Project Completion Report on

Development of a Test Setup for Solar Thermal Collector with Air as Working Fluid And Design a Microcontroller-Based Mechanism for Controlling the Collector Output

Submitted to

Assam Science Technology and Environment Council
Bigyan Bhawan, Guwahati

Prepared by:
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February 2017

Project Completion Report – 2014 Feb – Jan 2017

Project Summary:

1) Project Title:	Development of a test setup for solar thermal collector with air as working fluid and design a microcontroller-based mechanism for controlling the collector output
2) Principal investigator:	PRADYUMNA KUMAR CHOUDHURY Assistant Professor, Deptt. of Energy, Tezpur Central University, P.O.- Napaam, Tezpur – 784028, Assam, India, Tel: 03712 275300, 03712 275309 Email: pkc@tezu.ernet.in, chpk2k2@yahoo.com
3) Duration:	Three (03) years
4) Date of commencement of the project	01/02/2014

Details Fund:

1) Total Project cost:	:	**Rs.1,60,000.00**
2) Sanctioned Amount	:	**Rs. 1,25,000.00**
3) Sanction letter No	:	ASTEC/S&T/192(151)/2012-13/300 dtd. 21/11/2013
4) Fund Released	:	**Rs.1,24,312.00**
5) Fund Utilized	:	**Rs.1,24,312.00**

Acknowledgement

We sincerely acknowledge the support and assistance received from all individuals and organizations for successful completion of the project.

Most importantly, we are indebted to the **Assam Science Technology and Environment Council, Guwahati,** for providing financial support for execution of the project.

The necessary supports and guidance received from time to time from the competent authority of Tezpur University is sincerely acknowledged.

We highly acknowledge the kind supports received from various offices, sections or departments of Tezpur University including Office of the Registrar, Dean R & D, Finance section and the Department of Energy as well.

Last, but not the least, we sincerely acknowledge the supports and guidance received from all individuals which helped directly or indirectly in timely completion of the project.

Place: Tezpur
Date: 24/2/2017

(Pradyumna Kumar Choudhury)
PI & Assistant Professor
Department of Energy
Tezpur University

Project Completion Report – 2014 Feb – Jan 2017

Background:

The increased use of renewable energy sources will eventually lead to the significant saving of fossil fuel. In order to use the solar air heater for a particular application, it is often required to have constant temperature output from the air heater. However, under the varying weather conditions as well as solar radiation, there must be a control mechanism which will take care of these variations and uncertainties and facilitate the collector to provide a constant output. Also to design an efficient and reliable control mechanism, an appropriate test setup is required for the investigation of effects of different parameter on the collector output. The proposed project will facilitate a dedicated study on a particular collector and is expected to lead to reliable design of a control mechanism.

A solar hot air generator can be used suitably for drying of food products, industrial process heat requirements, room heating and other similar applications requiring hot air. Various research works have been reported in the field of efficiency improvement of solar flat plat collector. However more specific studies are required to obtain output from solar air heater as per the temperature requirement. The proposed study will include the development of a test setup for performance evaluation of solar flat plat collector generating hot air. The flat plat collector will be fitted with all the necessary equipments and sensors for measurement of parameters such as, temperature, solar radiation and flow rate. The performance of the system will be evaluated as per standard procedure under varying operating conditions and the effect of varying operating conditions on the collector output as well as efficiency will be studied and analyzed. This study will explore the possibility of efficiently controlling the temperature of the hot air at the output of flat plat collector for temperature specific/constant temperature applications and aims to design a micro-controller based control mechanism for the purpose. The result of this study is expected to be used for the development of an automatic control mechanism for providing load specific output.

With the above background the objectives for the project were set to develop a test setup for testing of solar flat plat collector with air as working fluid with respect to operational parameters and design a control mechanism for providing constant output under varying operational conditions

Review of Previous Works and Fabrication of the Test Facility:

Solar air heating systems based on flat plate collectors have been found to be very suitable, particularly for low temperature applications in the ranges of 50 - 80^0 C. These systems are applicable for drying of products such as tea leaves/ coffee beans, and also for processing of fruits, spices, vegetables, fish, seafood cereals, mushroom, papad etc. Hot air is also required in industries such as leather, textiles, chemicals, rubber, paper, pharmaceuticals etc. It is estimated that over 800 million kgs of tea leaves are being produced and dried in Southern states, Himachal Pradesh, West Bengal, Assam and North East States. Another 250 million kgs of coffee beans are also being produced and dried every year. Millions of tonnes of food and industrial products are also being dried annually in various industries in the country. The systems installed in industries for drying of various products have been saving a significant amount of fossil fuel, apart from improving the quality of end product and reducing GHG emissions. A typical system of 100 sq. m. of flat plate collector area may cost around Rs. 5-6 lakh which could save up to 6000 liters of conventional fuel for a period of over 15-20 years. Over 60 such systems of different capacities comprising of 12,000 sq. m of collector area are functioning in the country [1].

In drying and space heating, solar energy is an ideal choice because the warm air can be used directly, eliminating any need for an extra heat exchanger in the thermal system. Most fruits and vegetables contain more than 80% water and are, therefore, highly perishable. Losses of fruits and vegetables in developing countries are estimated to be 30–40% of production and, in India alone, yearly losses worth more than US$1.5 billion [2]. The need to reduce postharvest losses is of paramount importance for these countries. Prospect of solar drying applications in the ASEAN region is enormous [3].

Solar energy collectors are special kind of heat exchangers that transform solar radiation energy to internal energy of the transport medium. The major component of any solar system is the solar collector. This is a device which absorbs the incoming solar radiation, converts it into heat, and transfers this heat to a fluid (usually air, water,) flowing through the collector. The solar energy thus collected is carried from the circulating fluid either directly to the hot water or space conditioning equipment, or to a thermal energy storage tank from which can be drawn for use at night and cloudy days [4].

Solar drying has been used since time out of mind to dry plants, seeds, fruits, meat, fish, wood, and other agricultural, forest products. In order to benefit from the free and renewable energy source provided by the sun several attempts have been made in recent years to develop solar drying mainly for preserving agricultural and forest products. However, for large scale production the limitations of open-air drying are well known. The drying time required for a given commodity can be quite long and result in postharvest losses (more than 30%). Solar drying of agricultural products in enclosed structures by forced convection is an attractive way of reducing post-harvest losses and low quality of dried products associated with traditional open sun-drying methods [5]. In such conditions, solar dryers appear increasingly to be attractive as commercial proposals [6, 7].

Grainger *el al.* extensively reviewed various drying methods using only solar energy alone, as well as those using solar along with other auxiliary energy source [8]. Sharma *et al.* described the design details and performance of two types of low cost solar crop dryers, conventional cabinet dryer with direct heating mode and an integrated solar collector-cum-drying system based on the principle of natural convection [9]. Experimentations were done with different types of vegetables viz. cauliflower, green peas and potato showed satisfactory overall efficiency and performance of both dryers.

Imre *et al.* discussed in detail about the construction principles of solar dryers and flat plate collectors along with their economics and performance evaluation [10]. Jairaj *et al.* established that solar drying of grapes is technically feasible and economically viable [11]. The chemical treatment of grapes prior to drying decreases drying time required to reach the safe moisture content for storage.

Fudholi *et al* reported that the use of solar drying for agricultural and marine products has a large potential from the technical and energy saving point of view [12]. Numerous types of solar dryers have been designed and developed in various parts of the world, yielding varying degrees of technical performance.

Test set-up:

The test setup includes different system/ components which are appropriately integrated through necessary hardware as well as software. The outdoor set up is installed in the façade attached to hybrid energy laboratory of the Department of Energy, Tezpur University, Tezpur, Assam (Lat. 26.6528° N, Long. 92.7926° E). The tilt of the collector is set at 26° (latitude of Tezpur).

Major equipments:

The list of major equipment/ component procured for the set up following the Tezpur University procedure is given in the Table –I.

Table – I: List of Equipment/ components procured

Sl. No.	Name of equipment/ item	Spec./ Model/ Make	Qty.	Cost (Rs.)
1.	Solar flat Plat Collector	2 sqm approx. with mounting structure, Alishan Steel Fab. & Ind.	1	35,200.00
2.	Microcontroller Development Kit	Easy Start 8051, Mikroelectronica	1	26,368.00
3.	Digital Temperature Indicator	PT 100, Samson Automation	5	13,568.00
4.	Blower	GBL 800E, Bosch	2	8,389.00
5.	Hot air anemometer	AM 4204 , Lutron	1	16,005.00
	TOTAL			**99,530.00**
	(Rupees Ninety Nine Thousand Five Hundred and Thirty Only)			

The **certified fund utilization certificate and statement of expenditure** are attached herewith as **Annexure I & II.**

Monitoring and control system

An integrated data logging system developed in this work, is capable of recording data as well as controlling inlet air temperature as per requirement of the testing. The hardware interfaces are based on 8085 micro-controller while the software interfaces are based on MATLAB. The system can perform three main functions: (a) measurements/ recording, (b) storing and (c) controlling.

Microcontroller

The main component in this integrated system is ATMEL AT89S52 microcontroller. Its major specifications as per manufacturer [17] are given below.

- 8K Bytes of In-System Programmable (ISP) Flash Memory
- Endurance: 10,000 Write/Erase Cycles
- Operating Range : 4.0V to 5.5V
- Fully Static Operation: 0 Hz to 33 MHz
- 256 x 8-bit Internal RAM
- 32 Programmable I/O Lines
- Full Duplex UART Serial Channel
- Low-power Idle and Power-down Modes
- Watchdog Timer
- Flexible ISP Programming (Byte and Page Mode)

The pin configurations are shown in Fig. 1. The operating voltage used is 5V dc. This necessitates all other signals to be conditioned to appropriate voltage level.

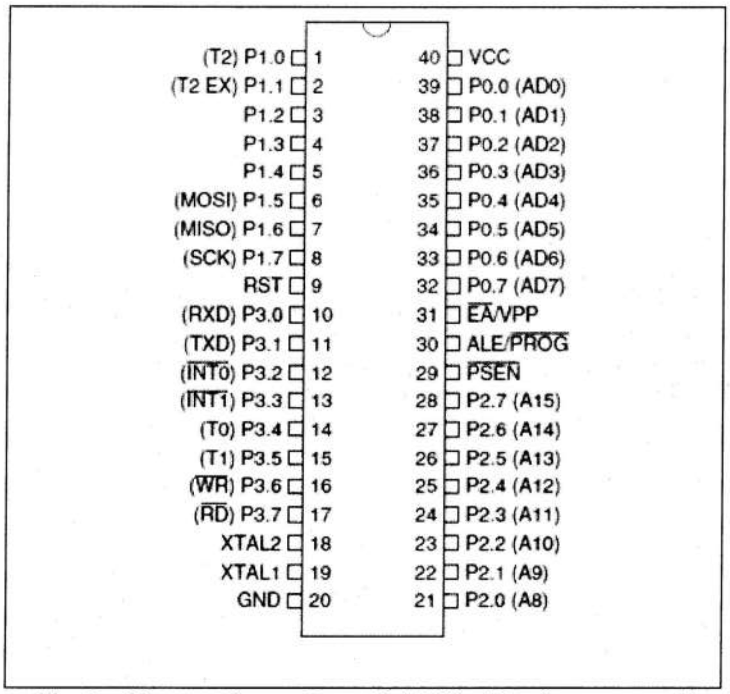


Fig.1 - Pin configuration of AT89s52 microcontroller [17].

Measurements/ recording

The primary parameters considered for measurements through this system are (a) temperature and (b) solar irradiance

Temperature

Considering the operating range, the temperature sensor Maxim DS18B20 is used. It facilitates programmable resolution (9 to 12 bit) and it can be used to measure temperature in the range of -55 °C to 125 °C. The critical specifications of this sensor according to manufacturer [18] are given below.

- Unique 1-Wire protocol Interface Requires Only One Port Pin for Communication
- Measures Temperatures from -55°C to +125°C (-67°F to +257°F)
- ±0.5°C Accuracy from -10°C to +85°C
- Programmable Resolution from 9 Bits to 12 Bits
- Each Device Has a Unique 64-Bit Serial Code Stored in On-Board ROM
- Can Be Powered from Data Line; Power Supply Range is 3.0V to 5.5V

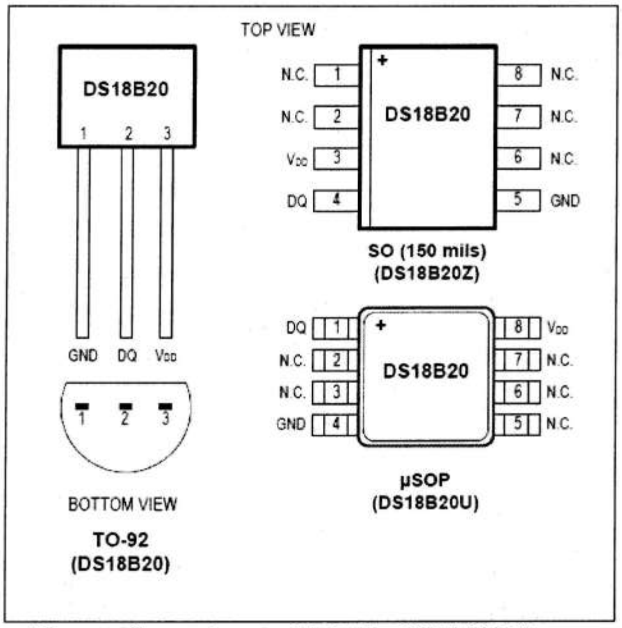


Fig. 2 - Pin configurations of Maxim DS18B20 sensor [18].

The pin configurations are shown in Fig. 2. The sensor is a three terminal sensor, two for power supply while the other is for I/O signal. The signal terminal can be easily fed to microcontroller where the signal is processed and the measured temperature is display in the LCD (Fig. 3). The major advantage of using this sensor is that it uses one –wire protocol and each sensor has 64 bit unique identification number. Thus a number of sensors can be connected on the same wire and data can be read by in calling individual sensor. In order to communicate this sensor through microcontroller only one port pin is required. Besides, these sensors can derive power from data line or parasite power and can work without an external power supply. The advantage of using this sensor is that it facilitates remote measurement and the measured data at the outdoor locations can be easily transferred in the indoor.

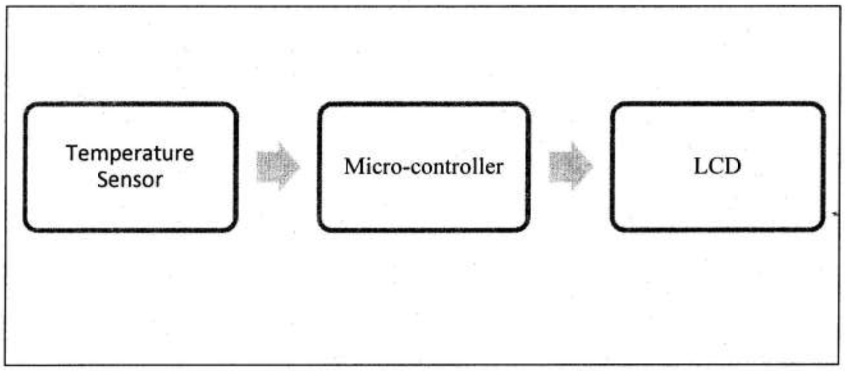


Fig. 3 - Schematic layout of interfacing temperature sensor.

Four numbers of such sensors are used for measurement of inlet and outlet temperature, absorber plate temperature and the ambient temperature. The PT100 temperature indicators are used to display instantaneous temperatures while DS18B20 sensors are used for data logging as well as temperature controlled triggering of desired event.

The necessary hardware/ software development for monitoring –cum-controlling is done using Microelectronica development board. The microcontroller used in the setup is ATMEL 89S52. This is 40 pin microcontroller with 4 I/O port. The programming is done using MikroC Pro. In order to make addressing of sensor at different locations more flexible and independent, the 64 bit unique ROM identification code is read by writing appropriate program in microcontroller and displaying in LCD. These codes are then stored in an EPROM (24C02) by writing appropriate programme in the microcontroller. Finally another program is written for microcontroller to read the temperature by each sensor and is displayed in the LCD along with its sl. no.

Solar irradiance

For measuring the solar irradiance, a Kipp and Zonen pyranometer (CMP11) is used. In order to condition the output signal of the pyranometer for suitably processing by the microcontroller a signal conditioning circuit is used which is fabricated using OP07. Calibration of the circuit is done by giving varying input from a regulated power supply and then the measurements are done using microvolt meter and digital multimeter. The signal coming from the pyranometer is connected to the input of the signal conditioning circuit and the output is fed to the microcontroller via ADC 0804 (Fig. 4). An appropriate programme is written for the microcontroller and the linear regression equation of the I/O Calibration curve of the signal conditioning circuit is used for measurement of the solar irradiance sensed by the pyranometer which is displayed in the LCD.

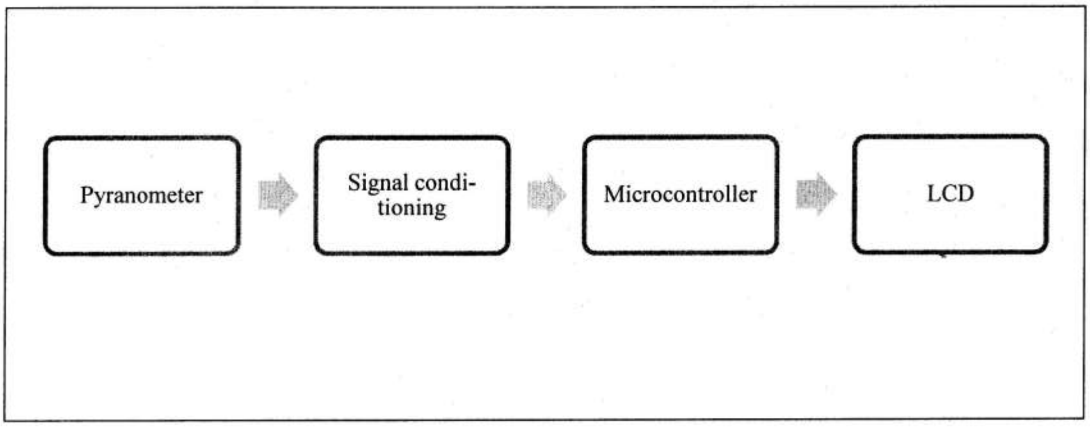


Fig. 4- Schematic layout of solar irradiance measurement.

Heater Control

The heater is fabricated with four numbers of 500 W heating coils fitted in a 0.3 m × 0.3 m × 0.9 m asbestos insulated wooden chamber. The electric power to the heater is supplied through a solid state relay of 25 A capacity and switching control is done via microcontroller. Appropriate programme is written in the microcontroller which makes the heater to switch on and off at the desired range of temperature dictated by the user input. The heating chamber temperature is also shown in the LCD (Fig.5).

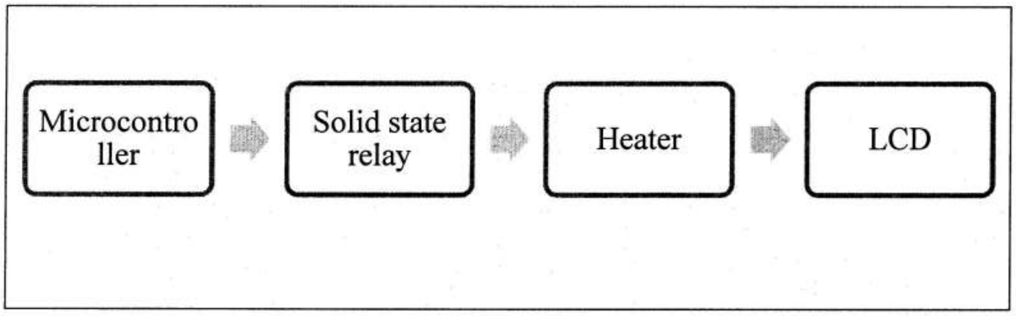


Fig. 5- Schematic layout of heating chamber control unit.

PC Interfacing

MATLAB is used to interface the hardware with PC. The functions of MATLAB programmes are (a) to communicate with the hardware through USB ports (b) to input the air velocity and other specifications of the collector, (c) to input the temperature setting of the heater control hardware (d) to start the log data at specified time and recording data from the sensors at desired time intervals and (e) to store the data sets with date and time stamps in excel sheet in appropriate structure to facilitate suitable processing of the data by subsequent MATLAB programme. Some of the programmes are written as functions for convenience in calling separately as and when required.

All the components of the integrated system are controlled and operated by a master program written in MATLAB. The flow chart of the integrated systems is shown in the Fig. 6. The Schematic Diagram is shown in the Fig. 8.

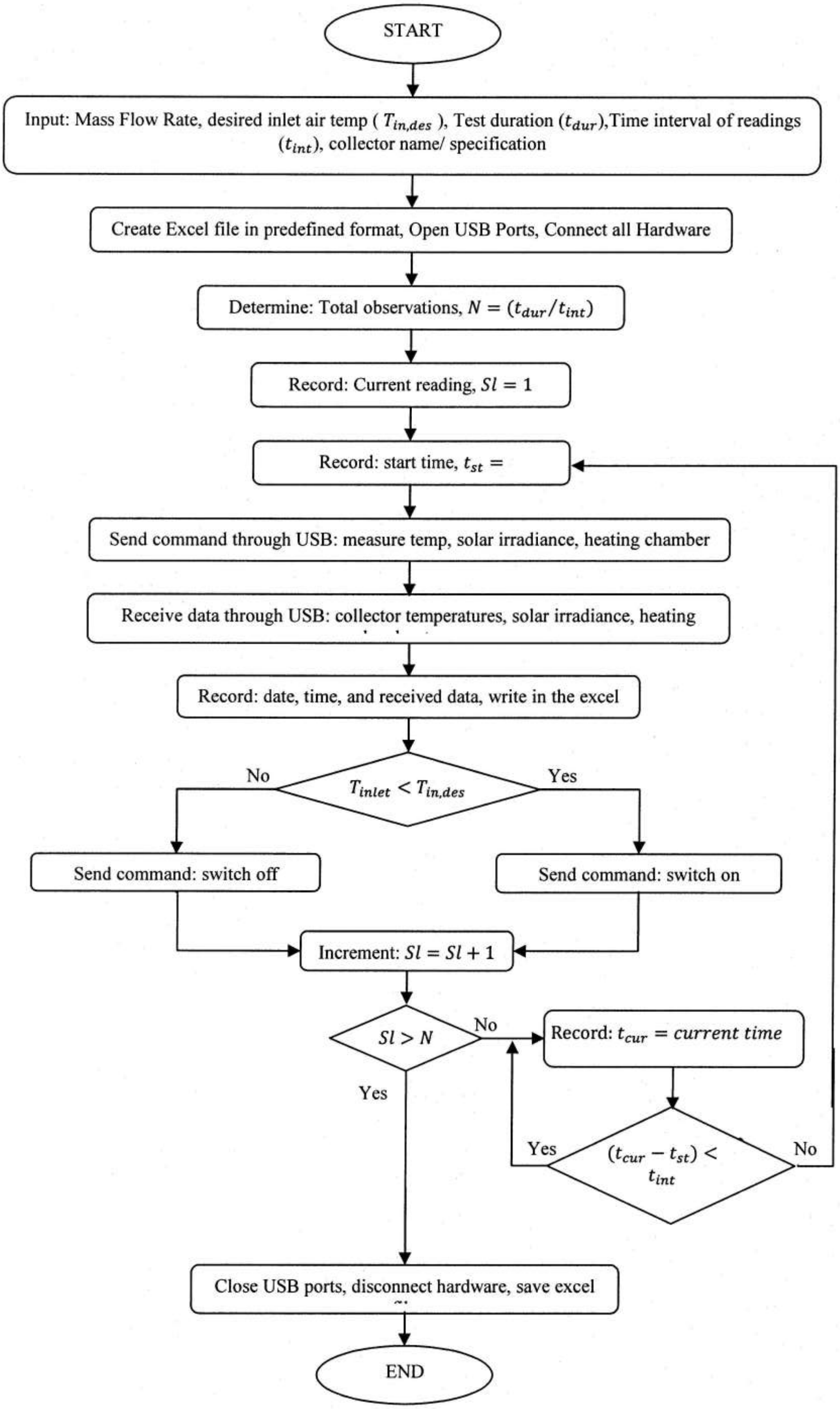
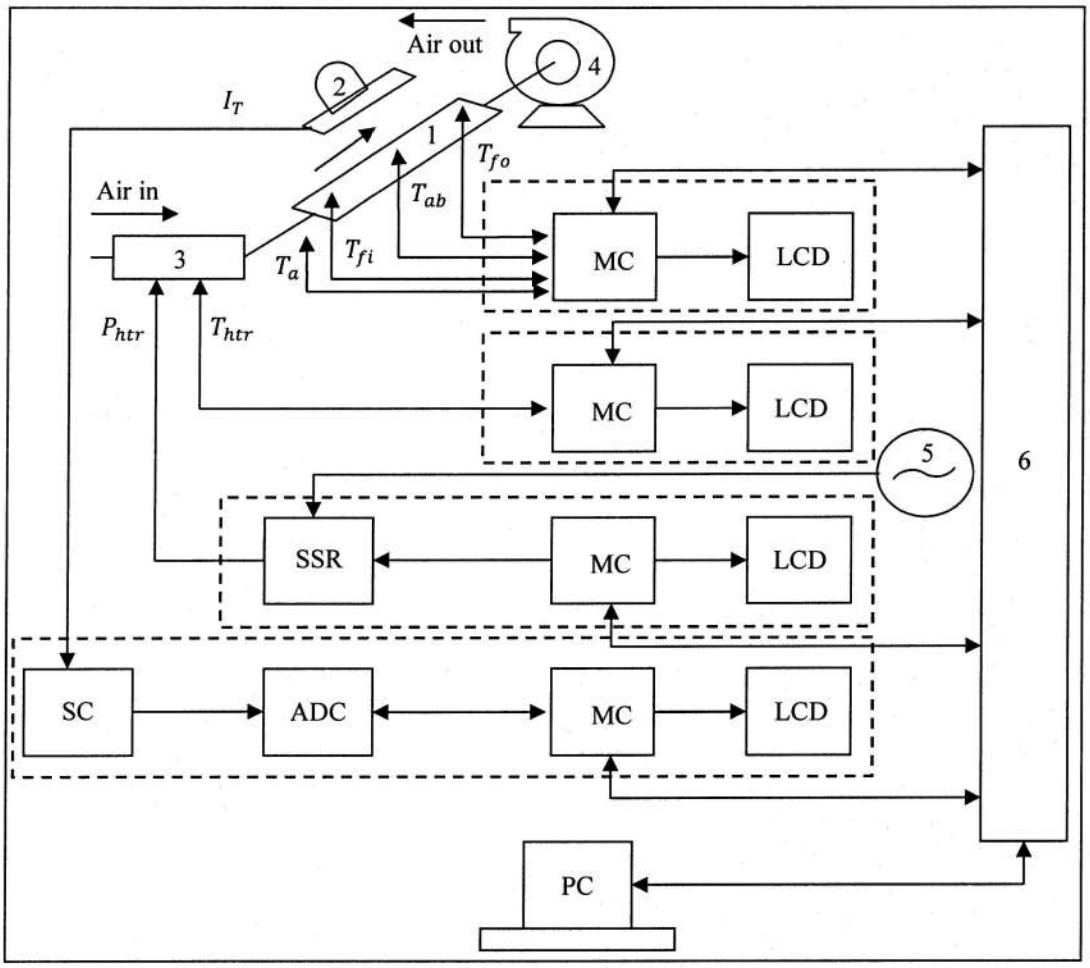


Fig. 7 – Flow chart of the master program for the integrated system.



1	:	Collector	3	:	Electric heater	5	:	Electric power supply for heater
2	:	Pyranometer	4	:	Blower	6	:	USB communication ports

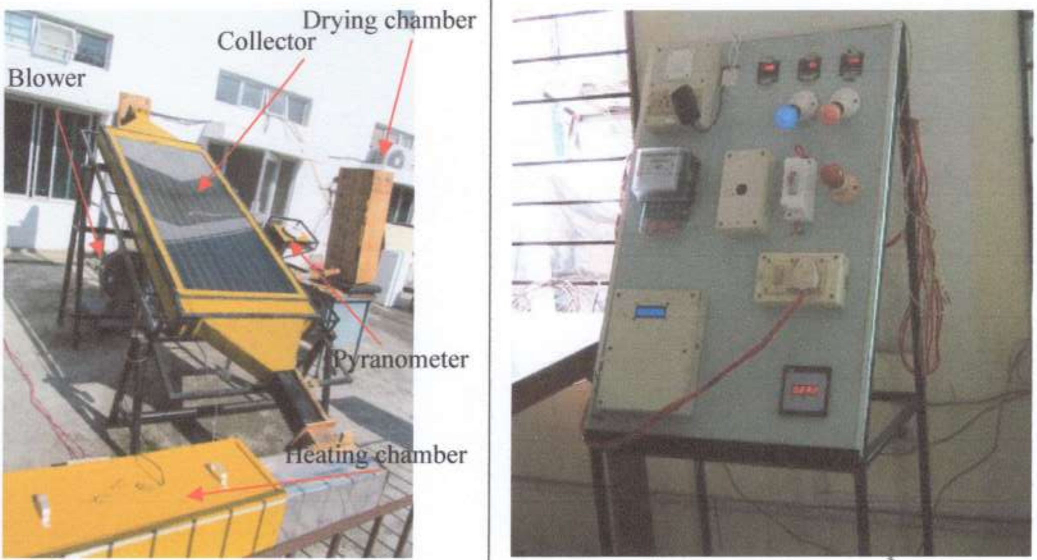
Fig. 8 – Schematic diagram of the integrated monitoring and control system.

Experimental observations:

The system components interconnected appropriately and eexperiments are conducted following ASHRAE 93-77 guidelines [13, 14, 15, 16]. Picturês of the test setup are shown in Figs. 9 & 10. Using this set-up eextensive observations are made to acquire data under required meteorological condition. Operating conditions are varied by (a) supplying air at different mass flow rates and (b) supplying inlet air at different temperature (in the range of 35 to 65 deg C). After giving sufficient time for preconditioning of collector, necessary temperature and radiation measurements are observed in one minute interval during four hours before and after solar noon. Observations fulfilling ASHRAE guidelines ($I_T \geq 790$ W/sqm and wind speed < 4.5 m/s) during experiments are considered for determining efficiency curve. The required quasi-steady state test periods (5 min. duration) are identified for each test condition (characterized by $\dot{m}$ and T_1) before and after solar noon [16]. The periods, during which fluctuations in solar irradiance is within +/- 32 W/sqm from average value and variations in T_a and T_1 lies within +/-1.5 deg C and +/- 2% respectively, are considered as quasi-steady state test periods [16]. A number of experiments are done with set up for determining the thermal performance curve of the collector.

(a) Collector assembly | (b) Display of funding agency

Fig.9 – Outdoor test setup components and display of funding agency.



(a) Interconnection with other equipments / instruments during test | (b) Indoor control panel for experiment

Fig. 10 – Experimentation with test setup for determination of collector performance.

In order to determine the efficiency curves, a computer program is developed. The program gathers the recorded data files from storage system, performs necessary processing and then outputs the thermal performance curve in bmp format. Some of the typical performance curves determined from experimental data under different radiation levels are shown in Figs.11 & 12. Fig.11 shows the solar irradiance on different days while Fig. 12 shows the performance curves under corresponding meteorological conditions.

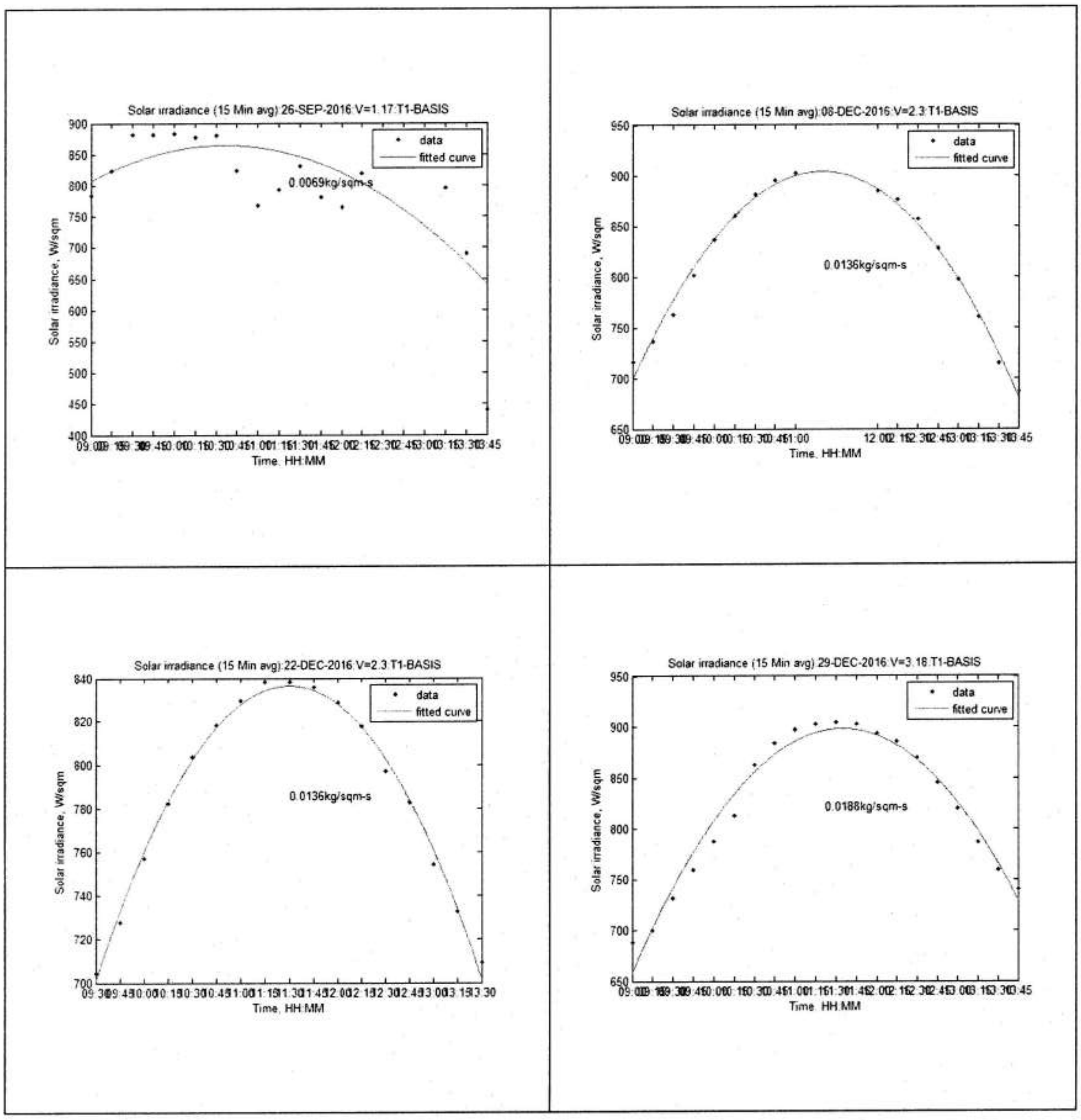


Fig.11- Experimental observation of solar irradiance in different days of thermal performance tests for the collector.

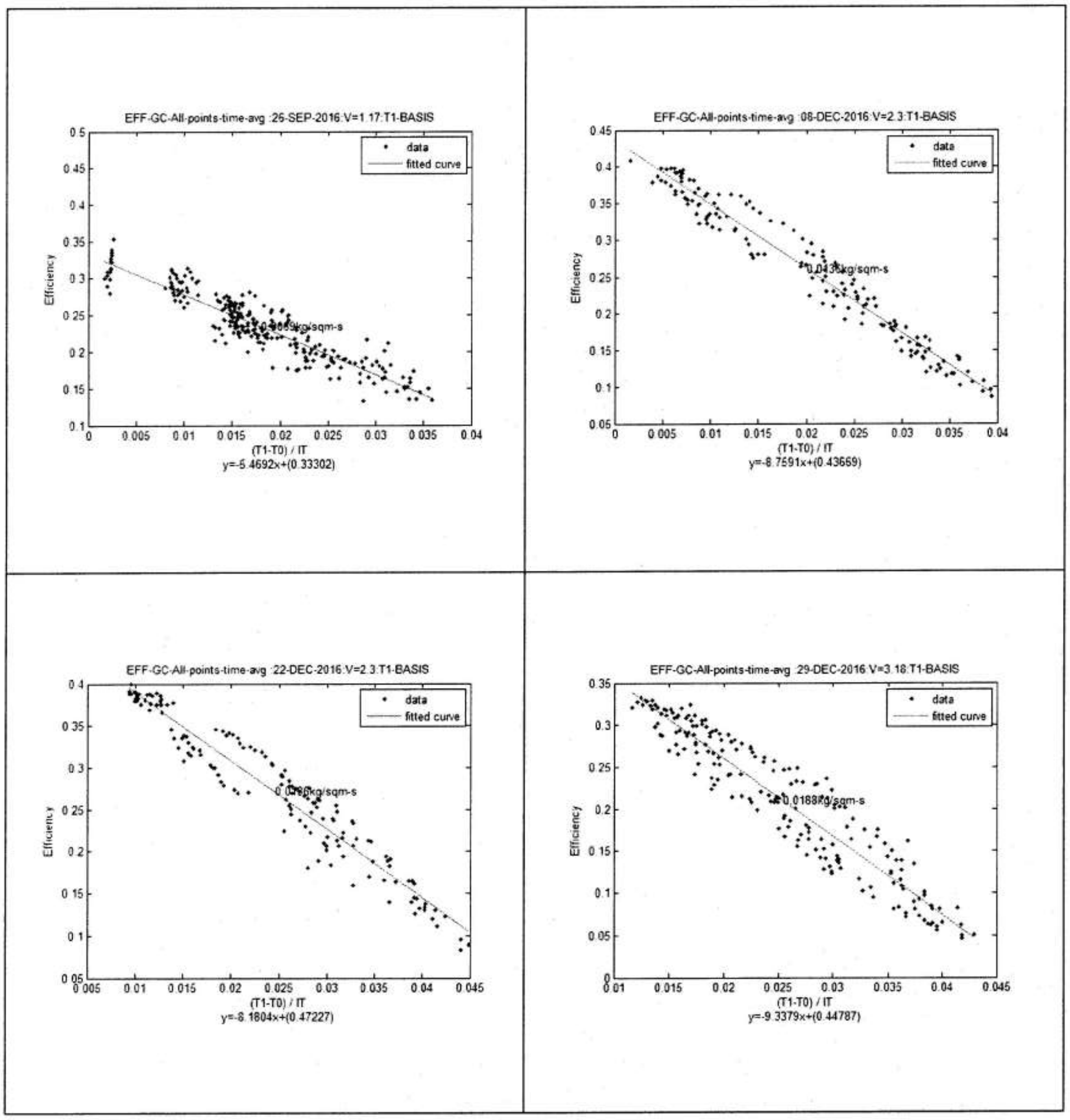


Fig. 12 - Experimental observation of thermal performance curve of the solar flat plate collector under different operating conditions.

Conclusion

Experimental results under different climatic as well as operating conditions indicate steep change in efficiency at higher mass flow rates. The value changes from 5.5 to 9.3 in the range of air mass flux 0.0069 to 0.0188 kg/sqm-s. The maximum efficiency observed at the air mass flux 0.0069 kg/sqm-s is 33 % while at 0.0188 kg/sqm-s is 44 %. On the other hand, maximum efficiency observed for 0.0136 kg/sqm-s varies from 43 to 47 % under different meteorological conditions. The major factor causing this variation is the sudden change of solar irradiance on different days as well as ambient air condition.

Further experimentation are going on for investigating differences in performance under different operating condition as well as during different seasons of a year in order to develop an optimized model for output control mechanism. Also considering variations of the weather condition round the year, appropriate arrangements are required for the outdoor setup to protect from corrosion or damage.

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ANNEXURE-I

Certified copy

FINAL UTILIZATION CERTIFICATE
(FOR THE PERIOD FROM 01/02/2014 TO 06/07/2016

Certified that out the grant of **Rs 1,24,312.00 (Rupees One Lakh Twenty Four Thousands Three Hundred and Twelve only**) released for the purpose **R & D Project Entitled "Development of a test setup for solar thermal collector with air as working fluid and design a microcontroller-based mechanism for controlling the collector output"** to Tezpur University under the investigator-ship of **Mr. P. K. Choudhury, Assistant Professor, Dept. of Energy** vide your letter no. **ASTEC/ S&T/ 192(151)/ 2012-13/ 300 dtd. 21.11.2013**, an amount of **Rs. 1,24,312.00 (Rupees One Lakh Twenty Four Thousands Three Hundred and Twelve only**) has been utilized for the purpose for which it was sanctioned.

Sd/-
(P. K. Choudhury)
Principal Investigator

15.12.16
Finance Officer
Tezpur University
Finance Officer
Tezpur University

Registrar
Tezpur University
Registrar
Tezpur University

Internal Audit Officer,
Tezpur University

For SURAJIT CHAKRABORTY & CO.
CHARTERED ACCOUNTANTS
10.01.2017
CA. SURAJIT CHAKRABORTY
(Proprietor)
Membership No.- 305054

ANNEXURE-II

CERTIFIED COPY

FINAL STATEMENT OF EXPENDITURE FOR THE R & D PROJECT ENTITLED
"DEVELOPMENT OF A TEST SETUP FOR SOLAR THERMAL COLLECTOR WITH AIR AS WORKING FLUID AND DESIGN A MICROCONTROLLER-BASED MECHANISM FOR CONTROLLING THE COLLECTOR OUTPUT"
(FOR THE PERIOD FROM 01/02/2014 TO 06/07/2016)

SPONSORING AGENCY :-	Assam Science Technology and Environment Council (ASTEC), Guwahati, Assam.	
NAME OF P.I :-	P. K. Choudhury, Dept. of Energy, Tezpur University	
Project Cost : Rs. 1,60,000.00	**Amount Sanctioned : Rs. 1,25,000.00**	**Grant Received : Rs. 1,24,312.00**
Date of commencement of the project: 1/2/2014		

Grant Received	**1st Year**	**2nd Year**	**3rd Year**	**Total Fund Received (Rs.)**
Amount (Rs.)	**85,000.00**	**39,312.00**	**0.00**	**1,24,312.00**

Head of Expenditure	**2014-2015**	**2015-2016**	**2016-2017**	**Total**	**Total Expenditure**
Equipment	79,375.00	**NIL**	20,155.00	99,530.00	**1,24,312.00**
Consumables	0.00	**NIL**	18,550.00	18,550.00	
Contingency	4,937.00	**NIL**	1,295.00	6,232.00	
Total Expenditure	**84,312.00**	**NIL**	**40,000.00**	**1,24,312.00**	

Sd/-

P. K. Choudhury
Principal Investigator

Internal Audit Officer,
Tezpur University

For SURAJIT CHAKRABORTY & CO.
CHARTERED ACCOUNTANTS
10.01.2017
CA. SURAJIT CHAKRABORTY
(Proprietor)
Membership No.- 305054

Finance Officer 15.12.16
Tezpur University
Finance Officer
Tezpur University