6	42.2	35.8	42.4	13.0	0.014	1.7	0.33
13:00	11.17	1024.07	29.8	24.1	63.8	59.3	73.4	87.5	73.4	43.6	39.7	44.0	14.2	0.014	1.6	0.34
13:15	8.78	804.49	30.4	24.7	64.2	62.6	75.2	89.6	75.8	45.4	39.5	44.5	14.1	0.017	2.2	0.43
13:30	10.48	960.71	30.9	24.3	65.7	60.4	71.4	87.4	73.1	42.2	41.4	45.0	14.1	0.015	0.7	0.38
13:45	9.73	892.41	30.8	24.9	62.8	58.3	67.4	84.9	70.2	39.4	37.9	43.9	13.1	0.015	1.0	0.37
14:00	7.32	671.46	31.2	25.9	63.2	56.3	63.4	80.1	66.6	35.4	37.3	44.6	13.4	0.020	0.8	0.49
14:15	9.63	883.15	31.1	25.5	60.4	57.7	64.7	78.2	66.9	35.8	34.9	43.0	11.9	0.013	1.2	0.35
14:30	8.54	783.31	30.9	26.5	59.1	55.8	62.8	75.8	64.8	33.9	32.6	42.8	11.9	0.015	2.3	0.36
14:45	8.65	793.12	31.2	26.7	58.7	53.9	62.4	73.4	63.2	32.0	32.0	42.7	11.5	0.014	2.0	0.35
15:00	8.17	749.21	31.1	26.9	57.1	52.6	61.1	69.1	60.9	29.8	30.2	42.0	10.9	0.015	1.2	0.35
15:15	7.78	713.27	31.3	27.7	58.1	53.4	58.7	68.4	60.2	28.9	30.4	42.9	11.6	0.016	1.5	0.37
15:30	7.64	700.16	31.3	27.9	55.6	53.2	58.1	66.4	59.2	27.9	27.7	41.8	10.5	0.015	2.2	0.35
15:45	6.77	621.04	31.7	28.9	53.6	51.8	56.4	65.1	57.8	26.1	24.7	41.3	9.6	0.015	1.6	0.35
16:00	6.27	574.38	32.1	29.7	51.2	49.3	56.1	64.7	56.7	24.6	21.5	40.5	8.4	0.015	1.5	0.33
16:15	5.77	529.36	32.2	29.8	49.1	47.5	53.5	62.6	54.5	22.3	19.3	39.5	7.3	0.014	2.2	0.32
16:30	5.31	486.45	32.4	30.8	48.2	47.4	51.7	59.4	52.8	20.4	17.4	39.5	7.1	0.015	1.6	0.31
16:45	4.89	448.13	32.2	31.8	46.4	45.9	49.6	57.8	51.1	18.9	14.6	39.1	6.9	0.015	1.3	0.29
17:00	4.22	386.71	32.4	32.2	44.1	44.3	49.2	57.7	50.4	18.0	11.9	38.2	5.8	0.015	1.5	0.27
Average		717.73	28.9	24.6	50.9	50.3	57.9	68.3	58.8	29.9	26.3	37.8	8.8	0.012	1.6	0.31
Std. Deviation		160.77	3.2	3.8	10.5	7.9	10.0	13.4	10.4	8.7	9.3	6.4	3.7	0.004	0.6	0.07

Time of day	Solar rad.	Solar rad.	T _a	T _i	T _o	T _{p1}	T _{p2}	T _{p3}	T _{p.av.}	(T _{p.av.} -T _a)	(T _o -T _i)	T _m	(T _m -T _a)	(T _m -T _a)/I	Wind vel.	Th _{eff}
(Hrs)	(mV)	I (W/m ²)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(m ² oC/W)	v (m/s)	
9:00	4.74	434.65	19.5	15.9	28.7	26.6	33.3	38.9	32.9	13.4	12.8	22.3	2.8	0.01	1.4	0.26
9:15	5.16	473.25	19.8	16.1	31.7	29.1	35.9	41.4	35.5	15.7	15.6	23.9	4.1	0.01	2.3	0.29
9:30	5.85	536.05	19.9	16.1	33.6	32.8	37.5	43.8	38.0	18.1	17.5	24.9	5.0	0.01	3.1	0.29
9:45	6.21	569.70	20.4	16.7	35.8	33.4	39.4	46.5	39.8	19.4	19.1	26.3	5.9	0.01	0.7	0.29
10:00	6.92	634.70	20.1	17.3	38.7	35.8	43.5	49.1	42.8	22.7	21.4	28.0	7.9	0.01	4.2	0.30
10:15	7.49	687.05	21.5	18.1	40.1	38.3	47.2	52.7	46.1	24.6	22.0	29.1	7.6	0.01	1.7	0.28
10:30	7.90	723.91	23.2	18.5	42.2	41.3	49.7	56.1	49.0	25.8	23.7	30.4	7.2	0.01	4.3	0.29
10:45	8.39	768.92	22.9	19.4	45.2	46.9	51.6	61.4	53.3	30.4	25.8	32.3	9.4	0.01	2.3	0.29
11:00	8.77	804.40	23.2	19.9	48.7	51.9	54.4	64.4	56.9	33.7	28.8	34.3	11.1	0.01	3.8	0.31
11:15	8.91	817.24	25.4	20.7	50.7	56.8	58.2	68.8	61.3	35.9	30.0	35.7	10.3	0.01	1.9	0.32
11:30	9.37	858.58	25.7	20.1	53.6	58.4	62.1	72.4	64.3	38.6	33.5	36.9	11.2	0.01	2.8	0.34
11:45	9.40	862.16	26.8	21.5	56.3	62.1	64.4	75.8	67.4	40.6	34.8	38.9	12.1	0.01	1.7	0.35
12:00	9.67	886.18	26.8	20.0	60.7	64.6	67.1	77.8	69.8	43.0	40.7	40.4	13.6	0.02	3.7	0.40
12:15	9.81	899.38	27.7	22.2	63.6	66.9	69.1	80.1	72.0	44.3	41.4	42.9	15.2	0.02	4.1	0.40
12:30	9.95	911.94	28.5	23.9	64.9	69.9	71.0	83.7	74.9	46.4	41.0	44.4	15.9	0.02	0.9	0.39
12:45	9.86	904.33	29.2	25.4	66.2	71.2	72.1	89.7	77.7	48.5	40.8	45.8	16.6	0.02	0.5	0.39
13:00	9.99	916.07	28.9	25.4	68.6	69.8	73.4	94.1	79.1	50.2	43.2	47.0	18.1	0.02	2.4	0.41
13:15	10.15	930.92	29.9	25.9	70.6	64.1	73.2	98.7	78.7	48.8	44.7	48.3	18.4	0.02	4.7	0.42
13:30	9.95	912.58	30.1	27.2	74.7	66.7	75.5	104.1	82.1	52.0	47.5	51.0	20.9	0.02	3.6	0.46
13:45	9.76	895.16	32.1	27.9	75.8	64.5	76.7	107.9	83.0	50.9	47.9	51.9	19.8	0.02	2.4	0.47
14:00	9.58	878.66	31.8	28.7	74.6	65.2	74.7	109.7	83.2	51.4	45.9	51.7	19.9	0.02	3.1	0.46
14:15	9.19	842.17	30.9	29.1	74.9	67.5	75.8	108.4	83.9	53.0	45.8	52.0	21.1	0.03	3.4	0.48
14:30	8.86	812.10	31.4	29.5	71.9	66.5	72.6	103.7	80.9	49.5	42.4	50.7	19.3	0.02	2.3	0.46
14:45	8.57	785.97	31.2	29.5	70.6	63.6	69.2	98.1	77.0	45.8	41.1	50.1	18.9	0.02	1.2	0.46
15:00	8.22	753.33	32.1	29.7	69.8	61.1	67.9	94.2	74.4	42.3	40.1	49.8	17.7	0.02	3.7	0.47
15:15	7.75	710.80	32.3	30.9	67.1	60.2	65.7	89.5	71.8	39.5	36.2	49.0	16.7	0.02	1.3	0.45
15:30	7.33	671.56	32.7	31.1	65.1	58.6	66.7	84.2	69.8	37.1	34.0	48.1	15.4	0.02	2.2	0.44
15:45	6.98	639.65	33.0	32.1	64.1	56.2	64.9	79.8	67.0	34.0	32.0	48.1	15.1	0.02	2.7	0.44
16:00	6.61	605.73	33.2	32.3	62.4	54.6	63.2	75.4	64.4	31.2	30.1	47.4	14.2	0.02	1.8	0.43
16:15	6.05	555.03	33.2	32.6	60.4	48.8	59.3	70.5	59.5	26.3	27.8	46.5	13.3	0.02	1.4	0.44
16:30	5.61	513.87	32.9	32.8	56.4	46.1	54.6	68.4	56.4	23.5	23.6	44.6	11.7	0.02	1.0	0.40
16:45	5.03	460.69	33.2	34.1	53.7	44.3	53.1	66.1	54.5	21.3	19.6	43.9	10.7	0.02	2.3	0.37
17:00	4.68	429.25	33.4	33.4	51.8	43.1	50.6	64.7	52.8	19.4	18.4	42.6	9.2	0.02	1.6	0.38
Average		729.88	28.0	25.0	57.4	54.1	60.4	76.4	63.6	35.7	32.4	41.2	13.2	0.02	2.4	0.38
Std deviation		159.65	4.7	5.9	13.7	13.0	12.6	20.5	15.1	12.1	10.4	9.2	5.1	0.01	1.1	0.07

Time of day	Solar rad.	Solar rad.	T _a	T _i	T _o	T _{p1}	T _{p2}	T _{p3}	T _{p.av.}	(T _{p.av.} -T _a)	(T _o -T _i)	T _m	(T _m -T _a)	(T _m -T _a)/I	Wind vel.	Th _{eff}
(Hrs)	(mV)	I (W/m ²)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(m ² C/W)	v (m/s)	
9:00	4.59	421.22	20.5	17.1	28.5	27.8	32.7	37.9	32.8	12.3	11.4	22.8	2.3	0.005	3.0	0.24
9:15	5.27	482.93	21.9	17.4	30.7	28.9	34.1	41.8	34.9	13.0	13.3	24.1	2.2	0.004	1.7	0.24
9:30	6.66	610.29	21.5	17.5	32.9	32.9	36.9	43.7	37.8	16.3	15.4	25.2	3.7	0.006	3.8	0.22
9:45	6.84	627.43	22.1	18.4	36.0	34.1	41.9	49.9	42.0	19.9	17.6	27.2	5.1	0.008	3.0	0.25
10:00	6.92	634.49	22.1	18.4	38.5	35.1	43.6	51.2	43.3	21.2	20.1	28.5	6.4	0.010	3.1	0.28
10:15	7.53	690.61	22.9	18.1	41.1	39.5	47.4	58.3	48.4	25.5	23.0	29.6	6.7	0.010	2.4	0.29
10:30	7.73	708.31	24.7	19.6	44.8	44.6	51.7	61.9	52.7	28.0	25.2	32.2	7.5	0.011	1.8	0.31
10:45	6.70	614.51	24.9	19.1	48.9	49.8	55.8	66.8	57.5	32.6	29.8	34.0	9.1	0.015	1.0	0.42
11:00	8.79	806.14	26.2	19.3	51.7	51.7	59.8	71.9	61.1	34.9	32.4	35.5	9.3	0.012	1.1	0.35
11:15	8.86	812.74	26.7	20.9	55.1	54.5	62.7	76.4	64.5	37.8	34.2	38.0	11.3	0.014	2.2	0.37
11:30	9.12	836.12	26.5	20.7	59.0	58.3	67.1	83.4	69.6	43.1	38.3	39.9	13.4	0.016	4.2	0.40
11:45	9.46	866.93	27.6	21.8	61.4	59.9	69.1	85.1	71.4	43.8	39.6	41.6	14.0	0.016	4.0	0.40
12:00	9.63	882.88	27.7	21.5	64.8	61.4	70.7	88.7	73.6	45.9	43.3	43.2	15.5	0.017	0.7	0.43
12:15	9.84	902.60	29.9	22.8	66.4	61.5	72.2	92.7	75.5	45.6	43.6	44.6	14.7	0.016	2.4	0.42
12:30	9.99	915.80	29.8	23.6	68.8	63.5	73.4	95.1	77.3	47.5	45.2	46.2	16.4	0.018	0.6	0.43
12:45	10.11	927.35	30.5	24.7	68.8	65.4	74.8	99.7	80.0	49.5	44.1	46.8	16.3	0.018	2.7	0.42
13:00	10.11	927.08	30.2	25.9	72.0	64.7	76.8	99.4	80.3	50.1	46.1	49.0	18.8	0.020	2.4	0.44
13:15	9.93	910.85	32.2	26.5	70.8	63.8	74.9	102.4	80.4	48.2	44.3	48.7	16.5	0.018	1.6	0.43
13:30	9.77	895.99	32.2	26.4	70.9	65.8	69.9	100.5	78.7	46.5	44.5	48.7	16.5	0.018	2.6	0.43
13:45	9.64	883.62	32.1	27.2	71.2	63.8	74.1	107.8	81.9	49.8	44.0	49.2	17.1	0.019	2.9	0.44
14:00	9.31	853.82	32.6	28.5	72.3	63.2	75.4	110.7	83.1	50.5	43.8	50.4	17.8	0.021	2.1	0.45
14:15	9.17	841.16	32.3	28.9	70.4	64.1	77.4	114.3	85.3	53.0	41.5	49.7	17.4	0.021	1.2	0.43
14:30	8.87	813.47	32.8	29.1	68.7	63.1	75.1	109.5	82.6	49.8	39.6	48.9	16.1	0.020	1.0	0.43
14:45	8.46	775.33	32.6	30.3	67.4	61.9	72.1	105.5	79.8	47.2	37.1	48.9	16.3	0.021	1.7	0.42
15:00	8.19	751.31	33.2	31.1	64.9	60.2	67.5	98.2	75.3	42.1	33.8	48.0	14.8	0.020	1.1	0.39
15:15	7.77	712.43	33.2	31.6	65.4	59.4	66.1	92.4	72.6	39.4	33.8	48.5	15.3	0.021	3.1	0.42
15:30	7.26	665.85	33.9	31.3	62.8	57.4	63.1	87.5	69.3	35.4	31.5	47.1	13.2	0.020	3.2	0.41
15:45	6.83	626.43	33.5	32.7	60.3	54.9	59.2	83.2	65.8	32.3	27.6	46.5	13.0	0.021	1.2	0.39
16:00	6.25	572.70	34.5	32.8	58.4	51.8	57.4	79.6	62.9	28.4	25.6	45.6	11.1	0.019	1.5	0.39
16:15	5.84	535.29	34.5	33.1	56.8	49.6	56.3	74.1	60.0	25.5	23.7	45.0	10.5	0.020	3.1	0.39
16:30	5.20	476.51	34.6	33.4	55.8	47.8	54.2	71.4	57.8	23.2	22.4	44.6	10.0	0.021	1.3	0.41
16:45	4.78	438.46	33.9	33.4	54.4	46.1	51.2	68.7	55.3	21.4	21.0	43.9	10.0	0.023	4.4	0.42
17:00	4.28	392.25	34.1	33.3	51.9	44.1	49.8	66.4	53.4	19.3	18.6	42.6	8.5	0.022	1.5	0.41
Average		721.60	29.3	25.3	57.3	53.0	61.0	81.1	65.1	35.7	32.0	41.3	12.0	0.016	2.2	0.38
Std deviation		162.71	4.5	5.7	12.9	11.4	13.0	21.2	15.1	12.4	10.6	8.4	4.7	0.005	1.0	0.07

Time of day	Solar rad.	Solar rad.	T _a	T _i	T _o	T _{p1}	T _{p2}	T _{p3}	T _{p.av}	(T _{p.av} -T _a)	(T _o -T _i)	T _m	(T _m -T _a)	(T _m -T _a)/I	Wind vel.	Th _{eff}
(Hrs)	(mV)	I (W/m ²)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(m ² °C/W)	v (m/s)	
9:00	4.65	426.45	18.8	16.8	28.5	20.4	27.1	32.8	26.8	8.0	11.7	22.7	3.9	0.009	2.6	0.24
9:15	5.00	458.73	20.4	17.1	30.6	24	27.4	38.8	30.1	9.7	13.5	23.9	3.5	0.008	1.4	0.26
9:30	5.49	503.01	21.2	17.4	32.3	27.2	33.6	40.1	33.6	12.4	14.9	24.9	3.7	0.007	2.5	0.26
9:45	6.39	585.62	23.7	17.9	34.3	29.6	38.8	44.9	37.8	14.1	16.4	26.1	2.4	0.004	3.2	0.25
10:00	6.64	608.36	23.5	18.9	36.5	32.4	43.9	48.1	41.5	18.0	17.6	27.7	4.2	0.007	3.9	0.25
10:15	7.23	662.74	24.6	18.3	38.8	37.4	43.2	54.4	45.0	20.4	20.5	28.6	4.0	0.006	2.3	0.27
10:30	7.64	700.33	25.7	18.9	41.1	42.8	48.5	59.1	50.1	24.4	22.2	30.0	4.3	0.006	4.0	0.28
10:45	8.30	761.39	26.3	19.2	45.6	45.5	52.4	64.2	54.0	27.7	26.4	32.4	6.1	0.008	2.4	0.30
11:00	8.64	792.48	27.4	19.2	49.8	49.2	56.7	69.4	58.4	31.0	30.6	34.5	7.1	0.009	5.5	0.34
11:15	8.88	814.53	27.9	19.7	53.5	52.5	59.8	73.9	62.1	34.2	33.8	36.6	8.7	0.011	1.9	0.36
11:30	9.13	836.85	27.9	20.1	57.2	55.9	64.8	78.2	66.3	38.4	37.1	38.7	10.8	0.013	5.2	0.39
11:45	9.67	886.30	28.2	20.8	61.5	58.4	67.5	82.6	69.5	41.3	40.7	41.2	13.0	0.015	3.5	0.40
12:00	9.57	877.47	29.2	21.9	65.1	62.7	72.4	87.4	74.2	45.0	43.2	43.5	14.3	0.016	3.8	0.43
12:15	9.82	900.03	29.1	23.24	68.3	64.4	76.9	92.4	77.9	48.8	45.1	45.8	16.7	0.019	1.7	0.44
12:30	9.99	915.62	29.9	24.1	70.8	65.7	77.2	98.9	80.6	50.7	46.7	47.5	17.6	0.019	2.7	0.45
12:45	10.18	933.40	30.8	23.6	72.9	69.4	80.2	105.2	84.9	54.1	49.3	48.3	17.5	0.019	0.3	0.46
13:00	10.33	946.97	31.4	25.3	74.4	73.8	84.2	108.4	88.8	57.4	49.1	49.9	18.5	0.019	5.0	0.45
13:15	9.79	897.55	30.1	25.5	73.7	74.1	84.5	112.5	90.4	60.3	48.2	49.6	19.5	0.022	3.5	0.47
13:30	9.59	879.58	31.1	26.8	75.4	78.2	87.1	115.1	93.5	62.4	48.6	51.1	20.0	0.023	2.4	0.48
13:45	9.09	833.65	31.4	27.2	73.1	76.5	86.9	114.2	92.5	61.1	45.9	50.2	18.8	0.022	2.0	0.48
14:00	8.89	815.22	31.6	27.7	73.7	75.6	85.8	110.2	90.5	58.9	46.0	50.7	19.1	0.023	2.9	0.49
14:15	8.62	790.00	31.2	27.4	72.8	72.8	81.1	108.7	87.5	56.3	45.4	50.1	18.9	0.024	2.1	0.50
14:30	8.44	774.23	31.4	29.4	73.4	68.1	76.5	102.1	82.2	50.8	44.0	51.4	20.0	0.026	1.9	0.50
14:45	7.92	725.73	31.8	29.6	71.1	66.7	73.5	98.2	79.5	47.7	41.5	50.4	18.6	0.026	2.3	0.50
15:00	7.55	692.35	32.6	29.7	68.7	62.8	70.9	95.6	76.4	43.8	39.0	49.2	16.6	0.024	3.0	0.49
15:15	7.24	664.02	32.7	30.4	66.2	60.9	68.7	92.4	74.0	41.3	35.8	48.3	15.6	0.023	1.6	0.47
15:30	7.12	653.20	32.3	30.4	65.8	60.1	68.7	88.7	72.5	40.2	35.4	48.1	15.8	0.024	2.0	0.47
15:45	6.49	595.16	32.4	30.9	63.9	57.6	65.8	83.4	68.9	36.5	33.0	47.4	15.0	0.025	3.3	0.49
16:00	5.84	535.65	32.5	30.7	60.6	54.7	63.4	80.8	66.3	33.8	29.9	45.7	13.2	0.025	3.2	0.49
16:15	5.32	487.70	32.4	31.1	57.6	49.9	59.8	76.7	62.1	29.7	26.5	44.4	12.0	0.025	1.1	0.48
16:30	5.00	458.08	33.2	32.5	54.6	48.8	56.4	72.5	59.2	26.0	22.1	43.6	10.4	0.023	1.5	0.42
16:45	4.79	439.10	33.1	32.9	53.8	46.8	53.7	69.4	56.6	23.5	20.9	43.4	10.3	0.023	1.5	0.42
17:00	4.60	421.59	33.9	32.7	51.1	44.9	51.8	66.7	54.5	20.6	18.4	41.9	8.0	0.019	2.0	0.38
Average		705.25	29.1	24.8	58.1	54.8	63.3	80.8	66.3	37.2	33.3	41.4	12.3	0.017	2.7	0.41
Std. Deviation		166.38	4.0	5.3	14.6	15.8	17.0	23.4	18.7	16.0	12.0	9.2	5.9	0.007	1.2	0.63

Date: 12 - 02 - 05		Test No. 43		Flow-rate: 30 ± 3litres/hr.												
Time of day	Solar rad.	Solar rad.	T _a	T _i	T _o	T _{p1}	T _{p2}	T _{p3}	T _{p.av.}	(T _{p.av.} -T _a)	(T _o -T _i)	T _m	(T _m -T _a)	(T _m -T _a)/I	Wind vel.	Th _{eff}
(Hrs)	(mV)	I (W/m ²)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(m ² °C/W)	v (m/s)	
9:00	4.748	435.30	19.5	15.2	27.6	27.6	31.8	36.9	32.1	12.6	12.4	21.4	1.9	0.004	2.7	0.25
9:15	5.278	483.89	20.4	15.5	30.7	32.4	34.5	40.6	35.8	15.4	15.2	23.1	2.7	0.006	1.5	0.27
9:30	5.824	533.94	20.9	15.9	33.2	33.2	35.2	45.9	38.1	17.2	17.3	24.6	3.7	0.007	3.9	0.28
9:45	6.289	576.58	21.7	16.1	36.8	36.9	39.4	52.1	42.8	21.1	20.7	26.5	4.8	0.008	1.8	0.31
10:00	6.882	630.94	21.8	15.9	40.8	39.8	44.9	56.9	47.2	25.4	24.9	28.4	6.6	0.010	2.4	0.35
10:15	7.431	681.27	22.6	16.2	44.1	41.9	50.1	61.5	51.2	28.6	27.9	30.2	7.6	0.011	2.7	0.36
10:30	7.74	709.60	22.8	16.2	48.5	45.2	53.4	65.8	54.8	32.0	32.3	32.4	9.6	0.013	2.6	0.40
10:45	8.05	738.02	21.6	17.2	52.3	48.7	58.9	69.9	59.2	37.6	35.1	34.8	13.2	0.018	3.4	0.42
11:00	8.478	777.26	22.3	18.2	57.3	52.4	60.9	72.2	61.8	39.5	39.1	37.8	15.5	0.020	1.8	0.44
11:15	8.81	807.70	22.3	17.5	59.9	56.2	63.7	77.4	65.8	43.5	42.4	38.7	16.4	0.020	3.5	0.46
11:30	9.154	839.24	22.6	17.8	60.7	60.3	67.5	85.6	71.1	48.5	42.9	39.3	16.7	0.020	2.3	0.45
11:45	9.498	870.78	23.2	18.5	64.1	63.9	72.4	92.6	76.3	53.1	45.6	41.3	18.1	0.021	1.5	0.46
12:00	9.684	887.83	24.3	18.8	69.8	66.4	78.1	98.5	81.0	56.7	51.0	44.3	20.0	0.023	3.6	0.50
12:15	9.89	906.72	25.4	19.8	71.5	69.9	80.7	103.2	84.6	59.2	51.7	45.7	20.3	0.022	2.2	0.50
12:30	9.902	907.82	27.3	20.1	74.9	70.4	81.2	105.5	85.7	58.4	54.8	47.5	20.2	0.022	3.7	0.53
12:45	9.989	915.79	26.9	21.1	75.4	73.3	83.4	108.6	88.4	61.5	54.3	48.3	21.4	0.023	2.9	0.52
13:00	10.101	926.06	27.4	22.5	77.1	74.4	85.6	110.4	90.1	62.7	54.6	49.8	22.4	0.024	4.5	0.52
13:15	9.844	902.50	29.5	22.7	79.4	78.3	84.2	115.2	92.6	63.1	56.7	51.1	21.6	0.024	3.8	0.55
13:30	9.822	900.48	29.2	24.5	80.6	79.1	86.6	119.2	95.0	65.8	56.1	52.6	23.4	0.026	1.8	0.55
13:45	9.53	873.71	29.1	25.1	78.8	77.4	87.8	110.2	91.8	62.7	53.7	52.0	22.9	0.026	1.5	0.54
14:00	9.373	859.32	30.6	26.2	77.9	72.8	84.9	107.9	88.5	57.9	51.7	52.1	21.5	0.025	1.9	0.53
14:15	9.184	841.99	30.1	26.5	75.4	69.1	82.7	101.2	84.3	54.2	48.9	51.0	20.9	0.025	5.4	0.51
14:30	8.728	800.18	32.1	27.7	72.6	67.2	76.8	94.1	79.4	47.3	44.9	50.2	18.1	0.023	3.9	0.49
14:45	8.614	789.73	32.6	28.1	68.3	64.5	72.6	89.6	75.6	43.0	40.2	48.2	15.6	0.020	1.2	0.45
15:00	8.167	748.75	32.8	29.6	65.8	62.4	70.7	84.8	72.6	39.8	36.2	47.7	14.9	0.020	1.7	0.42
15:15	7.933	727.30	32.4	29.4	63.9	59.4	67.9	80.2	69.2	36.8	34.5	46.7	14.3	0.020	1.6	0.42
15:30	7.385	677.06	32.5	29.6	62.8	56.4	65.4	77.7	66.5	34.0	33.2	46.2	13.7	0.020	1.7	0.43
15:45	7.171	657.44	32.9	30.8	60.8	53.9	62.7	76.4	64.3	31.4	30.0	45.8	12.9	0.020	3.4	0.40
16:00	6.653	609.95	33.5	32.3	57.7	50.4	59.5	73.2	61.0	27.5	25.4	45.0	11.5	0.019	3.4	0.36
16:15	6.131	562.09	33.3	31.9	56.8	49.4	57.7	70.7	59.3	26.0	24.9	44.4	11.1	0.020	4.1	0.39
16:30	5.742	526.43	33.9	32.2	54.4	47.4	54.9	69.8	57.4	23.5	22.2	43.3	9.4	0.018	5.1	0.37
16:45	5.285	484.53	33.2	33.4	52.9	44.9	53.4	67.8	55.4	22.2	19.5	43.2	10.0	0.021	5.2	0.35
17:00	4.978	456.38	33.9	34.2	50.8	42.4	51.7	62.7	52.3	18.4	16.6	42.5	8.6	0.019	2.9	0.32
Average		728.68	27.4	23.2	60.1	56.6	64.9	81.3	67.6	40.2	36.9	41.7	14.3	0.020	2.9	0.43
Std. Deviation		152.51	4.9	6.2	14.7	14.3	16.2	22.0	17.5	12.6	13.7	9.0	6.2	0.041	1.2	0.08

Thermal performance of collector with copper pipes on aluminium absorber plate with reflectors in position.

Date: 13 - 02 - 05

Test No. 44

Flow-rate: 30 ± 3litres/hr

Time of day	Solar rad.	Solar rad.	T _a	T _i	T _o	T _{p1}	T _{p2}	T _{p3}	T _{pav}	(T _{pav} -T _a)	(T _o -T _i)	T _m	T _m -T _a	(T _m -T _a)/I	Wind vel	Th _{eff}
(Hrs)	(mV)	I (w/m ²)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(m ² °C/W)	v (m/s)	
9:00	4.48	410.54	19.4	14.3	25.7	27.6	33.4	38.6	33.2	13.8	11.4	20.0	0.6	0.001	1.7	0.24
9:15	4.99	457.02	20.1	14.2	30.1	31.4	36.1	42.2	36.6	16.5	15.9	22.2	2.1	0.004	4.7	0.30
9:30	5.85	536.05	19.8	14.7	32.4	33.9	39.6	45.1	39.5	19.7	17.7	23.6	3.8	0.007	2.1	0.29
9:45	6.25	572.54	20.4	14.5	34.8	36.6	43.7	49.2	43.2	22.8	20.3	24.7	4.3	0.007	2.6	0.31
10:00	6.87	630.21	20.8	14.9	37.4	39.1	47.2	53.4	46.6	25.8	22.5	26.2	5.4	0.008	2.4	0.31
10:15	7.26	665.41	22.1	15.1	39.7	42.4	49.8	57.2	49.8	27.7	24.6	27.4	5.3	0.008	2.8	0.32
10:30	7.78	713.45	21.9	14.7	44.7	45.1	52.2	61.3	52.9	31.0	30.0	29.7	7.8	0.011	3.0	0.37
10:45	7.98	731.97	22.1	15.8	47.4	48.5	54.6	64.2	55.8	33.7	31.6	31.6	9.5	0.013	4.5	0.38
11:00	8.29	759.94	22.4	16.1	49.7	50.1	56.3	66.7	57.7	35.3	33.6	32.9	10.5	0.014	5.5	0.39
11:15	9.11	835.02	23.9	17.2	51.8	52.8	56.9	68.6	59.4	35.5	34.6	34.5	10.6	0.013	2.6	0.36
11:30	9.36	857.76	24.3	17.9	53.8	53.7	57.7	69.4	60.3	36.0	35.9	35.9	11.6	0.013	2.1	0.37
11:45	9.58	878.39	24.6	17.6	56.1	54.8	59.4	73.9	62.7	38.1	38.5	36.9	12.3	0.014	2.7	0.38
12:00	10.00	916.43	25.2	19.0	59.1	57.8	62.4	75.5	65.2	40.0	40.1	39.1	13.9	0.015	3.1	0.38
12:15	9.93	910.20	26.2	19.8	62.7	56.7	65.7	78.1	66.8	40.6	42.9	41.3	15.1	0.017	1.0	0.41
12:30	9.80	898.01	26.5	19.9	65.5	59.1	68.4	84.8	70.8	44.3	45.6	42.7	16.2	0.018	3.6	0.44
12:45	9.42	863.44	27.5	21.3	67.4	64.2	71.5	91.1	75.6	48.1	46.1	44.4	16.9	0.020	2.9	0.47
13:00	9.28	851.16	27.4	21.5	71.1	66.8	75.2	96.4	79.5	52.1	49.6	46.3	18.9	0.022	1.4	0.51
13:15	9.09	832.91	27.8	22.5	73.4	68.7	78.9	100.2	82.6	54.8	50.9	48.0	20.2	0.024	6.0	0.53
13:30	9.69	888.10	28.9	22.8	74.9	72.7	81.2	105.1	86.3	57.4	52.1	48.9	20.0	0.022	3.1	0.51
13:45	9.20	843.73	30.1	24.3	75.5	73.8	78.6	104.8	85.7	55.6	51.2	49.9	19.8	0.023	2.4	0.53
14:00	9.17	840.80	30.6	24.8	72.8	70.5	75.8	98.7	81.7	51.1	48.0	48.8	18.2	0.022	1.5	0.50
14:15	8.74	801.19	31.5	27.0	69.9	69.5	73.7	90.4	77.9	46.4	42.9	48.5	17.0	0.021	1.8	0.47
14:30	8.67	795.05	32.7	27.0	65.9	67.7	74.8	87.5	76.7	44.0	38.9	46.5	13.8	0.017	1.9	0.43
14:45	8.69	796.88	31.7	27.2	63.6	66.1	73.3	85.4	74.9	43.2	36.4	45.4	13.7	0.017	5.1	0.40
15:00	7.48	685.95	31.9	29.8	62.7	66.6	71.2	83.4	73.7	41.8	32.9	46.3	14.4	0.021	5.6	0.42
15:15	7.15	655.05	32.4	31.8	60.4	59.8	68.4	80.4	69.5	37.1	28.6	46.1	13.7	0.021	4.3	0.38
15:30	6.78	621.96	32.9	31.3	61.8	57.8	63.4	75.9	65.7	32.8	30.5	46.6	13.7	0.022	2.7	0.43
15:45	6.46	592.07	33.1	29.9	59.5	58.1	62.4	73.9	64.8	31.7	29.6	44.7	11.6	0.020	1.8	0.44
16:00	5.94	544.67	32.9	32.1	56.8	55.2	59.8	69.4	61.5	28.6	24.7	44.5	11.6	0.021	1.9	0.40
16:15	5.38	493.06	33.1	32.8	54.8	55.3	58.2	68.2	60.6	27.5	22.0	43.8	10.7	0.022	1.7	0.39
16:30	4.93	451.52	33.8	32.9	53.7	56.4	57.9	66.7	60.3	26.5	20.8	43.3	9.5	0.021	2.3	0.40
16:45	4.59	420.54	33.4	32.7	53.1	53.8	55.9	65.4	58.4	25.0	20.4	42.9	9.5	0.023	1.8	0.42
17:00	4.39	402.38	33.9	32.9	52.4	49.8	52.9	63.7	55.5	21.6	19.5	42.7	8.8	0.022	2.7	0.42
Average		701.62	27.4	22.7	55.8	55.2	61.1	73.8	63.4	35.9	33.0	39.3	11.8	0.017	2.9	0.40
Std. Deviation		164.13	4.9	6.7	13.2	12.0	12.4	17.3	13.8	11.4	11.3	8.8	5.1	0.006	1.3	0.07

Date: 14 - 02 - 05

Test No. 45

Flow-rate 40 ± 3l/hr.

Time of day	Solar rad.	Solar rad.	T _a	T _i	T _o	T _{p1}	T _{p2}	T _{p3}	T _{p.av.}	(T _{p.av.} -T _a)	(T _o -T _i)	T _m	(T _m -T _a)	(T _m -T _a)/I	Wind vel.	Th _{eff.}
(Hrs)	(mV)	I (W/m ²)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(m ² °C/W)	v (m/s)	
9:00	4.214	386.34	20.5	16.2	25.8	25.2	29.9	42.5	32.5	12.0	9.6	21.0	0.5	0.001	1.1	0.22
9:15	4.715	432.27	22.5	17.8	29.9	30.4	37.4	44.1	37.3	14.8	12.1	23.9	1.4	0.003	1.6	0.24
9:30	6.379	584.83	23.3	18.1	33.4	35.8	40.2	47.6	41.2	17.9	15.3	25.8	2.5	0.004	2.2	0.23
9:45	6.654	610.04	23.6	18.9	36.7	36.3	44.8	50.2	43.8	20.2	17.8	27.8	4.2	0.007	1.4	0.26
10:00	7.184	658.63	24.7	19.6	38.8	38.4	46.3	54.1	46.3	21.6	19.2	29.2	4.5	0.007	3.2	0.26
10:15	7.257	665.32	24.9	20.9	39.6	41.6	48.1	59.4	49.7	24.8	18.7	30.3	5.4	0.008	1.6	0.25
10:30	7.878	722.26	25.5	20.2	44.6	44.8	51.2	63.7	53.2	27.7	24.4	32.4	6.9	0.010	1.0	0.30
10:45	7.932	727.21	27.1	21.3	48.8	49.9	53.8	66.1	56.6	29.5	27.5	35.1	8.0	0.011	3.4	0.33
11:00	8.745	801.74	27.7	21.6	50.8	52.1	57.9	69.2	59.7	32.0	29.2	36.2	8.5	0.011	2.6	0.32
11:15	9.714	890.58	27.1	21.1	53.3	54.9	59.6	71.4	62.0	34.9	32.2	37.2	10.1	0.011	1.2	0.32
11:30	9.502	871.14	28.8	21.5	56.4	56.2	62.4	74.6	64.4	35.6	34.9	39.0	10.2	0.012	1.6	0.35
11:45	9.821	900.39	29.7	22.8	58.8	59.1	66.4	79.7	68.4	38.7	36.0	40.8	11.1	0.012	0.8	0.35
12:00	9.207	844.10	30.2	22.5	60.8	61.9	67.6	82.2	70.6	40.4	38.3	41.7	11.5	0.014	1.3	0.40
12:15	9.976	914.60	30.9	22.4	63.8	65.8	69.1	86.7	73.9	43.0	41.4	43.1	12.2	0.013	2.9	0.40
12:30	10.475	960.35	30.9	22.8	65.4	69.1	71.2	88.7	76.3	45.4	42.6	44.1	13.2	0.014	2.5	0.39
12:45	10.542	966.49	31.5	23.6	68.5	71.2	73.1	90.4	78.2	46.7	44.9	46.1	14.6	0.015	3.7	0.41
13:00	10.789	989.14	33.1	25.9	70.6	72.7	75.2	98.7	82.2	49.1	44.7	48.3	15.2	0.015	3.3	0.40
13:15	10.926	1001.70	32.9	27.1	72.7	72.9	76.2	101.2	83.4	50.5	45.6	49.9	17.0	0.017	0.7	0.40
13:30	9.981	915.06	32.4	30.8	73.1	73.4	75.1	103.4	84.0	51.6	42.3	52.0	19.6	0.021	2.5	0.40
13:45	10.291	943.48	33.0	28.9	75.4	71.3	73.3	99.4	81.3	48.3	46.5	52.2	19.2	0.020	2.6	0.43
14:00	10.003	917.08	33.0	28.8	74.1	69.9	72.7	95.4	79.3	46.3	45.3	51.5	18.5	0.020	3.4	0.43
14:15	9.542	874.81	32.9	29.1	72.8	67.9	69.7	91.2	76.3	43.4	43.7	51.0	18.1	0.021	3.8	0.44
14:30	9.565	876.92	32.8	29.4	70.7	65.6	70.8	92.7	76.4	43.6	41.3	50.1	17.3	0.020	5.0	0.41
14:45	8.952	820.72	33.3	31.1	69.7	62.9	69.8	90.1	74.3	41.0	38.6	50.4	17.1	0.021	4.5	0.41
15:00	8.316	762.41	34.1	31.2	66.8	59.8	68.2	86.2	71.4	37.3	35.6	49.0	14.9	0.020	3.1	0.41
15:15	8.812	807.88	33.7	31.3	65.2	56.9	69.2	84.7	70.3	36.6	33.9	48.3	14.6	0.018	2.1	0.37
15:30	7.877	722.16	33.6	32.8	63.7	55.4	65.7	80.3	67.1	33.5	30.9	48.3	14.7	0.020	1.9	0.37
15:45	7.177	657.99	34.3	32.9	61.8	54.3	65.7	81.6	67.2	32.9	28.9	47.4	13.1	0.020	1.3	0.38
16:00	7.325	671.56	34.2	32.8	61.2	55.2	67.1	77.9	66.7	32.5	28.4	47.0	12.8	0.019	1.2	0.37
16:15	6.475	593.63	33.9	33.8	58.1	51.2	65.2	73.6	63.3	29.4	24.3	46.0	12.1	0.020	2.1	0.36
16:30	5.199	476.64	34.4	34.1	54.7	46.8	62.4	70.4	59.9	25.5	20.6	44.4	10.0	0.021	1.9	0.38
16:45	4.996	458.03	33.9	33.8	52.6	44.4	56.7	67.8	56.3	22.4	18.8	43.2	9.3	0.020	2.7	0.36
17:00	4.895	448.77	34.1	34.4	50.4	42.8	52.1	63.2	52.7	18.6	16.0	42.4	8.3	0.018	1.9	0.31
Average		753.77	30.3	26.0	57.2	55.0	61.6	76.6	64.4	34.2	31.2	41.6	11.4	0.015	2.3	0.36
Std. Deviation		176.42	4.1	5.7	13.6	13.1	11.8	16.7	13.9	10.9	11.0	8.8	5.2	0.029		0.54

Thermal performance of collector with copper pipes on aluminium absorber with reflectors in position

Date: 15 - 02 - 05

Test No. 47

Flow-rate: 30 ± 3 litres/hr.

Time of day	Solar rad.	Solar rad.	T _a	T _i	T _o	T _{p1}	T _{p2}	T _{p3}	T _{p.av.}	(T _{p.av.} -T _a)	(T _o -T _i)	T _m	(T _m -T _a)	(T _m -T _a)/I	Wind vel.	Th _{eff.}
(Hrs)	(mV)	I (W/m ²)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(m ² °C/W)	v (m/s)	
9:00	4.52	414.03	19.8	16.1	25.3	24.4	31.7	35.7	30.6	10.8	9.2	20.7	0.9	0.002	1.4	0.13
9:15	5.00	457.94	20.7	16.7	29.8	28.9	34.7	39.8	34.5	13.8	13.1	23.3	2.6	0.006	2.0	0.18
9:30	5.61	514.42	21.9	16.5	31.3	30.6	35.7	46.4	37.6	15.7	14.8	23.9	2.0	0.004	3.4	0.21
9:45	6.13	562.27	22.0	17.5	34.4	33.3	39.3	51.8	41.5	19.5	16.9	26.0	4.0	0.007	2.7	0.24
10:00	6.84	627.09	22.2	16.7	38.2	36.9	45.7	55.1	45.9	23.7	21.5	27.5	5.3	0.008	1.7	0.30
10:15	7.39	677.88	23.3	17.6	42.3	39.4	49.5	59.8	49.6	26.3	24.7	30.0	6.7	0.010	2.2	0.35
10:30	7.86	720.24	23.8	17.4	45.1	43.9	52.5	64.9	53.8	30.0	27.7	31.3	7.5	0.010	2.8	0.39
10:45	8.16	747.83	25.0	18.0	49.5	47.5	56.2	68.1	57.3	32.3	31.5	33.8	8.8	0.012	1.9	0.44
11:00	8.61	789.55	25.3	19.8	53.7	50.9	60.4	73.8	61.7	36.4	33.9	36.8	11.5	0.015	1.8	0.47
11:15	8.89	815.22	26.0	19.9	56.4	55.9	62.1	76.3	64.8	38.8	36.5	38.2	12.2	0.015	3.1	0.51
11:30	9.28	850.79	27.7	20.1	58.5	58.8	65.4	79.9	68.0	40.3	38.4	39.3	11.6	0.014	2.2	0.54
11:45	9.50	871.33	27.8	20.6	63.4	59.5	69.1	84.9	71.2	43.4	42.8	42.0	14.2	0.016	2.0	0.60
12:00	9.70	889.66	27.4	21.7	68.4	64.4	74.8	90.2	76.5	49.1	46.7	45.1	17.7	0.020	0.7	0.65
12:15	9.94	910.84	29.9	22.1	70.5	66.5	78.6	98.8	81.3	51.4	48.4	46.3	16.4	0.018	1.2	0.68
12:30	10.07	922.76	29.8	23.7	72.8	68.7	83.2	105.6	85.8	56.0	49.1	48.3	18.5	0.020	2.1	0.69
12:45	10.13	928.54	29.8	23.8	76.4	72.8	87.7	109.8	90.1	60.3	52.6	50.1	20.3	0.022	1.8	0.74
13:00	10.16	931.10	30.7	25.2	78.7	76.0	89.1	111.5	92.2	61.5	53.5	52.0	21.3	0.023	2.4	0.75
13:15	10.07	922.76	29.9	26.4	82.5	77.1	89.7	114.8	93.9	64.0	56.1	54.5	24.6	0.027	2.3	0.79
13:30	9.89	906.90	30.8	27.0	83.6	79.9	90.1	119.4	96.5	65.7	56.6	55.3	24.5	0.027	2.0	0.79
13:45	9.63	883.06	31.9	28.2	82.2	76.8	87.5	112.8	92.4	60.5	54.0	55.2	23.3	0.026	1.7	0.76
14:00	9.29	852.07	32.8	28.4	80.9	74.8	86.9	110.2	90.6	57.8	52.5	54.7	21.9	0.026	5.4	0.74
14:15	9.21	844.46	32.3	28.4	78.9	76.8	85.8	113.8	92.1	59.8	50.5	53.7	21.4	0.025	2.2	0.71
14:30	8.98	823.38	33.0	29.4	79.9	74.7	81.2	110.1	88.7	55.7	50.5	54.7	21.7	0.026	4.2	0.71
14:45	8.53	782.21	33.1	29.5	76.0	67.7	78.5	106.2	84.1	51.0	46.5	52.8	19.7	0.025	3.7	0.65
15:00	8.17	749.12	32.4	29.8	74.9	66.9	77.8	104.4	83.0	50.6	45.1	52.4	20.0	0.027	3.8	0.63
15:15	7.77	712.72	33.8	28.9	73.8	64.8	74.4	101.5	80.2	46.4	44.9	51.4	17.6	0.025	2.3	0.63
15:30	7.38	676.69	33.9	30.5	70.1	62.4	72.4	99.2	78.0	44.1	39.6	50.3	16.4	0.024	3.8	0.55
15:45	6.79	622.69	33.5	30.5	68.7	58.4	69.8	94.2	74.1	40.6	38.2	49.6	16.1	0.026	2.6	0.53
16:00	6.41	587.49	33.7	30.5	66.4	54.8	65.7	88.7	69.7	36.0	35.9	48.5	14.8	0.025	3.3	0.50
16:15	5.84	535.69	34.0	32.8	61.9	51.8	63.8	78.2	64.6	30.6	29.1	47.4	13.4	0.025	2.9	0.41
16:30	5.35	490.03	34.3	32.1	58.7	49.5	60.2	69.4	59.7	25.4	26.6	45.4	11.1	0.023	4.8	0.37
16:45	5.01	459.50	33.4	32.1	55.8	45.6	58.9	66.6	57.0	23.6	23.7	44.0	10.6	0.023	3.7	0.33
17:00	4.79	438.69	34.6	32.8	52.9	44.1	56.2	64.7	55.0	20.4	20.1	42.9	8.2	0.019	2.6	0.28
Average		724.82	29.1	24.6	61.9	57.1	67.1	85.0	69.8	40.6	37.3	43.2	14.1	0.019	2.6	0.52
Std. deviation		165.32	4.5	5.6	16.8	15.6	17.0	23.9	18.8	15.9512	13.7	10.5	6.8	0.008	1.0	0.19

Time of day (Hrs.)	Solar rad. (mV)	Solar rad. I (W/m ²)	Wind vel. v (m/s)	Amb. Temp. T _a (°C)	Inlet temp. T _i (°C)	Av. Discharge temp. T _d (°C)	No. of valve discharge/15min.	Pasteurised water discharged/15min. (litres)	Cumulative vol. of discharged water. (litres)
9:00	6.12	560.99	1.4	21.8	14.8	—	0	0.0	0.0
9:15	6.46	592.34	2.4	21.6	16.9	—	0	0.0	0.0
9:30	6.58	603.35	1.8	22.1	17.9	—	0	0.0	0.0
9:45	5.82	533.94	1.2	23.7	18.9	—	0	0.0	0.0
10:00	6.16	565.12	0.8	24.1	20.7	—	0	0.0	0.0
10:15	7.53	690.08	0.4	24.9	19.9	—	0	0.0	0.0
10:30	6.79	622.69	1.1	24.9	20.4	—	0	0.0	0.0
10:45	7.61	698.05	2.6	25.1	21.4	—	0	0.0	0.0
11:00	8.00	733.81	3.2	27.1	21.7	86.5	1	4.2	4.2
11:15	9.23	846.39	1.3	26.9	22.4	—	0	3.9	8.1
11:30	8.44	773.69	1.7	27.1	22.7	85.5	1	3.8	11.9
11:45	10.21	935.96	0.4	27.3	23.8	—	0	0.0	11.9
12:00	9.99	916.07	0.2	28.2	23.9	84.5	1	3.7	15.6
12:15	11.31	1036.44	1.6	30.2	24.1	—	0	0.0	15.6
12:30	11.16	1023.06	1.3	30.4	24.3	85.0	1	3.6	19.2
12:45	11.50	1054.50	0.7	31.7	24.7	83.5	1	3.6	22.8
13:00	9.85	903.05	1.1	31.8	24.9	84.0	1	3.4	26.2
13:15	10.87	996.65	2.3	32.2	25.1	85.0	1	3.5	29.7
13:30	11.18	1024.52	1	32.1	25.8	84.0	1	3.5	33.2
13:45	11.16	1022.78	1	32.7	26.1	84.5	1	3.4	36.6
14:00	10.75	985.84	0.6	32.6	27.3	85.0	0	0.0	36.6
14:15	7.38	676.97	2.2	32.8	29.3	85.0	1	3.4	40.0
14:30	9.66	885.17	1.5	32.9	28.7	84.5	1	3.5	43.5
14:45	9.12	836.30	1.7	33.2	29.3	85.0	1	3.3	46.8
15:00	8.41	771.30	2.9	33.1	31.2	83.0	0	0.0	46.8
15:15	5.94	544.67	1.8	32.9	32.4	83.5	1	3.3	50.1
15:30	5.49	503.51	0.4	33.1	32.6	84.5	1	3.3	53.4
15:45	6.90	632.68	0.9	32.9	31.3	84.0	0	0.0	53.4
16:00	5.74	526.33	1.7	33.6	32.4	84.0	1	3.2	56.6
16:15	5.05	463.08	1.1	33.3	32.6	—	0	0.0	56.6
16:30	5.34	489.30	1.3	33.7	32.5	84.5	1	3.2	59.8
16:45	4.18	383.31	0.6	33.4	33.1	—	0	0.0	59.8
17:00	3.99	365.53	2.8	33.6	33.4	83.5	1	3.2	63.0
		733.26	1.4242424	29.6060606	25.651515	84.5	17	63.0	

Date: 17 - 02 - 05

Test No. 49

Time of day (Hrs.)	Solar rad. (mV)	Solar rad. I (W/m ²)	Wind vel. v (m/s)	Amb. Temp. T _a (°C)	Inlet temp. T _i (°C)	Average Absorber plate temp. T _{p,av.} (°C)	Average Discharge temp. T _d (°C)	No. of valve discharge/15min.	Pasteurised water discharged/15min. (litres)	Cumulative vol. of discharged water. (litres)
9:00	4.52	414.03	1.0	20.7	18.3	29.8	—	0	0.0	0.0
9:15	5.61	514.42	1.9	20.5	18.1	38.4	—	0	0.0	0.0
9:30	5.94	544.76	2.3	21.2	18.8	43.7	—	0	0.0	0.0
9:45	6.54	599.77	1.6	21.5	19.1	53.2	—	0	0.0	0.0
10:00	6.99	640.48	3.7	24.1	19.4	64.4	—	0	0.0	0.0
10:15	7.46	683.66	2.2	25.6	19.7	76.2	—	0	0.0	0.0
10:30	7.93	727.11	1.2	25.3	19.9	86.1	—	0	0.0	0.0
10:45	8.43	772.40	0.8	25.8	20.6	82.5	85.2	1	4.1	4.1
11:00	8.64	792.02	3.6	26.8	20.7	68.6	—	0	0.0	4.1
11:15	9.25	847.58	2.3	27.9	21.4	85.7	85.1	1	3.9	8.0
11:30	9.65	884.25	2.9	27.9	22.2	79.2	84.5	1	3.8	11.8
11:45	7.45	683.20	2.1	28.2	21.9	71.9	85.1	1	3.8	15.6
12:00	8.25	756.73	1.6	28.4	22.1	82.9	86.2	1	3.7	19.3
12:15	7.59	695.76	0.9	28.6	22.4	85.2	86.5	1	3.7	23.0
12:30	11.46	1050.84	0.7	28.7	22.4	72.9	—	0	0.0	23.0
12:45	9.73	891.86	1.1	28.9	23.3	79.3	85.4	1	3.7	26.7
13:00	10.72	982.72	2.1	29.1	24.4	79.7	86.8	2	7.2	33.9
13:15	10.96	1004.90	2.7	29.8	24.9	73.9	—	0	0.0	33.9
13:30	10.40	953.38	2.2	29.3	24.7	85.9	84.1	2	7.3	41.2
13:45	10.51	963.83	4.3	29.9	24.9	91.1	85.4	1	3.6	44.8
14:00	10.38	951.27	2.2	30.4	25.2	82.4	83.8	2	6.9	51.7
14:15	10.41	954.66	1.4	31.3	25.8	81.7	84.7	1	3.5	55.2
14:30	8.93	818.89	1.0	32.5	26.7	69.9	85.2	1	3.3	58.5
14:45	7.20	659.82	3.8	32.5	28.4	88.3	83.1	2	6.7	65.2
15:00	8.16	747.65	2.4	32.3	28.4	83.1	—	0	0.0	65.2
15:15	9.13	837.41	3.8	32.1	28.6	89.8	84.6	1	3.4	68.6
15:30	6.83	626.45	1.6	32.5	29.1	84.2	85.7	1	3.3	71.9
15:45	6.69	613.06	1.6	32.7	29.1	88.3	83.6	1	3.2	75.1
16:00	6.27	574.47	1.5	33.9	29.5	74.7	—	0	0.0	75.1
16:15	6.14	563.10	0.8	33.8	30.9	83.5	84.4	1	3.2	78.3
16:30	4.55	417.05	2.8	33.4	32.7	81.9	84.8	1	3.1	81.4
16:45	4.41	404.68	0.5	33.9	34.2	72.2	—	0	0.0	81.4
17:00	4.15	380.75	1.5	34.1	33.7	86.2	84.3	1	3.1	84.5
Sum								24	84.5	
Average		725.85	2.0	28.9	24.6	75.7	84.3			
Std. deviation		189.89	1.0085268	4.0	4.6	14.8				

Time of day (Hrs.)	Solar rad. (mV)	Solar rad. I (W/m ²)	Wind vel. v (m/s)	Amb. Temp. T _a (°C)	Inlet temp. T _i (°C)	Av. Absorber plate temp. T _{p.av.} (°C)	Av. Discharge temp. T _d (°C)	No. of valve discharge/15min.	Pasteurised water discharged/15min. (litres)	Cumulative vol. of discharged water. (litres)
9:00	4.625	424.02	0.8	20.1	15.8	29.8	—	0	0.0	0.0
9:15	5.193	476.09424	1.4	20.5	16.2	37.9	—	0	0.0	0.0
9:30	5.764	528.44352	2.1	21.2	17.4	43.6	—	0	0.0	0.0
9:45	6.331	580.42608	1.0	22.3	17.1	50.5	—	0	0.0	0.0
10:00	6.926	634.97568	0.9	22.9	17.8	62.7	—	0	0.0	0.0
10:15	7.597	696.49296	1.3	23.6	18.1	70.2	—	0	0.0	0.0
10:30	7.949	728.76432	1.9	24.1	18.4	79.5	85.6	1	4.1	4.1
10:45	8.519	781.02192	1.8	25.5	18.9	83.4	—	0	0.0	4.1
11:00	8.929	818.61072	1.4	26.4	19.6	73.5	84.7	1	3.9	8.0
11:15	9.368	858.85824	0.7	25.9	19.6	88.7	—	0	0.0	8.0
11:30	9.425	864.084	1.1	27.8	20.2	82.3	84.8	1	3.9	11.9
11:45	9.767	895.43856	0.7	29.4	21.2	74.1	84.2	1	3.7	15.6
12:00	10.089	924.95952	1.0	28.9	23.2	69.6	83.7	1	3.7	19.3
12:15	10.132	928.90176	0.6	29.6	23.8	89.6	83.4	1	3.8	23.1
12:30	10.307	944.94576	1.9	30.1	24.5	88.5	83.3	1	3.7	26.8
12:45	10.068	923.03424	1.6	31.4	25.1	92.9	83.1	1	3.8	30.6
13:00	10.189	934.12752	2.7	31.8	25.9	92.4	82.9	1	3.6	34.2
13:15	10.086	924.68448	0.9	31.8	25.9	90.7	82.5	2	7.2	41.4
13:30	9.881	905.89008	2.2	32.3	26.4	88.8	82.6	1	3.7	45.1
13:45	9.749	893.78832	2.6	32.6	26.7	94.2	82.4	1	3.6	48.7
14:00	9.469	868.11792	3.1	33.7	27.6	78.9	82.2	2	7.1	55.8
14:15	9.317	854.18256	2.8	33.3	28.9	82.2	82.6	1	3.6	59.4
14:30	9.092	833.55456	1.4	34.5	28.3	83.3	82.2	2	6.9	66.3
14:45	8.872	813.38496	3.5	34.6	28.8	81.9	82.4	1	3.5	69.8
15:00	8.336	764.24448	1.5	33.8	29.1	84.3	82.4	1	3.4	73.2
15:15	7.863	720.87984	4.8	33.6	29.4	83.7	82.7	1	3.5	76.7
15:30	7.393	677.79024	2.8	34.7	29.2	81.6	82.1	1	3.4	80.1
15:45	6.869	629.74992	2.6	34.7	31.7	86.2	82.6	1	3.3	83.4
16:00	6.059	555.48912	3.1	34.4	33.2	75.9	83.1	0	0.0	83.4
16:15	5.832	534.67776	1.0	34.2	33.1	88.7	82.9	1	3.5	86.9
16:30	5.147	471.87696	1.1	34.1	33.6	79.8	—	0	0.0	86.9
16:45	4.854	445.01472	1.0	33.9	33.1	81.4	83.9	1	3.2	90.1
17:00	4.512	413.66016	0.7	34.1	34.2	69.5	—	0	0.0	
Sum								25	90.1	
Average		734.85	1.76	29.8	24.9	77.0	83.14347826			
Std. Deviation		175.35	1.0	4.8	5.8	15.8	0.919274803			

Time of day (Hrs.)	Solar rad. (mV)	Solar rad. I (W/m ²)	Wind vel. v (m/s)	Amb. Temp. T _a (°C)	Inlet temp. T _i (°C)	Average Absorber plate temp. T _{p,av.} (°C)	Average Discharge temp. T _d (°C)	No. of valve discharge/15min.	Pasteurised water discharged/15min. (litres)	Cumulative vol. of discharged water. (litres)
9:00	4.80	439.88	2.1	20.6	15.5	30.1	—	0	0.0	0.0
9:15	5.19	475.54	2.7	21.1	16.9	39.3	—	0	0.0	0.0
9:30	5.62	515.33	3.6	21.7	17.2	45.5	—	0	0.0	0.0
9:45	6.02	552.01	2.9	22.1	17.2	54.6	—	0	0.0	0.0
10:00	6.75	618.66	1.8	22.3	18.7	64.2	—	0	0.0	0.0
10:15	7.25	665.05	1.2	22.7	19.1	69.7	—	0	0.0	0.0
10:30	7.69	704.56	1.9	23.1	19.5	78.7	85.1	1	4.2	4.2
10:45	8.18	749.85	2.5	23.5	19.5	82.5	—	0	0.0	4.2
11:00	8.61	788.91	1.0	23.7	19.8	68.7	84.7	1	3.8	8.0
11:15	8.77	803.85	0.9	23.9	20.2	83.5	—	0	0.0	8.0
11:30	9.05	829.34	1.7	24.9	21.7	67.5	84.7	1	3.9	11.9
11:45	9.33	855.10	4.3	26.1	21.7	86.9	84.3	1	3.8	15.7
12:00	9.88	905.34	0.2	26.7	21.9	84.6	83.9	1	3.9	19.6
12:15	10.06	922.67	0.8	26.9	22.5	83.1	—	0	0.0	19.6
12:30	10.22	936.88	1.2	27.2	22.7	78.9	82.7	2	7.6	27.2
12:45	10.17	931.93	3.3	28.7	22.9	74.5	83.1	1	3.8	31.0
13:00	10.41	954.66	1.9	29.8	23.4	78.2	—	0	0.0	31.0
13:15	10.25	939.44	1.6	29.6	23.7	79.5	83.4	2	7.2	38.2
13:30	10.48	961.17	2.5	29.6	23.9	85.4	82.8	1	3.7	41.9
13:45	9.84	902.13	1.8	31.8	24.1	88.8	82.2	2	7.1	49.0
14:00	9.22	844.83	3.9	31.6	24.8	86.6	82.5	1	3.6	52.6
14:15	8.79	805.68	1.6	32.1	26.8	87.4	82.1	2	6.8	59.4
14:30	7.59	695.76	1.6	32.2	27.7	80.4	82.1	1	3.5	62.9
14:45	7.27	666.79	1.7	33.1	28.1	90.4	82.7	1	3.6	66.5
15:00	6.92	634.70	3.9	34.1	28.7	86.8	82.5	1	3.5	70.0
15:15	7.89	723.45	4.7	33.8	27.9	87.2	82.7	1	3.4	73.4
15:30	7.28	667.06	2.0	34.2	27.9	84.2	82.6	1	3.4	76.8
15:45	6.86	629.11	3.0	33.9	29.7	80.7	82.9	1	3.4	80.2
16:00	6.42	588.31	2.6	34.8	30.5	73.4	—	0	0.0	80.2
16:15	5.75	527.25	1.1	34.1	31.2	88.7	83.3	1	3.4	83.6
16:30	5.39	493.79	1.6	34.7	32.8	82.8	82.3	1	3.2	86.8
16:45	4.95	453.91	0.8	34.6	33.1	88.2	—	0	0.0	86.8
17:00	4.42	405.32	1.1	34.6	33.2	78.2	82.1	1	3.3	90.1
Sum								25	90.1	
Average		714.80	2.1	28.6	24.1	76.3	83.1			
Std. deviation		169.31		4.9	5.0	14.5	0.9			

Time of day (Hrs.)	Solar rad. (mV)	Solar rad. I (W/m ²)	Wind vel. v (m/s)	Amb. Temp. T _a (°C)	Inlet temp. T _i (°C)	Average Absorber plate temp. T _{p.av.} (°C)	Average Discharge temp. T _d (°C)	No. of valve discharge/15min.	Pasteurised water discharged/15min. (litres)	Cumulative vol. of discharged water. (litres)
9:00	4.80	439.61	1.8	20.1	16.1	31.2	—	0	0.0	0.0
9:15	5.22	478.66	1.2	20.7	16.9	43.7	—	0	0.0	0.0
9:30	5.87	537.89	2.4	21.3	17.7	51.6	—	0	0.0	0.0
9:45	6.46	592.07	1.5	21.4	17.7	61.9	—	0	0.0	0.0
10:00	7.14	654.78	1.4	22.7	18.1	69.5	—	0	0.0	0.0
10:15	7.72	707.59	2.9	22.5	18.3	79.8	—	0	0.0	0.0
10:30	8.29	760.21	2.4	24.2	18.7	76.9	85.4	1	4.1	4.1
10:45	8.54	783.04	1.4	24.9	19.4	83.6	—	0	0.0	4.1
11:00	9.01	826.40	1.2	25.1	20.2	73.4	84.6	1	3.9	8.0
11:15	9.55	875.09	1.8	25.4	20.6	84.7	—	0	0.0	8.0
11:30	9.82	900.11	0.9	25.2	20.9	84.5	84.2	1	3.7	11.7
11:45	10.08	924.41	2.2	26.4	21.7	78.9	83.8	1	3.7	15.4
12:00	10.21	936.24	1.1	26.9	21.7	72.7	83.9	1	3.8	19.2
12:15	10.47	960.07	2.7	28.5	22.3	69.8	84.8	1	3.9	23.1
12:30	10.54	966.12	3.5	27.9	22.7	71.4	84.1	1	3.8	26.9
12:45	10.44	956.96	3.8	28.8	23.4	77.8	84.4	1	3.8	30.7
13:00	10.31	944.95	1.7	28.4	23.9	79.2	84.6	1	3.8	34.5
13:15	10.05	921.57	2.6	29.9	24.3	77.2	84.9	2	7.3	41.8
13:30	9.99	915.79	1.5	29.7	25.1	81.1	84.1	1	3.7	45.5
13:45	9.83	900.76	1.6	31.5	26.2	90.7	83.8	2	7.2	52.7
14:00	9.57	877.29	0.9	31.7	26.9	88.4	84.6	1	3.6	56.3
14:15	9.36	857.67	1.1	31.9	26.7	74.5	83.7	1	3.5	59.8
14:30	9.08	832.27	3.2	33.3	27.9	83.2	83.2	1	3.5	63.3
14:45	8.74	801.10	3.1	33.4	28.6	87.8	83.8	1	3.4	66.7
15:00	8.33	763.42	0.6	34.1	29.3	90.4	82.9	1	3.4	70.1
15:15	7.93	727.21	4.0	34.4	29.7	87.7	83.1	1	3.4	73.5
15:30	7.54	690.90	1.5	33.8	30.5	88.6	84.1	1	3.3	76.8
15:45	6.94	635.89	0.4	34.5	31.2	93.1	84.9	1	3.2	80.0
16:00	6.24	572.36	1.1	34.3	31.9	88.4	82.7	1	3.1	83.1
16:15	5.82	533.58	1.6	34.1	32.4	82.7	83.2	1	3.1	86.2
16:30	5.42	497.18	0.8	34.9	32.9	75.1	82.8	1	3.1	89.3
16:45	5.03	460.97	1.8	34.8	33.1	86.6	82.7	1	3.0	92.3
17:00	4.70	430.44	1.4	34.5	33.1	79.4	82.9	1	2.9	95.2
Sum								27	95.2	
Average		747.35	1.8	28.8	24.5	77.1	83.8			
Std. deviation		173.60	0.9	4.8	5.3	13.3	0.7			

Time of day (Hrs.)	Solar rad. (mV)	Solar rad. I (W/m ²)	Wind vel. v (m/s)	Amb. Temp. T _a (°C)	Inlet temp. T _i (°C)	Av. Absorber plate temp. T _{p.av.} (°C)	Av. Discharge temp. T _d (°C)	No. of valve discharge/15min.	Pasteurised water discharged/15min. (litres)	Cumulative vol. of discharged water. (litres)
9:00	4.53	414.85	3.0	20.7	16.1	29.7	-	0	0.0	0.0
9:15	5.28	484.35	2.0	22.7	16.7	39.8	-	0	0.0	0.0
9:30	5.87	538.07	2.5	23.4	16.7	49.4	-	0	0.0	0.0
9:45	6.21	569.06	4.6	23.2	17.9	58.5	-	0	0.0	0.0
10:00	6.96	637.73	1.1	24.6	18.3	68.4	-	0	0.0	0.0
10:15	7.42	680.63	0.6	24.9	18.7	76.4	-	0	0.0	0.0
10:30	7.98	731.79	3.2	24.7	19.5	83.2	-	0	0.0	0.0
10:45	8.53	782.31	1.8	25.2	20.4	83.7	83.1	1	4.1	4.1
11:00	8.98	823.01	2.2	27.6	20.3	68.7	-	0	0.0	4.1
11:15	9.43	864.45	1.1	27.7	20.5	86.4	85.4	1	3.8	7.9
11:30	9.70	888.93	1.6	29.2	21.4	76.4	-	0	0.0	7.9
11:45	9.98	914.51	1.2	29.8	22.5	90.3	84.4	1	3.8	11.7
12:00	10.05	921.66	1.6	29.3	23.5	88.6	83.2	1	3.8	15.5
12:15	10.16	931.65	1.0	29.3	23.6	90.2	84.1	1	3.7	19.2
12:30	10.43	956.31	2.5	29.3	25.1	89.7	83.8	1	3.7	22.9
12:45	10.54	966.67	1.7	30.8	26.3	91.2	84.5	1	3.7	26.6
13:00	10.47	960.07	2.6	31.6	27.2	92.6	83.2	2	7.3	33.9
13:15	10.26	940.91	3.3	31.6	26.9	82.4	83.9	1	3.6	37.5
13:30	10.14	929.54	2.1	32.2	27.9	87.8	82.9	2	7.1	44.6
13:45	10.05	921.57	2.6	32.4	28.4	91.1	83.7	1	3.5	48.1
14:00	9.91	908.73	3.1	32.3	28.1	83.6	84.1	1	3.5	51.6
14:15	9.64	883.52	4.3	33.5	28.9	90.4	83.6	2	6.9	58.5
14:30	9.33	855.28	1.3	33.9	28.9	92.2	83.2	1	3.5	62.0
14:45	9.14	837.59	1.9	33.9	29.1	75.5	83.6	1	3.4	65.4
15:00	8.55	783.50	2.6	34.1	29.7	80.8	82.8	1	3.4	68.8
15:15	8.03	736.56	4.4	33.9	30.3	84.7	83.4	1	3.3	72.1
15:30	7.84	719.05	1.6	34.4	30.9	85.1	84.2	1	3.4	75.5
15:45	7.25	664.77	1.2	34.3	31.3	81.4	82.7	1	3.3	78.8
16:00	6.90	632.87	2.3	34.4	31.9	77.1	83.1	1	3.3	82.1
16:15	6.43	589.59	3.7	33.9	31.9	75.4	82.7	1	3.0	85.1
16:30	5.84	535.04	2.4	34.4	32.1	90.4	82.9	1	3.1	88.2
16:45	5.09	466.19	2.9	34.1	32.8	83.8	83.1	1	2.9	91.1
17:00	4.50	412.74	2.8	34.5	33.4	88.4	82.6	1	2.8	93.9
Sum								27	93.9	
Average		754.05	2.3	30.1	25.4	79.2	83.4			
Std. deviation		173.12	1.0	4.2	5.4	14.9	0.6			

Time of day (Hrs.)	Solar rad. (mV)	Solar rad. I (W/m ²)	Wind vel. v (m/s)	Amb. Temp. T _a (°C)	Inlet temp. T _i (°C)	Av. Absorber plate temp. T _{p.av.} (°C)	Av. Discharge temp. T _d (°C)	No. of valve discharge/15min.	Pasteurised water discharged/15min. (litres)	Cumulative vol. of discharged water. (litres)
9:00	4.59	420.63	3.9	19.8	15.4	37.2	—	0	0.0	0.0
9:15	5.05	462.71	1.1	20.9	16.2	46.7	—	0	0.0	0.0
9:30	5.75	527.53	2.9	21.5	16.8	56.2	—	0	0.0	0.0
9:45	6.15	563.37	3.5	21.5	16.8	59.4	—	0	0.0	0.0
10:00	6.90	632.96	3.6	22.8	17.2	66.4	—	0	0.0	0.0
10:15	7.70	705.75	2.2	23.4	17.5	72.3	—	0	0.0	0.0
10:30	8.24	755.17	2.3	23.8	18.3	79.7	—	0	0.0	0.0
10:45	8.45	774.33	1.2	25.7	18.1	82.2	85.1	1	4.2	4.2
11:00	8.96	821.82	4.4	25.7	17.9	69.6	—	0	0.0	4.2
11:15	9.50	870.87	3.2	25.9	18.9	86.7	84.9	1	3.8	8.0
11:30	9.76	894.43	1.2	26.8	19.6	81.4	—	0	0.0	8.0
11:45	10.08	924.23	0.4	27.6	20.2	72.6	84.2	1	3.8	11.8
12:00	10.19	933.76	2.1	27.3	21.2	87.9	84.1	1	3.8	15.6
12:15	10.23	937.98	1.5	29.3	22.3	85.4	84.7	1	3.8	19.4
12:30	10.44	957.51	1.9	29.2	23.1	87.3	83.9	1	3.7	23.1
12:45	10.27	941.46	4.6	30.6	24.3	85.4	84.8	1	3.7	26.8
13:00	10.36	950.08	1.3	29.7	25.7	90.7	82.9	1	3.7	30.5
13:15	10.30	943.85	1.5	31.8	27.1	72.4	82.7	2	7.1	37.6
13:30	9.97	913.96	2.9	31.2	26.9	82.5	83.7	1	3.5	41.1
13:45	9.78	897.00	1.9	32.6	27.1	87.6	84.1	1	3.6	44.7
14:00	9.70	889.20	3.5	32.8	27.9	91.2	82.8	2	7.1	51.7
14:15	9.50	870.50	1.3	32.9	27.4	78.9	83.4	1	3.5	55.2
14:30	8.97	822.55	1.0	33.9	28.5	86.3	84.4	1	3.4	58.6
14:45	8.70	797.43	1.1	34.1	29.4	91.6	84.1	1	3.4	62.0
15:00	8.45	774.88	2.4	33.8	30.1	92.3	83.8	1	3.4	65.4
15:15	8.06	738.48	2.4	34.7	31.2	87.4	83.2	1	3.3	68.7
15:30	7.90	723.91	2.2	34.5	31.6	77.6	84.1	1	3.2	71.9
15:45	7.39	677.42	4.7	34.7	31.9	91.4	83.9	1	3.1	75.0
16:00	6.90	632.96	2.5	34.9	32.1	94.4	82.9	1	3.0	78.0
16:15	6.42	588.40	4.1	35.1	32.7	88.5	83.4	1	3.0	81.0
16:30	5.83	534.40	1.2	34.9	33.1	81.1	82.7	1	2.9	83.9
16:45	5.30	485.54	0.7	35.3	33.5	91.7	83.5	1	2.7	86.6
17:00	4.69	430.16	0.4	35.7	33.3	78.9	82.9	1	2.8	89.4
Sum								26	89.4	
Average		751.37	2.3	29.5	24.6	79.4	83.6			
Std. deviation		169.14	1.2	5.0	6.0	13.3	0.6			

Time of day (Hrs.)	Solar rad. (mV)	Solar rad. I (W/m ²)	Wind vel. v (m/s)	Amb. Temp. T _a (°C)	Inlet temp. T _i (°C)	Av. Absorber plate temp. T _{p.av.} (°C)	Av. Discharge temp. T _d (°C)	No. of valve discharge/15min.	Pasteurised water discharged/15min. (litres)	Cumulative vol. of discharged water. (litres)
9:00	4.95	453.36	1.8	22.2	15.4	35.7	—	0	0.0	0.0
9:15	5.60	513.22	3.3	22.4	15.9	39.5	—	0	0.0	0.0
9:30	6.23	571.44	2.3	22.7	16.3	44.9	—	0	0.0	0.0
9:45	6.94	636.44	1.6	22.9	17.4	54.4	—	0	0.0	0.0
10:00	7.36	674.49	0.7	23.1	17.8	62.2	—	0	0.0	0.0
10:15	7.97	730.51	2.6	25.3	17.8	68.8	—	0	0.0	0.0
10:30	8.33	763.42	1.8	25.1	18.1	72.4	—	0	0.0	0.0
10:45	8.76	802.93	3.1	26.9	18.4	77.2	—	0	0.0	0.0
11:00	9.16	839.33	3.4	26.9	19.5	84.4	—	0	0.0	0.0
11:15	9.53	873.99	1.6	27.9	19.7	72.2	—	0	0.0	0.0
11:30	9.81	899.29	2.0	28.9	20.8	79.7	86.4	1	3.7	3.7
11:45	10.26	940.91	0.8	30.3	21.3	70.8	—	0	0.0	3.7
12:00	10.30	944.03	1.2	31.1	22.8	84.6	—	0	0.0	3.7
12:15	10.18	933.58	1.6	30.9	23.9	74.1	84.7	1	3.6	7.3
12:30	10.40	953.01	3.5	31.8	24.8	86.3	—	0	0.0	7.3
12:45	10.09	925.14	1.9	32.4	25.2	84.4	83.8	1	3.4	10.7
13:00	10.23	938.07	1.6	32.3	25.1	74.5	82.9	1	3.3	14.0
13:15	10.06	922.21	1.9	33.3	24.9	86.5	—	0	0.0	14.0
13:30	10.00	916.62	1.1	33.4	25.4	87.3	84.1	1	3.5	17.5
13:45	9.79	897.46	0.6	34.7	26.2	77.3	83.7	1	3.4	20.9
14:00	9.70	889.66	1.9	34.2	26.9	64.7	82.9	1	3.4	24.3
14:15	9.41	862.53	2.6	34.9	26.9	88.1	—	0	0.0	24.3
14:30	8.84	810.82	0.7	34.9	27.4	78.2	83.9	1	3.5	27.8
14:45	8.45	774.60	1.0	35.1	29.9	88.4	—	0	0.0	27.8
15:00	8.04	737.20	0.5	35.2	30.6	84.2	83.4	1	3.4	31.2
15:15	7.72	708.14	1.4	35.1	31.4	64.7	82.7	1	3.3	34.5
15:30	7.22	662.30	0.9	35.7	32.1	84.5	83.1	1	3.3	37.8
15:45	6.85	628.10	0.7	35.1	33.1	89.8	82.9	1	3.3	41.1
16:00	6.25	573.37	0.8	35.4	33.1	76.6	—	0	0.0	41.1
16:15	5.69	521.48	1.8	35.6	32.7	83.7	83.6	1	3.4	44.5
16:30	4.99	457.85	2.1	35.4	33.2	84.9	—	0	0.0	44.5
16:45	4.54	416.59	1.3	35.4	33.9	83.1	—	0	0.0	44.5
17:00	3.95	361.95	2.4	35.9	34.2	78.4	83.8	1	3.4	47.9
Sum								14	47.9	
Average		743.46	1.7	31.0	24.9	74.7	83.8			
Std. deviation		176.48	0.8	4.7	6.0	13.8	0.0			

Time of day (Hrs.)	Solar rad. (mV)	Solar rad. I (W/m ²)	Wind vel. v (m/s)	Amb. Temp. T _a (°C)	Inlet temp. T _i (°C)	Average Absorber plate temp. T _{p.av.} (°C)	Average Discharge temp. T _d (°C)	No. of valve discharge/15min.	Pasteurised water discharged/15min. (litres)	Cumulative vol. of discharged water. (litres)
9:00	4.33	396.61	0.5	21.6	15.9	29.3	—	0	0.0	0.0
9:15	4.89	448.13	2.6	21.9	15.7	36.4	—	0	0.0	0.0
9:30	5.44	498.46	1.0	22.9	16.2	44.6	—	0	0.0	0.0
9:45	6.13	561.91	1.4	23.7	17.7	49.2	—	0	0.0	0.0
10:00	6.64	608.94	1.7	24.8	17.8	56.4	—	0	0.0	0.0
10:15	7.09	650.38	2.3	26.1	18.9	62.6	—	0	0.0	0.0
10:30	7.52	689.62	1.2	26.5	18.9	66.9	—	0	0.0	0.0
10:45	7.99	732.34	2.0	26.3	18.8	74.3	—	0	0.0	0.0
11:00	8.42	771.76	1.7	28.2	19.5	77.9	—	0	0.0	0.0
11:15	8.68	796.15	1.3	28.8	20.2	83.1	85.5	1	3.8	3.8
11:30	9.21	844.10	2.4	29.7	20.8	77.4	—	0	0.0	3.8
11:45	9.49	869.68	2.0	30.4	20.9	79.1	—	0	0.0	3.8
12:00	9.65	884.99	1.7	31.3	21.9	85.7	85.4	1	3.9	7.7
12:15	9.81	899.11	0.6	31.4	23.1	82.4	—	0	0.0	7.7
12:30	9.89	906.62	1.2	32.1	23.1	64.8	84.7	1	3.6	11.3
12:45	9.85	903.41	1.3	33.1	23.9	86.6	—	0	0.0	11.3
13:00	9.79	897.82	1.0	33.7	24.9	77.8	84.2	1	3.5	14.8
13:15	9.62	882.14	2.2	33.9	25.1	72.6	83.1	1	3.3	18.1
13:30	9.59	879.03	1.8	33.7	26.6	87.2	—	0	0.0	18.1
13:45	9.40	862.16	1.1	33.9	26.9	75.9	84.3	1	3.5	21.6
14:00	9.17	841.07	2.0	33.7	27.4	91.6	82.9	1	3.3	24.9
14:15	9.06	830.35	2.2	34.1	28.8	85.3	—	0	0.0	24.9
14:30	8.83	809.08	1.7	34.3	28.9	68.9	84.5	1	3.4	28.3
14:45	8.38	768.00	0.9	34.6	29.7	86.8	82.7	1	3.2	31.5
15:00	7.94	728.31	1.0	34.3	30.7	74.8	—	0	0.0	31.5
15:15	7.66	702.36	1.2	34.1	31.1	88.4	83.4	1	3.4	34.9
15:30	7.11	651.75	1.6	33.9	32.4	76.9	82.6	1	3.3	38.2
15:45	6.69	612.97	2.5	34.1	32.2	86.7	—	0	0.0	38.2
16:00	6.13	562.37	2.6	34.5	32.5	72.4	83.1	1	3.4	41.6
16:15	5.70	522.30	2.2	34.7	33.1	81.2	—	0	0.0	41.6
16:30	5.20	476.83	2.3	34.5	33.2	86.1	—	0	0.0	41.6
16:45	4.64	425.49	2.6	34.1	33.9	84.7	83.3	1	3.4	45.0
17:00	4.01	368.00	1.2	34.7	34.5	75.2	—	0	0.0	45.0
Sum								13	45.0	
Average		705.52	1.7	30.9	25.0	73.6	83.8			
Std. deviation		167.75	0.6	4.2	6.0	15.1	1.0			

Time of day (Hrs.)	Solar rad. (mV)	Solar rad. I (W/m ²)	Wind vel. v (m/s)	Amb. Temp. T _a (°C)	Inlet temp. T _i (°C)	Av. Absorber plate temp. T _{p,av.} (°C)	Av. Discharge temp. T _d (°C)	No. of valve discharge/15min.	Pasteurised water discharged/15min. (litres)	Cumulative vol. of discharged water. (litres)
9:00	4.33	396.61	0.5	21.6	15.9	29.3	—	0	0.0	0.0
9:15	4.89	448.13	2.6	21.9	15.7	36.4	—	0	0.0	0.0
9:30	5.44	498.46	1.0	22.9	16.2	44.6	—	0	0.0	0.0
9:45	6.13	561.91	1.4	23.7	17.7	49.2	—	0	0.0	0.0
10:00	6.64	608.94	1.7	24.8	17.8	56.4	—	0	0.0	0.0
10:15	7.09	650.38	2.3	26.1	18.9	62.6	—	0	0.0	0.0
10:30	7.52	689.62	1.2	26.5	18.9	66.9	—	0	0.0	0.0
10:45	7.99	732.34	2.0	26.3	18.8	74.3	—	0	0.0	0.0
11:00	8.42	771.76	1.7	28.2	19.5	77.9	—	0	0.0	0.0
11:15	8.68	796.15	1.3	28.8	20.2	83.1	85.5	1	3.8	3.8
11:30	9.21	844.10	2.4	29.7	20.8	77.4	—	0	0.0	3.8
11:45	9.49	869.68	2.0	30.4	20.9	79.1	—	0	0.0	3.8
12:00	9.65	884.99	1.7	31.3	21.9	85.7	85.4	1	3.9	7.7
12:15	9.81	899.11	0.6	31.4	23.1	82.4	—	0	0.0	7.7
12:30	9.89	906.62	1.2	32.1	23.1	64.8	84.7	1	3.6	11.3
12:45	9.85	903.41	1.3	33.1	23.9	86.6	—	0	0.0	11.3
13:00	9.79	897.82	1.0	33.7	24.9	77.8	84.2	1	3.5	14.8
13:15	9.62	882.14	2.2	33.9	25.1	72.6	83.1	1	3.3	18.1
13:30	9.59	879.03	1.8	33.7	26.6	87.2	—	0	0.0	18.1
13:45	9.40	862.16	1.1	33.9	26.9	75.9	84.3	1	3.5	21.6
14:00	9.17	841.07	2.0	33.7	27.4	91.6	82.9	1	3.3	24.9
14:15	9.06	830.35	2.2	34.1	28.8	85.3	—	0	0.0	24.9
14:30	8.83	809.08	1.7	34.3	28.9	68.9	84.5	1	3.4	28.3
14:45	8.38	768.00	0.9	34.6	29.7	86.8	82.7	1	3.2	31.5
15:00	7.94	728.31	1.0	34.3	30.7	74.8	—	0	0.0	31.5
15:15	7.66	702.36	1.2	34.1	31.1	88.4	83.4	1	3.4	34.9
15:30	7.11	651.75	1.6	33.9	32.4	76.9	82.6	1	3.3	38.2
15:45	6.69	612.97	2.5	34.1	32.2	86.7	—	0	0.0	38.2
16:00	6.13	562.37	2.6	34.5	32.5	72.4	83.1	1	3.4	41.6
16:15	5.70	522.30	2.2	34.7	33.1	81.2	—	0	0.0	41.6
16:30	5.20	476.83	2.3	34.5	33.2	86.1	—	0	0.0	41.6
16:45	4.64	425.49	2.6	34.1	33.9	84.7	83.3	1	3.4	45.0
17:00	4.01	368.00	1.2	34.7	34.5	75.2	—	0	0.0	45.0
Sum								13	45.0	
Average		705.52	1.7	30.9	25.0	73.6	83.8			
Std. deviation		167.75	0.6	4.2	6.0	15.1	1.0			

Time of day (Hrs.)	Solar rad. (mV)	Solar rad. I (W/m ²)	Wind vel. v (m/s)	Amb. Temp. T _a (°C)	Inlet temp. T _i (°C)	Av. Absorber plate temp. T _{p,av.} (°C)	Av. Discharge temp. T _d (°C)	No. of valve discharge/15min.	Pasteurised water discharged/15min. (litres)	Cumulative vol. of discharged water. (litres)
9:00	4.689	429.88752	1.9	20.4	15.5	39.2	-	0	0.0	0.0
9:15	5.158	472.88544	1.5	21.9	16.7	44.3	-	0	0.0	0.0
9:30	5.689	521.56752	1.3	22.8	16.7	47.2	-	0	0.0	0.0
9:45	6.247	572.72496	1.3	22.9	17.3	50.3	-	0	0.0	0.0
10:00	6.674	611.87232	1.5	23.3	17.7	54.7	-	0	0.0	0.0
10:15	7.284	667.79712	1.2	24.1	17.9	58.9	-	0	0.0	0.0
10:30	7.754	710.88672	0.7	24.9	18.3	62.8	-	0	0.0	0.0
10:45	8.032	736.37376	2.6	26.1	18.9	70.7	-	0	0.0	0.0
11:00	8.478	777.26304	2.3	26.2	19.2	75.9	-	0	0.0	0.0
11:15	8.647	792.75696	1.3	26.5	19.1	79.8	85.2	1	3.8	3.8
11:30	8.926	818.33568	1.7	26.6	20.1	69.8	-	0	0.0	3.8
11:45	9.091	833.46288	0.2	27.8	21.2	82.5	84.7	1	3.8	7.6
12:00	9.274	850.24032	1.3	28.2	21.5	80.2	-	0	0.0	7.6
12:15	9.407	862.43376	2.7	29.9	22.2	78.4	83.9	1	3.6	11.2
12:30	9.841	902.22288	0.3	30.7	23.3	63.8	-	0	0.0	11.2
12:45	9.451	866.46768	0.8	31.5	23.6	82.9	84.1	1	3.6	14.8
13:00	9.394	861.24192	2.1	31.5	23.7	71.2	83.4	1	3.5	18.3
13:15	9.247	847.76496	0.9	32.8	24.8	86.6	-	0	0.0	18.3
13:30	9.234	846.57312	1.6	33.3	25.7	75.5	84.2	1	3.5	21.8
13:45	9.153	839.14704	2.1	33.7	26.8	90.4	82.9	1	3.4	25.2
14:00	8.943	819.89424	1.5	33.8	27.1	84.6	83.1	1	3.3	28.5
14:15	8.664	794.31552	2.5	34.1	28.5	76.4	82.7	1	3.2	31.7
14:30	8.346	765.16128	1.2	34.2	29.8	89.8	83.1	1	3.2	34.9
14:45	8.076	740.40768	2.0	34.1	30.4	80.5	-	0	0.0	34.9
15:00	7.716	707.40288	3.0	33.9	30.9	90.5	83.4	1	3.3	38.2
15:15	7.147	655.23696	1.5	33.9	31.3	88.1	-	0	0.0	38.2
15:30	6.882	630.94176	0.9	34.1	32.6	74.2	83.6	1	3.2	41.4
15:45	6.247	572.72496	1.9	34.3	32.4	83.1	-	0	0.0	41.4
16:00	5.887	539.72016	0.8	34.1	32.8	84.4	82.9	1	3.2	44.6
16:15	5.298	485.72064	2.8	34.3	33.6	86.1	-	0	0.0	44.6
16:30	4.885	447.8568	2.6	34.2	33.9	74.1	83.5	1	3.1	47.7
16:45	4.669	428.05392	2.1	33.7	34.1	76.4	-	0	0.0	47.7
17:00	4.214	386.33952	0.5	33.9	34.1	80.4	-	0	0.0	47.7
Sum								14	47.7	
Average		690.78	1.6	29.9	24.9	73.7				
Std. deviation		154.95	0.7	4.5	6.1	13.7				

Time of day	Solar rad. (mV)	Solar rad. (I (W/m ²))	Wind vel. (v (m/s))	Amb. Temp. (T _a (°C))	Inlet temp. (T _i (°C))	Average Absorber plate temp. (T _{p.av.} (°C))	Average Discharge temp. (T _d (°C))	No. of valve discharge/15min.	Pasteurised water discharged/15min. (litres)	Cumulative vol. of discharged water. (litres)
9:00	4.45	408.07	1.2	20.7	15.6	38.4	—	0	0.0	0.0
9:15	4.87	446.85	1.5	21.4	15.8	45.6	—	0	0.0	0.0
9:30	5.27	483.52	2.3	22.1	16.1	49.7	—	0	0.0	0.0
9:45	5.86	537.43	2.4	22.4	15.9	56.2	—	0	0.0	0.0
10:00	6.26	573.55	2.9	23.9	16.7	61.4	—	0	0.0	0.0
10:15	6.75	618.56	2.1	23.9	17.5	65.7	—	0	0.0	0.0
10:30	7.26	665.41	2.5	24.6	17.7	69.3	—	0	0.0	0.0
10:45	7.79	713.91	2.7	25.1	18.2	73.8	—	0	0.0	0.0
11:00	8.45	774.24	2.0	25.2	18.8	78.5	—	0	0.0	0.0
11:15	8.79	805.59	1.5	26.4	19.3	81.4	85.4	1	3.6	3.6
11:30	9.23	845.75	1.3	26.5	19.7	70.8	—	0	0.0	3.6
11:45	9.32	854.73	1.4	26.9	19.7	81.4	84.7	1	3.5	7.1
12:00	9.56	876.19	2.0	27.1	20.5	69.4	—	0	0.0	7.1
12:15	9.71	890.03	2.4	27.9	21.2	84.5	84.9	1	3.5	10.6
12:30	9.89	906.62	1.3	28.7	22.5	70.6	—	0	0.0	10.6
12:45	9.90	907.72	1.4	29.8	23.4	79.8	84.2	1	3.5	14.1
13:00	9.98	915.06	1.1	30.6	24.1	77.9	83.5	1	3.3	17.4
13:15	9.70	889.57	0.9	29.9	25.4	85.9	—	0	0.0	17.4
13:30	9.78	896.54	1.9	31.2	25.6	84.9	83.7	1	3.4	20.8
13:45	9.45	866.65	1.3	32.2	26.8	75.4	82.9	1	3.3	24.1
14:00	9.34	856.47	1.0	32.3	27.2	90.2	82.7	1	3.3	27.4
14:15	9.06	830.16	1.6	32.7	27.4	79.1	—	0	0.0	27.4
14:30	8.95	820.44	1.2	33.2	28.6	81.6	83.4	1	3.4	30.8
14:45	8.39	769.01	1.3	33.5	28.9	83.2	—	0	0.0	30.8
15:00	7.97	731.06	0.9	33.9	30.2	65.9	83.1	1	3.3	34.1
15:15	7.32	671.19	0.7	34.1	31.2	82.4	82.8	1	3.2	37.3
15:30	6.95	637.54	1.6	33.9	32.3	70.4	—	0	0.0	37.3
15:45	6.35	581.71	1.3	34.1	32.7	81.6	83.1	1	3.2	40.5
16:00	5.87	538.53	1.6	33.8	32.9	69.8	—	0	0.0	40.5
16:15	5.49	503.23	1.5	33.9	33.1	79.5	83.3	1	3.2	43.7
16:30	5.09	466.56	1.0	33.9	33.3	82.5	—	0	0.0	43.7
16:45	4.74	434.75	2.1	33.7	33.7	84.2	—	0	0.0	43.7
17:00	4.35	399.17	1.3	33.9	33.7	72.1	82.6	1	2.9	46.6
Sum								14.0	46.6	
Average		700.48	1.6	29.2	24.4	73.4	83.6			
Std. deviation		171.50	0.5	4.4	6.2	11.9	0.7			

Time of day (Hrs.)	Solar rad. (mV)	Solar rad. I (W/m ²)	Wind vel. v (m/s)	Amb. Temp. T _a (°C)	Inlet temp. T _i (°C)	Av. Absorber plate temp. T _{p.av.} (°C)	Av. Discharge temp. T _d (°C)	No. of valve discharge/15min.	Pasteurised water discharged/15min. (litres)	Cumulative vol. of discharged water. (litres)
9:00	4.23	387.53	2.1	24.6	15.8	38.1	—	0	0	0
9:15	4.91	450.06	1.7	25.2	16.6	43.9	—	0	0	0
9:30	5.49	502.86	2.2	26.4	17.3	48.5	—	0	0	0
9:45	5.85	535.87	1.3	26.3	17.3	52.4	—	0	0	0
10:00	6.26	573.64	1.8	26.9	17.7	58.7	—	0	0	0
10:15	6.97	639.38	1.3	27.4	17.9	63.4	—	0	0	0
10:30	7.49	686.41	2.2	27.8	18.3	66.1	—	0	0	0
10:45	8.05	738.39	2.1	28.2	18.8	70.7	—	0	0	0
11:00	8.94	819.25	2.0	28.4	19.7	73.7	—	0	0	0
11:15	8.96	821.54	1.0	28.6	19.7	77.3	—	0	0	0
11:30	8.85	811.09	2.7	29.2	20.2	81.9	85.4	1	3.7	3.7
11:45	9.39	860.97	1.9	28.9	21.7	75.4	—	0	0	3.7
12:00	9.07	831.45	1.3	29.3	22.9	83.5	85.1	1	3.6	7.3
12:15	9.85	903.14	1.7	29.2	23.5	82.4	—	0	0	7.3
12:30	10.23	937.61	1.7	29.3	24.4	92.1	84.7	1	3.5	10.8
12:45	9.07	831.26	2.5	29.5	25.1	85.7	83.5	1	3.3	14.1
13:00	8.14	746.37	3.4	29.6	25.9	81.5	—	0	0	14.1
13:15	9.55	875.91	1.6	29.8	26.2	87.4	83.9	1	3.4	17.5
13:30	9.79	897.91	2.8	29.9	26.7	83.5	82.8	1	3.3	20.8
13:45	9.26	849.32	1.3	31.5	26.7	74.9	82.9	1	3.1	23.9
14:00	9.40	861.52	1.2	31.5	27.4	85.8	82.7	1	3.1	27
14:15	9.39	860.42	1.9	31.7	27.7	76.7	—	0	0	27
14:30	8.84	810.63	0.9	31.8	27.9	84.8	83.1	1	3.3	30.3
14:45	8.75	802.57	1.4	32.1	28.1	69.4	82.6	1	3.1	33.4
15:00	8.43	773.05	2.7	32.5	28.5	75.6	—	0	0	33.4
15:15	7.81	716.30	2.0	32.7	28.5	77.4	83.1	1	3.2	36.6
15:30	7.26	665.32	1.0	32.8	30.1	65.8	—	0	0	36.6
15:45	6.99	640.57	1.6	33.7	30.5	86.7	82.8	1	3.3	39.9
16:00	6.39	586.02	1.8	33.3	31.8	82.7	—	0	0	39.9
16:15	6.22	570.62	1.6	33.6	31.8	63.4	83.1	1	3.3	43.2
16:30	5.26	481.96	2.4	33.7	32.8	79.4	—	0	0	43.2
16:45	5.18	475.27	2.6	33.9	32.5	78.6	—	0	0	43.2
17:00	4.72	433.10	0.5	33.6	32.6	76.2	82.6	1	3.1	46.3
Sum								14	46.3	
Average		708.40	1.8	30.1	24.6	73.4	83.5			
Std. deviation		157.91	0.6	2.6	5.3	12.9	0.9			