COMPARATIVE PERFORMANCE STUDY AND TECHNO-ECONOMIC ANALYSIS OF DIFFERENT SOLAR WATER HEATER IN BANGLADESH

THESIS PAPER

A dissertation presented as a partial fulfillment for the
degree of MS in Renewable Energy Technology

SUPERVISED BY
Dr. S.M. Nafis Shams
Assistant Professor,
Institute of Energy,
University of Dhaka,
Dhaka-1000.

SUBMITTED BY
MrinmoyBagchi
Roll No.: 00520, Reg. No.: Ha-211
Session: 2014-2015 and
Md. MahmudulHasan
Roll No.: 00529, Reg No.: Ha-316
Session: 2013-2014

INSTITUTE OF ENERGY, UNIVERSITY OF DHAKA
DHAKA, BANGLADESH
SEPTEMBER, 2016

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EXAM. ROLL NO.: 00520
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&
MAHMUDUL HASAN
EXAM. ROLL NO.: 00529
REG. NO.: Ha-316
SESSION: 2013-2014

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SEPTEMBER, 2016

DECLARATION

This thesis paper has been prepared by me to submit as a requirement for the partial fulfillment of MS in Renewable Energy Technology and it has not been submitted in any previous application for any degree. Exclusively I executed the work, reported within, unless otherwise stated.

…..……………………………..

MrinmoyBagchi
Exam. Roll No.: 00520
Reg. No.: Ha-21, Session: 2014-2015
Institute of Energy, University of Dhaka
Dhaka, Bangladesh.

…..……………………………..

MD. MahmudulHasan
Exam. Roll No. 00529
Reg. No. Ha-316, Session: 2013-2014
Institute of Energy, University of Dhaka
Dhaka, Bangladesh.

CERTIFICATION

This is to certify that MrinmoyBagchi, Exam. Roll No.: 00520, Reg. No.: Ha-211, Session: 2014-2015 and Md. MahmudulHasan, Exam. Roll No. 00529, Reg. No. Ha-316, Session 2013-2014, student of MS in Renewable Energy Technology in Institute of Energy, University of Dhaka, has successfully prepared this thesis paper entitled **"Comparative Performance Study And Techno-Economic Analysis Of Different Solar Water Heater In Bangladesh"** under my supervision and guidance. However, this thesis paper has been prepared and submitted to the Institute of Energy, University of Dhaka, for the partial fulfillment of the requirement for the degree of MS in Renewable Energy Technology.

………………………………………

(Dr. Nafis Shams)
Assistant Professor,
Institute of Energy,
University of Dhaka,
Dhaka, Bangladesh.

DEDICATED

TO

MY RESPECTABLE

TEACHERS

AND

BANGLADESHI

SCIENTISTS

ACKNOWLEDGEMENT

At first, I vow my head to the Almighty Allah for without his mercy, I could not complete this thesis paper and who gives me the energy and sound health to endure the rigor of this tedious work.

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Author
September, 2016

Abstract

FPC and ETC solar water heater has many potential markets in the camping, outdoors living, and humanitarian sectors in Bangladesh and huge opportunity at winter. The study was conduct to compare the performance of FPC at various flow rates with ETC and techno-economic analysis in Bangladesh prospects.The output water temperature and thetemperature difference of input-output water highest found 64.94^{0}C and 28.020C inETC at 4.5 l/m.The efficiency at different flow rate found ETC is 79.28% at 4.5 l/m and FPC is 28.32% at 3.4 l/m. At the stagnant condition the output temperature found highest 89^{0}C and 94^{0}C of FPC and ETC respectively when the glass surface and covered metal surface of the FPC found 50^{0}C and 48^{0}C respectively.The highest efficiency found of FPC found 89% at average 145W/m^2 daily radiation and of ETC highest efficiency 93% at average 246W/m^2 at 2.5 l/m flow rate. The swimming pool in University of Dhaka need Tk.51,98,000.00 and 1155m^2 area for FPC, on the other hand Tk. 90,86,000.00 and 770m^2 area for ETC to run at winter.

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LIST OF ABBREVIATIONS

BBS	Bangladesh Bureau of Statistics
BER	Bangladesh Economic Review
FPC	Flat Plat Collector
ETC	Evacuated Tube Collector
DMC	Dhaka Medical College
DU	Dhaka University
IE	Institute of Energy
NGO	Non-Government Organization

CHAPTER ONE
Introduction

1.1 General Concept

A portable solar water heater has many potential markets in the camping, outdoors living, and humanitarian sectors (lovetheoutdoors, 2015). People interested in any of these activities often need to heat a small amount of water quickly, for drinking or to sanitizing equipment. In such situations, making a fire or using a stove would be cumbersome and impractical, so a simpler, more compact solution is sought.

Here, a solar heater presents itself as a strong solution, as solar energy has several advantages applicable to camping and outdoors activities. Firstly, no special equipment is needed to generate solar energy – no wood or gas. Secondly, insolation is very energy-dense, providing 1 KW per square meter on a clear day (Wikipedia, 2011). Finally, solar energy is available on demand for an average of 12 hours per day: even on overcast days, 150 W of energy per square meter still hits the Earth's surface at mid-latitudes (Stine & Geyer, 2001). All of this makes solar energy a consistent, powerful source of heat. This solar water heater has two essential requirements: portability and rate of heating (Sun et al, 2013).

1.2 Objectives of the study

This study is based on the overview of the following objectives:

1. To analyse the performance of FPC at various flow rate and ETC
2. To compare the performance of FPC and ETC of solar water heater
3. Techno-economic analysis of FPC and ETC in Bangladesh prospects

CHAPTER TWO

Literature Review

2.1 Solar Water Heater

The principle of thermosyphone(Khan &Obaidullah, 2008) is just like boiling the water. In a flat bed collector cold water flows to the collector, it gets warm by sunshine and flows upward due to buoyancy and stored in the tank which can be used directly.

A collector essentially consists of the following components:

1) A coated flat plate which absorbs solar radiation and transforms it into thermal energy
2) An insulated storage tank used to reduce thermal losses of heated water glass or plastic
3) Cover to reduce upward thermal losses of the collector
4) Bottom insulation to reduce downward thermal losses
5) Tubes and channels for circulating water to collect thermal energy
6) Wooden or metallic frame to house the collector assembly
7) Solar water heater is basically a flat-plate (Mengda et al. 2009) collector in which heat transfer fluid is water. In Figure 1, the working principle of solar water heater has been shown.

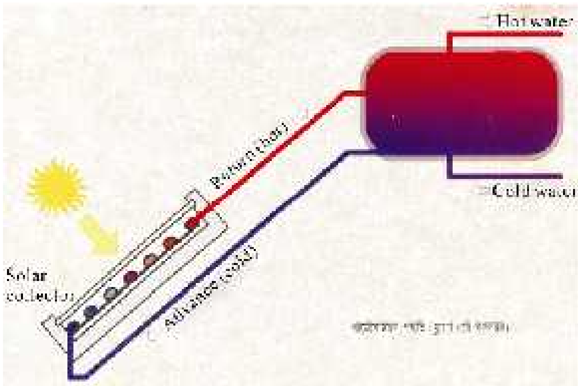

Figure 2.1: Thermosyphone principle of solar water heater (Khan & Islam, 2011)

2.2 Types of solar collector

Generally three types of solar collectors are used for residentialapplications that are described follows:

2.2.1 Flat plate collector

Glazed flat plate collectors are equipped with insulation andweather proofed boxes that contain a dark absorber plate underone or plastic (polymer) or more glass covers. Unglazed flat platecollectors heaters having a dark absorber plate made of metal orpolymer, without a cover or enclosure are typically used for solarpool (Baldini et al., 2009).

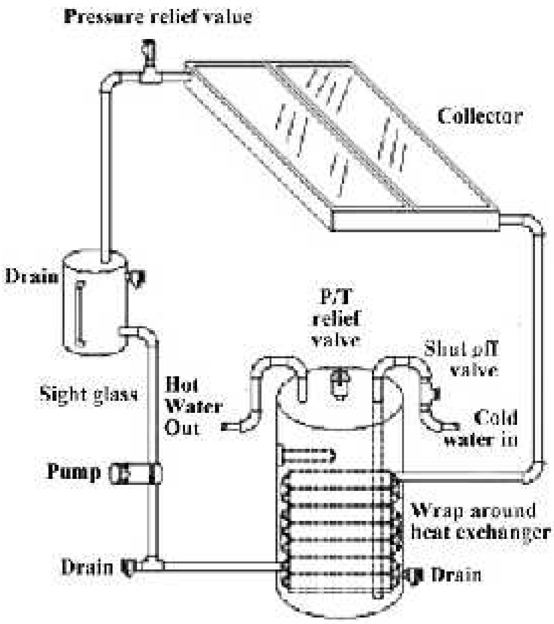

Figure2.2: Integral collector storage system (Pedia, 2010)

2.2.2 Integral collector storage systems

Furthermore, ICS (integral collector storage) or batch systemsfeature one or more black tanks or tubes in an insulated, glazed box.The water then continues on the conventional backup water heater,providing a reliable source of hot water. They should be installedonly in the mild freeze climates because the outdoor pipes couldfreeze in severe the cold weather. Fig. 10 shows an integral solar water heater (Pedia IA., 2010).

2.2.3 Evacuated tube solar collectors

They feature parallel rows of transparent glass tubes. Each tubecontainsaglassoutertubeandmetalabsorbertubeattachedtoafin.The fin's coating absorbs solar energy but inhibits radioactive heatloss. These collectors are used more frequently for U.S. commercialapplication. In Figure 3, the evacuated tube solar water heater hasbeen shown which a very popular solar collector is in present time.This is a very effective way to collect hot water from the sun, but itis also expensive to set up (Gillies, 2008).

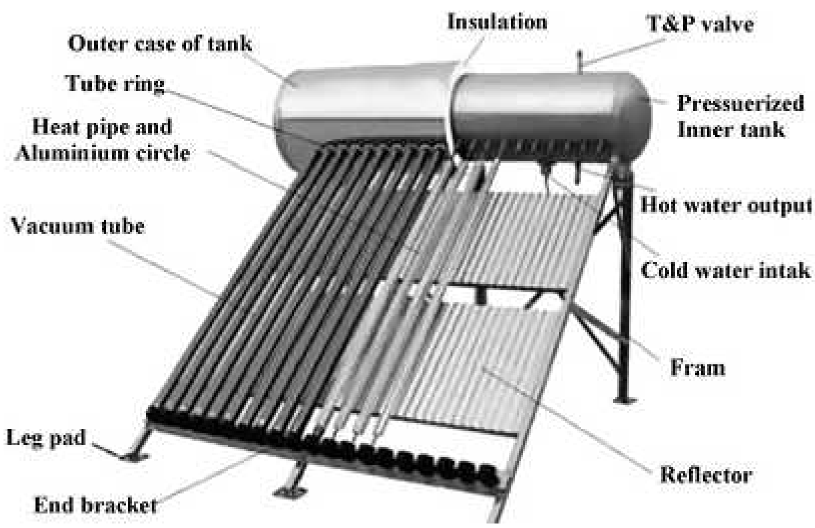

Figure 2.3: Evacuated tube solar water heater collectors (Gillies, 2008).

2.3 Active solar water heating system

There are two types of active solar water heating systems. Theseare direct circulation system and indirect circulation system. Theseare discussed in the following sections.

2.3.1 Direct circulation system

Pumps are used to circulate household water through the collectors and supply to the house. They work well in climate whereit rarely freezes. Figure 2, shows how direct circulation system works(Marion & Wilcox, 1990).

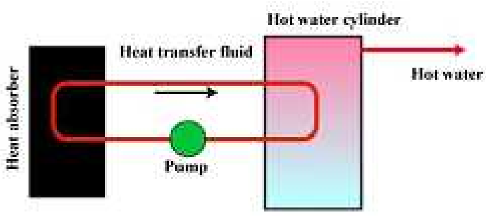

Figure2.4: Indirect circulation systems (Pedia IA., 2010).

2.3.2 Indirect circulation system

Pumps circulate a non-freezing, heat transfer fluid through thecollectors and a heat exchanger. This heats the water then flow intothe home. They are popular in climates prone to freezing temperatures. Figure 4 shows the indirect circulation system of a solar waterheater. This is a very simple system for heating water. The pumponly circulates water between a heat absorber and a water cylinder,and then the hot water flows outside the storage tank (Pedia, 2010).

2.4 Flat plate thermal performance

How to measure the thermal performance and useful energygain or the collector efficiency of a flat plate? Figure5 shows aschematic drawing of the heat flow through a collector. There are 80% of the sun heat energy is absorbed in the collector plate. The radiant heat reflects and heat loss in the collector surface is around 10–35% shown in Figure 6 (Struckmann, 2008).

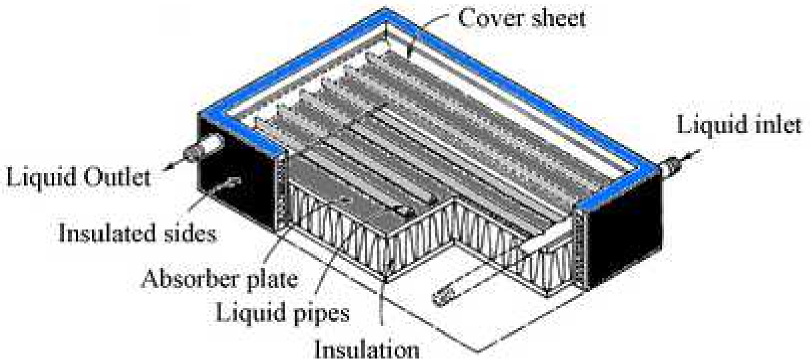

Figure2.5: A typical liquid flat plate collector(Struckmann, 2008).

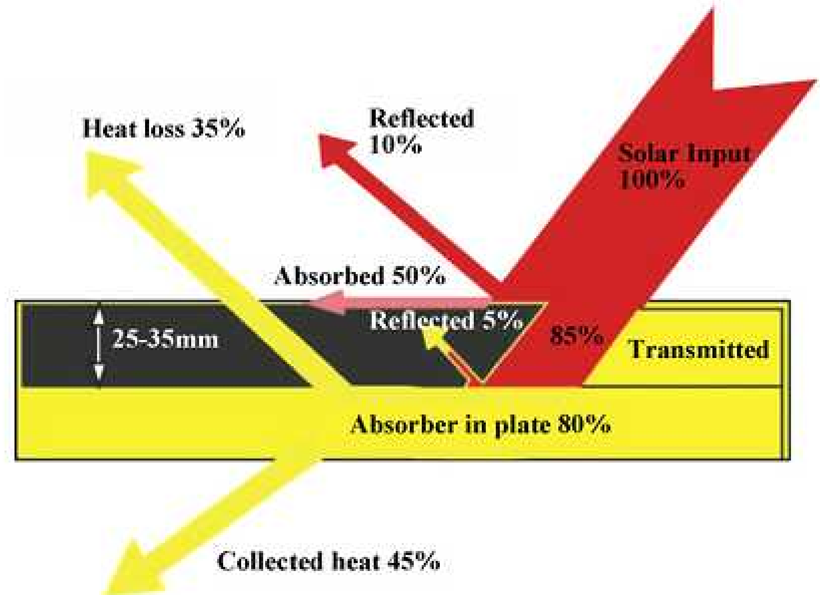

Figure2.6: Heat flow through a flat plate solar collector (Struckmann, 2008).

It is very essential to define the singular heat flow equationsstepwise, in order to find the principal equation of the collectorsystem. There are other some examples for calculating solar energy.

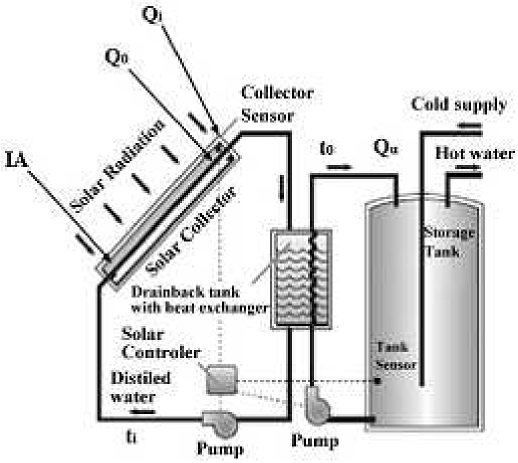

Figure2.7: Typical solar energy collection system (W.B.S.N.E., 2011).

Figure 8 depicts the simple schematic design of a typical solar platesystem using a storage tank and flat plate solar collector (W.B.S.N.E., 2011).If I is the intensity of solar radiation, in W/m2, incident on theaperture plane of the solar collector with a collector surface areaof A, in m2, then the amount of solar radiations received by thecollector can be expressed by the following equation (Struckmann, 2008):

Qi = IA (10)

Where,

Qi is collector heat input-W,
I is intensity of solar radiationW/m2,
A is collector area.

2.5 Integrated collector storage solar water heater

The system consists of a roof top steel water storage tank.In our set up the storage tank is nearly cubical in shape and is made of galvanized steel sheets of 16 gauge (88 cm × 88 cm × 78 cm). The azimuthal orientation of the storage tank is such that its walls face south east, south west, north east and north west directions which has been found to the best orientation for the solar energy gain for a cuboid (Kaushika& Sharma, 1994). The sunlit walls and top surface of the tank are blackened (using black Japan, a coal tar enamel paint) and covered with transparent insulating material. The off sunlit walls and the bottom surface are covered with sheets of polystyrene (thermocole) of 1 cm thickness, which is a good insulating material. The transparent insulating material used is locally available air bubbled polythene sheets. It is pasted on the blackened walls with bubbled surface inside. This forms an air film of small thickness which is non-convective and acts as excellent transparent insulator. Both these materials are used in packaging and can be obtained easily. The transparent insulation material degrades in one season and was replaced at the beginning of the each winter season. It was dusted and cleaned time to time to remove the accumulated dust. The thermocole insulation does not degrade and can last for two to three years but curiously attacked by the pigeons. Figure 8 shows the front view of the tank with its transparent insulation cover.

Figure 2.8: Front view of the integrated collector storage solarwater heater

The tank which may contain the residual water fromprevious night is filled fully with fresh water from themains in the morning so that its top layer touches the topsurface of the tank. The inlet and the outlet valves areclosed and the water is left undisturbed throughout theday when it absorbs the solar heat. Solar heat is conducted through the top surface and the walls facing southeast and south west and the water in the tank is heated.The transparent insulation cover enables efficient absorption of solar radiant energy and minimization of thermal loss. In the evening the outlet valve is opened and the hotwater from the tank is utilized. Depending upon the consumption some water remains in the tank which becomes cold during the night (Mozumder& Singh, 2013).

2.6 Performance improvement

Their performance improvement result was found Sivakumar et al., 2012 as follows:

The Natural circulation solar water heater was tested in the month of March, 2011 at intervals of one hour between 9.00 hours and 17.00 hours. The incident solar radiation intensity was measured using pyranometer. The water inlet and outlet temperatures for the collector as well as ambient air were measured by thermometer with a precision of 0.5˚C. The mass flow rate of the system was measured by rotometer with the accuracy of 0.005 liters. The collector efficiency of the system was calculated.

The hourly variation of the solar intensity, collector efficiency and collector water outlet temperatures are shown in Figures 9, 10, 11 and 12.The solar intensity is increasing from 9.00 hours to 13.00 hours, reaching a maximum value of 918 W/m2 at 13.00 hour in Figure 9. The collector efficiency is also compared with three different cases and it's depicted inFigure10.

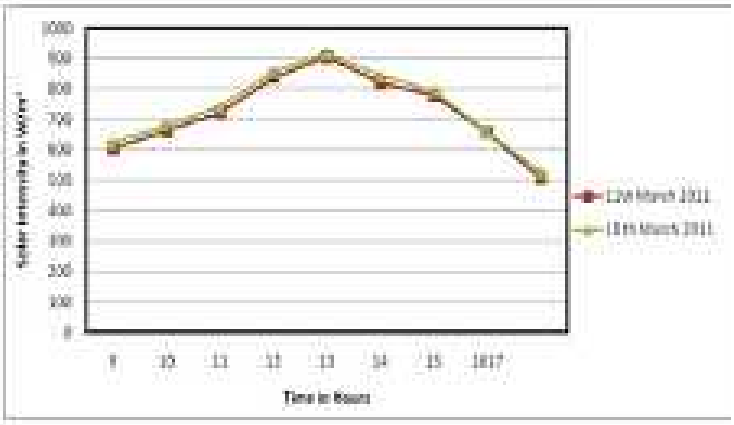

Figure 2.9: The curve for solar intensity against time

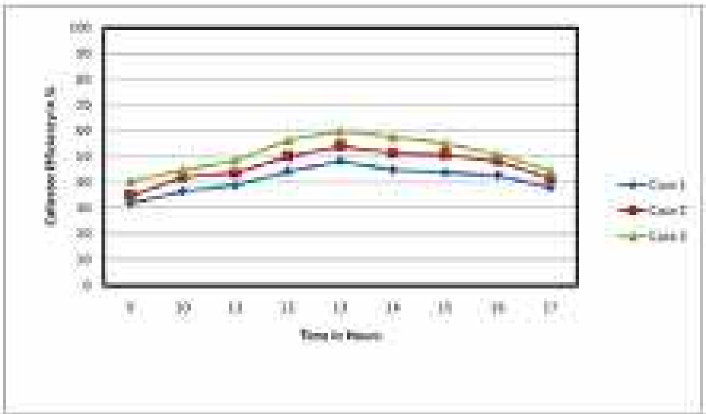

Figure 2.10: The curve for Collector efficiency against time on 11th March, 2011

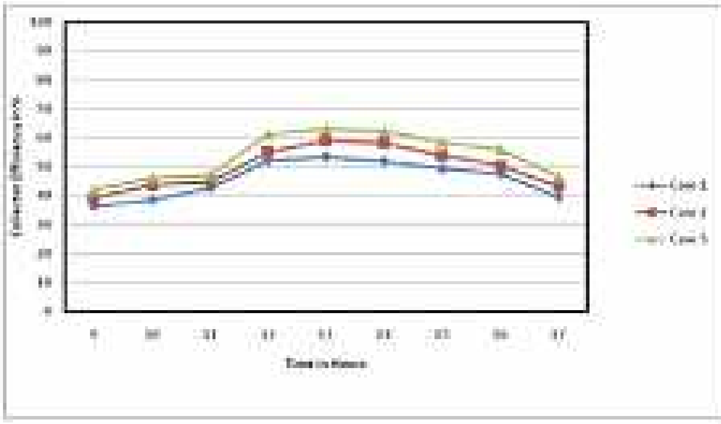

Figure 2.11: The curve for Collector efficiency against time on 18th March, 2011

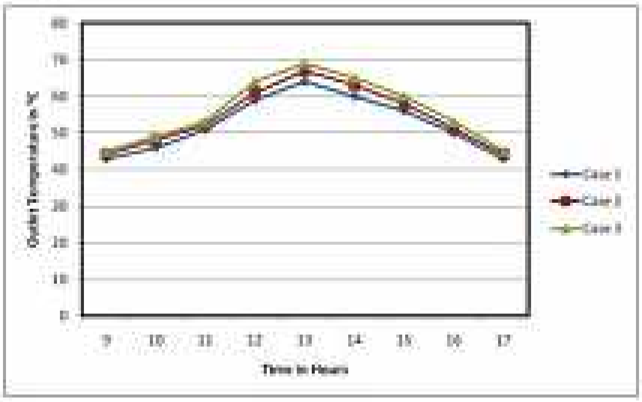

Figure 2.12: The curve for Hourly variation of fluid outlet temperature by changing the dimensions on 18th March, 2011

The collector efficiency at 9.00 hour is 36.4% for9 riser tubes, 39.2% for 12 riser tubes and 42.00% for zigzag arrangement system. The maximum efficiency isobserved at the time 13.00 hour in all the three cases as53.38%, 59.09%, and 62.90%, respectively.The collector efficiency decreases after 13.00hour till 17.00 hour in the same manner. The collectorefficiency is shown in Figure11. The graph reveals that themaximum efficiency is at 13.00 hour in all the three cases.The collector outlet temperatures are shown inFigure12. The outlet temperatures at 9.00 hour is 43˚C,44˚C and 46˚C for 9 riser tubes, 12 riser tubes and zig-zagarrangement respectively. The maximum outlettemperatures were recorded at 13.00 hour for all threecases. The outlet temperature reduced after 13.00 houruntil 17.00 hour for all three cases.Figure9.The curve for solar intensity against time.Figure10.The curve for Collector efficiency againsttime on 11th March, 2011.Figure 11.The curve for Collector efficiency againsttime on 18th March, 2011.Figure12. The curve for Hourly variation of fluid outle

2.7 Review of previous study

Kalogirou (2004) presents a survey of the various types of solar thermal collectors and applications. All the solar systems which utilize the solar energy and its application depends upon the solar collector such as flat-plate, compound parabolic, evacuated tube, parabolic trough, Fresnel lens, parabolic dish and heliostat field collectors which are used in these system. The solar collectors are used for domestic, commercial and industrial purposes. These include solar water heating, which comprise thermosyphon, integrated collector storage, direct and indirect systems and air systems, space heating and cooling, which comprise, space heating and service hot water, air and water systems and heat pumps, refrigeration, industrial process heat, which comprise air and water systems and steam generation systems, desalination, thermal power systems, which comprise the parabolic trough, power tower and dish systems, solar furnaces, and chemistry applications.

Table 2.1: Comparision of the Collectors (Kalogirou, 2004)

Motion	Collector type	Absorber type	Concentration ratio	temperature range (°C)
Stationary	(FPC)	Flat	1	30–80
	(ETC)	Flat	1	50–200
	(CPC)	Tubular	1–5	60–240
Single-axis tracking	(LFR)	Tubular	15-45	60–250
	(PTC)	Tubular	15–45	60–300
	(CTC)	Tubular	10–50	60–300
Two-axes tracking	(PDR)	Point	100–1000	100–500
	(HFC)	Point	100–1500	150–2000

Sadrin et al. (2009) present the alternative method of solar water heating system. This automated system would allow the user to get hot water from the solar water heater as long as the solar water heater can supply hot water above a set temperature. If the solar water heater is unable to supply water above the set temperature, then only will the electric water heater come into action. It is efficient because our controller ensures that the solar water heater is used to supply hot water 80% of the time, and the rest 20% will be supplied by the electric water heater. It is cheap because, our system runs on solar energy which is abundant and free. It uses very small amount of electricity and therefore, reduces the expenses for the user.

Prasad et al. (2010) present experiment analysis of flat plate collector and comparison of performance with tracking collector. A flat plate water heater, which is commercially available with a capacity of 100 liters/day is instrumented and developed into a test-rig to conduct the experimental work. Experiments were conducted for a week during which the atmospheric conditions were almost uniform and data was collected both for fixed and tracked conditions of the flat plate collector. The results show that there is an average increase of 40C in the outlet temperature. The efficiency of both the conditions was calculated and the comparison shows that there is an increase of about 21% in the percentage of efficiency.

Ratismith et al. (2012) describes the design of the PTC in which increase the outlet temperature by reducing heat loss. In this design the maximum efficiency of the collector is 32% and has an ability to achieve high output temperature, the maximum temperature at header of evacuated tube is 235 degrees Celsius, and is therefore suitable for high temperature application such as industrial uses.

Uzuneanu et al. (2010) describe optimum tilt angle for solar collectors with low concentration ratio. The performance of any solar energy system depends very much on the availability of solar radiation and the orientation of solar collectors. Solar collectors need to be inclined at the optimum angle to maximize the receiving energy. In this work, we proposed to analyse the optimum tilt angle for compound parabolic collectors CPC with different concentration ratios. There are analyzed the energy gains when the collector keeps the same position during the whole year and when the collector changes its tilt twice a year, on summer and on winter.

Herrero et al. (2011) describe enhancement techniques for flat-plate liquid solar collectors. Tube-side enhancement passive techniques can consist of adding additional devices which are incorporated into a smooth round tube (twisted tapes, wire coils), modifying the surface of a smooth tube (corrugated and dimpled tubes) or making special tube geometries (internally finned tubes). For the typical operating flow rates in flat-plate solar collectors, the most suitable technique is inserted devices. Based on previous studies from the authors, wire coils were selected for enhancing heat transfer. This type of inserted device provides better results in laminar, transitional and low turbulence fluid flow regimes.

AKTAŞ et al. (2006) describe experimental analysis of optimum fin size, which can be used in heat exchanger in solar energy systems, has been performed. For this purpose, two systems, one of which is classic and the other finned, were designed and manufactured. According to the experimental tests, which lasted for six days, the system with a fin is 7% more efficient than the classical system. Therefore, it has been concluded that it is useful to use fins in solar energy systems with a suitable sizing.

CHAPTER THREE

Methodology

In this chapter experimental analysis, test equipment, performance calculation, test experimental set up are discussed. All these work are done by using international standard condition and procedure. For precise result data are taken for small interval of time.

3.1 Test equipment

The equipment that is used for experiments and analysis of these study is given below:

3.1.1 Pyranometer

Pyranometers are broadband instruments that measure global solar irradiance incoming from a 2p solid angle on a planar surface. A typical pyranometer is schematically represented in Figure 3.6. It consists of a white disk for limiting the acceptance angle to 180 and two concentric hemispherical transparent covers made of glass. The two domes shield the sensor from thermal convection, protect it against weather threat (rain, wind, and dust) and limit the spectral sensitivity of the instrument in the wavelength range 0.29–2.8 lm. A cartridge of silica gel inside the dome absorbs water vapor. A pyranometer can be also used to measure the diffuse solar irradiance Gd, provided that the contribution of the direct beam component is eliminated. For this, a small shading disk can be mounted on an automated solar tracker to ensure that the pyranometer is continuously shaded. Alternatively, a shadow ring may prevent the direct component Gb from reaching the sensor whole day long. Because the daily maximum Sun elevation angle changes day by day, it is necessary to change periodically (days lag) the height of the shadow ring. On the other hand, because the shadow ring also intercepts a part of the diffuse radiation, it is necessary to correct the measured values. The percentage of diffuse radiation intercepted by the shadow ring varies during the year with its position and atmospheric conditions (Siren, 1987).

Figure 3.6: Pyranometer

3.1.1.1 Procedure

The pyranometer installed on a horizontal surface. There was shadow disc facility to record diffuse radiation from the same pyranometer. Then calibration factor/conversion factor of pyranometer (Sensitivity 5.02 μV/Wm-2) used to convert the reading in voltage in radiation unit.

3.1.2 Water flow meter

Turbine meters Figure 3.2 are less accurate at low flow rates, but the measuring element does not occupy or severely restrict the entire path of flow. The flow direction is generally straight through the meter, allowing for higher flow rates and less pressure loss than displacement-type meters. They are the meter of choice for large commercial users, fire protection and as master meters for the water distribution system. Strainers are generally required to be installed in front of the meter to protect the measuring element from gravel or other debris that could enter the water distribution system. Turbine meters are generally available for 1-½" to 12" or higher pipe sizes. Turbine meter bodies are commonly made of bronze, cast iron or ductile iron. Internal turbine elements can be plastic or non-corrosive metal alloys. They are accurate in normal working conditions but are greatly affected by the flow profile and fluid conditions (Sensotronic, 2015).

3.1.2.1 Features

- Flow range: 0.22 to 132 GPM
- Designed for metering pump pacing or water treatment control
- Hall-effect sensor, reed switch or totalizer only models available
- Accurate to 1-1/2% of reading

- Hot (to 194°F) or cold (to 105°F) water models
- Rugged epoxy-coated bronze bodies with union ends
- 100:1 turndown
- Wide range of field-changeable pulse rates
- True dry-top construction

Figure 3.2: Flow meter

3.1.2.2 Procedure

- At first take the meter reading
- Start the experiment
- After completion the experiment again take the meter reading
- The difference of two reading shows the flowing water
- The rate found after divided by time

3.1.3 Temperature data measurement and logging

The temperature data measure with a digital data logger in Figure 3.3 digital thermometer directly logged on computer.

Figure 3.3: Temperature digital data logger

3.1.3.1 Description

The DS18B20 Digital Thermometer provides 9 to 12-bit (configurable) temperature readings which indicate the temperature of the device. Information is sent to/from the DS18B20 over a 1-Wire interface, so that only one wire (and ground) needs to be connected from a central microprocessor to a DS18B20. Power for reading, writing, and performing temperature conversions can be derived from the data line itself with no need for an external power source. Because each DS18B20 contains a unique silicon serial number, multiple DS18B20s can exist on the same 1-Wire bus. This allows for placing temperature sensors in many different places. Applications where this feature is useful include HVAC environmental controls, sensing temperatures inside buildings, equipment or machinery, and process monitoring and control (Maximintegrated, 2016).

3.1.3.2 Features

- Unique 1-Wire interface requires only one port pin for communication
- Multidrop capability simplifies distributed temperature sensing applications
- Requires no external components
- Can be powered from data line. Power supply range is 3.0V to 5.5V
- Zero standby power required
- Measures temperatures from -55°C to +125°C. Fahrenheit equivalent is -67°F to +257°F ±0.5°C accuracy from -10°C to +85°C
- Thermometer resolution is programmable from 9 to 12 bits
- Converts 12-bit temperature to digital word in 750 ms (max.)

- User-definable, nonvolatile temperature alarm settings
- Alarm search command identifies and addresses devices whose temperature is outside of programmed limits (temperature alarm condition)
- Applications include thermostatic controls, industrial systems, consumer products, thermometers, or any thermally sensitive system

3.1.3.3 Setup

One sensor are setting along with the inlet pipe where taking input water temperature and another sensor with the outlet pipe where taking output water temperature. A flexible long water pipe can be used for short cable of sensor. Short cable of sensor increases accuracy.

Figure 3.4: Sensor connection at inlet and outlet

3.1.3.4 Procedure

- At first set a sensor at inlet
- Another sensor set at outlet
- The power connection given through an adaptor
- Data logger connect with computer by USB data cable
- An software install in the computer
- Set the port of the computer
- On the data logger power switch
- Then automatic data logged at an interval 5 seconds
- After completing data logging it need to be saved
- After saving another experiment can be started as same procedure

Figure 3.5: Data saving in computer

3.1.4 AZ9881K Thermometer

Figure 3.6: AZ9881K Thermometer

3.1.4.1 Description:

The complete set of this data logger device contain Figure 3.6

i. Meter
ii. 4pcs AA batteries
iii. Printing thermo-paper
iv. Operation manual
v. Carry case
vi. K type thermo couple
vii. RS 232 cable
viii. Software CD

This thermometer designed with three measurement modes:

1. Single point measurement.

2. Multiple points measurements

3. Automatically logging.

3.1.4.2 Features:

1. Measuring / Programming anywhere, anytime.
2. User friendly interface.
3. RS232 cable and software enable to link with PC to download and upload.
4. Backlight function.
5. Tripod mountable for long time use.
6. Power off time selectable.
7. Big Dot matrix LCD.
8. Powered by 4pcs AA (98X1) or AAA (96X1) batteries or 9V adaptor.
9. Total memory points 4000.

3.1.4.3 Procedure:

a) To set up begin date, start-time, end date, suspend time and sample rate from the meter.

b) Each meter starts to record from Begin-Date & time with specified sample rate until Suspend-time.

c) Automatically start again next day from Start-Time until End-Date.

d) Logging stops recording when End-Date or max. Memory points are achieved.

e) Logging can be stopped and start again with the same setting.

3.1.4.4 Set up:

One of the probes is attached in the inlet and another in the outlet of the Evacuated tube solar water heater. A flexible pipe is fixed with outlet of the evacuated tube and attached with one probe. After recording data has saved in computer using software.

3.2 Experimental setup

First of all water flow meter is installed. Different flow rate is taken by synchronising with the valve. At first 4.6l/m, 3.4 l/m, 2.5 l/m flow rates are taken for Flat plate collector. For Evacuated tube 4.5l/m has taken. Different temperature has taken at different flow rate by temperature sensor with data logging device. Pyranometer is used to measure solar irradiance. In second stage the flow rate of the experiments is fixed to 2.5l/m for both solar water heater. Two temperature sensor data logger is used so that temperature can be obtained simultaneously for both solar water heaters from 9 am to 6pm. Data has taken for three successive days. Solar irradiance data are taken by Pyranomter after 15 minutes interval for three days.

3.3 Performance analysis methodology

In this topic equations which are used, to obtain results are discussed. All the parameters haschosen considering those equations. Equations are used for getting output energy and efficiency.

3.3.1 Efficiency analysis

η = Input Energy/ Output Energy

This equation is used to compare between two solar water heaters. Between Evacuated Tube (ET) solar water heater and Flat Plate Collector (FPC), Evacuated has higher efficiency. This equation helps us to decide which heater is better for our daily use.

3.3.2 Output energy

$H = mc\Delta T$

Where

m is the mass of water

c is the Specific heat Capacity of water (4.2 KJ /kg K)

ΔT is the temperature difference between inlet and outlet of solar water heater.

3.4Data collection

The survey on hot water consumer for their energy demand data collection specifically hot water production as those types-

-Hospital
-Canteen
-Fast food shop
-Swimming pool

3.5 Data processing and analysis

The collected digital data and flow meter data were compiled to measure potential heat transfer, input-output water temperature, temperature rising, efficiency, energy absorption, comparison of two types of solar water heater at various flow rate etc. processed with the help of MS Excel.

CHAPTER FOUR

Outdoor Comparative Performance Analysis

4.1 Temperature rises of water at different flow rate from FPC

The figure 4.1 shows that the input water temperature, output water temperature, ambient temperature and input-output water temperature difference at flow rate 4.6 litre/min. The highest output temperature found 41.38^{0}C at 14:14 where input temperature and ambient temperature also highest follows as 35.48^{0}C and 32.87^{0}C. At same time the temperature difference of input and output also highest 5.96^{0}C. The graph shows upward direction with time.

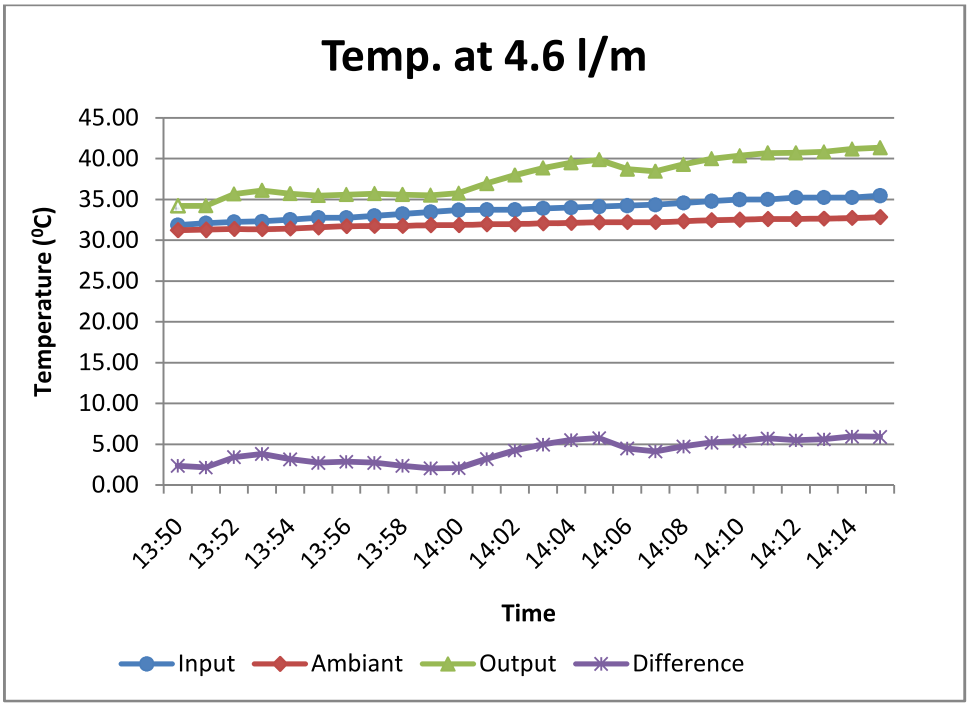

Figure 4.1: Input, output, ambient and input-output difference tem. at 4.6 L/m of flat plate water heater.

The figure 4.2 shows that the input water temperature, output water temperature, ambient temperature and input-output water temperature difference at flow rate 3.4 litre/min. The highest the input water temperature, output water temperature, ambient temperature and input-output water temperature difference was found at 15:23 as follows 33.65^{0}C, 38.96^{0}C, 32.88^{0}C and 5.32^{0}C successively.

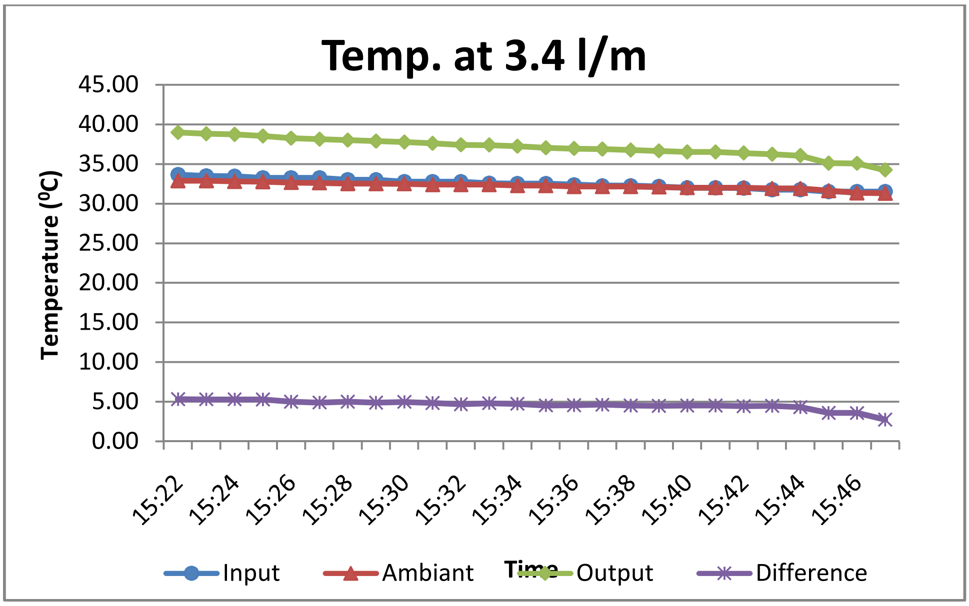

Figure 4.2: Input, output, ambient and input-output difference tem. at3.4 L/m of flat plate water heater.

The figure 4.3 shows that the input water temperature, output water temperature, ambient temperature and input-output water temperature difference at flow rate 2.5 litre/min. The highest the input water temperature, output water temperature, ambient temperature and input-output water temperature difference was found from 14:47 to 14:49 as follows 35.25^{0}C, 42.09^{0}C, 33.58^{0}C and 7.09^{0}C successively.

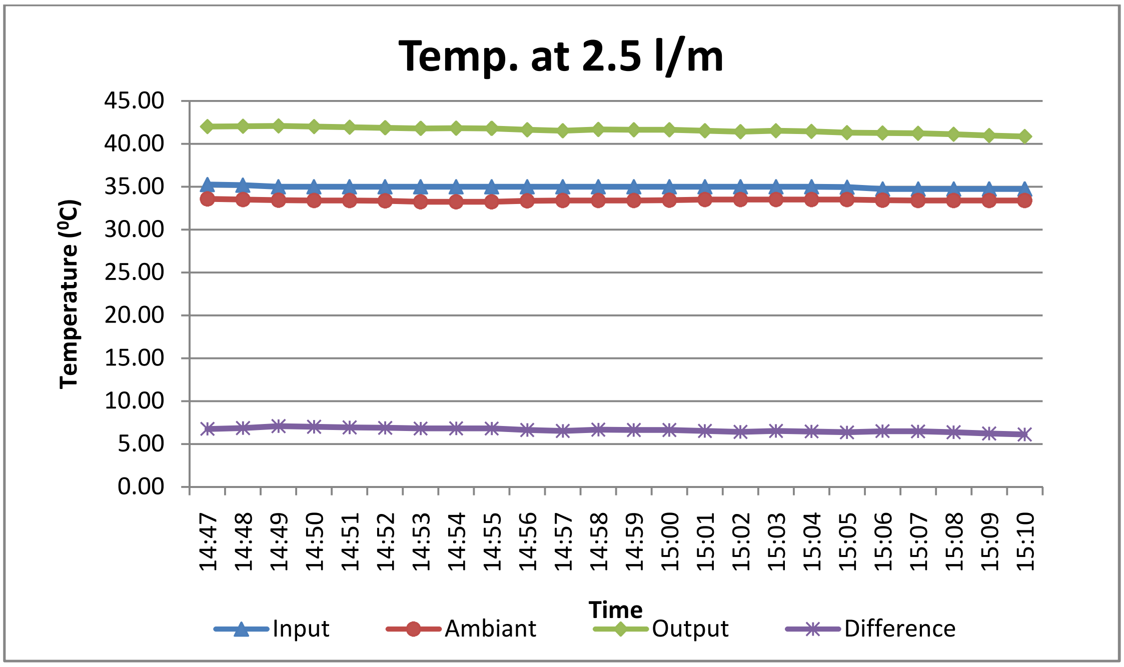

Figure 4.3: Input, output, ambient and input-output difference temp. at 2.5 L/m of flat plate water heater.

4.2 Temperature rises of ETC

The figure 4.4 shows that the input water temperature, output water temperature, ambient temperature and input-output water temperature difference at flow rate 5 litre/min of evacuated tube solar water heater. The highest the input water temperature, output water temperature, ambient temperature and input-output water temperature difference was found as follows 65.75^{0}C at 16:18, 64.94^{0}C at 16:11, 31.16^{0}C at 16:01 and 29.62^{0}C at 16:04successively.

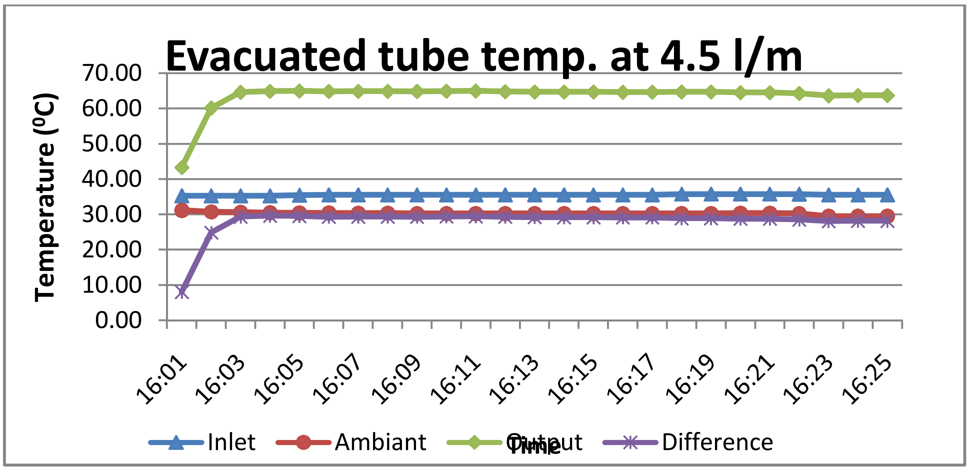

Figure 4.4: Input, output, ambient and input-output difference temp. at 2.5 L/m of evacuated tube collector.

4.3 Comparison between input and output energy

Figure 4.5 reveals that highest 11.74 MJ solar energy has taken by flat plate solar water heater from 13:50 to14:15 when absorbed solar energy by water also highest 1.98 MJ. The lowest 1.08 MJ solar energy taken from 16:01 to 14:25 andwater absorbed 0.65 MJ of energy by evacuated tube solar water heater.

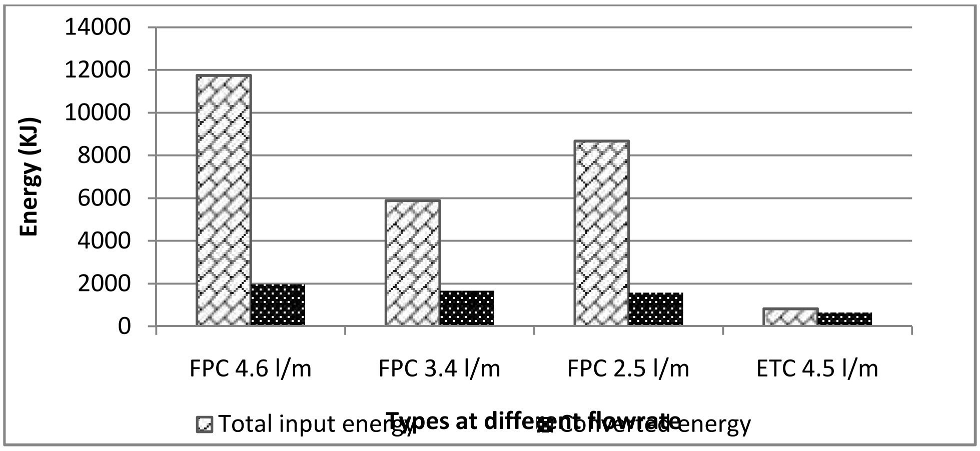

Figure 4.5: Comparison between input and output energy of flat plate and evacuated tube solar water heater.

4.4 Comparison among avg. input water, output water temp. and temp. rise

Figure 4.6 shows that average input temperature of water almost same from 32.51^{0}C to 35.51^{0}C but the output water temperature highest found in 64.94^{0}C at evacuated tube solar water heater. The temperature difference of input and output water found highest in evacuated tube solar water heater as 28.02^{0}C and lowest in flat plate water heater at 4.6 l/m flow rate as 4.09^{0}C.

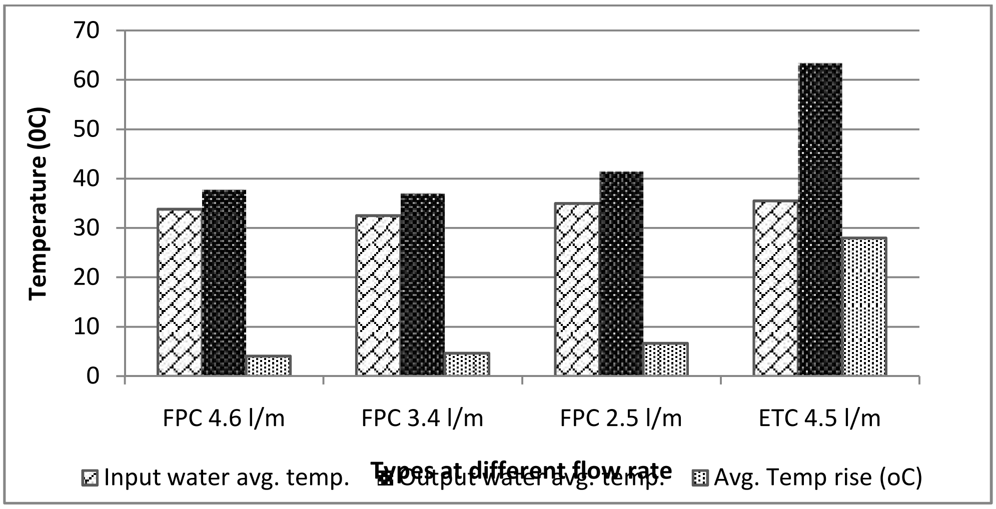

Figure 4.6: Comparison among avg. input, output and temp. rise of FPC and ETC.

4.5 Efficiency and insolation at experiment

Figure 4.7a shows that the efficiency as the heat transfer ratio found height at evacuated tube solar water heater (79.28%) and the lowest efficiency was flat plate solar water heater (16.82%) at 4.6 l/m flow rate. Figure 4.7a shows that theinsolation of the data collecting time was height at flat plate solar water heater (386.05W/m^2)of flow rate 4.6 l/m and the lowest found at evacuated tube solar water heater (99.6 W/m^2).

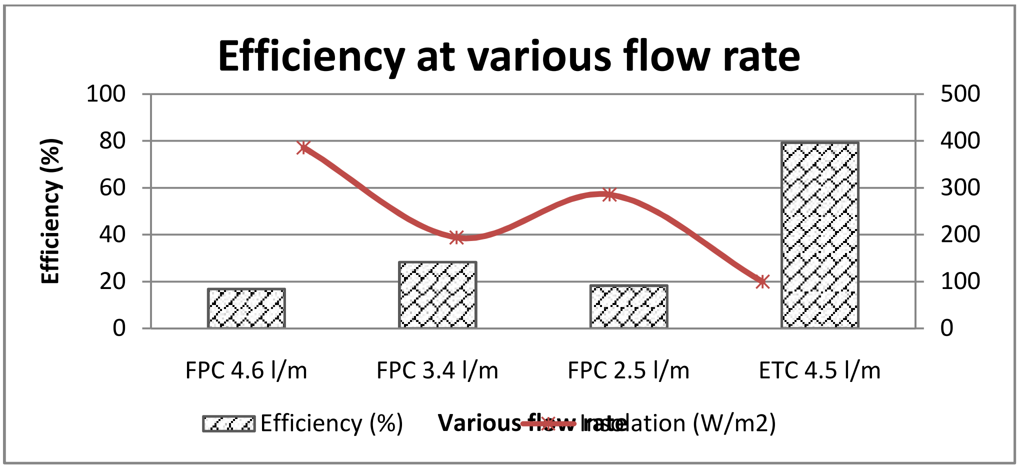

Figure 4.7: Efficiency at FPC and ETC at various flow ratewith solar radiation at experiment time.

4.6Hourly variation of ambient, fluid inlet, fluid outlet temperature by changing the dimensions on successively three days

Figure 4.8a shows that the day was varied as sunny partly as morning and at noon. The ETC temperature increases with the radiation and FPC output temperature significantly with respect of radiation. The radiation has taken downwards then the output temperature of ETC takes the increasing trends and fall after half an hour. After 14:30 the radiation took nearly zero and the output of ETC and FPC also downwards. Figure 4.8b shows the temperature difference of input and output of FPC and ETC. The difference also shows that when radiation increase then the temperature rising also increases and when the radiation tends zeros the rising of temperature also decreases.

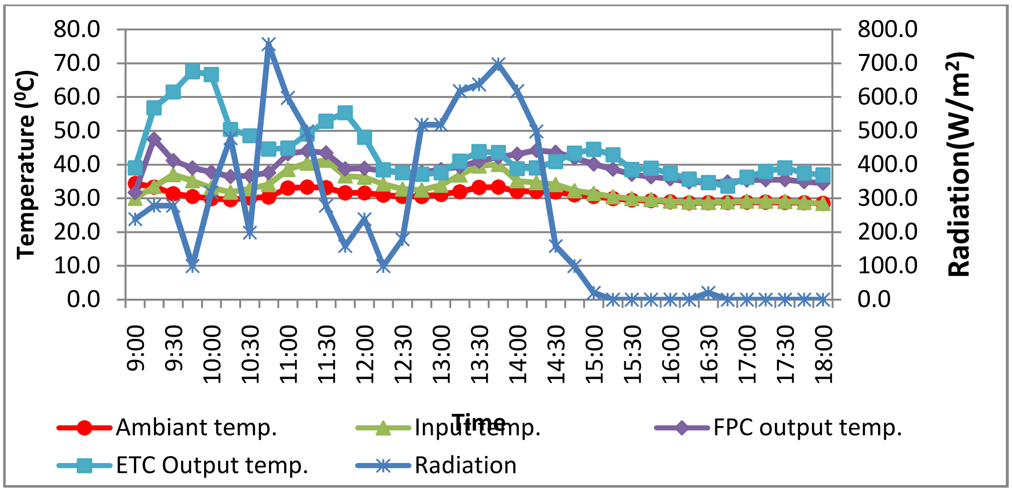

Figure 4.8: The curve for Hourly variation of ambient, fluid inlet, fluid outlet temperature by changing the dimensions on 27th September, 2016.

Figure 4.9 shows that the day was cloudy that the radiation highest of 300W/m^2. The ETC output temperature increases very low rate but d FPC output temperature significantly increases with respect of radiation. The radiation has taken downwards then the output temperature of ETC takes a regular trends but FPC output temperature has remaining their trends at lower radiation. The response at lower radiation found better in FPC then ETC. After 16:30 the radiation took downwards nearly zero and the output of ETC and FPC also downwards. The temperature difference of input and output of FPC and ETC. The difference also shows that when radiation increasesslightly then the temperature rising also increases in FPC but ETC took regular difference at lower radiation of 28th September, 2016.

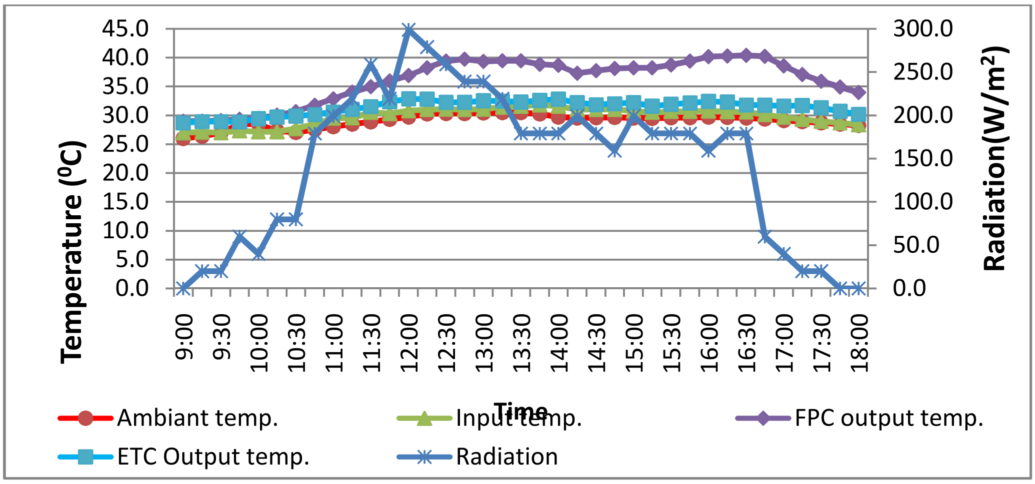

Figure 4.9: The curve for Hourly variation of ambient, fluid inlet, fluid outlet temperature by changing the dimensions on 28th September, 2016.

Figure 4.10 shows that the day was varied as sunny and cloudy. The ETC temperature increases with respect the radiation and FPC output temperature significantly with respect of radiation. The radiation has taken downwards then the output temperature of ETC takes the increasing trends and fall after half an hour. After 14:30 the radiation took downwards to nearly zero and the output of ETC and FPC also downwards. The temperature difference of input and output of FPC and ETC. The difference also shows that when radiation increase then the temperature rising also increases and when the radiation tends low the rising of temperature also decreases.

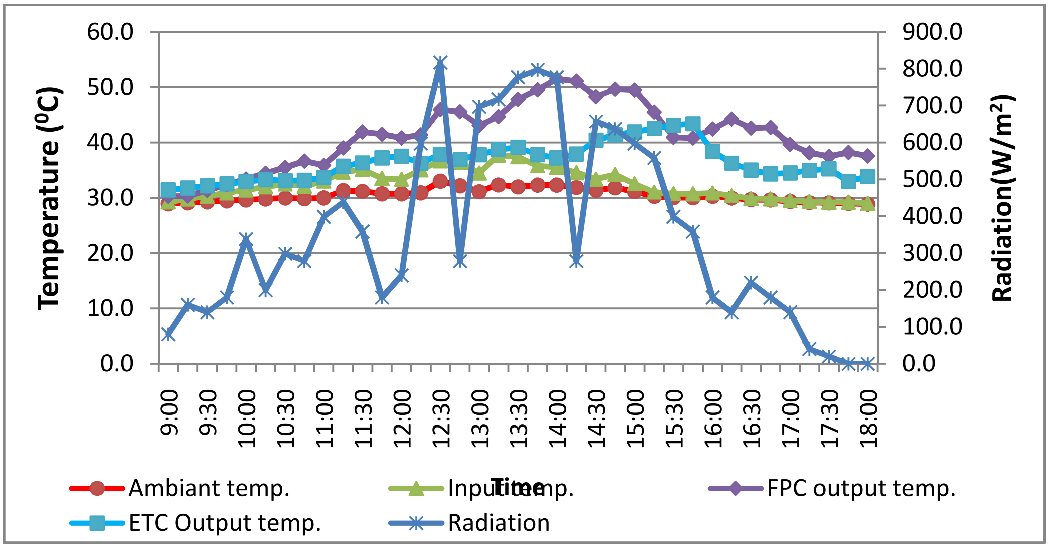

Figure 4.10: The curve for Hourly variation of ambient, fluid inlet, fluid outlet temperature by changing the dimensions on 29th September, 2016.

4.7 Temperature at stagnant condition and surface

The output temperature found highest 89^{0}C and 94^{0}C of FPC and ETC respectively. The glass surface and covered metal surface of the FPC found 50^{0}C and 48^{0}C respectively.

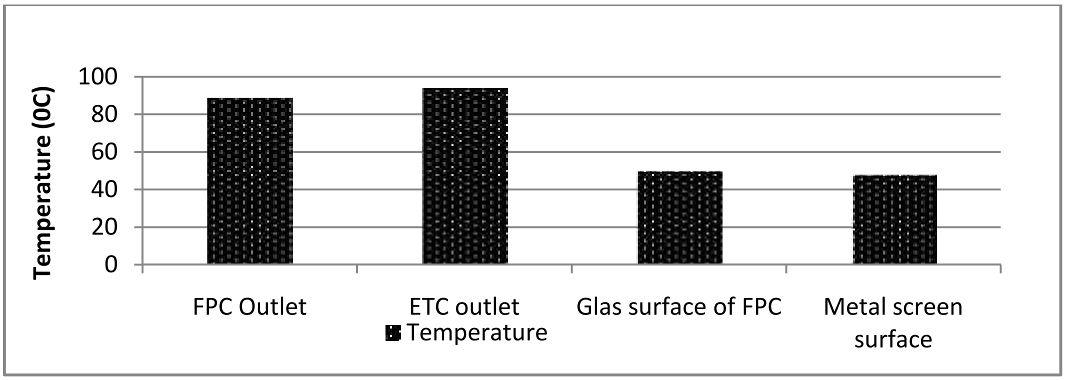

Figure 4.11. The highest temperature of FPC output, ETC outlet, glass surface of FPC and metal screen surface of FPC at stagnant condition.

4.8 Efficiency of FPC and ETC at different daily radiation

Figure 4.12 revels that the efficiency of FPC and ETC varies on radiation at the flow rate of 2.5 lit/min. The highest efficiency of FPC found 89% at average 145W/m^2 daily radiation but ETC has lowest efficiency 82%. ETC found highest efficiency 93% at average 246W/m^2 daily radiation but FPC found lowest 35%.

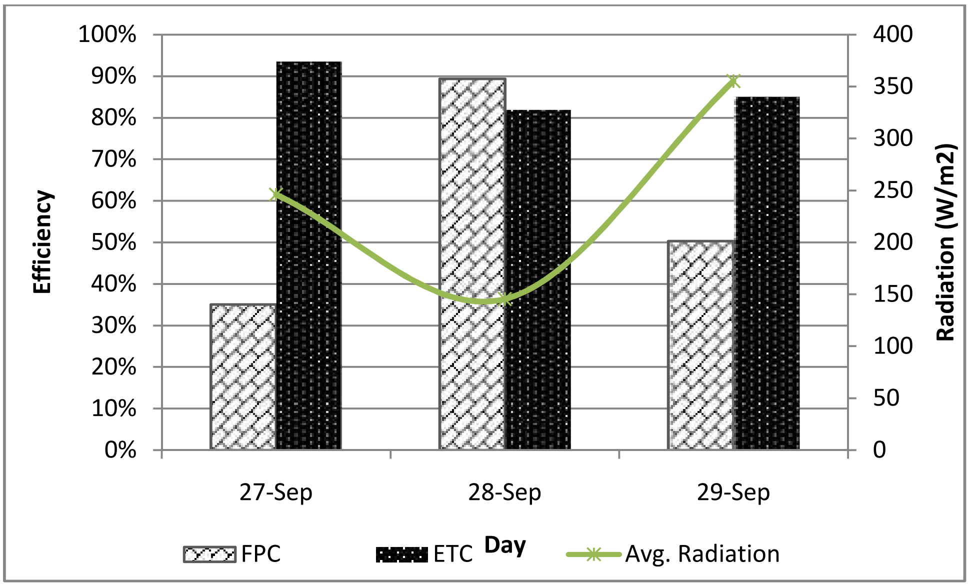

Figure 4.12 Efficiency of FPC and ETC at different daily radiation

4.9 Comparative performance analysis

The performance study on the evacuated tube and flat plat solar water heater at three different flow rate as 2.5 l/m, 3.4 l/m and 4.6 l/m at different time at different insolation. The input water and output water temperature reveals that the temperature rise means energy transfer from solar collector to water. Insolation and the area of collector shows how much energy comes from the Sun. The performance of the water heater is the transfer rate of heat from solar collector to water. At mid-day the insolation is high than other time of the day.

The highest flow rate of flat plate collector absorbs more and more heat from collector so the output water temperature was not rise at a high although the solar insolation was high. The lower flow rate takes high temperature water output than higher flow rate but the insolation comparatively lower. The optimal flow rate with lower insolation also gives lower temperature output of flat plate solar heater.

The FPC has a high response at lower radiation but ETC response is better at high radiation. So cloudy day the flat plate collector is better than ETC. The temperature rising also more at FPC than ETC at lower radiation. At high radiation the performance of FPC is lower than ETC. The efficiency of FPC also shows same pattern. At lower radiation FPC showing high efficiency than higher radiation. FPC also shows lower efficiency when the radiation varies up and down. So FPC shows high efficiency when the radiation is similar at full day means lower radiation variation shows higher efficiency. One of the causes may the metal screen on the FPC for protecting the glass surface from any throwing element. ETC has a good performance at variation of radiation but at lower radiation shows lower efficiency. Temperature rising in ETC is better at variation radiation.

The fluid of ETC has contained more heat and rise temperature than FPC at stagnant condition. The glass surface and metal screen surface contain high temperature and loss heat occurred. For those reason ETC has high peak temperature than FPC. The specific heat capacity of water in FPC was higher than ETC at 27th September but at 28th and 29th September it was reversing. The radiation varies in 27th September, so when the radiation varies the heat capacity of water in FPC increases but in ETC decreases.

The evacuated tube solar water heater absorbs more heat and rise the output water temperature at a very lower insolation. The input and output temperature difference found also highest in the evacuated tube solar water heater. It absorbs minimum solar energy but it transfer the energy to water very efficiently that the output temperature of water was highest comparatively flat plate collector.

The evacuated tube solar water heater found highly efficient than flat plate collector. The flat plate collector at medium flow rate and comparatively lower insolation shows higher efficiency but higher insolation increase output water temperature, but lower flow rate or higher flow rate also shows lower efficiency that means the optimal flow rate shows highly efficiency.

CHAPTER FIVE

Techno-economic analysis

5.1 Demand analysis

The demand of hot water in various purposes such as swimming pool, canteen, fast food shop, hospital etc. discussed as following:

5.1.1Case Study 1

A swimming pool located at the gymnasium in front of Institute of Energy in University of Dhaka. The swimming pool is 50m length and 21m width. The water depth of the pool varies 1.02m at one side and 1.83m of the other end. The overall capacity of the pool is about 1,613,000 litre equal to the volume of 1613m^3. The pool is active 8.5 months of a calendar year and rest of the time close. Due to lower temperature of water from the mid-November to end of February the pool has difficulties to operate and use. At the winter the temperature varies 8^{0}C to 18^{0}C in Dhaka and surrounding area.

At the winter solar water heater can be used for increasing temperature of the swimming pool. According to ASHRAE 55-1992 the comfortable temperature of water at winter season is 22.5^{0}C. 50628GJ heat energy needsper day to increase the water temperature from 15^{0}C at comfortable point. The energy can gather from solar energy at winter season.

Figure 5.1: Swimming pool at gymnasium in University of Dhaka

5.1.2 Case Study 2

A canteen situated at Mathematics Building in University of Dhaka. The canteen open five days weekly and consume large amount of water. For boiling rice consume 204 litre of water and for tea need 14 litre of water. The temperature of the water needs 100^0C. The water has boiled by gas source and need 90 minutes. Total energy need for boiling the water is 68.43GJ/day. The solar energy can give average 74.6-100GJ/day from $1m^2$ area. For boiling they can use slightly hot water that called pre-heated water. Due to using pre heated water, the consumption of gas can reduce at significantly for water boiling purpose. Solar water heater can produce about 94^0C of Evacuated Pipe Collector and 89^0C of flat plate collector at stagnant condition.

Figure 5.2: Canteen ofMathematics building in University of Dhaka

5.1.3 Case Study 3

A fast food shop and canteen in Dhaka Medical College has also using hot water for coffee purpose. The shop holder is using an electric oven for coffee purpose. There has about 10 litre of water needed for coffee making. They also facing a problem at winter that the filter drinking water temperature tends to low. So the water demand is to be low at winter. Mild hot water demand increase at winter. Sometime some patient or their relative's needs mild hot water and they seek for hot water. If they provide hot water, their business would be increase and their service providing also increase as good service provider. There has a daily demand of 125 litre at monsoon, and 185 litre at winter season but they use only 10 litre of hot water. The electric device directly uses normal water and it hot internally. If the input raw water pre heated at 70^0C then the electric consumption would be decreases and time requirements also decrease. The energy need9.4GJ/day at monsoon and 13.95GJ/day at winter.

Figure 5.3: Fast food shopin Dhaka medical college

5.1.4 Case Study 4

A 25 bed hospital named Nandina General Hospital situated at Nandina bazar in JamalpurSadarUpazila. The hospital regularly needs to hot water at various purposes. For patients and children bathing needs mild hot water, medium hot water use at the purpose of hand washing at Operation Theatre, floor washing etc. and very hot water needed for disinfection purpose of tools and other materials. The mild hot water temperature is about 40^0C, general hot water temperature is about 60^0C and the very hot water temperature is about 100^0C. The needed hot water is about 100 litre of mild hot water, 200 litre of hot water and very hot water is about 200 litre. An automatic electric device setting at roof has used for prepare hot water. The electric consumption is about 6.5KW for electric device. The device tends to the temperature about 70^0C. The mild hot water and hot water user needs to adding cold water for their serving purpose. The hot water device has taken cold water for production of hot water. If the device feed pre heated water then the electric consumption decrease significantly. The pre heated water can be prepared using solar collector. The energy demand for rising water 105GJ/day at winter but the requirements is low at monsoon.

5.2 Techno-economic analysis

For the techno economic analysis of the purpose that already surveyed those parameter has assumed and calculate the

Assume,

The efficiency of FPC	-58%
The efficiency of ETC	-87%
Average solar irradiance at winter	- 20.98 MJ/m2 (according to Datta 2014)
Daily solar hour at winter	- 5 hour
Cost of FPC/m^2	-Tk.11800.00
Cost of ETC/m^2	-Tk.4500.00

Table 5.1: Techno-economic analysis of various purposes

Purpose	Energy requirements	Needed area for sunshine	FPC need area	ETC need area	Estimation for FPC	Estimation for FPC
Swimming pool	50628GJ	670m^2	1155 m^2	770 m^2	Tk. 51.98 lacs	Tk. 90.86 lacs
Canteen	68.43GJ	0.91 m^2	1.57 m^2	1.57 m^2	Tk.7065.00	Tk.18526.00
Fast food	13.95GJ	0.2 m^2	0.34 m^2	0.22 m^2	Tk.4500.00	Tk.11800.00
Hospital	105GJ	1.40 m^2	2.41 m^2	1.61 m^2	Tk.10845.00	Tk.16520.00

CHAPTER SIX

Conclusion

6.1 Conclusion

The types of solar water heater as FPC and ETC at different flow rate has different scenario at their performance and their potentiality. At medium flow rate 3.4 lit/min FPC has a good performance but the solar radiation also effect on the performance. The FPC shows high efficiency at lower radiation but at higher radiation the efficiency goes down. The temperature rise also highest in FPC at 2.5 lit/min flow rate but the evacuated tube at 28.02^{0}C at 4.5 lit/min flow rate.

Hourly variation of outlet water temperature of FPC and ETC at 2.5 lit/min flow rate successively three days has more variation in ETC at high radiation. The hourly variation shows that at low radiation FPC has a good efficiency 87% than medium or high radiation, on the other hand ETC has a good efficiency 93% at comparatively high radiation. The temperature at stagnant condition has highest about 94^{0}C from ETC and 89^{0}C at FPC when the glass surface temperature about 50^{0}C and the metallic screen temperature about 48^{0}C.

The costing of ETC is higher than FPC but the performance of ETC is better than FPC. The efficiency as the ratio of heat transfer rate is better in ETC and FPC need more collector area than ETC. So, ETC is efficient and space effective but FPC is cost effective.

This study can help in design and estimation as sizing of FPC and ETC at community where daily hot water needed such as canteen, hospital, household, coffee shop or any special purposes such as swimming pool.

5.2 Limitations

The limitations of the study is shown in here that can uses in future

- Inadequate literature in FPC and ETC at Bangladesh perspective
- Low facility of technical support
- There has no flow meter at the inlet of ETC, so ETC performance at various flow rate could not examine
- FPC has a metallic screen that absorbs some heat energy and decrease the efficiency

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Appendix-1a

FPCat 4.6 l/m flow rate

Flow rate			115	25	4.60	lit/min
		Time	Input	Ambiant	Output	Difference
1	20/09/2016	13:50	31.85	31.25	34.24	2.39
13	20/09/2016	13:51	32.08	31.33	34.25	2.17
25	20/09/2016	13:52	32.25	31.39	35.69	3.44
37	20/09/2016	13:53	32.31	31.38	36.14	3.83
49	20/09/2016	13:54	32.54	31.46	35.72	3.18
61	20/09/2016	13:55	32.75	31.59	35.50	2.75
73	20/09/2016	13:56	32.75	31.74	35.63	2.88
85	20/09/2016	13:57	33.00	31.77	35.75	2.75
97	20/09/2016	13:58	33.25	31.77	35.63	2.38
109	20/09/2016	13:59	33.48	31.88	35.54	2.06
121	20/09/2016	14:00	33.71	31.88	35.79	2.09
133	20/09/2016	14:01	33.75	32.00	36.97	3.22
145	20/09/2016	14:02	33.75	32.00	38.00	4.25
157	20/09/2016	14:03	33.92	32.11	38.89	4.97
169	20/09/2016	14:04	34.00	32.14	39.52	5.52
181	20/09/2016	14:05	34.13	32.22	39.91	5.78
193	20/09/2016	14:06	34.25	32.25	38.74	4.49
205	20/09/2016	14:07	34.35	32.25	38.48	4.13
217	20/09/2016	14:08	34.58	32.35	39.33	4.74
229	20/09/2016	14:09	34.81	32.48	40.02	5.21
241	20/09/2016	14:10	35.00	32.53	40.40	5.40
253	20/09/2016	14:11	35.02	32.63	40.73	5.71
265	20/09/2016	14:12	35.25	32.63	40.75	5.50
277	20/09/2016	14:13	35.25	32.68	40.87	5.62
289	20/09/2016	14:14	35.25	32.75	41.21	5.96
301	20/09/2016	14:15	35.48	32.87	41.38	5.91
	Avg		33.80	32.05	37.89	4.09

Appendix-1b

FPCat 3.4 l/m flow rate

			85	25	3.40	lit/min
		Time	Input	Ambiant	Output	Difference
1100	20/09/2016	15:22	33.65	32.88	38.96	5.32
1112	20/09/2016	15:23	33.50	32.88	38.79	5.29
1124	20/09/2016	15:24	33.44	32.78	38.72	5.28
1136	20/09/2016	15:25	33.25	32.75	38.51	5.26
1148	20/09/2016	15:26	33.25	32.65	38.24	4.99
1160	20/09/2016	15:27	33.23	32.61	38.11	4.88
1172	20/09/2016	15:28	33.00	32.51	37.99	4.99
1184	20/09/2016	15:29	33.00	32.50	37.86	4.86
1196	20/09/2016	15:30	32.77	32.49	37.74	4.97
1208	20/09/2016	15:31	32.75	32.38	37.59	4.84
1220	20/09/2016	15:32	32.75	32.38	37.40	4.65
1232	20/09/2016	15:33	32.56	32.37	37.37	4.81
1244	20/09/2016	15:34	32.50	32.26	37.22	4.72
1256	20/09/2016	15:35	32.50	32.25	37.02	4.52
1268	20/09/2016	15:36	32.38	32.14	36.93	4.56
1280	20/09/2016	15:37	32.25	32.13	36.86	4.61
1292	20/09/2016	15:38	32.25	32.13	36.74	4.49
1304	20/09/2016	15:39	32.17	32.08	36.63	4.46
1316	20/09/2016	15:40	32.00	32.00	36.50	4.50
1328	20/09/2016	15:41	32.00	32.00	36.50	4.50
1340	20/09/2016	15:42	31.96	32.00	36.37	4.41
1352	20/09/2016	15:43	31.75	31.90	36.21	4.46
1364	20/09/2016	15:44	31.75	31.88	36.04	4.29
1376	20/09/2016	15:45	31.50	31.62	35.09	3.59
1388	20/09/2016	15:46	31.50	31.34	35.05	3.55
1400	20/09/2016	15:47	31.50	31.29	34.22	2.72
	Avg.		32.55	32.28	37.22	4.67

Appendix-1c

FPC at 2.5 l/m flow rate

Flow rate			57	23	2.48	lit/min
		Time	Input	Ambiant	Output	Difference
690	20/09/2016	14:47	35.25	33.58	42.01	6.76
702	20/09/2016	14:48	35.19	33.50	42.05	6.87
714	20/09/2016	14:49	35.00	33.44	42.09	7.09
726	20/09/2016	14:50	35.00	33.38	42.00	7.00
738	20/09/2016	14:51	35.00	33.38	41.94	6.94
750	20/09/2016	14:52	35.00	33.37	41.88	6.88
762	20/09/2016	14:53	35.00	33.25	41.80	6.80
774	20/09/2016	14:54	35.00	33.25	41.82	6.82
786	20/09/2016	14:55	35.00	33.25	41.80	6.80
798	20/09/2016	14:56	35.00	33.36	41.64	6.64
810	20/09/2016	14:57	35.00	33.38	41.52	6.52
822	20/09/2016	14:58	35.00	33.38	41.68	6.68
834	20/09/2016	14:59	35.00	33.38	41.64	6.64
846	20/09/2016	15:00	35.00	33.43	41.63	6.63
858	20/09/2016	15:01	35.00	33.50	41.52	6.52
870	20/09/2016	15:02	35.00	33.50	41.42	6.42
882	20/09/2016	15:03	35.00	33.50	41.53	6.53
894	20/09/2016	15:04	35.00	33.50	41.46	6.46
906	20/09/2016	15:05	34.96	33.50	41.32	6.36
918	20/09/2016	15:06	34.75	33.42	41.25	6.50
930	20/09/2016	15:07	34.75	33.38	41.22	6.47
942	20/09/2016	15:08	34.75	33.38	41.13	6.38
954	20/09/2016	15:09	34.75	33.38	40.98	6.23
966	20/09/2016	15:10	34.75	33.38	40.85	6.10
	Avg.		34.96	33.41	41.59	6.63

Appendix-2

ETC at 4.5 l/m flow rate

Flow rate		108	24	4.50	lit/min
Time	Time	Inlet	Ambiant	Output	Difference
0	16:01	35.25	31.16	43.23	7.98
5	16:02	35.25	30.72	60.09	24.84
10	16:03	35.25	30.61	64.59	29.34
15	16:04	35.25	30.49	64.87	29.62
20	16:05	35.44	30.42	64.92	29.48
25	16:06	35.50	30.39	64.79	29.29
30	16:07	35.50	30.38	64.84	29.34
35	16:08	35.50	30.37	64.84	29.34
40	16:09	35.50	30.25	64.79	29.29
45	16:10	35.50	30.25	64.88	29.38
50	16:11	35.50	30.25	64.94	29.44
55	16:12	35.50	30.25	64.77	29.27
60	16:13	35.50	30.25	64.68	29.18
65	16:14	35.50	30.25	64.64	29.14
70	16:15	35.50	30.25	64.64	29.14
75	16:16	35.50	30.25	64.59	29.09
80	16:17	35.50	30.25	64.61	29.11
85	16:18	35.75	30.25	64.63	28.88
90	16:19	35.75	30.25	64.64	28.89
95	16:20	35.75	30.36	64.50	28.75
100	16:21	35.75	30.38	64.50	28.75
105	16:22	35.73	30.27	64.24	28.51
110	16:23	35.50	29.48	63.57	28.07
115	16:24	35.50	29.50	63.65	28.15
120	16:25	35.50	29.50	63.63	28.13
	Avg.	35.51	30.27	63.52	28.02

Appendix-6