DST Reference No: IDP/IND/2011/14 dated 18th September, 2012

PROJECT COMPLETION REPORT

INSTRUMENTED SOLAR HOT AIR GENERATOR (ISHAG) FOR OPTIMUM THERMAL LOAD IN TEA PROCESSING

1st October, 2012 to 30th September, 2016

Submitted to

INSTRUMENTATION DEVELOPMENT PROGRAMME
DEPARTMENT OF SCIENCE & TECHNOLOGY
GOVERNMENT OF INDIA, NEW DELHI

(D C Baruah, PI)

Department of Energy,
Tezpur University, Tezpur
Assam, India 784028

January, 2017

Contents

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The dedicated involvement of Biogen Industries, Jorhat, the industrial partner of the project, has helped to complete this project smoothly which is also acknowledged.

We are also grateful to Heat Pump Laboratory, IIT Bombay, Mumbai, Tocklai Tea Research Institute, Jorhat, Department of Mechanical Engineering, Jorhat Engineering College, Chandra Prabha Tea Factory, Golaghat and Rupai Tea Factory, Tinsukia for their constructive support to the project.

The hard and dedicated work of all the project staffs, more particularly, the sincere work of Mr Doljit Borah is happily acknowledged.

(Debendra Chandra Baruah)

PI, ISHAG

Tezpur, 07-01-2017

PROJECT SUMMARY SHEET

Project Title: Instrumented Solar Hot Air Generator (ISHAG) for optimum thermal load in tea processing.

DST Sanction No: IDP/IND/2011/14 dated September, 18, 2012

1. **PI (Name & Address)**:
   Debendra Chandra Baruah, Professor, Department of Energy,
   Tezpur University, Tezpur, Assam, India 784028
   Date of Birth: 01-06-1965
2. **Co-PI (Name & Address)**:
   Manabendra Bhuyan, Professor, Department of Electronics and Communication Engineering,
   Tezpur University, Tezpur, Assam, India 784028
   Date of Birth: 01-12-1955
3. **Industrial Partner:** Sri S N Phukan, Biogen Industries**,** KK Baruah Rd., Tarajan, Jorhat
4. **Research Staff**

Sl No	Name of Project Staff	Date of Joining	Date of Leave
1	Mr. S. Yograj	08-01-2013	11-06-2103
2	Mr. Pradeep Kumar Gautam	12-01-2013	23-08-2013
3	Mr. Doljit Borah	12-07-2013	31-08-2016
4	Ms. Abhishruti Bhuyan	13-09-2013	29-08-2014
5	Mr. Champak Talukdar	05-09-2014	05-03-2015
6	Mr. Parag Jyoti Bezbaruah	25-06-2015	31-08-2016
7	Mr. Champak Talukdar	26-10-2015	30-09-2016

5. **Broad area of Research:** Solar thermal for process heat generation
6. **Sub Area**: Thermal energy management using solar energy
7. **Approved Objectives of the Proposal :**
   - To assess the characteristics of thermal load required for tea processing
   - To develop a solar hot air generator (ISHAG) with control system suitable to supplement thermal energy in tea processing
   - To assess techno-economic feasibility of the solar hot air generator (ISHAG) and transfer of technology for extensive application
8. **Date of Start:** 1 October, 2012
9. **Date of completion:** 30 September, 2016 (with one year extension)
10. **Total Cost of the Project:** Rs. 37,22,560
11. **DST contribution**: Rs. 34,65,400.00 (Rupees Thirty Four Lakhs Sixty Five Thousand and Four Hundred) only (revised).
12. **Industrial partner contribution:** Rs. 2,57,160.00 (Two Lakh Fifty Seven Thousand One Hundred and Sixty only)
13. **Total Expenditure**: Rs. 37,04,732 (Rupees Thirty Seven Lakhs Four Thousand and Seven Hundred Thirty Two) only.

I. Introduction

Tea processing requires thermal energy for drying operation. Traditionally, hot air/flue gas with a temperature of about 110^{o}C generated from combustion of fossil fuel is used for drying of tea. Need of a device to generate hot air for process heat, using solar radiation has been felt for a long time due to increasing fuel prices and also for promotion of solar energy as a national mandate. There are many issues such as temporal variations of solar radiation, higher cost of available solar hot air generator, lower thermo-hydraulic performances, which require to be addressed for development of a solar hot air generator for local tea processing industries in Assam.

An instrumented solar hot air generator has been developed in this study through a series of laboratory and field experiments/demonstrations as per the outlines provided as below.

- Assessment of solar energy and its potential application for tea processing in Assam
- Assessment of thermal energy requirements for tea processing in Assam
- Design, fabrication and testing of Solar Hot Air Generators (SHAG)
- Comparative performance assessment of different SHAGs including IITB SHAG
- Selection of SHAG for fabrication and installation
- Design of ducting and assessment of pumping power
- Design of flow control system
- Installation of SHAG units in tea processing factory and field demonstration
- Economic analysis of ISHAG and technology transfer

Brief discussions of the above works are presented below.

II. Assessment of Solar Energy

There is seasonal variation of solar insolation availability among the tea growing areas of Assam. The monthly availability of solar insolation (kWh/m^2/day) for the Sonitpur district is shown in Fig.1. It is seen from the Figure that during the months from February to June, the availability of solar insolation (kWh/m^2/day) is higher as compared to remaining months of the year. Maximum insolation recorded is 5.5 kWh/m^2/day, in the month of April. Similarly, the minimum insolation for Sonitpur, district is more than 4.0 kWh/m^2/day, in the month of September. This information of temporal availability of solar insolation is useful for planning of utilization of solar thermal energy.

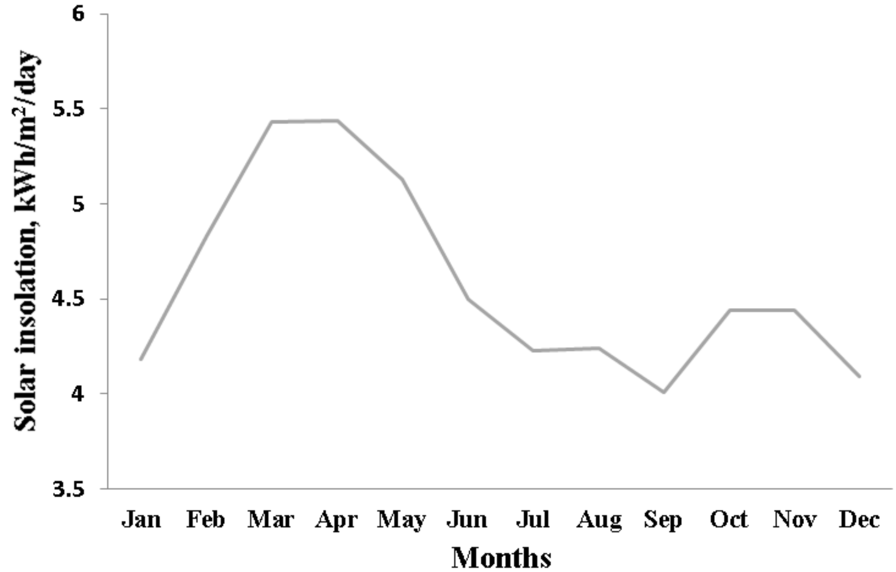


Fig. 1 Monthly variation of solar insolation in Sonitpur district, Assam

The solar radiation data measured with the Automatic Weather Station indicates that on an average about five (5) hours per day solar radiation above 350 W/m^2, is available for operation of Hot Air Generator (HAG). This radiation level is the threshold value as quoted by ASHRAE 93-2003 standard. The availability of solar radiation hour per day for Tezpur, Assam during the year 2008 to 2011 is shown in the Fig. 2 below (for the year 2008, data are available from the month of July onward). It is observed from the Fig. 2 that the highest solar radiation hour is obtained in September month (6 h/day) and the lowest solar radiation in December month (3 h/day). In month of July, duration of solar radiation is the highest (7 h/day) and it is lowest in the months of January and December (3 h/day).

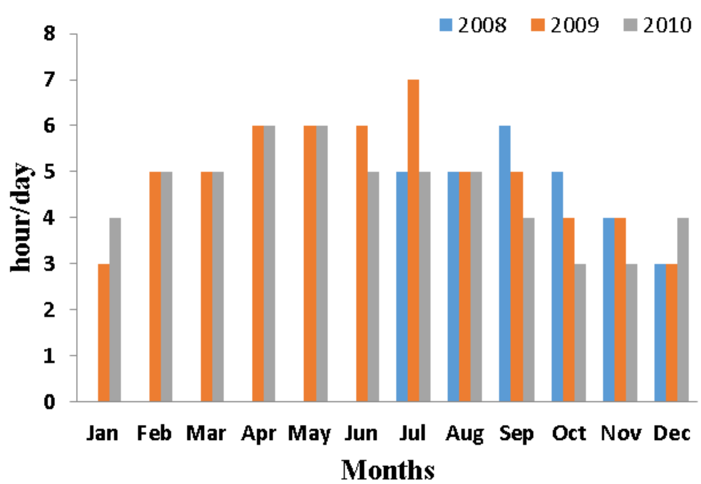


Fig. 2 Monthly variations of solar radiation hours per day at Tezpur

Ignoring the spatial variation within the tea growing regions of Assam, the above assessment values are used for designing the solar hot air generator for tea processing in Assam.

III. Thermal energy requirements in tea processing and need of solar thermal device

At present either coal or natural gas is being used for drying of tea. In case of coal, flue gas of pulverized coal combustion from furnace is passed through heat exchanger and then to chimney (Fig. 3). Ambient air is heated up to the desired temperature (100 -110 ^{o}C) in the heat exchanger which is then enters into the drying chamber. There is a variation of coal consumption, depending upon the type of coal and season, with an average of about one kg of coal per kg of made tea (with coal price at Rs 9.00 per kg). It is observed that about 200 kg of hot air is spent for processing each kg of made tea so as to remove moisture from 70% to 3% (wb).

(a) Furnace (b) Flue gas passage to heat exchanger

Fig. 3 Use of coal furnace in a small scale bought leaf factory (Chandraprabha tea factory, Golaghat)

(a) Tea dryer coupled with burner (b) Rear view of a burner

Fig. 4 Use of natural gas in a tea factory in Tinsukia district of Assam (Rupai Tea Factory, 200 kg per hour made tea production)

In case of natural gas, flue gas from the burner (Fig. 4) with appropriate mixing is transferred to the dryer. On an average, 0.69 m^3 (standard, ~40 MJ/m^3) natural gas is consumed per kg of made tea with a prevailing cost of Rs. 15 per m^3 (SCUM).

Hot air with a temperature of (ambient + 5°C) is also required in withering section of the tea processing (Fig. 5) for which gas or coal is burnt. Fuel consumption for withering operation is relatively less compared to drying.

Fig. 5 Gas burner in withering section used at Rupai Tea Factory

Keeping in view of the above and interaction with the people of tea industry, following points are summarized for design of the solar hot air generator for tea processing.

- The small scale "bought leaf tea factories" could be the immediate user of the proposed SHAG for partial replacement of conventional fuel (coal or gas)
- There could be three possibilities of hot air applications in coal fired units *viz*., (i) as primary air in furnace, (ii) as inlet air in heat exchanger instead of ambient air and (iii) as inlet air in drier.
- In case of a natural gas fired processing units, use of hot air in the burner inlet is expected to reduce the gas consumption.

IV. Design, fabrication and testing of Solar Hot Air Generators (SHAG)

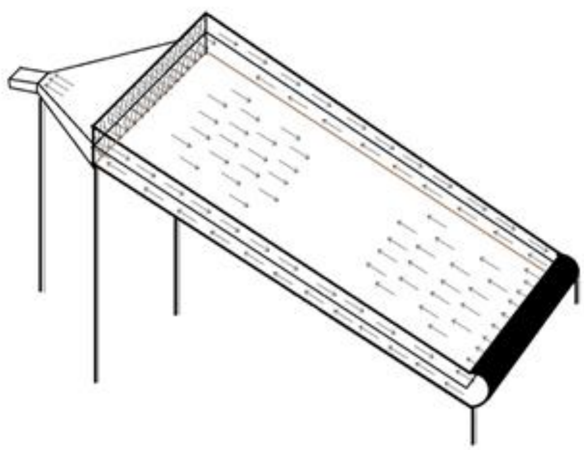
Solar Hot Air Generator (SHAG) is developed through a series of stages, details of which are presented below.

Development of SHAG I

Initially, a double pass, double glazing Solar Hot Air Generator (Fig. 6) was designed through numerical computation and then fabricated based on the most suitable parameters corresponding to highest possible thermal efficiency under range of solar insolation available in Tezpur. Absorber plate has fins to enhance heat transfer to air. Salient design parameters are provided in Table 1.

Table 1: Design parameters of SHAG I

Sl. No	Parameter	Value
1	Design ambient temperature	25 ^{O}C
2	Design inlet air temperature	27 ^{O}C
3	Design wind velocity	1 m/s
4	Thermal conductivity of absorber plate	211 W/mK
5	Transmittance of glass cover	0.92
6	Glass absorptivity	0.05
7	Glass emissivity	0.8
8	Plate emissivity	0.9
9	Plate absorptivity	0.95
10	Fin height	0.06
11	Number of fin	25
12	Design air mass flow rate	0.04 kg/s



(a) Schematic indicating air flow line **(b) SHAG I kept ready for experiment**

Fig. 6 A modular unit of SHAG I (1.2m ×2.4m)

Tests were conducted with variation of mass flow rate under a range of solar radiation conditions. The variation of outlet air temperature with respect to variation of solar insolation is shown in Fig. 7

and Fig 8 for air mass flow rates of 0.01 and 0.04 kg/s, respectively. It is seen that the outlet temperature initially increases as the solar insolation increases. In the later half the solar insolation decreases sharply, however the rate of decrease in outlet temperature is less. This is attributed to the thermal energy stored by the body of the flat plate collector in the initial stage, which gets released in the later phase. Figs. 9 and 10 show the temperature variations in different parts of the solar air heater, namely, ambient, inlet, bottom plate, outlet air and absorber plate, for mass flow rates of 0.01 and 0.04 kg/s, respectively. Knowledge on temperature profile is useful to understand the heat loss in the device.

It is seen that outlet temperature up to 92°C could be achieved from the SHAG I corresponding to 0.01 kg/s of air flow rate.

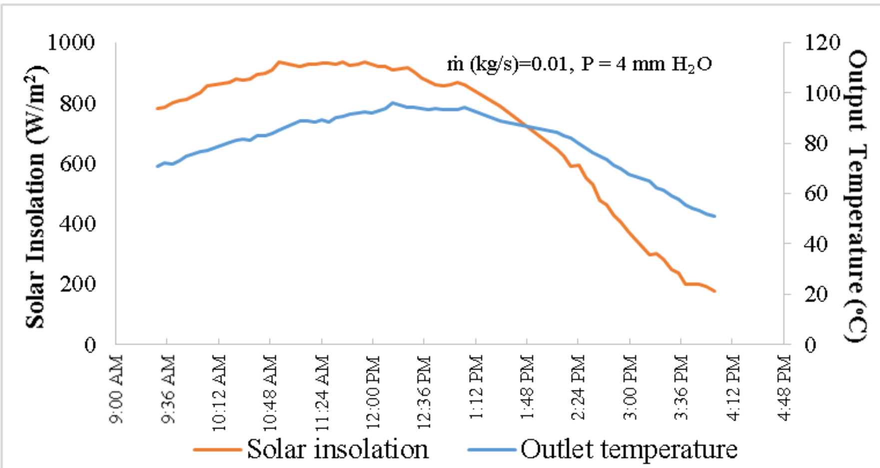


Fig. 7 Solar Insolation and Outlet Temperature during operation of SHAG I at 0.01 kg/s

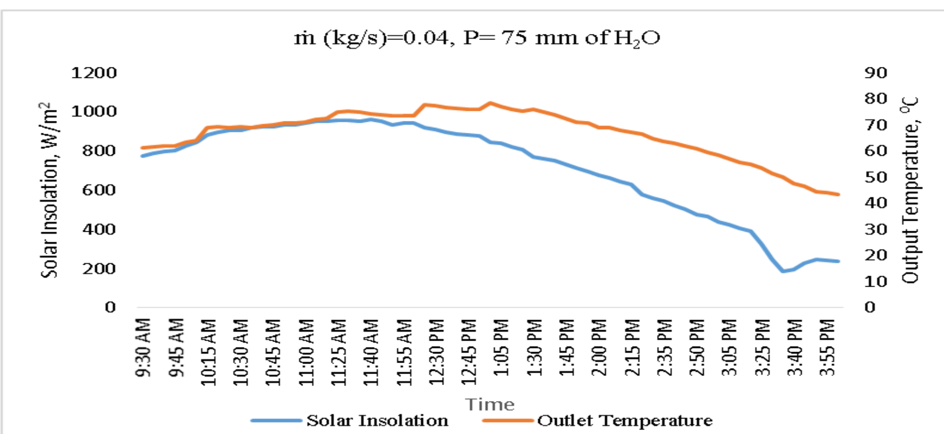


Fig. 8 Solar Insolation and Outlet Temperature during operation of SHAG I at 0.04 kg/s

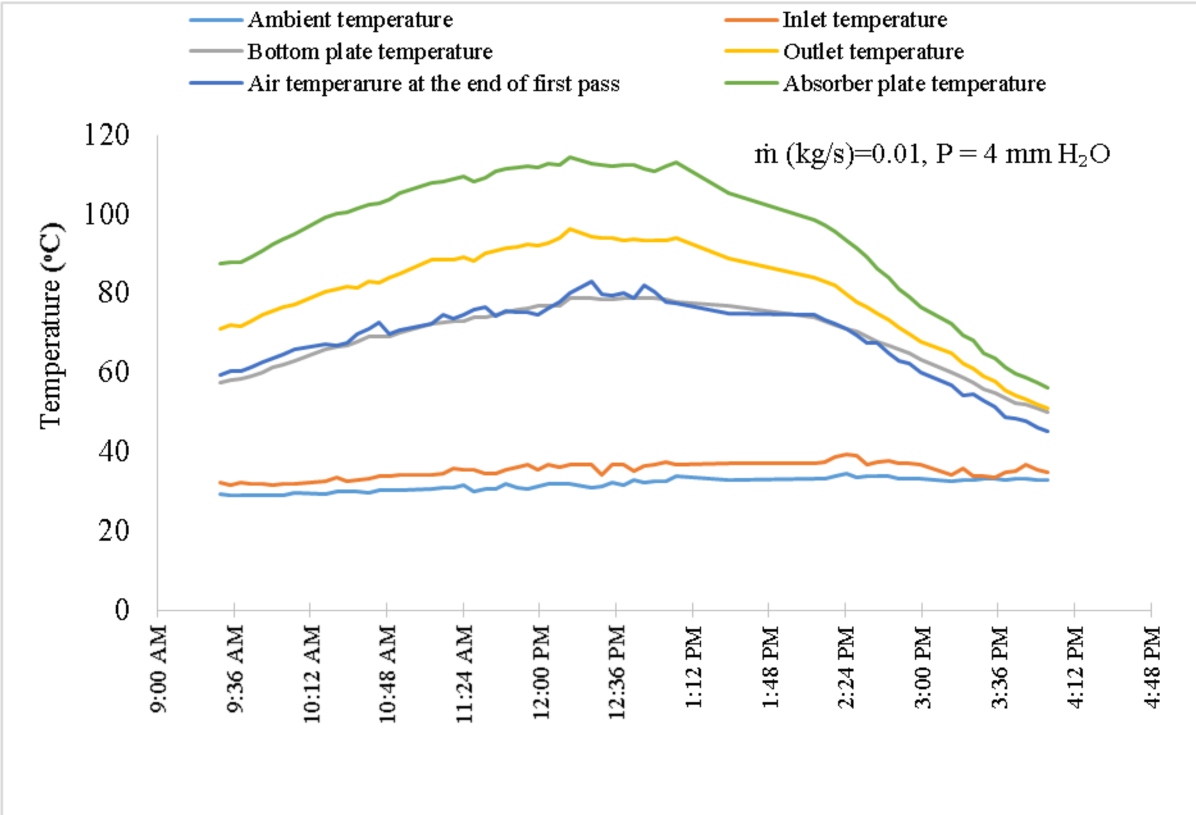


Fig. 9 Temperature profile at different locations during operation of SHAG I at 0.01 kg/s

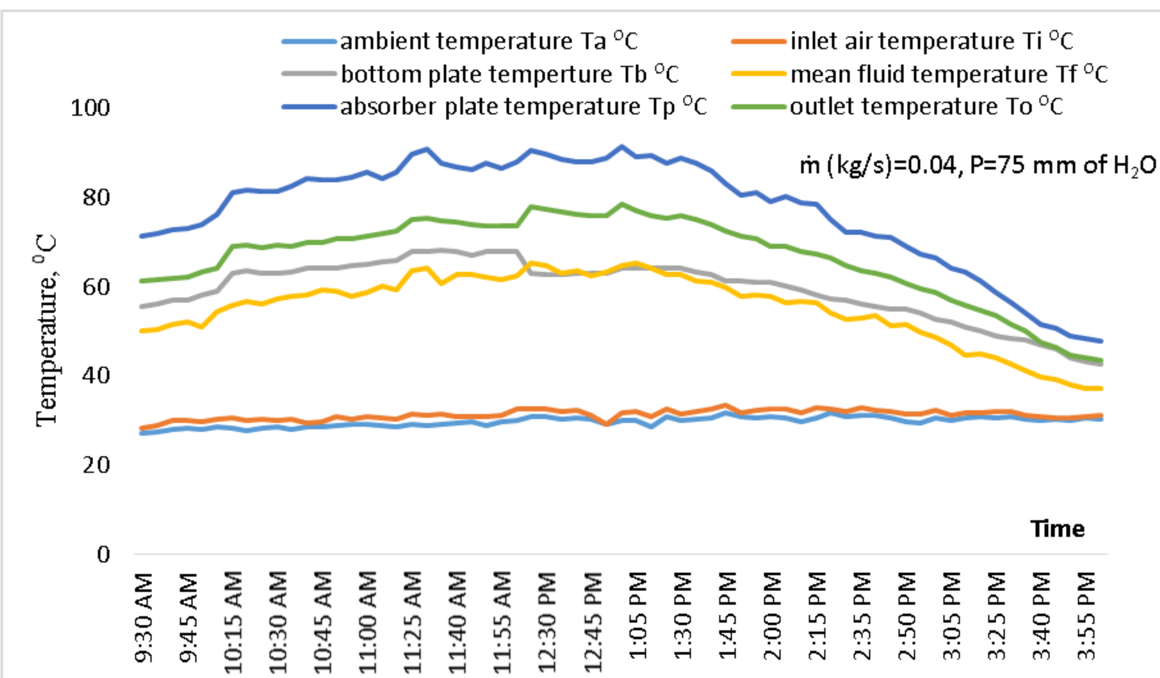
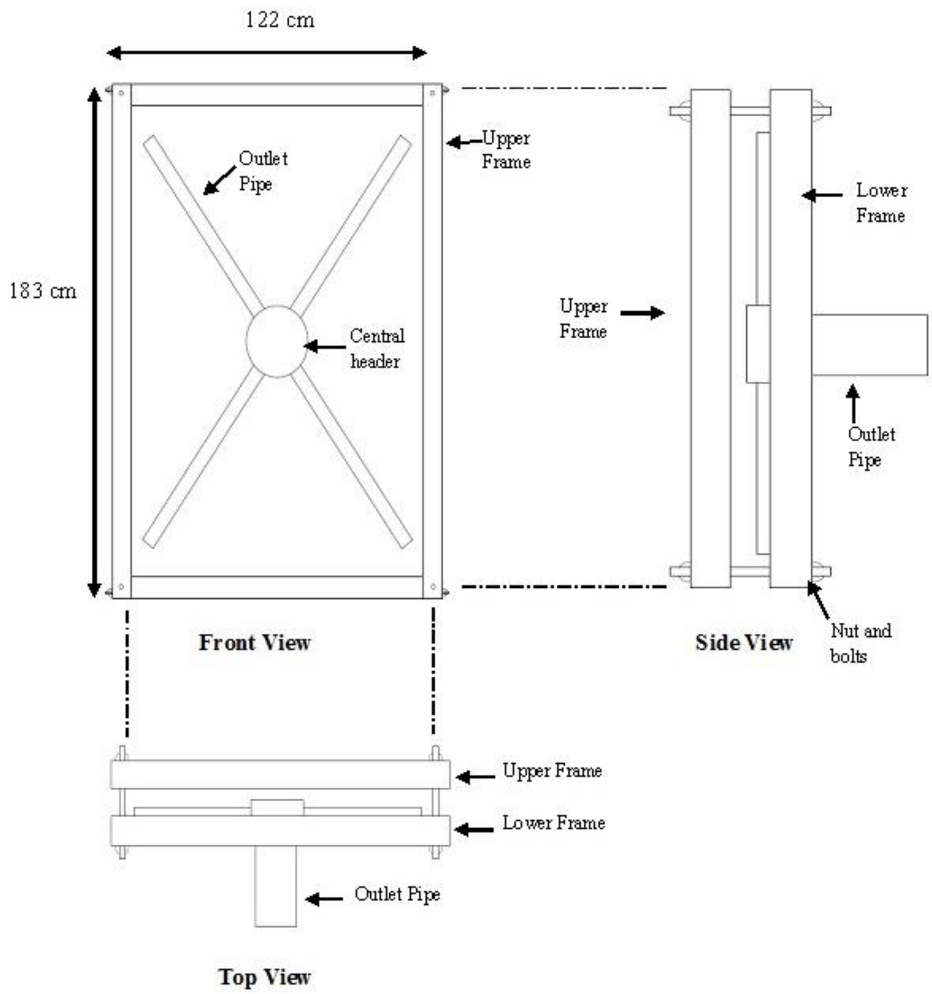


Fig. 10 Temperature profile at different locations during operation of SHAG I at 0.04 kg/s

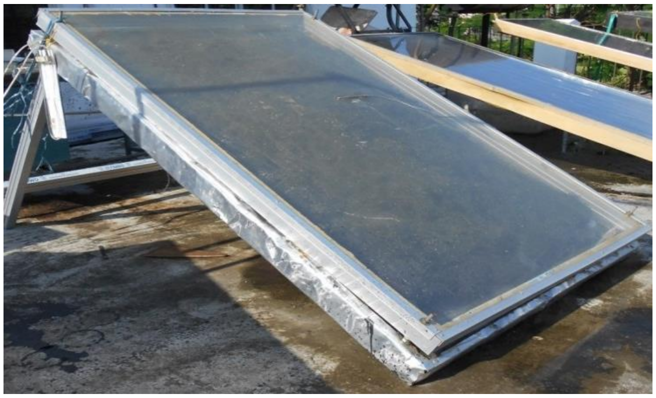
During long duration testing of SHAG I, the upper glazing plate (4 mm thick) was found broken, probably due to fluctuating thermal load. Moreover, though the thermo-hydraulic performance of the unit was good, there is limitation as the unit has been bulky with total weight of 80 kg. The double glass glazing made the system heavier as well as difficult to handle.

Development of SHAG II

In order to address the shortcoming of SHAG I without sacrificing its performance SHAG II is developed. A porous absorbing medium (aluminium wool) coated with black paint has been used in SHAG II instead of finned absorber plate. Further, to reduce weight, the unit has been fabricated using aluminium frame. Polycarbonate sheet was used as cover plate replacing heavy and fragile glass used in the previous design (SHAG I). Cross duct to collect hot air was introduced to reduce the pressure drop and improve the performance. Fig. 11 shows the cross duct porous medium SHAG II being tested in the Department of Energy, Tezpur University.



(a) Schematic view of SHAG II (1.2m ×1.8m)



(b) SHAG II kept ready for experiments

Fig. 11 Cross duct porous medium solar air heater (SHAG II)

The test results of SHAG II for a representative day of experiment have been presented in Figs. 12 through 14 for varying operating conditions as depicted in the Figures. With 0.04 kg/s of air flow rate, thermal efficiency variations between 61% and 98% (with corresponding air temperature 50^{o}C and 73^{o}C) have been observed indicating the prospect of the model. However, despite the better performance at laboratory, SHAG II could not be considered for development due to (i) non availability of cheaper porous material with safe and durable coating.

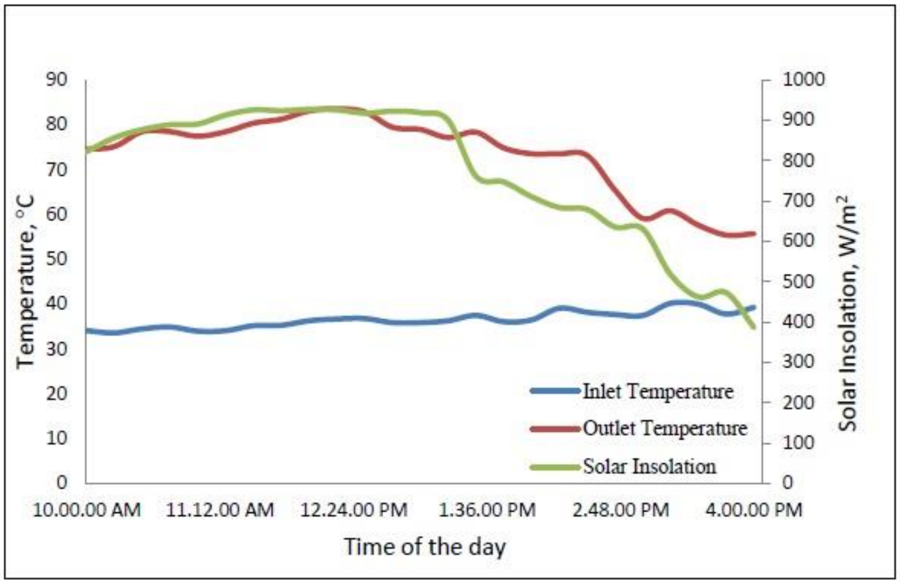


Fig. 12 Solar Insolation, inlet and outlet Temperature during operation of SHAG II at 0.01 kg/s (P=18 mm of H_2O)

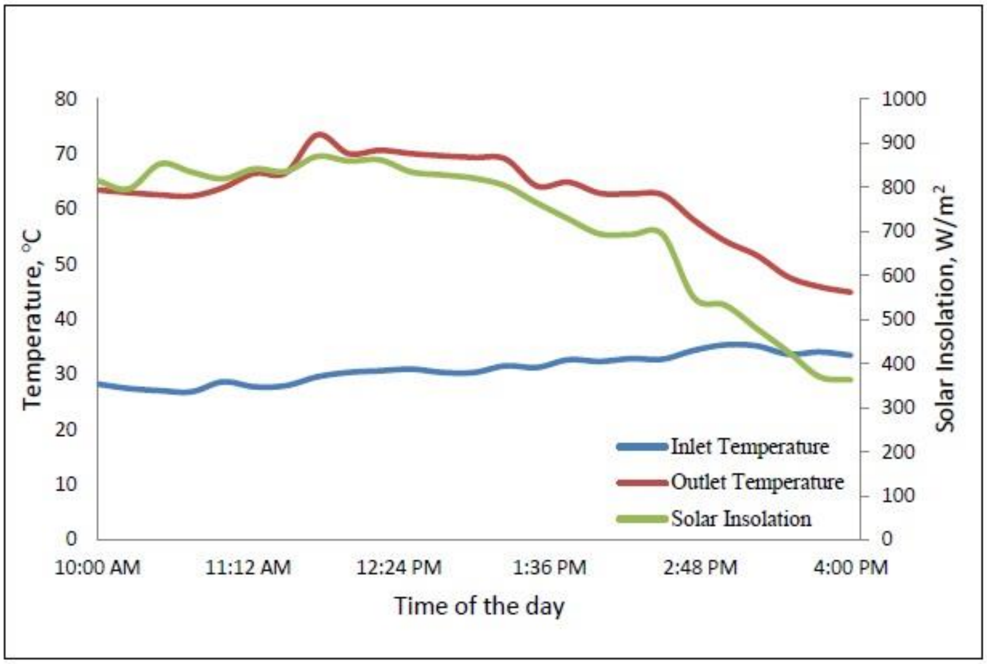


Fig. 13 Solar Insolation, inlet and outlet Temperature during operation of SHAG II at 0.04 kg/s (P=38 mm of H_2O)

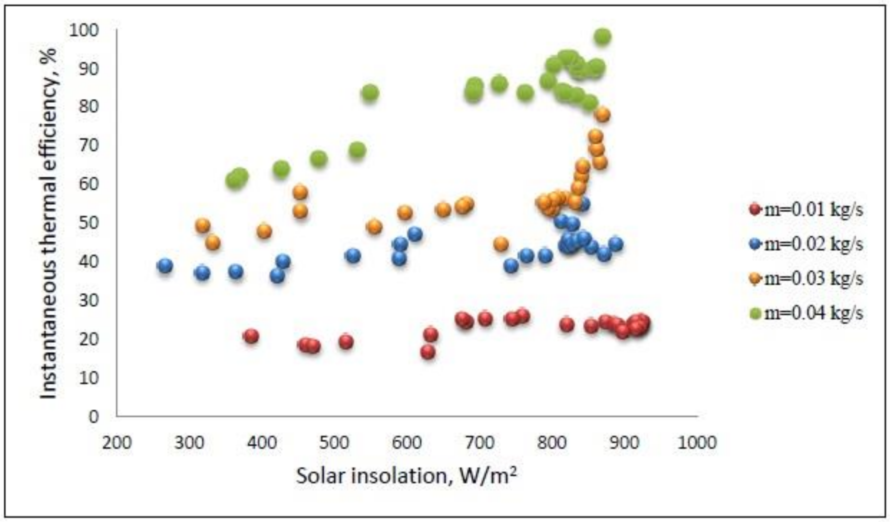


Fig. 14 Thermal efficiency at varying solar insolation at different flow rate

Testing of IITB SHAG

In order to address the issue of bulkiness, three SHAG units were procured from IIT Bombay with an aim to test and develop the system for tea processing in Assam. Weight of IITB SHAG (1.2m ×2.4m) is 35 kg while TU SHAG II (1.2m ×1.8m) is 30 kg. Tests of IITB SHAG and TU SHAG II were performed at the factory site at Golaghat (Fig. 15) to understand the comparative performance under identical conditions (mass flow rate and solar insolation). As can be seen from the Fig. 16, higher temperature could be achieved with IITB SHAG as compared with TU SHAG II under identical operating conditions.

Fig. 15 TU SHAG II (1.2m ×1.8m) and IITB SHAG (1.2m ×2.4m) test set up at Chandraprabha Tea Factory, Golaghat

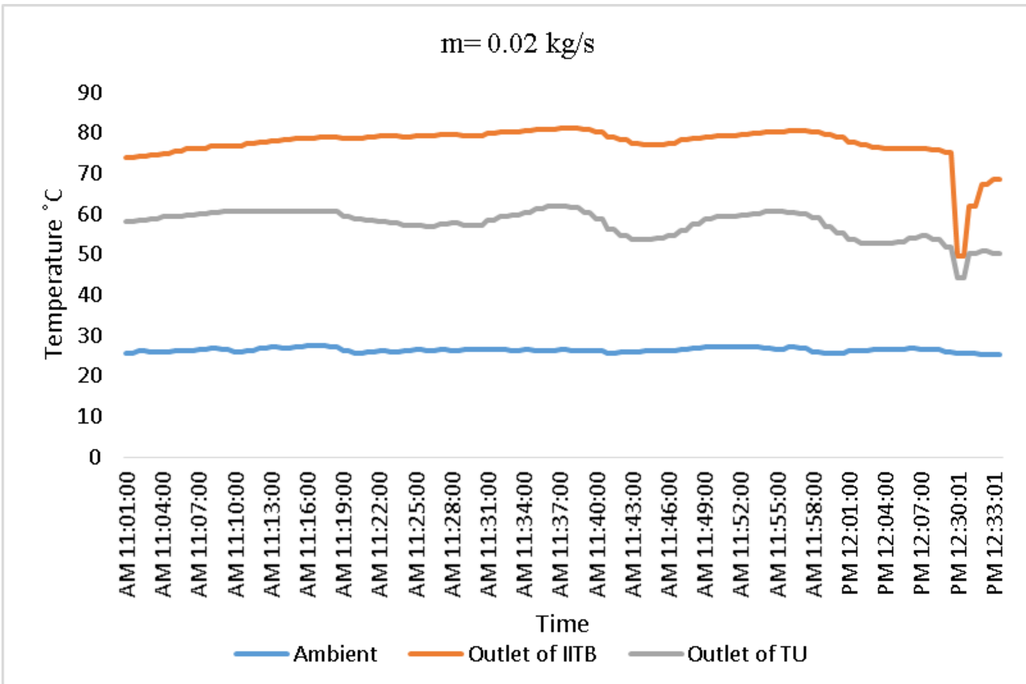


Fig. 16 Comparative performance results of IITB and TU SHAGs

IITB SHAG performs better than TU SHAG II as could be seen from the comparative test result, probably due to larger aperture (IITB is about 28% larger than SHAG II) associated with better heat transfer.

The procurement cost of IITB SHAG was Rs 50,000.00 (including transportation) while the manufacturing cost of SHAG II was Rs 12,500.00 (per unit). In order to reduce the cost and weight of the unit, effort was made to develop SHAG III as described below.

Design of SHAG III

SHAG III is attempted with a motivation to reduce weight and hence cost of manufacturing. A brief outline of the design of the SHAG III is provided below.

- The body of the SHAG III is made with rectangular aluminium sections. Aluminium sections are cut into desired size and holes were drilled into it. The sections were joined using pop rivets.
- 25 mm GI pipe is used as header (upper and lower header) where 19 mm diameter holes were drilled so as to fit 19 mm aluminium air collector tubes at a spacing of 177 mm (11 tubes per modular unit). The GI pipes were fitted to the aluminium frame, into the holes in the frame.
- Aluminium foil (6 µm thickness) is pasted on the upper surface of the collector tubes so as to act as absorber surface. The aluminium foil keeps the weight of the SHAG III unit low compared to absorber made from aluminium/copper sheets.
- Ceramic blanket is used for insulation. The blanket is laid under the collector pipes and is fixed to the frame with aluminium sheet (0.404 mm). The sheet is fixed to the frame using pop rivet.
- Black industrial grade paint is used to coat the aluminium foil absorber.
- Multilayer (two) polycarbonate sheet (10 mm thick) is used for glazing. The sheet is fixed to the frame using aluminium angles and pop rivet.
- Total weight of the module is 23 kg.

Except polycarbonate sheet, all other materials are available in the local market. Polycarbonate sheet is procured from Kolkata.

Performance Testing of SHAG III

A modular SHAG unit is tested in Golaghat at 0.04 kg/s of mass flow rate under varying insolation condition. The results are presented in Fig. 17. Maximum recorded thermal output is 2.2 kW with maximum temperature rise above the ambient as 55^{o}C. The pressure drop against flow at rated flow rate is found 22 mm of H_2O. The SHAG III is considered more suitable compared to all other units considered in the present study due to lower cost, light weight and ease of manufacturing and at equivalent

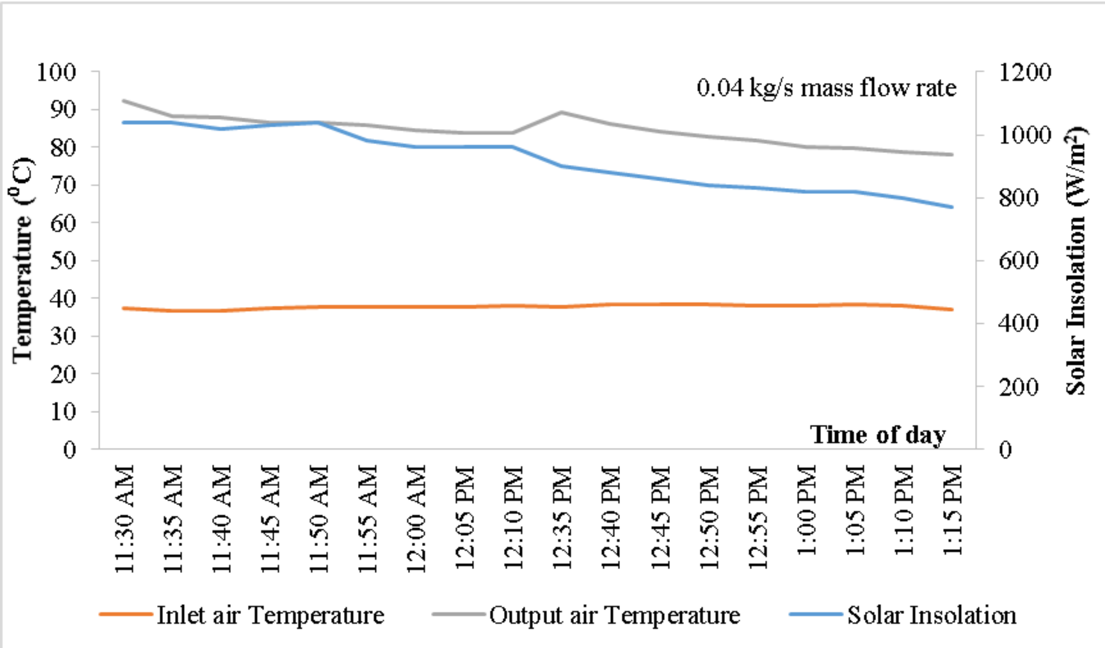


Fig. 17 Performance test results of SHAG III

V. Manufacturing and installation of SHAG III at Chandraprabha Tea Factory

A local manufacturing facility has been created with the initiative of Biogen Industries, the industrial partner in Golaghat to take up manufacturing of the SHAG III units. Few local artisans are trained to develop skill to manufacture the SHAG units. The major manufacturing steps are presented in Fig. 18 (a-f) and altogether 40 SHAG III units are manufactured using materials procured from local markets and Kolkata (polycarbonate sheet). Some of the initial defects such as non-uniform coating of black paint, rough finishing etc could be addressed as the manufacturing was progressing. The manufacturing units were inspected by the expert members and DST representative on 13th Feb 2016.

Ducting of the system and estimation of pumping power

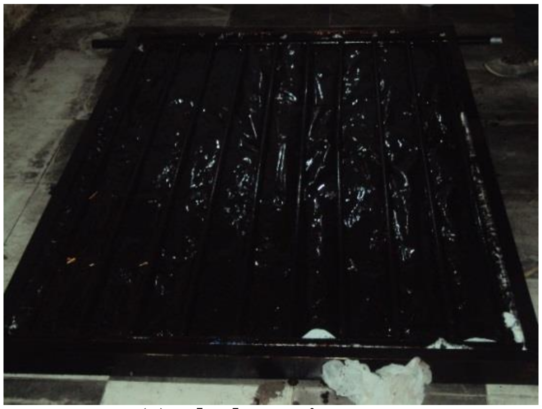
A ducting layout is designed with an aim to fabricate the unit at lowest possible cost while operating the system with minimum pumping power (Fig. 19). There could be additional options of design and operation. Doubling the header size reduces the pumping power as could be seen from Table 2.

Table 2: Pumping power required for hot air delivery with four different options (two designs at two different flow rates)

System Configuration of SHAG (header diameter, mm and flow rate m^3/minute)	Pumping Power Requirement (W) against rated 13 kW thermal power	Pumping Power requirement as % of available solar power
25 and 170	2877	22
25 and 200	4247	32
50 and 170	564	4
50 and 200	800	6

(a) Frames and collector pipes

(b) Pasting Aluminium foil



(c) Black coating

(d) Fixing of insulation

(e) Fixing back cover

(f) Finished product

Fig. 18 Fabrication steps of SHAG III at Golaghat

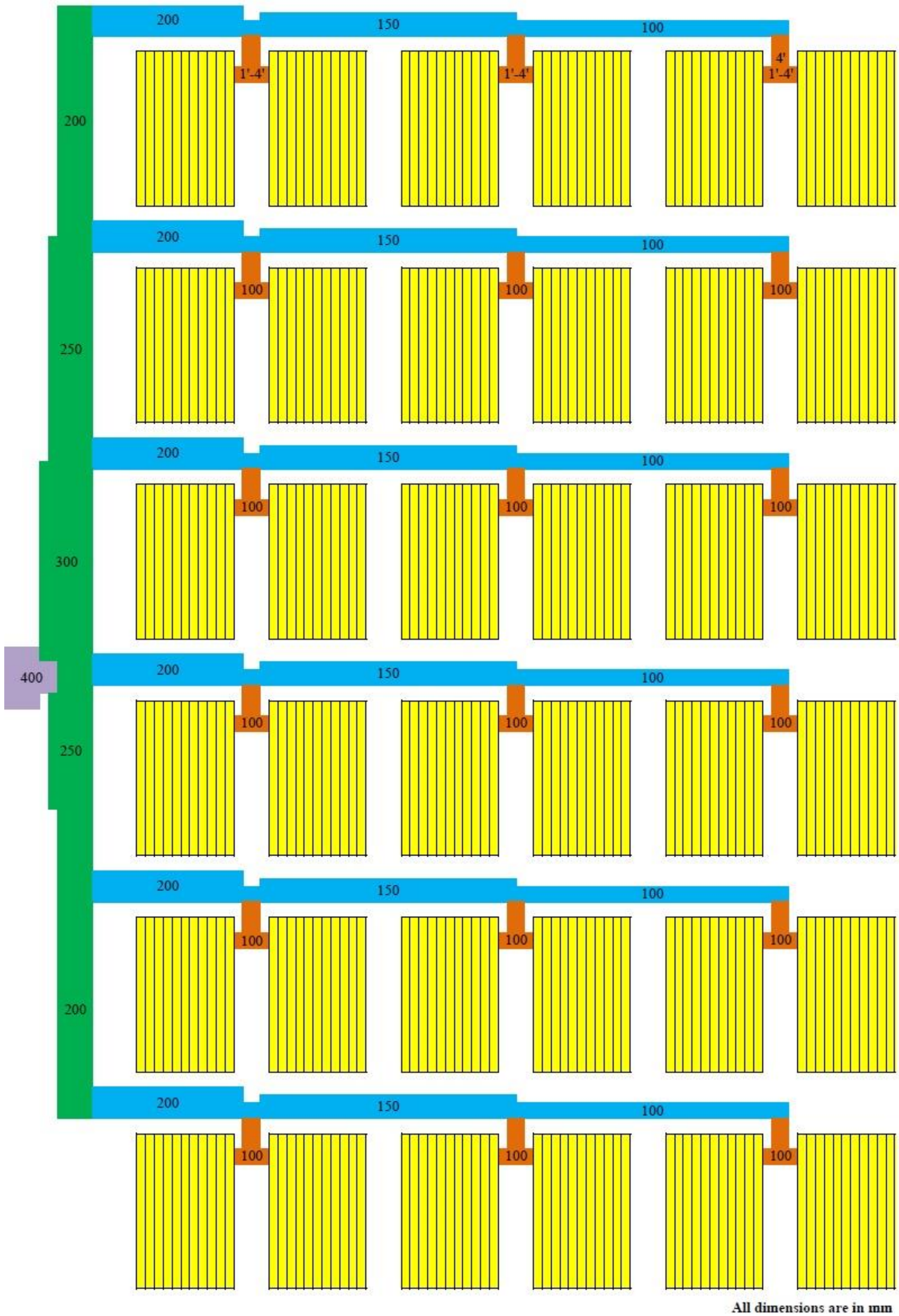


Fig. 19 Ducting layout for SHAG Arrays

Flow control system for SHAG

Control of flow as per the user's desired value is one important issue. The variations of solar insolation coupled with varying level of load necessitate control of air flow rate. A flow control system has been designed as per outlines given below:

i) Convert the outlet air temperature value of the SHAG to voltage and amplify it by using temperature sensor and amplifier circuit.

ii) To read and store the voltage in the microcontroller by using the analog to digital converter (ADC).

iii) To convert the voltage to temperature (T) by the microcontroller.

iv) To generate analog command signal (DACOUT) to control the speed of the blower for regulating the air flow rate by the microcontroller. To display the operating parameters in display device.

Flow chart of control operation executed by the instrumentation system is shown in Fig. 20.

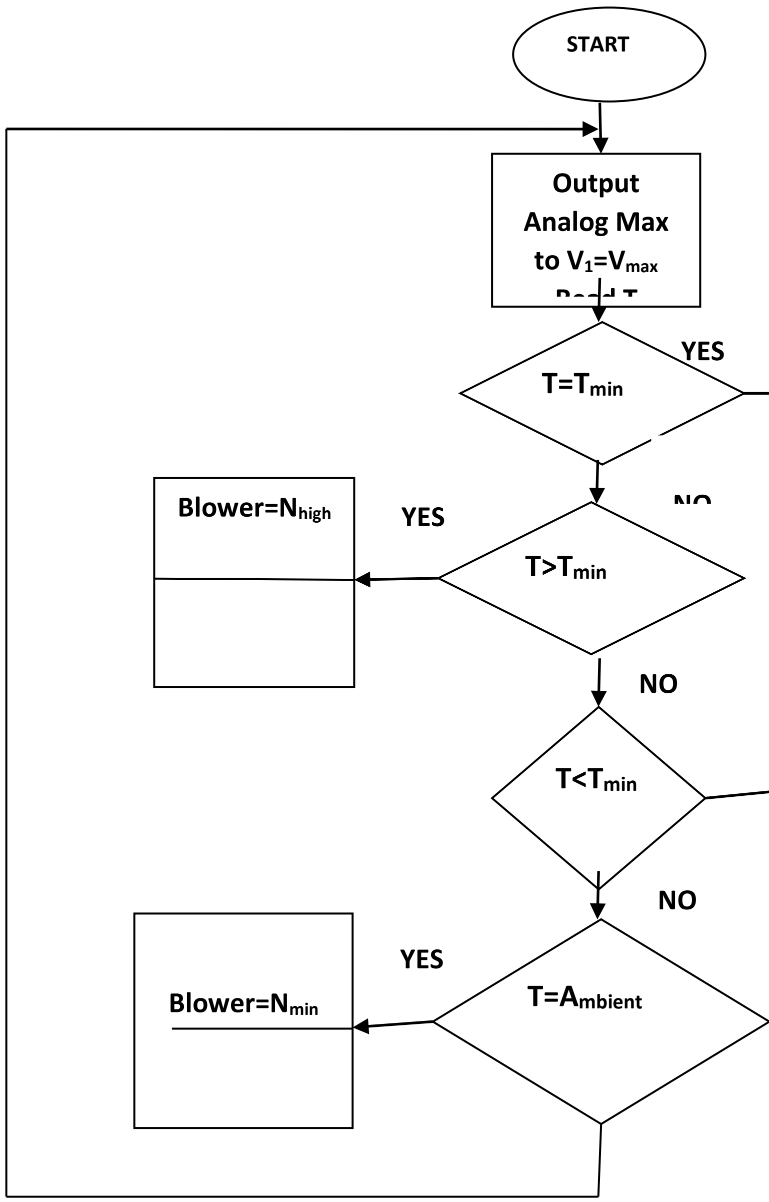
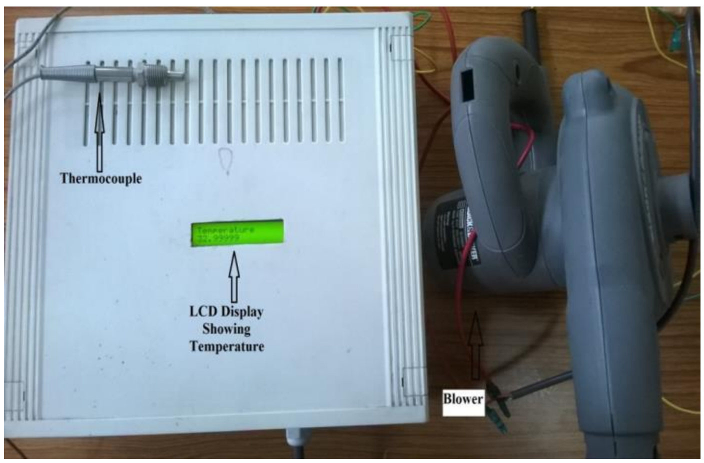
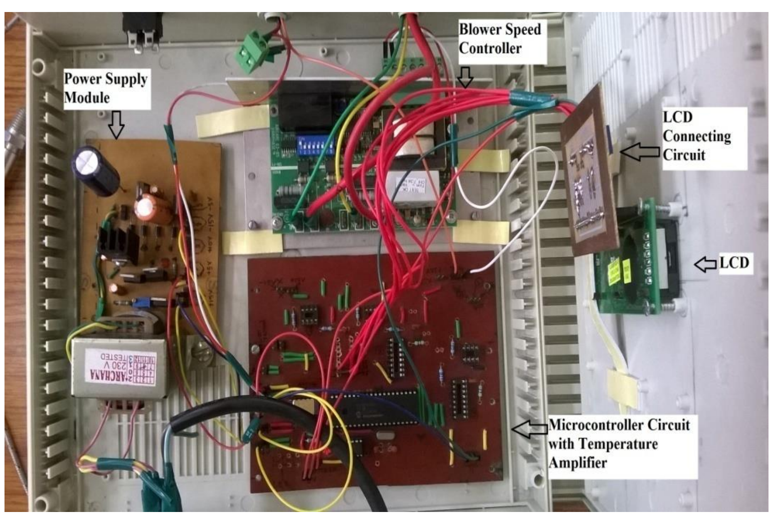


Fig. 20 Flow chart of control system used in SHAG

Initially, the flow control unit was developed for a laboratory scale ISHAG unit with a blower (600 W, 1 Φ) as shown in Fig. 21. Based on the performance of the laboratory scale model, instrumented control system for the multi-modular system is designed. The control system controls the speed of a 3 Phase 440 V, 1.5 kW induction motor. The motor is coupled to an impeller type blower which blows air from the ISHAG array. The Yaskawa motor controller has two operating modes *viz*., local and remote. The speed of the motor can be controlled by adjusting the frequency of the controller. The frequency ranges from 6 Hz to 60 Hz. According to the required flow rate, speed of the blower is adjusted using Variable Frequency Drive (VFD).



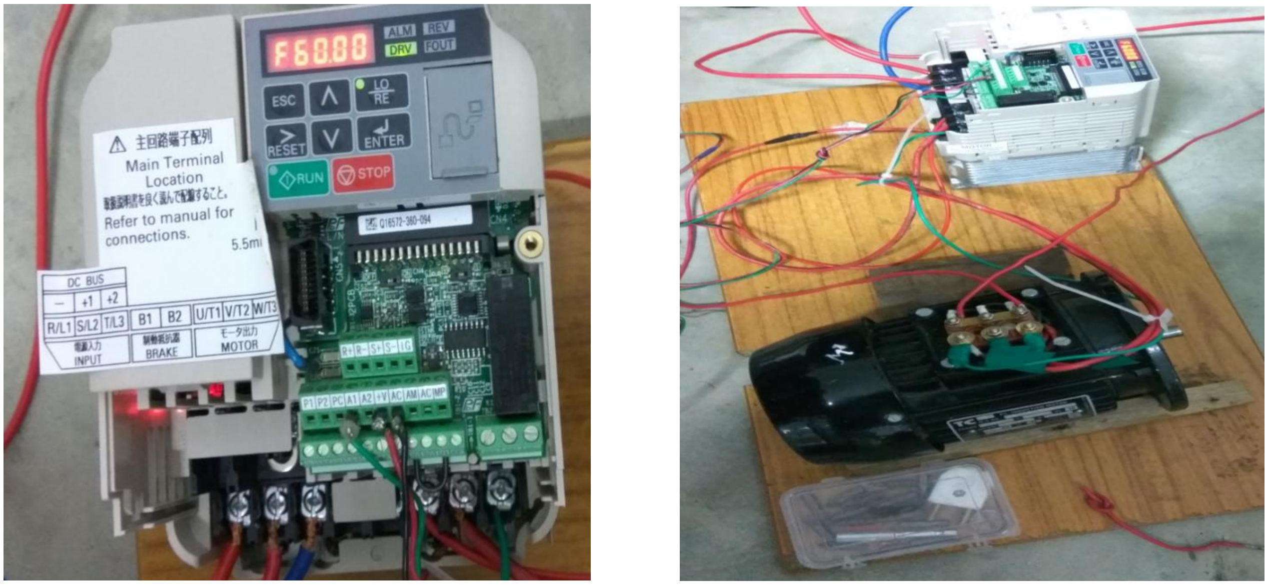
(a) Set up module (External View)



(b) Set up module (Internal View)

Fig. 21 Developed control unit (Lab Scale)

The control unit using the VFD controller is shown in the Fig. 22. The control system controls a 1.5 kW, 3 phase, Crompton Graves induction motor. It has a maximum current rating of 3.2 A and maximum power rating of 1.5 kW. The motor runs at 440 V AC supply and at a maximum speed of 1405 rpm.



(a) VFD Controller **(b) VFD Controller interfaced to 3Φ motor**

Fig. 22 Control Unit for ISHAG (industrial scale)

Installation of ISHAG in the roof top of Chandraprabha Tea Factory

The fabricated modular ISHAG units were installed at the roof top of the tea factory as shown in Fig. 23. Field test was conducted recording the thermal power output at varying flow rates.

Fig. 23 Arrays of ISHAG installed at rooftop of Chandraprabha Tea factory, Golaghat

VI. Cost Analysis and technology transfer

Costs of coal and gas, which are primarily used as fuel for tea drying, have a bearing on the acceptability of the SHAG technology. There have been hike in the prices of coal and gas in recent past which has created a demand for alternate energy. A convenient technology could fulfill such demand provided it becomes cost effective.

Cost Analysis

Cost analysis for thermal energy substitution in Chandraprabha tea factory is done with an assumption that hot air will be used in coal furnace to save coal. Unit cost of SHAG is estimated based on the actual expenditure as given below.

Table 3: Cost of fabrication of 20 units (2m^2 area/unit) of TU SHAG III

Sl. No	Particulars	Quantity		Cost	
		20 Units	Per unit	20 Units	Per unit
1	Aluminum Sections	122 m	6.1 m	16300	815
2	Aluminum Angle	122 m	6.1 m	11980	599
3	Polycarbonate Sheet	44.6 sq. m	2.23 sq. m	48000	2400
4	Black Paint	20 L	1 L	3600	180
5	Black Paint (Spray)	80 Nos.	2 Nos.	8800	440
5	Thinner	10 L	0.5 L	600	30
6	Ceramic Blanket	44.6 sq. m	2.23 sq. m	16900	845
7	Pop Rivets	1200 pieces	60 pieces	1000	50
8	Aluminum Pipe (3/4”)	366 m	18.2 m	16500	825
9	Aluminum Sheet	44.6 sq. m	2.23 sq. m	14680	734
10	G I Pipe (1”)	61 m	3.05 m	14000	700
11	Al Foil	46.45 sq. m	2.32 sq. m	760	38
12	Miscellaneous			8000	400
13	Labor			8500	425
			Total	169620	8481

Thermal power requirements as well as space availability will vary and depending upon these considerations, customer could require estimate for different number of units. Keeping in view of this, an estimate has been made to analyse the cost of varying numbers as provided in Table 4 (estimated with consideration of 6.7 kg/s air mass flow at 115°C to process 100 kg made tea per hour. 404 kW equivalent thermal power is required; design mass flow for ISHAG operation = 0.04 kg/s/m^2)

Table 4: Cost analysis for thermal energy substitution in Chandraprabha Tea factory using SHAG III

% thermal energy substitution	**10%**	**20%**	**30%**	**40%**	**50%**	**60%**	**70%**	**80%**	**90%**	**100%**
Annual saving of coal (kg)	10,000	20,000	30,000	40,000	50,000	60,000	70,000	80,000	90,000	1,00,000
Annual saving of fuel cost (Rs)	90,000	1,80,000	2,70,000	3,60,000	4,50,000	5,40,000	6,30,000	7,20,000	8,10,000	9,00,000
Number of modular units	17	33	50	66	83	100	116	132	148	165
Area required (m^2)	34	66	100	132	166	200	232	264	196	330
Anticipated cost of ISHAG (Rs.)	1,27,177	2,46,873	3,74,050	4,93,746	6,20,923	7,48,100	8,67,796	9,87,492	11,07,188	12,34,365
Simple payback period (Years)	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4

Technology Transfer and promotion

Biogen Industries has the manufacturing facility of SHAG and showing interest to market the product. Moreover, another firm, *Borah Online Services and Solution* from Golaghat also showed interest to own the technology for manufacturing and marketing (a letter of interest is enclosed at the end of this report).

Generation of hot air in the range of 40-90 °C is demonstrated by SHAG and hot air in this temperature range is useful in many applications. In addition to the tea processing units, SHAG could be useful for paddy/rice drying. Drying is a critical unit operation for rice milling as control drying could ensure better milling quality. Department of Agriculture, Govt of Assam has approached for some demonstration of SHAG.

Similarly, local Office of the Coffee board has also shown interest to use SHAG for drying of coffee beans, which remain as a critical operation.

ISHAG is now market ready product and requires some awareness and marketing for its commercial promotion.

One demonstration cum awareness Workshop will be useful to for its quicker dissemination and promotion.

Salient Research Achievements

Summary of the Work

- A low cost (~Rs 8500.00) and light weight (~23 kg) Solar Hot Air Generator (SHAG) is selected after a series of design, development and testing exercises conducted in the laboratory and fields. Black coated aluminum foil is used as a absorber as well as for heat transmission to air passed through the collector pipe.
- Local manufacturing capacities have been developed with appropriate training to local youths and it is ready to take up the large scale SHAG manufacturing work.
- Array of SHAG modular units becomes useful to generate hot air up to a temperature of 70°C at peak insolation.
- With an investment of Rs. 2.5 Lakh, 33 modular units could be installed and for a coal fired tea processing unit (with thermal load of 400 kW), 20% fuel saving is possible with about Rs. 1.8 Lakh annual cost saving.
- SHAG is a potential renewable energy technology for industrial applications in tea processing as well as for other low temperature drying of products.

PhD Theses

1) Hatibaruah, D. *Investigation of Microwave Assisted Hot Air Drying Behavior of CTC Tea (Camellia Assamica)* . Ph.D. Thesis, Department of Energy, Tezpur University, India, 2013.
2) Dutta, P. P. *Prospect of Renewable Thermal Energy in Black Tea Processing in Assam: An Investigation for Energy Resources and Technology*. PhD Thesis, Department of Energy, Tezpur University, India, 2014.
3) Choudhury, P. K. *Solar powered dryer* Ph.D. Thesis (to be submitted), Department of Energy, Tezpur University, India, 2017.

M. Tech Theses

1) Weingken, E.P. *Thermohydaulic Performance of a Double Pass Counter-Flow Solar Hot Air Generator with Longitudinal Fins*, Master Thesis, Department of Energy, Tezpur University, India, 2014

2) Bezbaruah, P. *Thermohydraulic Performance of a Packed Bed Solar Air Heater*. Master Thesis, Department of Energy, Tezpur University, India, 2015

List of Publications

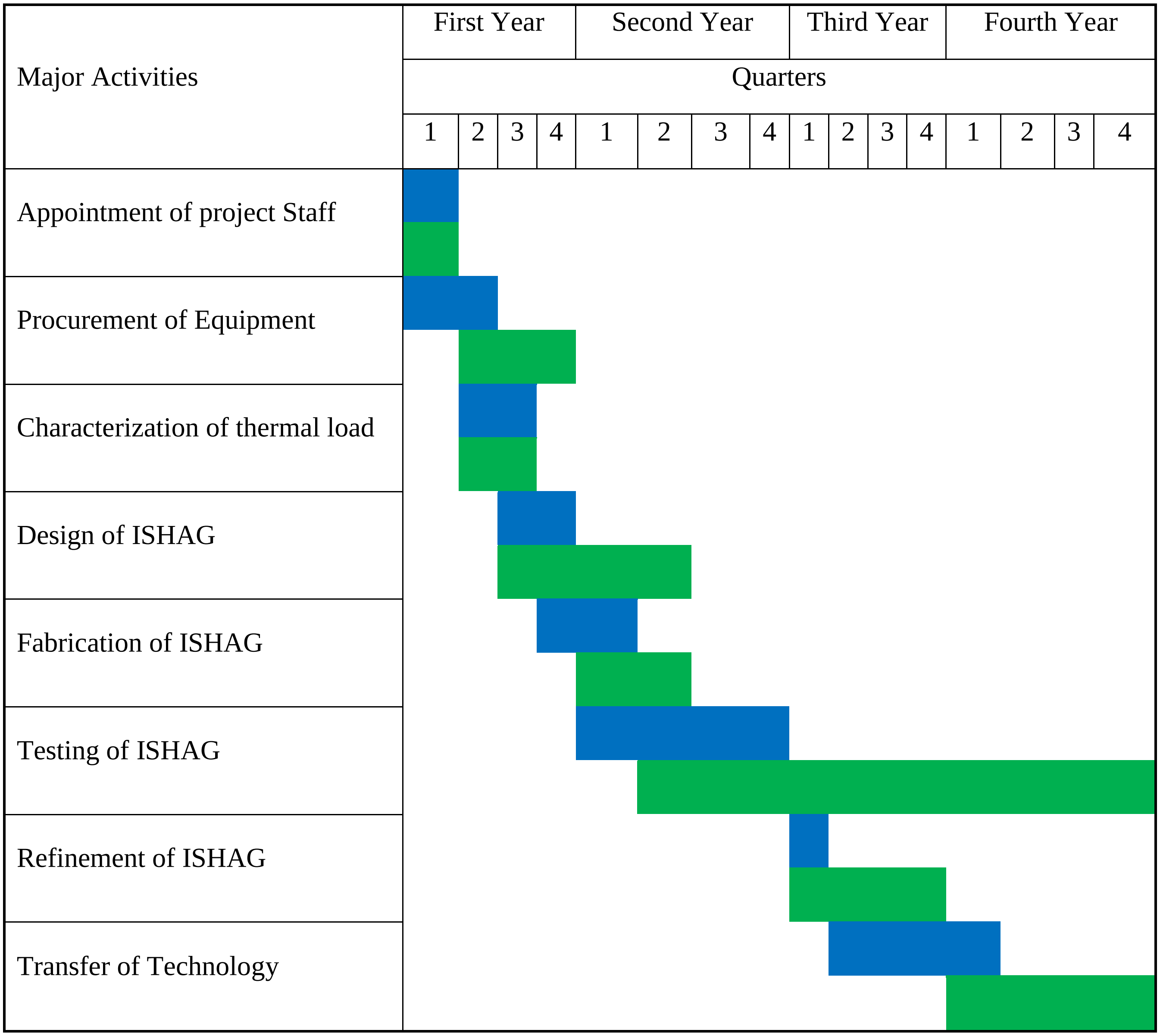
Journal Publications

1) Dutta, P.P., Keot, A., Gogoi, A., Bhattacharjee, A., Saharia, J., Sharma, N., and Baruah, D. (2013). A study on some techniques for improving thermohydraulic performance of solar air heater. *International Journal of Emerging Technology and Advanced Engineering*, 3 (3): 225-233.
2) Choudhury, P.K., and Baruah, D.C. (2014) Development of an Empirical Model for Assessment of Solar Air Heater Performance. *Distributed Generation and Alternative Energy Journal,* 29 (3): 56-75.
3) Thermo-hydraulic performance of packed bed solar air heater; *Bezbaruah P J, Borah D, Baruah D C* Journal: Journal of the Institution of Engineers in India, Springer

Conference Proceedings

1) Dutta, P.P., Saharia, J., Sharma, N., and Baruah, D.C. (2013). Thermal Performance studies of a rectangular duct solar air heater. In *22nd National and 11th International Conference of ISHMT, ASME, Heat and Mass Transfer Conference*, IITKgp. (28-31st December, 2013)
2) Dutta, P.P., Saharia, J., Sharma, N., Baruah, D.C., and Dutta, B. (2012). Studies on some Solar Thermal Collectors. *In International Seminar and Workshop on Energy, Sustainability and Development*, Sibasagar College, 12-14th October. 2013.

PERT Chart


Major Activities
First Year
Second Year
Third Year
Fourth Year
Quarters
1 2 3 4 1 2 3 4 1 2 3 4 1 2 3 4
Appointment of project Staff
Procurement of Equipment
Characterization of thermal load
Design of ISHAG
Fabrication of ISHAG
Testing of ISHAG
Refinement of ISHAG
Transfer of Technology

List of Major Equipment (Model and Make)

Sl No	Sanctioned List	Procured (Yes/No) Model & make	Cost (Rs)	Working (Yes/ No)	Utilization Rate (%)
01.	Flow Controller with accessories (two blowers with VFD motor, 500 to 1000 lpm)	No Alicate Scientific Inc.; MC-508CCM-D	1,55,000.00	--	--
02	Air mass flow meter	No Alicate Scientific Inc.; M-5SLPM-D	1,03,000.00	--	--
04	Multimeter - high resolution	No Rishab; Rish Multi 185	8,000.00	--	--
05	Temperature measuring sensor & indicator Radiation sensor	No CDL-28; Mallik Exim	54,000.00	--	--
06	Tubular SHAG setup from IITB	IITB	1,22,00.00	--	--
07	VFD Drive	Make: Yaskawa Model: V1000	19,500.00	Yes	--

Annexure- II

REQUEST FOR ANNUAL INSTALMENT WITH UP—TO—DATE STATEMENT OF EXPENDITURE

(Year Means **Financial Year i.e. 1st April 2016 to 30st September 2016**

1. Sanction Letter No.	i) ii)	IDP/IND/2011/14 (Capital) IDP/IND/2011/14 (General)
2. Total Project Cost		Rs. 28,54,800.00
3. Sanctioned/Revised Project cost (if applicable)		Rs. 34,65,400.00
4. Date of Commencement of Project		1st October 2012
5. Duration		36 **months + (12 months extension)**
6. Grant Received in each year		
a. I Year		**Rs.** 14,30,000.00
b. II Year		**Rs.** 4,00,000.00
c. III Year		**Rs.** 5,50,000.00
d. IV Year		**Rs. Not Received Yet** (10,00,000.00 (Loan from University))
e. Bank Interest received on grant (if any)		**Rs.** 6,350.00 + 26,500.00+4561.00+0.00
f. Total		**Rs.** 34,17,411.00
7. Total expenditure		**Rs.** 50,445.00 + 6,22,374.00+10,59,723.00+8,09,194+8,65,392+40,444^^ **=34,47,572.00**
8. Funds required for next year		**Rs. 10,30,161.00**

^^ Committed Expenditure

Contd./-

Finance Officer
Thapar University

Annexure – II

STATEMENT OF EXPENDITURE

(Period 01/10/2012 to 30/09/2016)

S l N o	Sanctioned Heads	Total Project Fund	Funds Received (*)	Expenditure Incurred						Committed expenditure @	Balance available as on date	Requirement of funds	Remark (if any)
				I Yr 2012-13	II Yr 2013-14	III Yr 2014-15	IV Yr 2015-16	V Yr 2016-17	Total				
I	II	III	IV	V					VI	VII	IV – (VI+VII)		
1	Manpower	18,35,400	11,48,850	43,807	3,63,004	4,27,135	4,13,342	5,65,366	18,12,654	Nil	-6,63,804	6,63,804	
2	Permanent Equipment	5,30,000	5,30,000	Nil	0.00	3,66,400	1,22,000	19,503	5,07,903	Nil	22,097	-22,097	
3	Other Costs		Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil		
4	Consumables	5,70,000	3,89,000	Nil	1,34,458	1,01,265	1,74,455	1,76,242	5,86,420	Nil	-1,97,420	1,97,420	
5	Travel	1,80,000	1,33,000	6,638	62,412	39,889	30,675	17,770	1,57,384	33,211	-57,595	57,595	
6	Contingency	1,00,000	79,561	Nil	Nil	51,295	37,472	4,000	92,767	7,233	-20,439	20,439	
7	Overhead Charges	2,50,000	1,37,000	Nil	62,500	73,739	31,250	82,511	2,50,000	Nil	-1,13,000	1,13,000	
8	Interest Earned		37,411	N/A	N/A	N/A	N/A	Nil	N/A	Nil	Nil#	-	
9	Total	34,65,400	**24,17,411	50,445	6,22,374	10,59,723	8,09,194	8,65,392	34,07,128	40,444	-10,30,161	10,30,161	

** The interest (Rs. 37,411) earned in the previous financial year has been distributed in the different sanctioned heads and hence not added again in the total.

As the balance of the project stands negative for the last two financial year, no interest is earned.

@ Expenditure incurred to attend DST EAG meeting to be held at New Delhi on 10 Jan 2017

Name & Signature
Principal Investigator : ....Debendra Chandra Baruah

Signature of Competent
Financial authority 5.1.17
Finance Officer
Date: ....Tezpur University

a)Expenditure under the sanctioned heads , at –any point of time , should not exceed funds allocated under that head , without prior approval of DST i.e. Figures in Column (V) should not exceed corresponding figure in Column (III).
b)Utilisation Certificate for each financial year ending 31st March has to be enclosed , along with request for carry-forward permission to next year.

Annexure- III

UTILISATION CERTIFICATE (TWO COPIES) FOR THE FINANCIAL YEAR (ENDING 30TH SEPTEMBER)

1	**Title of the Project/Scheme:** Instrumented Solar Hot Air Generator for Optimal Thermal Load in Tea Processing.	
2	**Name of the Institution :** Department of Energy, Tezpur University	
3	**Principal Investigator :** Prof. D. C. Baruah	
4	**Deptt of Science & Technology letter No & date of sanctioning the project** :	IDP/IND/2011/14 (Capital)
5	**Head of account as given in the original Sanction letter** :	**CAPITAL HEAD**
6	**Amount brought forward from the Previous financial year quoting DST letter No and date in which authority to carry forward the said amount was given** :	**i) Amount** Rs. 41,600.00 **ii) Letter No:** IDP/IND/14/2011(General) **iii) Dated** 23-08-2015
7	**Amount received during the financial year** *(Please give No & Date of DST's sanction letter for the amount)*	**i) Amount** Nil **ii) Letter No** **iii) Date**
8	**Total amount that was available for Expenditure** *(excluding commitments)* **during the financial year** (S No 6+7)	**Rs.** 41,600.00
9	**Actual expenditure** *(excluding commitments)* **Incurred during the financial year (upto 31st March)**	**Rs.** 19,503.00
10	**Balance amount available at the end of the financial year**	**Rs.** 22,097.00
11	**Unspent balance refunded if any** *(Please give details of cheque No etc)*	**Rs.** 0.00
12	**Amount to be carried toward to the next financial year** *(if applicable)*	**Rs.** 22,097.00

contd.

Finance Officer
Tezpur University

Annexure- III

UTILISATION CERTIFICATE (TWO COPIES) FOR THE FINANCIAL YEAR (ENDING 30TH SEPTEMBER)

1	**Title of the Project/Scheme :** Instrumented Solar Hot Air Generator for Optimal Thermal Load in Tea Processing.	
2	**Name of the Institution :** Department of Energy, Tezpur University	
3	**Principal Investigator :** Prof. D. C. Baruah	
4	**Deptt of Science & Technology letter No & date of sanctioning the project**	: IDP/IND/2011/14(General)
5	**Head of account as given in the original Sanction letter :**	**GENERAL HEAD**
6	**Amount brought forward from the Previous financial year quoting DST letter No and date in which the authority to carry forward the said amount was given**	**i) Amount** Rs. -1,65,925.00 **ii) Letter No** IDP/IND/14/2011 (General) **iii) Date:** 23-08-2015
7	**Amount received during the financial year** *(Please give No & Date of DST's sanction letter for the amount)*	**i) Amount** Nil **ii) Letter No** **iii) Date:**
8	**Total amount that was available for Expenditure** *(excluding commitments)* **during the financial year (S No 6+7)**	Rs. -1, 65,925.00
9 a	**Actual expenditure** *(excluding commitments)* **Incurred during the financial year (upto 31st March)**	Rs. 8, 65,392.00
9 b	**Committed Expenditure**	Rs. 40,444.00
10	**Balance amount available at the end of the financial year**	Rs. -10,30,161.00
11	**Interest earned (2014-2015)**	Rs. Nil
12	**Unspent balance refunded if any** *(Please give details of cheque No etc)*	Rs. 0.00
13	**Amount to be carried toward to the next financial year** *(if applicable)*	Rs. -10,30,161.00

contd.

Finance Officer
Tezpur University

Annexure- III

UTILISATION CERTIFICATE

Certified that out of **Rs. 0.00 (Zero)** of grants-in-aid sanctioned during the year **2016-2017** in favor of **D.C. Baruah, Professor, Department of Energy, Tezpur University** under this ministry/ Department Letter **No IDP/IND/14/2011 (General)** Dated **23/08/2015** and **Rs. -1,24,325.00 (One Lakhs Twenty Four Thousand Three hundred Twenty Five only)** on account of unspent balance of the previous year a sum of **Rs. 9,05,836.00** (including committed expenditure of Rs. 40,444.00) has been utilized for the purpose of **DST(Govt. of India)** funded research project **"Instrumented Solar Hot Air Generator (ISHAG) for optimum thermal load in tea processing"** for which it was sanctioned and that the balance of **Rs. -10,30,161.00** at the end of the year will be adjusted towards the grants-in-aid payable during the next year i.e. 2016-2017.

Signature of Principal Investigator Date 4.1.17	Signature of Registrar Accounts Officer with date and seal 5/1/17 Finance Officer Tezpur University	Signature of Head of the Institute with date and seal Registrar Tezpur University

(TO BE FILLED IN BY DST)

2 **Certified that I have satisfied myself that the conditions on which the grants-in –aid was sanctioned have been fulfilled / are being fulfilled and that I have exercised the following checks to see that the money was actually utilized for the purpose for which it was sanctioned :-**

Kinds of checks exercised

i)

ii)

Signature
Designation
Date